U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
WISCONSIN DEPARTMENT OF NATURAL RESOURCES

HYDROLOGIC INVESTIGATIONS ATLAS HA–731
Introduction, horizontal ground-water flow, and hydrogeologic sections, ground-water province I (north part)—SHEET 1 OF 4
Kammerer,P.A., and others, 1998, Geology, ground-water flow, and dissolved-solids concentrations in ground water along hydrogeologic sections through Wisconsin aquifers

INTRODUCTION

A cooperative project between the U.S. Geological Survey (USGS) and the Wisconsin Department of Natural Resources (DNR) was begun with the objectives of describing water quality and its relation to the hydrology of Wisconsin's principal aquifers and summarizing instances of ground-water contamination and quality problems from information available in DNR files. The first objective was met by a hydrologic investigation done by the USGS, and the second, by preparation of a report by the DNR, for their internal use, that describes the State's water resources and known ground-water quality and contamination problems and makes policy recommendations for ground-water management.

The USGS investigation was divided into two phases. The first phase consisted of compiling available water-quality and hydrogeologic data and collecting new data to describe general regional water-quality and hydrogeologic relations within and between Wisconsin aquifers. The second phase began concurrently with the later part of the first phase and consisted of an areal description of water quality and flow in the State's shallow aquifer system (Kammerer, 1995). The overall purpose of this investigation was to provide a regional framework that could serve as a basis for intensive local and site-specific ground-water investigations by State and local government agencies.

This report presents the results of the first phase of the USGS investigation. Regional hydrogeologic and water-quality relations within and between aquifers are shown along 15 hydrogeologic sections that traverse the State. Maps are used to show surficial geology of bedrock and unconsolidated deposits and horizontal direction of ground-water flow. Interpretations on the maps and hydrogeologic sections are based on data from a variety of sources and provide the basis for the areal appraisal of water quality in the State's shallow aquifer system in the second phase of the investigation.

The hydrogeologic sections are subdivided into segments on the basis of ground-water provinces described in this report. A group of two or three illustrations is presented for each segment of a section. The upper illustrations show the geology; stratigraphy is shown by color and symbols, and lithology is shown by patterns. The lower illustration(s) show(s) direction of vertical ground-water flow through confining units (for sections where confining units are present) and the dissolved-solids concentrations of the ground water. The surface topography is from 7½- and 15-minute USGS topographic quadrangle maps.

Geologic interpretations are based primarily on geologic logs prepared by the Wisconsin Geological and Natural History Survey (WGNHS). Supplemental information was compiled from published reports and geologic maps, well-construction reports from the Department of Natural Resources, academic theses, and unpublished data on file with WGNHS and the USGS. Geologic logs and well-construction information from as far as 6 miles on either side of a hydrogeologic section were used where necessary to supplement information along the section line.

Hydrogeologic sections and maps differ in detail with respect to the division of geologic units. Rocks of the Cambrian system are undivided on the geologic maps but are shown in detail in the hydrogeologic sections where possible. Precambrian rocks of the Keweenawan Supergroup (undivided sandstones of the Bayfield and Oronto Groups and the volcanic sequence) and the basement complex are divided on the geologic maps, but they are grouped as undivided Precambrian in the hydrogeologic sections.

An effort was made to document faults because of their possible hydraulic significance. Little is known about most faults in the State other than their stratigraphic displacement, but faults can either be avenues of ground-water flow or, if filled by impermeable materials, barriers to flow. Not all faults identified on the sections are shown on the corresponding geologic maps.

Geologic nomenclature used herein is that of the Wisconsin Geological and Natural History Survey (Ostrom, 1967; Mudrey and others, 1982) and does not necessarily follow usage of the USGS.

Representations of the direction of ground-water flow are based on a State map that shows the configuration of the water-table aquifer and on the results of flow simulations done as part of a USGS Regional Aquifer-System Analysis (RASA) Program investigation of the Cambrian-Ordovician aquifer system in the northern Midwest (Mandle and Kontis, 1992). The direction of horizontal ground-water flow is shown by arrows on the map of the water-table aquifer and on maps of the aquifer units for which flow simulations were done. The direction of vertical ground-water flow through confining units between aquifers is shown by arrows on the hydrogeologic sections in areas where confining units are present. An arrow that points upward indicates that the hydraulic head in the confining unit is lower than the head in the underlying aquifer. An arrow that points downward indicates that the hydraulic head in the confining unit is higher than the head in the underlying aquifer.

The concentration of dissolved solids is used as a general indicator of water quality and consequently, differences in water quality within and between aquifers. The dissolved-solids data are from published reports and unpublished chemical analyses by the USGS and State agencies; all data are stored in the USGS data base, WATSTORE (Water Data Storage and Retrieval System). Dissolved-solids data for water from deep aquifers are sparse because most deep wells tap more than one aquifer. Dissolved-solids concentrations in water from deep aquifers were estimated in areas where no concentration data were available. The dissolved-solids concentration in water from deep aquifers was estimated by comparing the dissolved-solids concentrations in water from deep multiaquifer wells to that in water from nearby shallow wells; general regional ground-water flow information was used to estimate the contributions of deep and shallow aquifers to the mix of water in multiaquifer wells. Ground-water-quality data for Wisconsin have been summarized in Kammerer (1981, 1984), and Holt and Skinner (1973), but no attempt was made to identify and document water-quality differences with depth.

Packer tests in which individual aquifer zones were isolated from other zones and tested separately were done in 13 multiaquifer wells in Wisconsin and northeastern Illinois. These tests were done as part of this and the RASA investigations to provide hydraulic-head and water-quality information for deeply buried geologic units. The locations of the wells that were tested are shown on the index map. Hydraulic characteristics and hydraulic-head data for wells where packer tests were done are summarized by Young (1992).

Generalized distribution of dissolved solids within and between aquifers is shown on the hydrogeologic sections as lines of equal concentration. The lines are dashed where concentrations are estimated.

WISCONSIN AQUIFERS

Wisconsin's principal aquifers consist of sedimentary rocks of Paleozoic age (Silurian dolomite and sandstone aquifers) and Quaternary age sand and gravel deposits. Minor aquifers are the Maquoketa Formation, Precambrian sandstones and lava flows, and the basement complex of predominantly crystalline Precambrian rocks that underlies most of the State. Wisconsin's bedrock geology is shown on the geologic map of the State. Stratigraphic relations and the dominant lithology of Wisconsin's bedrock are shown in the explanation for the geologic map. Glacial deposits from Pleistocene glaciations are as much as 600 feet thick over large parts of the State, but less than 200 feet thick and cover the bedrock over about three-quarters of the State.

The sand and gravel aquifer consists of unconsolidated deposits of sand and gravel within the glacial deposits and valley alluvium. Unlike most bedrock aquifers, this aquifer is not continuous but is present as broad, surficial outwash deposits, narrow fills, beach sand and gravel directly overlying bedrock, isolated lenses of sand and gravel within less permeable glacial till and lakebed deposits, and other water-bain deposits. The sand and gravel aquifer is present in every county in Wisconsin, although its occurrence is limited in the Driftless Area of southwestern Wisconsin, where it is present only as valley alluvium within the flood plains of large rivers.

Paleozoic rocks that compose principal bedrock aquifers are flat-lying marine sedimentary rocks that dip to the east, south, and west away from the Precambrian high in north-central Wisconsin.

The Silurian dolomite aquifer underlies all or parts of 15 counties along the eastern boundary of the State. The aquifer is mostly dolomite of Silurian age, but a small area of dolomite and shale of Devonian age also extends from Milwaukee to Sheboygan along Lake Michigan.

The sandstone aquifer consists of stratigraphically connected Ordovician sandstones and dolomites and Cambrian sandstones. The oldest and most extensive units in the sandstone are Cambrian sandstones that underlie 60 percent of the State. The contact between Cambrian sandstone units in the subsurface is difficult in most areas, but wells that draw water exclusively from rocks of the Tunnel City Group (considered to be part of a confining unit in some areas) or the Elk Mound Group were identified in some areas. These wells commonly were found in areas where one or more of the other Cambrian units is missing. Many of the characteristics used to differentiate between Cambrian units in outcrops are indistinguishable in rock cuttings from wells. Because of this, some of the contacts between Cambrian units shown on the hydrogeologic sections in this report are provisional, and in some areas, Cambrian units are undivided.

The remainder of the sandstone aquifer consists of Ordovician units that overlie the Cambrian sandstones. A dolomite unit, the Prairie du Chien Group, overlies the Cambrian sandstones in the western, southern, and eastern parts of the State. The Ancell Group overlies the Prairie du Chien but is smaller in areal extent. The Ancell Group, which includes the St. Peter and Glenwood Formations, represents a change in nomenclature used on the most recent published bedrock geology map of Wisconsin (Mudrey and others, 1982). The Ancell Group corresponds to the St. Peter Sandstone as described by Ostrom (1967) and used in previous statewide summaries of ground-water quality (Kammerer, 1981, 1984). Dolomites of the Sinnipee Group, which includes, in ascending order, the Platteville, Decorah, and Galena Formations, overlie the Ancell Group in southern and eastern Wisconsin. The Sinnipee Group also is known as the Galena-Platteville aquifer where it is the uppermost bedrock unit and is not overlain by the Maquoketa Formation. Small quantities of water are obtained from the Maquoketa Formation in some areas of eastern Wisconsin, but few wells are open exclusively to it. Generally, the Maquoketa Formation restricts ground-water flow and confines the sandstone aquifer.

Aquifers and confining units used in the RASA flow simulations (Mandle and Kontis, 1992) are combinations of the geologic units discussed here and shown in the explanation for the geologic map. The uppermost aquifer is the Silurian dolomite aquifer. The next older aquifer, comprised of the Ancell and Prairie du Chien Groups and the Galena Formation, is confined by the Maquoketa Formation in the east. Underlying the Ancell–Prairie du Chien aquifer is the St. Lawrence Formation and the Tunnel City Group (referred to collectively as the "St. Lawrence–Franconia confining unit" by Mandle and Kontis , (1992)), which confines the underlying Wonewoc Sandstone. The Wonewoc aquifer is referred to as the "Ironton–Galesville aquifer" by Mandle and Kontis (1992). The Eau Claire Sandstone underlies the Wonewoc Sandstone and confines the Mount Simon Sandstone. The St. Lawrence–Tunnel City and the Eau Claire confining units are discontinuous and are not differentiated on the geologic map. They are shown in the hydrogeologic sections where they are present.

Precambrian sandstone and lava flows are aquifers within a continental rift that crosses the northwestern corner of the State. The Precambrian sandstones also are referred to collectively as the "Lake Superior sandstone aquifer". Older Precambrian granitic and metamorphic crystalline rocks in north-central Wisconsin southeast of the rift are tapped for water supplies in some areas.

GROUND-WATER PROVINCES

Several of Wisconsin's aquifers extend over large areas. These extensive aquifers differ in thickness and lithology areally and are affected by differences in hydrologic conditions within the State. Wisconsin is divided into four flow groundwater provinces delineated on the geologic map on the basis of similarity of hydrogeologic regimes (Kammerer, 1984). The boundaries of the provinces were based on the areal extent of bedrock aquifers, regional ground-water flow and divides, and physical geography. Characteristics of the sand and gravel aquifer were not considered in delineating province boundaries.

Ground-water province I consists of deeply dissected Paleozoic rocks overlain by permeable glacial deposits in the north and east. It is bounded on the north by the northern limit of Paleozoic rocks, on the northeast by the Prairie du Chien Group Escarpment, and on the southeast by the eastern boundary of the recharge area for the deep flow system into ground-water province II. Paleozoic rocks become thicker and dip gently toward the south and west; each successively younger rock unit underlies a progressively smaller area. Cambrian sandstones are the uppermost bedrock in most of the province. The Prairie du Chien Group dolomites and younger units underlie the southern part of the province and its western edge. Dolomites of the Sinnipee Group are the youngest bedrock in the province except for small local areas underlain by shale of the Maquoketa Formation and the Silurian dolomite at its southern edge. The Sinnipee Group is present mostly in the south, where Paleozoic rocks are overlain by only thin soil or loess. The Paleozoic rocks in the south and east are deeply dissected by streams.

The southwestern part of the province is the Driftless Area, where glacial deposits consist of valley alluvium within the flood plain of large rivers. Highly permeable outwash mantles the central and plain in the northwestern part of the province.

Ground-water province II consists of thick Paleozoic rocks overlain by glacial deposits. The western boundary of the province is, from north to south, the western limit of Paleozoic rocks, the Prairie du Chien Group Escarpment, and the western edge of the recharge area of the deep flow system in the sandstone aquifer. Paleozoic rocks thicken to the east and south. Within the sandstone aquifer, Cambrian sandstones are the uppermost rocks only in the northwest; Ordovician rocks (the Prairie du Chien, Ancell, and Sinnipee Groups) overlie the Cambrian sandstones in the remainder of the province. The Maquoketa Formation restricts vertical movement of ground water and thus confines the underlying sandstone aquifer. The Silurian dolomite aquifer overlies the Maquoketa Formation along the eastern side of the province. Devonian dolomite and shale that extends from Sheboygan to Milwaukee is considered to be part of the Silurian dolomite aquifer.

Moderately thin glacial deposits overlie the province. Much of these deposits are low-permeability till and lake deposits, but more permeable deposits are in large areas in the western part.

Ground-water province III generally consists of permeable glacial deposits that overlie impermeable Precambrian crystalline rocks of the basement complex. Moderately thick, highly permeable, low-carbonate glacial deposits overlie metamorphic and intrusive igneous rocks that include quartzite and granite. Water can be obtained from rocks of the basement complex in areas where they are weathered or fractured, but the glacial deposits are the principal aquifer.

Ground-water province IV consists of glacial deposits that overlie Precambrian lava flows and sandstone. Stratigraphic relations of the bedrock are shown in the explanation for the geologic map. The uppermost aquifer is the Silurian dolomite aquifer. The next older aquifer, comprised of the Ancell and Prairie du Chien Groups and the Galena Formation, is confined by the Maquoketa Formation in the east. Underlying the Ancell–Prairie du Chien aquifer is the St. Lawrence Formation and the Tunnel City Group (referred to collectively as the "St. Lawrence–Franconia confining unit" by Mandle and Kontis , (1992)), which confines the underlying Wonewoc Sandstone. The Wonewoc aquifer is referred to as the "Ironton–Galesville aquifer" by Mandle and Kontis (1992). The Eau Claire Sandstone underlies the Wonewoc Sandstone and confines the Mount Simon Sandstone. The St. Lawrence–Tunnel City and the Eau Claire confining units are discontinuous and are not differentiated on the geologic map. They are shown in the hydrogeologic sections where they are present.

HORIZONTAL GROUND-WATER FLOW

The horizontal direction of water flow in the ground-water provinces is shown by means of arrows on maps. These directions of flow are based on water-table gradients in the water-table aquifer and on results of simulations done by use of a three-dimensional, finite-difference, ground-water-flow model for aquifers in Paleozoic rocks (Mandle and Kontis, 1992). These is some overlap between the flow representations shown here. Flow arrows for the water-table aquifer depict the general direction of ground-water flow for a composite aquifer that includes unconsolidated deposits and the uppermost consolidated bedrock aquifers. Confining units between aquifers in Paleozoic rocks for which flow simulations were done commonly are discontinuous or absent, especially in the updip areas of the aquifers. The bedrock aquifers are unconfined in these updip areas, and flow directions in the bedrock are governed by water-table gradients and generally will correspond to the flow directions shown for the water-table aquifer.

Flow arrows for the water-table aquifer are based on water-table gradients from a water-table map of Wisconsin at a scale of 1:1,000,000 with a water-table altitude contour interval of 50 feet (Kammerer, 1994, pl. 2). Flow arrows represent generalized regional gradients; the coarse contour interval and small scale of the map preclude representation of local flow systems. The direction of water flow in these local systems may differ considerably from the direction indicated on the map.

The maps that show directions of water flow in aquifers in Paleozoic rocks are modified from the simulated potential maps of Mandle and Kontis (1992). These flow directions also are highly generalized because of the large node spacing (16 miles) used in the model.

GROUND-WATER PROVINCE I

Flow in the composite water-table aquifer generally is from beneath topographic highs toward topographic lows. The shallowest ground-water discharges to nearby lakes and streams, but water at greater depths flows greater distances toward large rivers. The flow arrows on the map are most representative of flow in the regional flow systems. Ground-water-drainage divides that delineate ground-water-drainage basins for these large rivers generally are apparent on the map for the water-table aquifer.

The Driftless Area in the western part of the province has high relief, and ground-water discharge areas are under the bedrock ridges that also form the surface-water divides for the basins. In the northeast, the broad ground-water divide between the Wisconsin River and the Fox River is apparent in a permeable outwash.

In the southern part of the province, flow in the water-table aquifer radiates away from a ridge that extends west from Madison to the Mississippi River. Flow in this area also is toward the Wisconsin River, east and southeast toward the Mississippi River, and east and southeast toward the Sugar River. East of the Sugar River, shallow ground-water flow is toward the Madison area lakes and the Yahara River.

Ground-water flow in aquifers in Paleozoic rocks generally is toward the Wisconsin and Mississippi Rivers. These rivers are flow boundaries, as evidenced by the convergent flow shown on the maps. In the northeastern part of the province, flow in the Ancell–Prairie du Chien–Jordan and Wonewoc aquifers is toward the Fox River, which flows into Lake Winnebago, thus indicating that the river is a partially penetrating flow boundary. In southwestern Wisconsin, the direction of deep ground-water flow is similar to that of the shallow ground-water flow—namely, away from the topographic high west of Madison. Southward flow from this area follows the dip of the Paleozoic rocks into Illinois. Some of the deep ground-water along the eastern margin of province I flows eastward into province II, following the southeasterly dip of the Paleozoic rocks.

GROUND-WATER PROVINCE II

Ground water in the water-table aquifer moves toward rivers and the major surface-water bodies—Lake Winnebago, Green Bay, and Lake Michigan. A northeast/southwest ground-water divide extends along the length of the Door County peninsula between Green Bay and Lake Michigan. South of the peninsula and to the southern end of Lake Winnebago, the divide is less discernible. South of Lake Winnebago, the divide again becomes more evident; flow is toward the west and northwest to the Rock River and Lake Winnebago and to the east to Lake Michigan. West of Milwaukee, two north/south divides are discernible—one between the Rock and Fox (Illinois) Rivers, and the other between the Fox (Illinois) River and Lake Michigan.

The Silurian dolomite aquifer is present only in province II. North of Sturgeon Bay along the Door County peninsula, the Silurian dolomite aquifer, which is covered by a very thin mantle of ground moraine and glaciolacustrine deposits, is the water-table aquifer. South of Sturgeon Bay, the deposits of glacial till and outwash that overlie the Silurian dolomite aquifer are thicker than the glacial deposits to the north. Because the Silurian dolomite aquifer is so near the surface, ground-water flow directions are very similar to those in the water-table aquifer, even though flow in the Silurian dolomite aquifer is primarily through fractures. A north/south divide separates eastward flow to Lake Michigan from westward flow to Green Bay, the lower Fox River between Lake Winnebago and Green Bay, and the Rock River. The Fox (Illinois) River in the southern part of province II is a flow boundary for the Silurian dolomite aquifer.

Ground-water-flow directions in the deep aquifers in Paleozoic rocks that underlie the Silurian dolomite aquifer are similar and generally follow the dip of the Paleozoic rocks to the east and southeast. The east/west divide produced by hasw pumping in the Milwaukee and Chicago areas is present in all units. Convergent flow caused by pumping in the Green Bay area and urban areas on the western shore of Lake Winnebago is apparent at the small scale of these maps only in the Ancell–Prairie du Chien–Jordan aquifer.

GROUND-WATER PROVINCE III

Ground-water-flow paths in province III generally are shorter than those in province I or II because deep aquifers are absent in this part of Wisconsin and the glacial deposits are underlain by generally impermeable crystalline bedrock. Ground-water-flow systems are recharged locally, and discharge is to nearby streams, wetlands, and lakes. Glacial deposits are thick enough that underflow occurs under some lakes and streams in some areas, although the major rivers shown on the water-table-flow map probably are fully penetrating flow boundaries. Ground-water divides are evident between these major rivers. The multitude of small lakes and streams in this region of Wisconsin create a mosaic of small watersheds, which coalesce to form regional ground-water divides in the water-table aquifer that are shown on the map.

GROUND-WATER PROVINCE IV

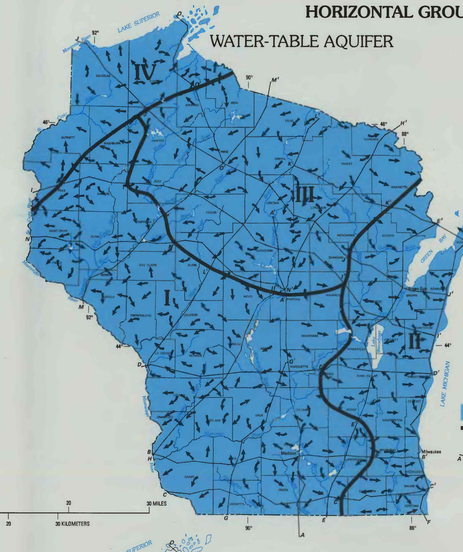
Most ground-water-flow paths in the glacial deposits of province IV are short, as they are in province III. Much of this region is underlain by Precambrian sandstones, which may contain deep flow paths. The presence of basaltic dikes within the sandstone units, however, would preclude the likelihood of long and continuous flow paths.

Ground-water flow in the water-table aquifer is primarily north toward Lake Superior and the Montreal River and southwest toward the St. Croix River. Ground-water divides are difficult do discern because of the complex geology and the paucity of available data in this part of Wisconsin.

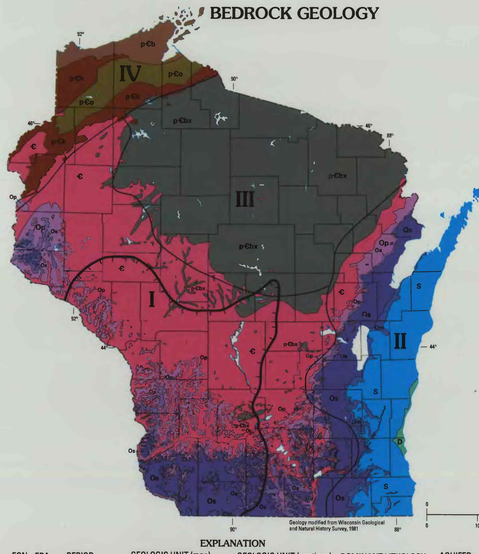
Flow in the Precambrian sandstones is poorly defined because few wells are completed in the sandstone units. It is likely, however, that any deep regional flow in these rocks reflects the flow directions in the water-table aquifer—namely, north to Lake Superior and southwest to the St. Croix River.

LOCATION OF WELLS USED FOR PACKER TESTS

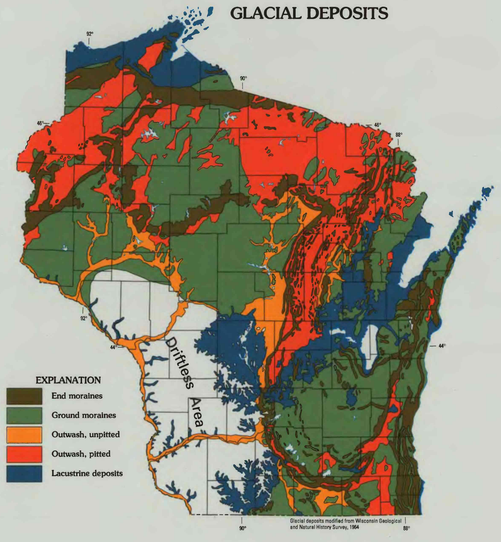
HORIZONTAL GROUND-WATER FLOW



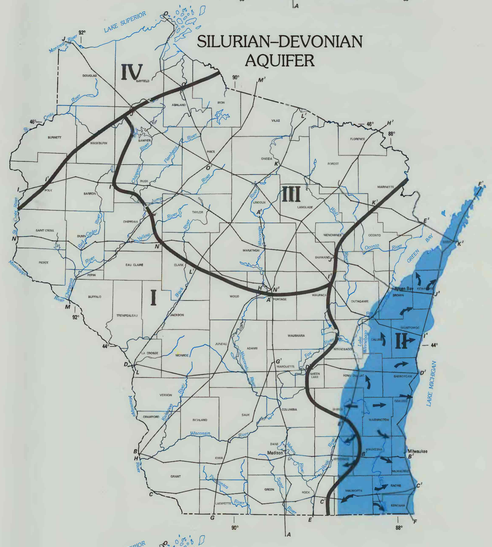
BEDROCK GEOLOGY



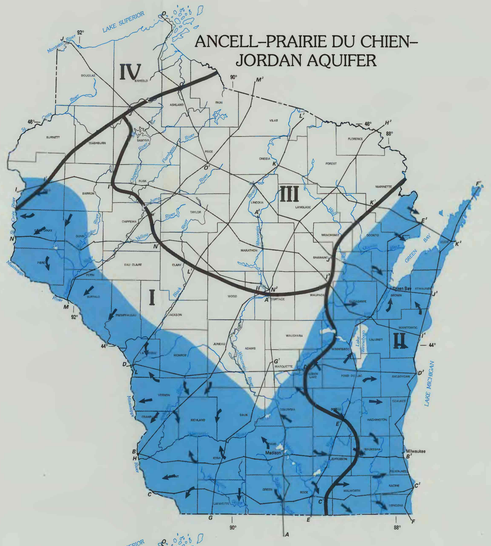
GLACIAL DEPOSITS



SILURIAN–DEVONIAN AQUIFER

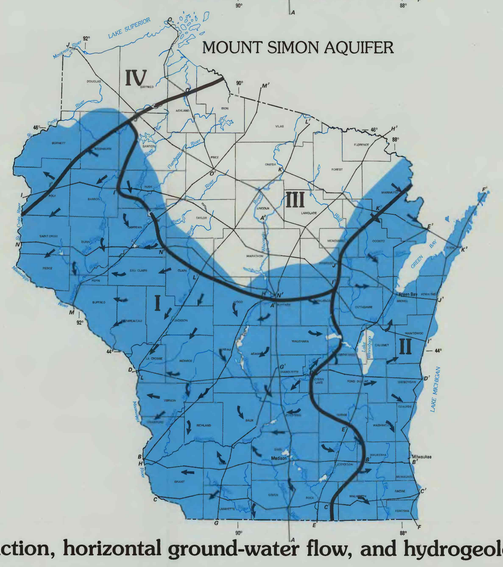


ANCELL–PRAIRIE DU CHIEN–JORDAN AQUIFER



WONEWOC AQUIFER

MOUNT SIMON AQUIFER



GROUND-WATER PROVINCE I (NORTH PART)

GEOLOGY

PRECAMBRIAN ROCKS

Precambrian rocks that underlie the northern part of province I are crystalline rocks of the basement complex and sandstone and lava flows of the Keweenawan Supergroup. The Precambrian surface is covered by Paleozoic sedimentary rocks except for a few outcrops of resistant rocks on hillsides and in exposures along some river valleys. All the Precambrian rocks are dense and impermeable and yield only small quantities of water where fractures have created secondary permeability.

Rocks of the Keweenawan Supergroup crop out on the uppermost rocks along the border with province IV to the north. These rocks do not crop out in sections I–I' or N–N'; therefore, little detail is known about their stratigraphy and lithology.

Several major faults have been described in the literature. The Cottage Grove Fault (Thwaites, 1931, p. 738) crosses section N–N' near Hudson and extends to the north where it crosses section I–I' between the Rock and the Fox (Illinois) Rivers, and the other between the Fox (Illinois) River and Lake Michigan.

The Silurian dolomite aquifer is present only in province II. North of Sturgeon Bay along the Door County peninsula, the Silurian dolomite aquifer, which is covered by a very thin mantle of ground moraine and glaciolacustrine deposits, is the water-table aquifer. South of Sturgeon Bay, the deposits of glacial till and outwash that overlie the Silurian dolomite aquifer are thicker than the glacial deposits to the north. Because the Silurian dolomite aquifer is so near the surface, ground-water flow directions are very similar to those in the water-table aquifer, even though flow in the Silurian dolomite aquifer is primarily through fractures. A north/south divide separates eastward flow to Lake Michigan from westward flow to Green Bay, the lower Fox River between Lake Winnebago and Green Bay, and the Rock River. The Fox (Illinois) River in the south is not an effective flow boundary for the Silurian dolomite aquifer, as it is for the water-table aquifer. Ground-water pumping at Milwaukee and Chicago and their suburbs has produced an east/west flow divide in the Silurian dolomite aquifer at the southern end of province II.

Ground-water-flow directions in the deep aquifers in Paleozoic rocks that underlie the Silurian dolomite aquifer are similar and generally follow the dip of the Paleozoic rocks to the east and southeast. The east/west divide produced by hasw pumping in the Milwaukee and Chicago areas is present in all units.

Convergent flow caused by pumping in the Green Bay area and urban areas on the western shore of Lake Winnebago is apparent at the small scale of these maps only in the Ancell–Prairie du Chien–Jordan aquifer.

PALEOZOIC ROCKS

The Precambrian rocks are overlain by Paleozoic sedimentary rocks that form the sandstone aquifer (the Mount Simon, the Eau Claire, and the Wonewoc Sandstones; the Tunnel City Group; the St. Lawrence Formation; the Jordan Sandstone; the Prairie du Chien and the Ancell Groups; and a small area of the Sinnipee Group) within most of this province.

Because of its depth and the large water-yielding capacity of aquifers near the surface, the Mount Simon Sandstone usually is not fully penetrated by wells except where it is the uppermost bedrock or near the bedrock surface. Data in this report (section L–L'), Eau Claire (section M–M'), and Menomonie (section N–N') indicate that the Mount Simon Sandstone contains shale and silt beds similar to those in the lower part of the Eau Claire Sandstone. However, the Mount Simon Sandstone is a highly productive aquifer over most of the province. It is a medium to coarse-grained sandstone that is poorly cemented by dolomite and locally by silica locally (M.E. Ostrom, Wisconsin Geological and Natural History Survey, written commun., 1982). The Mount Simon Sandstone has a maximum thickness of 500 feet in the northern part of province I along section M–M'.

The Eau Claire Sandstone usually is poorly cemented (but locally is well cemented) by dolomite (M.E. Ostrom, Wisconsin Geological and Natural History Survey, written commun., 1982). It usually can be divided into a lower sandy unit and an upper shaly unit where its thickness exceeds 100 feet. Where it is shaly, the Eau Claire Sandstone yields only moderate quantities of water and is a confining unit between the overlying and underlying aquifers.

The Wonewoc Sandstone differs consistently in thickness areally because it was deposited on and irregular erosion surface. The Wonewoc Sandstone generally is medium to coarse-grained and poorly cemented by dolomite and locally by silica (M.E. Ostrom, Wisconsin Geological and Natural History Survey, written commun., 1982); it yields large quantities of water where it is not cemented.

The Tunnel City Group is a well-cemented dolomitic sandstone that consists of two facies distinguished by the presence or absence of the mineral glauconite (Odom, 1978). The nonglauconitic facies is a southwestward-extending "tongue" within the glauconitic facies. This tongue is present west of Knapp (section N–N'), north of Eau Claire (section M–M'), and north of Melrose (section L–L'). The glauconitic facies is a fine to medium-grained, but commonly very fine-grained feldspathic sandstone. The nonglauconitic facies is a fine to medium-grained feldspathic sandstone or, locally, a sandy dolomite. The two facies are identifiable in outcrops, but generally are not distinguishable in well cuttings (M.E. Ostrom, Wisconsin Geological and Natural History Survey, written commun., 1982). The Tunnel City Group thickens gradually to the northwest from about 140 feet at Colfax (section N–N') to about 150 feet at Knapp (section N–N') where it contains shale layer. It yields moderate quantities of water to wells but is a confining unit in some areas.

The St. Lawrence Formation consists of interlingering facies of the dolomite and sandy dolomite of the Black Earth Member and the dolomite-cemented siltstone and the very fine-grained shaly sandstone of the Lodi Shale Member (M.E. Ostrom, Wisconsin Geological and Natural History Survey, written commun., 1982). Its thickness is variable areally because of pre-Jordan erosion. The sandy dolomite of the Black Earth Member forms a wedge about 10 feet thick that extends northward from Mindoro (section L–L') as far as Durand (section M–M') within the 80-foot-thick Lodi Shale Member. The St. Lawrence Formation is an unproductive source of water and is a confining unit.

The Jordan Sandstone is a very fine-grained to medium-grained white to orange sandstone. The upper part of the formation, the Coon Valley Member, is a sandy dolomite (Odom and Ostrom, 1978). The Jordan Sandstone thins eastward from the western part of the province to River Falls in Pierce County where it is about 110 feet thick. Well yields from this formation differ areally but are highest along the western border of the State where the formation generally is a well-sorted sandstone. Whether the Jordan Sandstone is poorly cemented by dolomite, well cemented by calcite, or very well cemented by silica depends on location (M.E. Ostrom, Wisconsin Geological and Natural History Survey, written commun., 1982).

Rocks of the Prairie du Chien Group are present only along the western edge of the northern part of province I. The maximum thickness of these rocks is about 260 feet at Roberts (section N–N'). The Prairie du Chien Group consists of dolomite, sandstone, chert, and oolite (M.R. Thomasson, University of Wisconsin, unpub. data, 1959). These rocks yield sufficient quantities of water for domestic wells in parts of St. Croix and Pierce Counties.

Rocks of the Ancell Group differ consistently in thickness areally because they were deposited on an irregular erosion surface cut into rocks of the Prairie du Chien Group. The Ancell Group is as thick as 120 feet at Roberts (section N–N'). In this part of the province, the Ancell Group is medium- to coarse-grained sandstone that is poorly cemented by dolomite in most places and by limonite locally; it generally is shaly at the bottom of deep channels (M.E. Ostrom, Wisconsin Geological and Natural History Survey, written commun., 1982). The Ancell Group is present only in small areas and generally is only partly saturated; it is used for water supplies in parts of Pierce and St. Croix Counties.

Dolomites of the Sinnipee Group are present only beneath the highest ridgetops in the western part of this area. These rocks generally are unsaturated.

UNCONSOLIDATED DEPOSITS

Unconsolidated deposits in this part of province I consist of Pleistocene glacial deposits and valley alluvium. Glacial deposits, which are absent in the Driftless Area in the south, range in thickness from less than 50 feet to greater than 200 feet (Trotta and Cotter, 1973). Glacial deposits generally are thinnest in the southwest where they commonly are less than 50 feet thick (sections M–M', L–L') and thickest in the north where they commonly are greater than 100 feet thick (section I–I') (Trotta and Cotter, 1973).

Valleys of the Mississippi River and its major tributaries contain alluvium with thicknesses that commonly range from 100 to 200 feet (Trotta and Cotter, 1973). Examples of these alluvium-filled river valleys can be seen where hydrogeologic sections intersect the Mississippi (section M–M'), the Chippewa (section N–N'), the Red Cedar (section N–N'), the La Crosse (section L–L'), and the Black (section L–L') Rivers.

VERTICAL GROUND-WATER FLOW

Flow simulations by Mandle and Kontis (1992) indicate vertical recharge to deep aquifers in Paleozoic rocks over most of this part of province I, as shown by the downward hydraulic gradients across the St. Lawrence–Tunnel City and the Eau Claire confining units. Near the St. Croix and the Mississippi Rivers and their major tributaries, hydraulic head increases with increasing depth (upward arrows). Which indicates ground-water discharge from deep aquifers to these rivers at the western ends of sections N–N' and M–M'. Upward gradients across deep confining units indicate that these rivers are flow boundaries and intercept horizontal flow in deep aquifers.

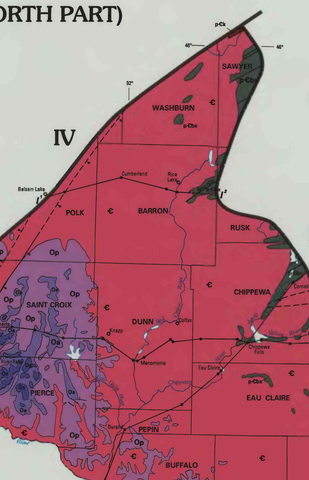
DISSOLVED-SOLIDS CONCENTRATION IN GROUND WATER

Dissolved-solids concentrations in ground water in this part of province I generally are lowest in the north and east in Cambrian sandstones and glacial deposits and highest in the west in water from Ordovician rocks of the Ancell and the Prairie du Chien Groups (section N–N'). Where the sandstone aquifer consists of Ordovician and Cambrian rocks, dissolved-solids concentrations tend to be higher in water from Ordovician rocks than in water from underlying Cambrian rocks (section N–N'). This relation of dissolved-solids concentrations in water from Ordovician and Cambrian units of the sandstone aquifer also has been reported by Borman (1976) and Young and Hindall (1972,1973). Dissolved-solids concentrations in water from alluvium in the valleys of major rivers (Mississippi River in section M–M', La Crosse River in section L–L') generally are similar to those in water from adjoining bedrock aquifers because the water in the alluvium generally is derived from the bedrock aquifers.

CONVERSION FACTORS

To obtain measurements in meters, multiply feet by 0.3048.

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NVGD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.



EXPLANATION
Geologic units in the north part of ground-water province I
Unit on map
Unit in section
QUATERNARY
Q Holocene alluvial and Pleistocene glacial deposits
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