Information Circular
Number 3

UNIVERSITY OF WISCONSIN

WISCONSIN GEOLOGICAL SURVEY

George F. Hanson, State Geologist

GROUND WATER IN WISCONSIN

By

William J. Drescher
Hydraulic Engineer
U. S. Geological Survey

Prepared in cooperation with the
U. S. Geological Survey

Madison, 1956

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GROUND WATER IN WISCONSIN [1]

By

William J. Drescher

INTRODUCTION

The purpose of this report is to describe in general the occurrence, source, movement, and use of ground water in Wisconsin in order that present problems of ground-water development may be understood and to point out the need for study and evaluation of the potential ground water available. Areas with specific problems are described as are other areas that are used as examples. For the sake of brevity complete reports of studies completed or under way are not included, but the general results of such studies are the basis for the report.

Ground water has long been recognized as an important natural resource of the State. T. C. Chamberlin (1877, p. 142) [2] stated that, "So far as possible all cities should be supplied by water from springs or artesian wells." Ground water is becoming increasingly important as a source of supply to meet the demands of an increasing population, a rapidly expanding industry, and increasing irrigation. It is estimated that in 1950 about 30 billion gallons a day of ground water was used in the United States, and about 300 million gallons a day (mgd) was used in Wisconsin (MacKichan, 1951). It is estimated that by 1975 the use of ground water will have doubled.

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[1] Publication authorized by the Director, U. S. Geological Survey

[2] See references at end of report

GROUND-WATER HYDROLOGY

Source

Ground water represents one phase of the hydrologic cycle. Precipitation is the source of all our fresh water supplies. Water from rain, snow, sleet, hail, and even dew is evaporated directly from the surface on which it falls, runs off as surface streams, or seeps into the soil. Some of that which runs off in streams also may subsequently seep into the ground. A portion of the water which percolates into the ground is evaporated by circulating air in the soil, and some of it is returned to the air by transpiration by plants. The rest descends to the zone of saturation, from which it is discharged by springs or seeps to streams, lakes, and oceans and is then evaporated. Very small amounts are released from or taken up by rocks owing to chemical action, but such amounts are so small that they may be disregarded here. It should be noted that, in each phase through which the water passes, evaporation may take place thus returning water to the atmosphere. The process by which water changes from precipitation to surface water and ground water and then by evapotranspiration goes back to the atmosphere is known as the hydrologic cycle.

Occurrence

In order that water may percolate into the ground the soil must be able to absorb the water and transmit it to underlying rocks. In turn the underlying rocks must be permeable if they are to transmit water to points of discharge. Permeability is a measure of the ease with which water moves through a material and depends upon the amount, size, and interconnection of pore space. Few rocks of the earth's crust when taken in the aggregate are entirely impermeable. The crystalline rocks, such as granites and quartzites of the Precambrian, have little pore space and are relatively impermeable except where they are fractured or weathered. Fine-grained rocks, such as clay and shale, may be very porous and contain a great amount of water, but are relatively impermeable owing to the very small size of the pore spaces. Limestones and dolomites generally have little primary permeability, but often have large secondary permeability owing to fractures and bedding planes along which water can move and which are sometimes enlarged by solution to open channels. In limestones and dolomites the permeability then depends to a large degree upon the interconnection of the fractures. The most uniformly permeable materials are gravel and sand. The permeability in such materials will depend upon the uniformity of grain size, the shape and orientation of the grains, and the amount of cementation.

A rock formation, part of a formation, or a group of formations that will transmit water to wells or springs is called an aquifer. The thickness of an aquifer as well as the permeabilities of the rocks comprising the aquifer determine its overall capacity to transmit water. Thus, just as we refer to permeability as indicating the ease with which a given cross-sectional area of a material will transmit water, we refer to transmissibility as indicating the ease with which an entire aquifer will transmit water.

Ground water occurs beneath the water table, which may be considered as the upper limit of the zone of saturation. In a humid climate such as Wisconsin's the water table is generally less than 100 feet below the surface except beneath high, steep-sided hills.

Wherever an aquifer is confined beneath a relatively impermeable bed (confining bed) and the water in a well rises above the top of the aquifer, the water is said to be under artesian conditions and the aquifer is called an artesian aquifer. The height to which the water will rise in a well penetrating an artesian aquifer may be, but is not necessarily, sufficient to cause the well to flow at the land surface.

Recharge

Recharge to an aquifer may be classed as direct, indirect, induced, or artificial.

Direct recharge is the percolation of water downward through the unsaturated zone to the water table. It includes recharge from a stream or other surface water, moving into the ground to become part of the ground-water reservoir.

Indirect recharge is that which occurs when one aquifer is recharged from another, possibly by leakage over a large area or for a long time through a relatively impermeable bed. Such leakage may be in any direction, depending on differences in head.

Induced recharge is caused by lowering the head or water table adjacent to a surface-water body or another aquifer, thereby increasing the movement of water into the aquifer. Induced infiltration is generally restricted to the area near supply wells because the principal method of lowering the water table is by pumping. Another example of induced recharge would be increasing the rate of movement through a confining bed either through wells or by removing a section of the confining bed.

Artificial recharge is accomplished in various ways, divided into two general groups: water spreading and recharge through wells. In water spreading, surface water, or sometimes waste cooling water, is ponded or diverted so that it will cover a large area underlain by an aquifer. The surface over which the water is spread may be treated chemically, biologically, or mechanically in order to increase the rate of infiltration. Recharge through wells is accomplished by pumping or by gravity flow of water into wells penetrating the aquifer. The water used is generally treated surface water or waste cooling water.

Discharge

Discharge of ground water may be classed as natural and artificial. Natural discharge from an aquifer includes spring flow, seepage to surface water, evaporation, and transpiration. Most shallow aquifers discharge by one or more of these methods. Discharge may occur from one aquifer into another through a partially confining bed. Artificial discharge includes pumping from wells or mines, development of springs, and the artificial drainage of marshland or cleaning of stream beds.

Movement

As indicated previously, ground water may move in any direction if there is a difference in head. The difference in head per unit length of travel is called the hydraulic gradient. As the rate of movement is dependent also upon permeability, water will move more readily in a highly permeable material than in one of low permeability. Aquifers generally are more permeable in the direction parallel to stratification than they are across the stratification. Thus, the greatest component of movement usually is parallel to the bedding planes of the aquifer. In the case of an aquifer through which the water moves in fractures, the greatest movement may not be parallel to the bedding planes.

In extensive unconfined aquifers the water table, or piezometric surface, is commonly a subdued replica of the surface topography, the water standing highest under the hills and lowest, near stream level, in the valleys. The depth from land surface to water table is greatest beneath the hills. The resultant hydraulic gradient causes movement of water toward the lowlands where it is discharged. If, however, the aquifer is partially overlain by a confining bed and if the dip of the beds is greater than the hydraulic gradient, the water in moving down gradient becomes confined, or artesian, water.

Water in confined aquifers follows the same physical laws as does unconfined water. That is, it continues to move in response to the hydraulic gradient along the most permeable path. In order to have movement, except in a temporary sense, it is necessary to have discharge. Discharge from confined aquifers may be by any of the methods, mentioned previously, and, as heads may be greater in the aquifer than above or below, it is quite possible to have movement in several directions simultaneously. Thus within the same aquifer water may be moving down dip, upward to the surface, and downward to another aquifer all at the same time.

Water-level fluctuations

Fluctuations of water levels in wells depend upon relative changes in recharge and discharge. In water-table wells there is a rapid rise in the water level in the spring of the year owing to snow melt and spring rains. The condition of the ground and the rate of melting of the snow cover and the rate of precipitation are factors in the rate of recharge to the ground water and, therefore, in the amount of water-level rise. After the spring rise, the discharge - including increased evaporation and transpiration - exceeds recharge, and the water level gradually declines until the following spring. Intermittent rain during the year may cause a rise in the water level or at least may temporarily interrupt the general seasonal decline. Artificial discharge, such as pumping from nearby wells, often causes a rapid decline in water level, but cessation of pumping causes a rapid recovery.

In artesian aquifers fluctuations of water levels are caused by changes in the rates of recharge and discharge and by other phenomena. Changes in barometric pressure cause changes in artesian water levels which last approximately as long as the barometric change. Where an artesian aquifer extends under a large body of surface water, changes in the level of the surface water caused by tides, winds, floods, etc., cause a loading effect on the aquifer and result in water-level fluctuations in nearby wells. A similar fluctuation occurs in some cases when a train passes by a well penetrating a confined aquifer. Earthquakes cause rapid fluctuations of short duration in some wells, but these, like the fluctuations due to loading or barometric pressure change, are not indicative of changes in storage. The water levels in artesian wells located near the recharge or discharge area fluctuate in response to changes in recharge or discharge, thus indicating changes in storage. The amplitude of such fluctuations decreases with increasing distance from the recharge or discharge areas.

Appraisal

The amount of water in the ground at a given time may be called water in transient storage. If water is pumped, the discharge from the aquifer is increased and the storage is decreased. In order to continue pumping without withdrawing all water from storage it is necessary that the hydrologic equation for an aquifer be balanced by an increase in recharge or by a decrease in natural discharge. The amount of ground water available on a continuing basis is that part of the precipitation which directly or indirectly becomes, or is induced to become, ground-water recharge.

An appraisal of the amount of ground water available must take into account each of the factors discussed above. Some of these factors are easily determined; others are determined in combination; and others are practically indeterminable by methods known at this time. Total precipitation can be determined by means of weather stations. Total runoff can be determined by stream measurements, but it includes direct runoff, changes in surface storage, and discharge from ground water. Evaporation, transpiration, and seepage losses are not readily determined on an areal basis. Ground-water movement and changes in storage can be determined by means of adequate and properly interpreted aquifer performance tests and by measurements of water levels in observation wells.

Aquifer performance tests

A study of water-level fluctuations in and near a pumping well will give an understanding of the hydraulic characteristics of the aquifer. A pumping test, or more accurately an aquifer performance test, consists of measuring the rate and amount of decline or recovery of water levels in response to pumping, or stopping the pumping, from a well. By properly interpreting the shape of the time rate of drawdown or recovery curves, the coefficients of transmissibility and storage can be computed. These coefficients in turn can be used to predict the effect of pumping at various rates and for various lengths of time on water levels in the vicinity of a pumping well. Aquifer performance tests are used to determine interference between wells, the location of nearby hydraulic boundaries, drawdown to be expected in a well at any given rate of pumping, the rate of movement of water, the effect of drainage ditches on the adjacent water table, and the amount of available water held in storage in an aquifer.

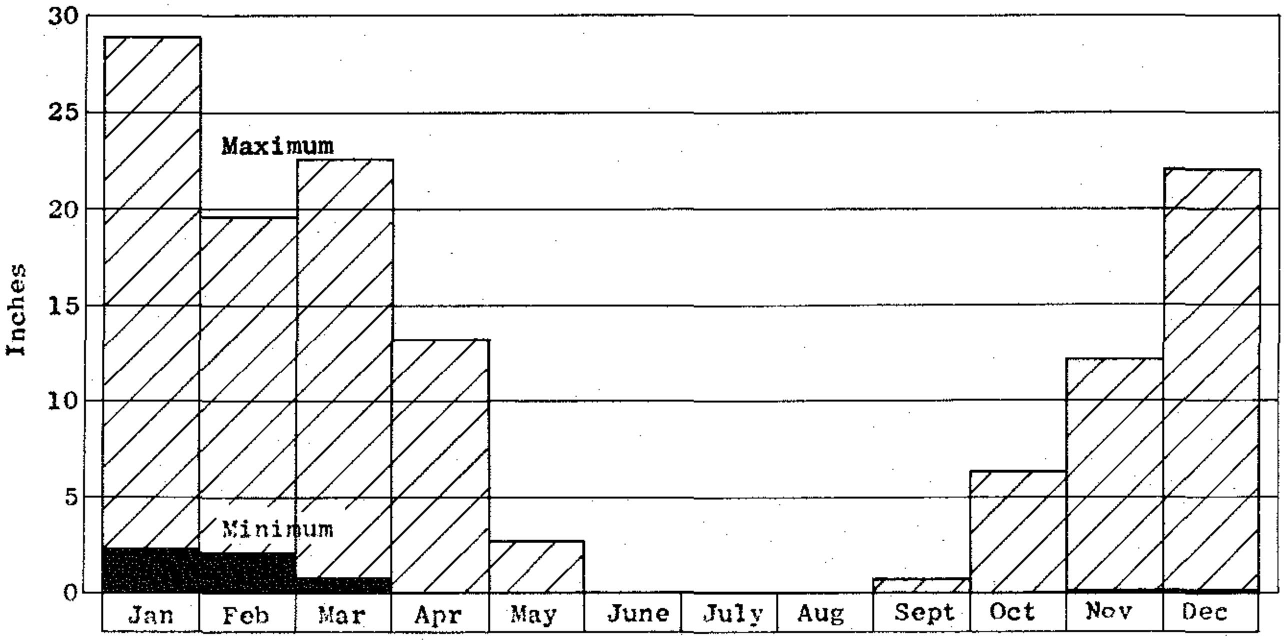
CLIMATE

Climate has a profound effect upon the relationship between various phases of the hydrologic cycle. With respect to ground water, climate influences the amount of water available for recharge, and the rate and amount of evaporation, infiltration, and transpiration.

Figure 1 shows the average, maximum, and minimum monthly precipitation for the State of Wisconsin and the amount of snowfall. Figure 2 shows the average, maximum, and minimum monthly temperatures for the State.

GROUND-WATER PROVINCES

Figure 3 shows the principal ground-water provinces in Wisconsin. The provinces are defined according to the principal aquifers. Figure 4 is a geologic map of the State showing the formations which would be exposed if the surficial material were removed. Table 1 lists the geologic formations and their general characteristics.



Monthly snowfall in Wisconsin 1891-1953

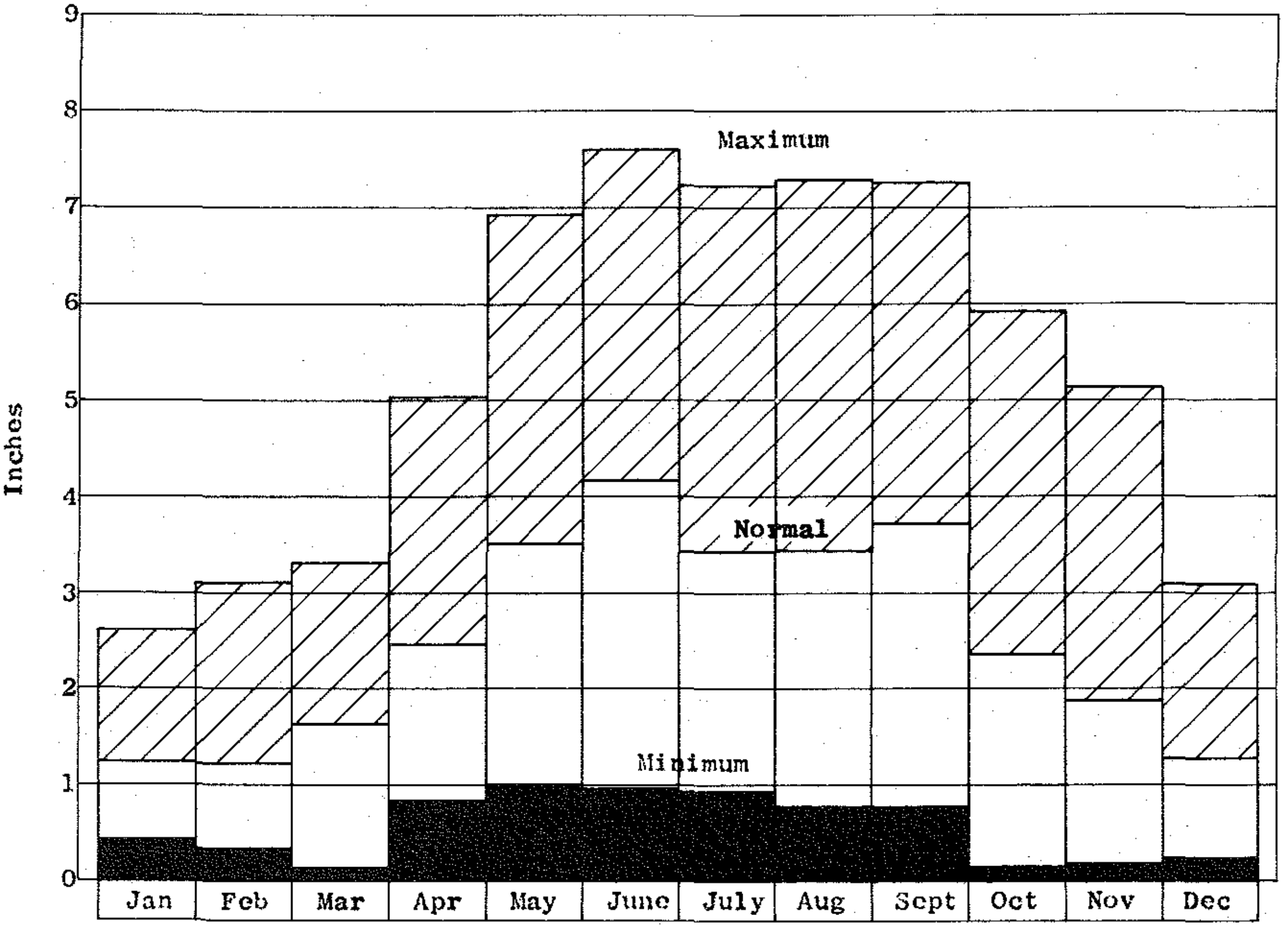


Figure 1.--Monthly precipitation in Wisconsin 1891-1953

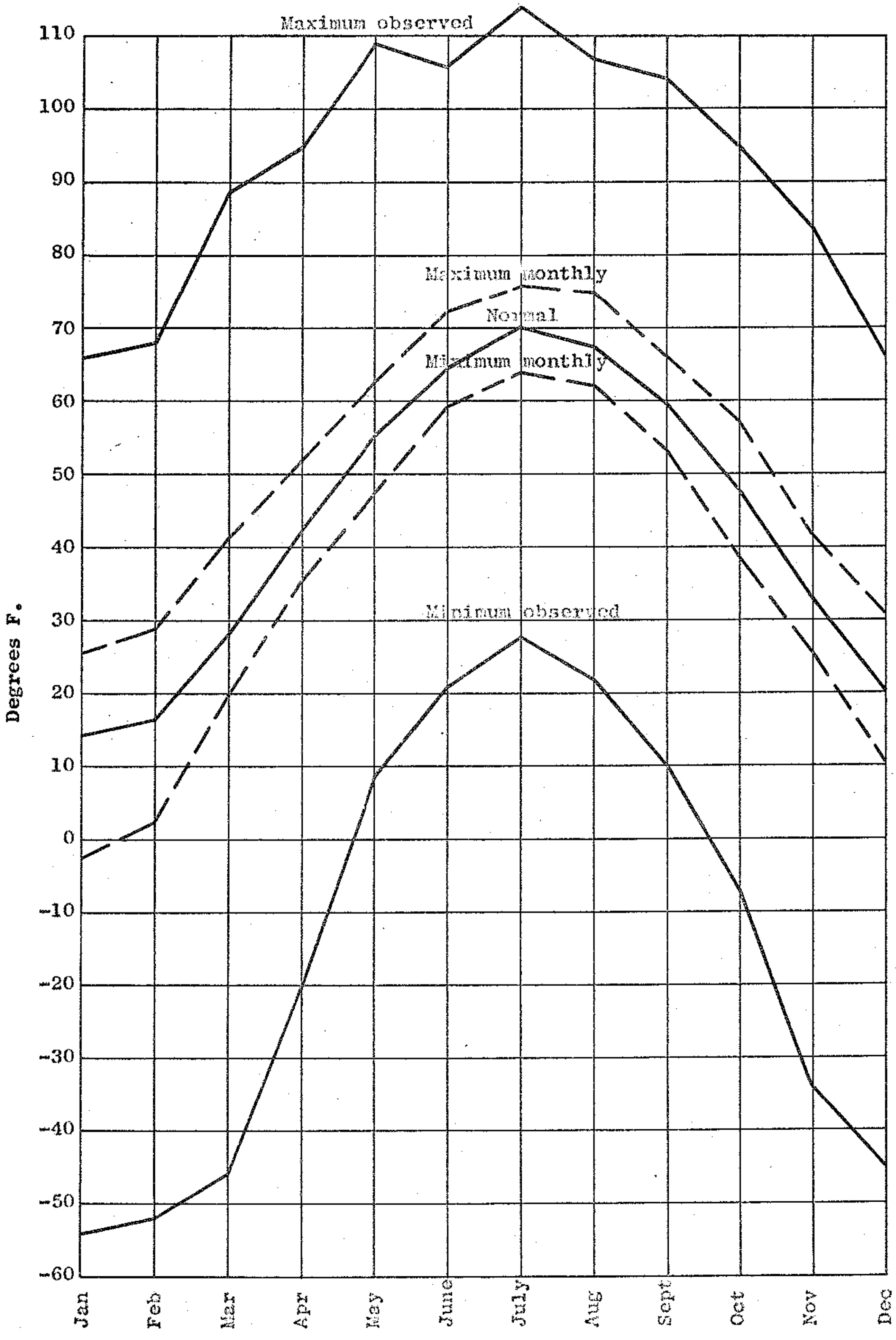


Figure 2.--Air temperatures in Wisconsin 1891-1953

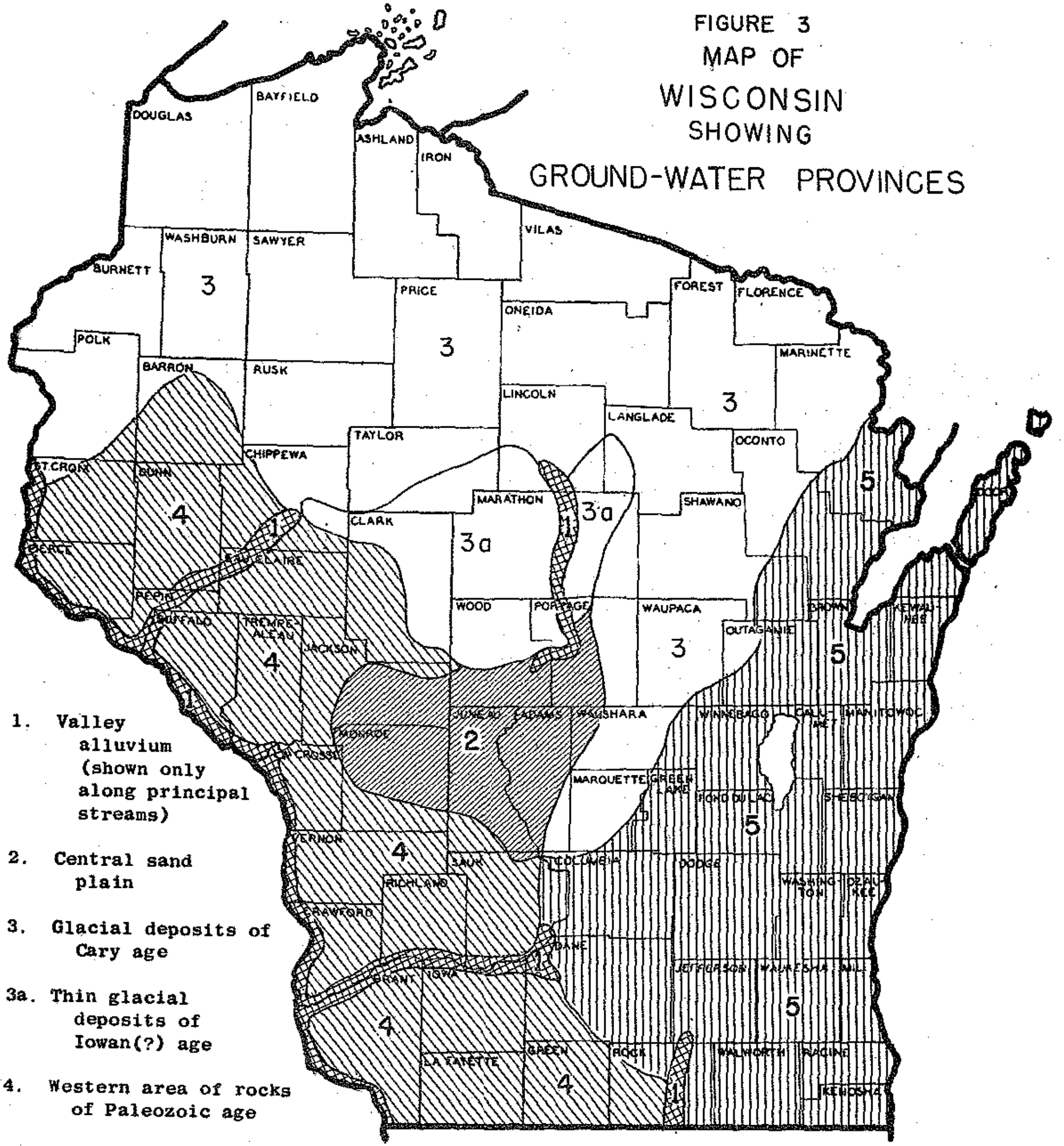


FIGURE 3
MAP OF
WISCONSIN
SHOWING
GROUND-WATER PROVINCES

1. Valley alluvium (shown only along principal streams)

2. Central sand plain

3. Glacial deposits of Cary age

3a. Thin glacial deposits of Iowan(?) age

4. Western area of rocks of Paleozoic age

5. Eastern area of rocks of Paleozoic age

Figure 4
MAP OF
WISCONSIN
SHOWING
BEDROCK GEOLOGY
AFTER BEAN

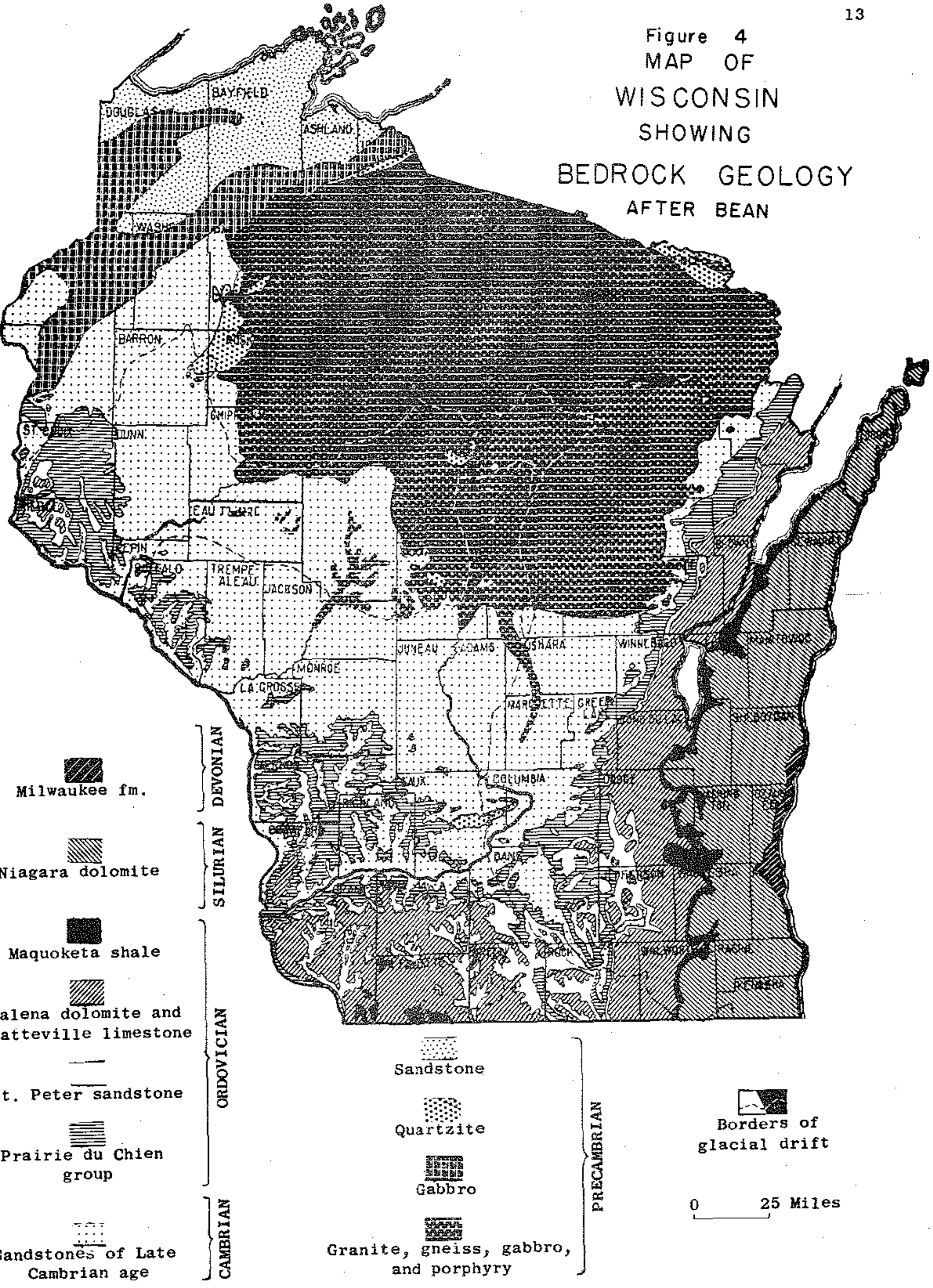


Table 1.--Geologic section for the State of Wisconsin

System	Stratigraphic unit	Thickness (feet)	Character	Water-bearing characteristics	Occurrence by province					
					1	2	3	3a	4	5
Quaternary 1/	Recent alluvium	0-100?	Sand, gravel, peat, muck, marl.	Small to large yields from sand and gravel.	x	x	x	x	x	x
	Pleistocene deposits	0-500	Boulder clay, silt, sand, gravel.		x	x	x	x		x
Cretaceous or Tertiary 1/	Windrow formation		Gravel.	Unimportant.					x	
Mississippian 1/	Unnamed unit	55	Black carbonaceous shale.	Not water yielding.						x
Devonian	Milwaukee formation Thiensville formation 2/	110 50	Shale, dolomite, limestone.	Yields small amounts of water.						x x
Silurian	Waubakee dolomite Niagara dolomite 2/	300-825	White to gray dolomite, some coral reefs. Crevices and solution channels locally abundant.	Yields small to moderate amounts of water.						x x
Ordovician	Maquoketa shale and Neda formation	50-540	Dolomitic shale. Some beds of dolomite up to 40 feet thick.	Usually not an aquifer. Yields small amounts locally.					x	x
	Galena dolomite Decorah shale 2/ Platteville limestone	200-350	Dolomite and limestone. Some shale (Decorah). Sandy at base.	Yields small supplies, principally in areas where not overlain by shale.					x	x
	St. Peter sandstone	0-330 (Missing in places)	Sandstone, fine to medium grained, white to light gray to pink, dolomitic in places, crossbedded. Red shale near base in some places.	Yields small to moderate amounts of water.					x	x
	Prairie du Chien group (Includes Shakopee dolomite and Oneota dolomite.)	0-200 (Missing in places)	Dolomite. Sandy in some zones.	Yields small to moderate amounts of water.					x	x
Cambrian	Trempealeau formation Franconia sandstone Dresbach sandstone 2/ Eau Claire sandstone Mount Simon sandstone	0-1000+	Fine to coarse grained sandstone, dolomitic, some shale and dolomite beds. Eau Claire and Franconia often shaly.	Yields small to large amounts of water depending upon permeability and thickness. Each formation may be an aquifer but usually considered in aggregate.					x	x
Precambrian	3/		Sandstone, quartzite, slate, granite, and other crystalline rocks.	Water in sandstone is highly mineralized. Other rock types yield small amounts of water where creviced or weathered.	x	x	x	x	x	x

1/ Not shown on map of bedrock geology (fig. 4).
2/ Not separated on map of bedrock geology.
3/ Shown by principal lithology on map of bedrock geology.

Valley Alluvium

Valley alluvium occurs principally in the areas designated by "1" on figure 3 along the Mississippi, Wisconsin, Chippewa, and Rock Rivers. Many other stream valleys, containing sand and gravel aquifers, belong in this province but are not shown on figure 3 because of their relatively small size. During Pleistocene time the river valleys were incised deep into the rocks. Subsequently the valleys were filled with sand and gravel and smaller amounts of silt and clay, deposited by the rivers as the runoff diminished. The sands and gravels are as much as 200 feet thick and comprise the most prolific aquifers in the State. In each case, except that of the upper Wisconsin River, the alluvial sand and gravel is underlain by sandstones of Cambrian age which also will yield water but at smaller rates owing to their lower transmissibilities. The upper Wisconsin River valley is underlain by crystalline rocks of the Precambrian which yield little or no water. Precipitation directly recharges the alluvial sand and gravel, and indirect recharge occurs in most of the valleys by water under artesian pressure leaking upward from the underlying sandstones. Induced recharge occurs where wells have been constructed near the rivers and water is moving from the river into the ground and toward the wells. Induced recharge could be increased greatly in this province. Artificial recharge by water spreading is feasible but has not been practiced.

Natural discharge from the alluvium is to surface streams and by evaporation and transpiration. Artificial discharge from wells makes up the remainder of the total discharge, except in a few places where discharge is to underlying aquifers.

Central Sand Plain

The central sand plain province is located in the central part of the State and includes glacial outwash and lake deposits, alluvium, and weathered sandstones. See area "2" on figure 3. The unconsolidated sands are underlain by sandstones of Cambrian age. The sandstones are less permeable and, therefore, of secondary importance as aquifers.

Recharge to the sand plain is by direct precipitation. Induced or artificial recharge would be possible in some places in the area. Discharge is to streams, by evaporation, transpiration, movement into the sandstones, and by wells, pits, and drainage ditches.

Glacial Deposits

In a large part of northern Wisconsin, area "3" on figure 3, the bedrock is composed of crystalline rocks of Proterozoic age or of sandstones of Cambrian age which contain very limited amounts of water. Plentiful supplies of ground water are obtained only from sands and gravels in the unconsolidated surficial deposits of glacial origin or from valley alluvium; in places where such deposits are scarce or lacking, such as area "3a", little or no ground water can be obtained.

Recharge and discharge in the glacial province is much the same as in the sand plain - that is, direct recharge from precipitation and discharge to streams and by evaporation and transpiration.

Western Area of Rocks of Paleozoic Age

Overlying the Precambrian rocks in western, southern, and eastern Wisconsin are rocks of Paleozoic age ranging from Cambrian through Early Devonian. In the western and southwestern parts of the State, designated as area "4" in figure 3, aquifers consist of sandstones of Cambrian and Ordovician age and limestones and dolomites of Ordovician age. The entire sequence of formations may act as a single aquifer or, where there are less permeable zones separating parts of the sequence, there may be several aquifers. This area was not covered by glacial deposits and is known as the "Driftless Area". The mantle material overlying the bedrock is generally thin and, therefore, is not important as a source of water.

Recharge to the aquifers is by precipitation and may be through overlying aquifers. Discharge is ultimately to streams, but many of the aquifers discharge into underlying aquifers. The aquifers may discharge also by natural seepage and evaporation where they are exposed on the hillsides. Movement of water in this province is complex. For instance, water from precipitation falling on the high land may move downward through successive aquifers until it reaches a point lower than the adjacent valley floor. If the mantle material along the bottom of the valley is permeable the water may then move toward the stream and return upward to be discharged at the surface. If on the other hand, the material in the bottom of the valley is relatively impermeable, the water may be under artesian pressure and will discharge only very slowly to the stream. A well drilled through this permeable material and into the aquifer below will be artesian and, if there is sufficient pressure, it will flow at the surface.

Within the western province of rocks of Paleozoic age, sufficient water for small-capacity wells usually can be obtained from either the sandstones or the limestones. Large-capacity wells usually must be drilled into the sandstones of Cambrian age.

Eastern Area of Rocks of Paleozoic Age

Overlying the Precambrian rocks in eastern and southeastern Wisconsin are formations of Paleozoic age which in turn are covered by glacial deposits of Pleistocene age. This province is designated as area "5" in figure 3. Locally any one of the formations except the Maquoketa shale may be considered an aquifer. Generally speaking, however, certain formations may be grouped and considered as a single aquifer. Thus, the sandstone aquifer is composed primarily of sandstones of Cambrian and Ordovician age but includes dolomite and limestone of Ordovician age. The "dolomite aquifer" consists mostly of the Niagara dolomite of Silurian age. In many places water may be obtained also from sand and gravel deposits of Pleistocene age.

Sandstone aquifer

The sandstone aquifer underlies the entire eastern area of rocks of Paleozoic age. It includes the Mount Simon, Eau Claire, Dresbach, Franconia, and Trempealeau formations of Cambrian age, all of which are composed mostly of sandstones with some interbedded shale and dolomite. Each of the formations contributes some water to wells but the Mount Simon and Dresbach sandstones are believed to be the most productive. The Prairie du Chien group, the Platteville limestone, and the Galena dolomite, all of Ordovician age, are important aquifers where they are exposed or are overlain only by glacial drift, but are believed to yield little water to wells where they are deeply buried, particularly where the Maquoketa shale overlies the Galena dolomite. The St. Peter sandstone, also of Ordovician age, yields some water to wells - the amount depending primarily upon the saturated thickness penetrated by the individual well.

Recharge to the sandstone aquifer is principally through the glacial drift in the area west of the west limit of the Maquoketa shale. Water from precipitation must percolate through the drift and through the limestones and dolomites, where present, in order to reach the sandstones.

Discharge from the sandstone aquifer is both natural and artificial. The principal natural discharge is to the Rock and Fox Rivers and their tributaries. Some discharge occurs by movement of water upward through the Maquoketa shale, Niagara dolomite, and mantle deposits and into Lake Michigan.

The sandstone aquifer is the most heavily pumped aquifer in Wisconsin, largely because of the concentration of population and industry in the eastern part of the State.

Dolomite aquifer

The dolomite aquifer includes the Niagara dolomite of Silurian age and, in parts of Milwaukee, Ozaukee, and Sheboygan Counties, some dolomite of Devonian age. The dolomite aquifer supplies moderate to large amounts of water to wells in the eastern part of the State (see fig. 4). In much of Ozaukee, Sheboygan, Manitowoc, Calumet, Kewaunee, and Door Counties the dolomite aquifer and the Pleistocene deposits are the only source of ground water because the water from the sandstone aquifer is saline.

Recharge to the dolomite aquifer is from direct precipitation on areas of outcrop and from water that percolates through the overlying glacial deposits.

Discharge from the dolomite aquifer takes place principally to streams and to Lake Michigan, but artificial discharge through wells also is important. Discharge, like recharge, is usually quite localized so that water does not travel great distances in the dolomite aquifer. Such travel is estimated to be less than 5 miles in most places.

In many places the dolomite aquifer is overlain by sand and gravel deposits of Pleistocene and Recent age. Such deposits are often hydraulically part of the dolomite aquifer but in places these deposits may form small independent aquifers.

USE OF GROUND WATER

The uses of ground water in Wisconsin may be grouped into three categories - municipal, industrial, and rural, but it should be recognized that there is considerable overlapping among the three categories. Municipal use includes much water pumped for industries which are wholly or partially dependent upon public supplies. Many suburban homes have their own wells which are included under rural supplies.

Municipal

Ground water is the source of water for about 1,113,000 people in Wisconsin living in 446 communities having public water supplies. Madison, the largest city using ground water for public supply, uses an average of 13 mgd. Table 2 lists the average pumpage and per-capita use of ground water for Wisconsin municipalities with populations of more than 10,000. Total municipal pumpage from ground-water sources is estimated to average about 95 mgd.

The remaining urban population, about 1,109,000 in 36 communities, is supplied with surface water, principally from Lakes Michigan and Superior.

Table 2.--Pumpage of ground water by Wisconsin municipalities of over 10,000 population

City	Population (1950)	Average pumpage (1952) (mgd)	Pumpage per capita (1952) (gpd/capita)
Beaver Dam	11,867	.865	73
Beloit	29,590	5.11	173
Chippewa Falls	11,088	1.90	172
Eau Claire	36,058	10.00	277
Fond du Lac	29,936	2.60	87
Green Bay	52,735	6.55	124
Janesville	24,899	4.17	167
La Crosse	47,535	7.15	150
Madison	96,056	12.81	133
Manitowoc	27,598	4.15	150
Marshfield	12,394	1.23	100
Stevens Point	16,564	1.47	89
Watertown	12,417	1.07	86
Waukesha	21,233	2.84	134
Wausau	30,414	3.46	114
Wauwatosa	33,324	3.27	98
Wisconsin Rapids	13,496	1.55	115

Industrial

Table 3 lists industrial use of ground water in the Milwaukee-Waukesha area (Foley and others, 1953, table 6) and in the Green Bay area (Drescher, 1953, table 4) in 1949. It is estimated that total industrial pumpage in Wisconsin, exclusive of that pumped by municipalities, exceeds 100 mgd.

Rural

Rural use is applied here to all ground-water use in rural areas except that used by industries. Such use includes water used for domestic purposes, stock watering, and irrigation.

About 1,212,000 people in Wisconsin live in rural homes or in small villages not having public water supplies. It is estimated that the use of water for domestic purposes by the rural population averages 40 gallons a day per capita. Thus, since virtually all rural supplies are from ground water, about 48 mgd of ground water supplies rural domestic needs.

The amount of ground water used for stock watering cannot be calculated accurately. It is estimated, however, that about 65 mgd is used for this purpose.

Irrigation of farm crops has been an additional rural use of ground water for the past several years. Ground water may be used for irrigation by spraying, by flooding, or by regulation of the water table (subirrigation). Subirrigation is used in several areas in the State, largely on muck or peat lands. Water used for subirrigation is usually a part of that which would otherwise be drained off either naturally or artificially. No data are available on which to base estimates of the amount of water used for subirrigation.

Table 3.--Industrial use of ground water in the Milwaukee-Waukesha 1/ and Green Bay 2/ areas in 1949

Type of industry	Average use (mgd)	
	Milwaukee-Waukesha 3/	Green Bay 4/
Paper manufacturing	----	1.98
Malting	5.17	----
Metal working and fabrication	4.22	.16
Brewing	3.33	.40
Meat packing	.91	.24
Dairy-products processing	.68	.58
Tannery processes	.68	----
Food canning and processing	.57	.91
Cold storage and ice manufacture	.39	.67
Railroads	.13	.18
Gas and power generation	----	.18
Laundries	----	.09
Miscellaneous commercial	1.34	1.08
Miscellaneous industrial	.02	.05
Total	17.44	6.52

1/ (Foley, 1953)
2/ (Drescher, 1953)
3/ Excludes water from municipal supplies of Wauwatosa, Waukesha, Town of Lake, Greendale, Pewaukee, and Menomonee Falls.
4/ Excludes water from municipal supplies of DePere and Allouez.

Most water for irrigation in the State is applied by spraying or sprinkling owing largely to the sandy nature of the soil in irrigated areas which precludes irrigation by flooding. The largest single use is for irrigation of potatoes, but many truck-garden crops also are irrigated. In southwestern Langlade County (Harder and Drescher, 1954, p. 29) about 18 acre-feet of ground water was used for irrigation in 1949. In 1953 about 1,500 acre-feet was used for irrigation in Portage County. It is estimated that about 2,500 acre-feet of ground water was used for irrigation in the entire State in 1953.

Table 4 shows the total estimated use of ground water in Wisconsin in 1953.

QUALITY

The geology is such that, by proper construction of wells, water usually can be obtained free from bacteriological contamination. Only in the few limited areas where a very thin glacial drift covers crystalline rock does the development of safe water supplies pose a problem. In areas where shallow limestone aquifers may be subject to contamination, safe supplies often can be obtained by utilizing deeper aquifers.

The mineral content of ground waters varies materially and is related to the geology. The approximate hardness of well waters in the different sections of the State is shown on figure 5. This figure shows that the softest water is in the north-central part of the State and the hardest water is in the eastern part of the State. Saline waters are found at depth in the eastern and northwestern parts of the State and also at a few other isolated places. In the areas where saline water is found, it is usually possible to develop suitable water supplies from other formations.

Table 4.--Estimated use of ground water in Wisconsin in 1953

Type of Use	Population served	Acre-feet	Millions of gallons a day
Municipal ------------------	1,113,000	---------	95
Industrial 1/ ------------	---------	---------	100 2/
Rural ---------------------	---------	---------	-------
Domestic ---------------	1,212,000	---------	48
Stock ------------------	---------	---------	65
Irrigation -------------	---------	2,500 2/	2 2/
Total ---------------	2,325,000	---------	310

1/ Exclusive of that pumped by municipalities.
2/ Based in part on figures from 1949.

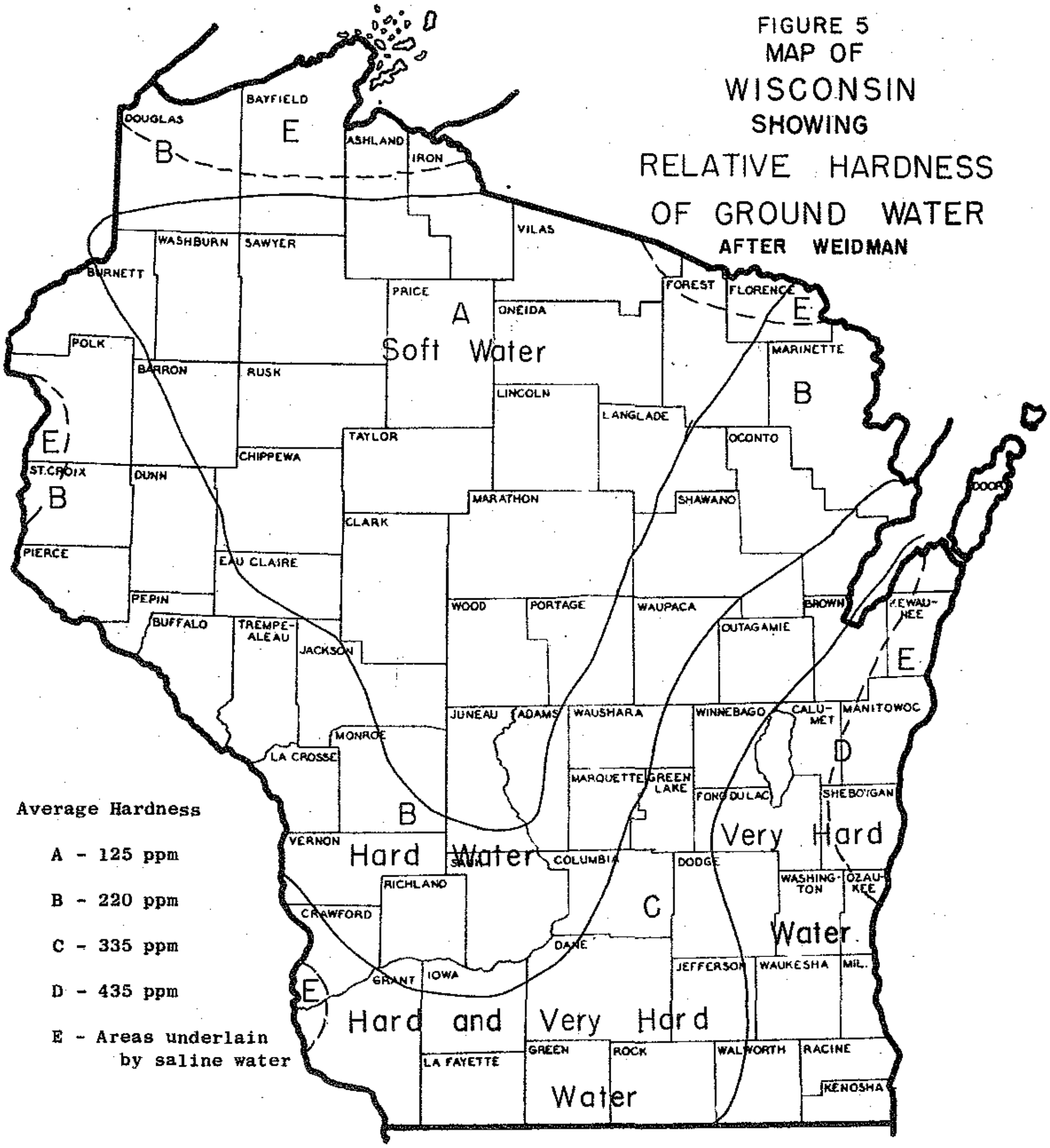


FIGURE 5
MAP OF
WISCONSIN
SHOWING
RELATIVE HARDNESS
OF GROUND WATER
AFTER WEIDMAN

Average Hardness

A - 125 ppm

B - 220 ppm

C - 335 ppm

D - 435 ppm

E - Areas underlain by saline water

The iron content of water from wells drilled for domestic purposes ranges from zero to about 25 parts per million. Most of the waters high in iron content are derived from the sandstones or from the glacial drift. In the sandstones, the iron content often increases with depth. Through site and aquifer selections, based on studies of existing wells or on test drilling, it is usually feasible to develop supplies having an iron content of less than 0.3 part per million. Where this is not possible, the concentration usually can be held within treatable limits.

Except for a narrow belt extending from Green Bay to the Illinois State Line, ground waters have a low fluoride content. The maximum content of 2.8 parts per million was found in a Green Bay city well which produces water from the sandstone aquifer. A content of 1.0 to 1.5 parts per million of fluoride in drinking water is considered helpful in reducing tooth decay in children without danger of the mottling of tooth enamel that occurs at higher concentrations. Only 13 of the public-utility ground-water supplies show a natural fluoride content of 1.0 part per million or more.

The areas of the State which are known to be underlain by aquifers containing saline waters are shown in figure 5. The source of salt is not known, but these waters are commonly referred to as connate. Connate water is usually defined as water trapped during deposition of the sediments, but it is probable that the saline water now entrapped is water from seas which covered all or part of Wisconsin at a later time than that of original deposition. In the saline-water areas potable water supplies may usually be developed from shallower aquifers.

GROUND-WATER PROBLEMS IN WISCONSIN

The ground-water problems of Wisconsin may be classed in several ways. A very broad separation may be made of the problems of obtaining sufficient water from those of eliminating excess water or, more simply, supply problems and drainage problems.

Supply problems may be broken down into geologic problems, quality problems, and economic problems. In each case, however, these classifications overlap so that any one problem is apt to be a combination of two or more categories. Drainage problems involve draining of farm lands and dewatering of mines.

Economic Problems

Milwaukee-Waukesha area

In 1946 the University in cooperation with the U. S. Geological Survey started an investigation of ground-water conditions in the Milwaukee-Waukesha area. A report (Foley and others, 1953) was published describing in detail the findings of the investigation. An average of about 40 mgd of ground water is pumped in the area. Water levels in the sandstone aquifer have declined about 400 feet since 1875. Water levels in the dolomite aquifer have declined very little except in downtown Milwaukee. The decline in water levels in the sandstone aquifer is a result of (1) concentrated withdrawal in an area more than 25 miles from the recharge area and (2) the low transmissibility of the aquifer. Water levels will continue to decline so long as the rate of pumping continues to increase.

Possible remedial measures include water conservation, dispersing wells to the west, pumping a larger percentage of water from the dolomite and glacial aquifers, and artificial recharge.

Artificial recharge might be done by injecting cool lake water into wells in the winter time. Such water could be drawn from the filtered supply of the city of Milwaukee during periods of low demand. In effect it would be storing cool water underground until it is needed in the summer months. Inasmuch as most of the ground water is pumped because of its constant temperature, which in the summer is lower than that of surface water, such artificial recharge might prove particularly advantageous.

Green Bay area

A report (Drescher, 1953) has been published on the ground-water conditions in the sandstone aquifer underlying the Green Bay area. The problem at Green Bay is somewhat similar to that at Milwaukee. Water levels have declined about 400 feet because of concentrated withdrawal from an aquifer of low transmissibility. Pumpage amounts to about 11 mgd. The principal recharge area begins about 7 miles west of Green Bay. Water levels will continue to decline so long as the rate of pumping continues to increase. At least 30 mgd is estimated to be available for development in the recharge area.

The City of Green Bay is now (1956) in the process of changing to a supply from Lake Michigan. Other possible remedial measures consist of dispersing wells to the west toward the recharge area, drilling wells into the dolomite aquifer east of the City, or using other surface water as a source of supply. No means of artificial recharge appears to be feasible.

Geologic Problems

Fond du Lac

The Fond du Lac area has a combined economic and geologic problem. An investigation, started in the area in September 1953, is still in progress. In addition to the problem of concentrated withdrawal, there is a problem of geologic structure. A buried ridge of the Precambrian rocks impedes the movement of water and also causes a decreased thickness of the sandstone aquifer. The study will aim at determining the location and extent of the Precambrian ridge, locating areas of sandstone of adequate thickness that are locally recharged, and determining whether other aquifers may be effectively utilized.

Marshfield

Within the area designated as province "3a" on figure 3, a number of cities and villages have had difficulty in locating sufficiently productive aquifers. Marshfield is chosen for discussion because it is one of the communities which, with the aid of scientific knowledge, has solved its problem for the present. Faced with the threat of extreme shortage, owing to increasing demand for water, the City embarked in the middle 1940's on a program of test drilling. Of the many locations tested, only one proved promising enough to put down a supply well. This new well was put into use immediately, but the supply was insufficient for the near future. In 1949 the City arranged with the University of Wisconsin for geophysical exploration work. At that time the U. S. Geological Survey, with which the University cooperates on groundwater investigations, was looking for an area in which to test electrical-resistivity methods for location of water-bearing gravels in preglacial valleys. The result was that geophysical work was done in the Marshfield area in 1949 and 1950 and a gravel-filled preglacial valley was found. A well was drilled by the City into this gravel and has proved to be one of the best wells in the area. By distributing pumping among the new and old wells, the City has been able to meet all demands and hopes to drill new wells into the same gravel-filled valley as demand increases.

Neillsville

Geophysical methods of exploration were tried at Neillsville in an effort to test the methods and at the same time find a suitable aquifer. Electric resistivity did not accurately portray geological horizons, and two test holes drilled by the City failed to penetrate an aquifer. The Geophysical Section of the Department of Geology, University of Wisconsin, used seismic methods in the area and found no favorable location for test drilling. As a result the City in this case gave up looking for a ground-water supply and continued use of the Black River. It is of interest that, under the geologic conditions at Neillsville, seismic methods gave more accurate results than did electrical resistivity methods.

Quality Problems

Quality problems exist in areas of saline water (high chloride and/or sulfate), and also in areas of high-iron water. With respect to the saline-water areas it is to be noted that existing data are far from sufficient to permit accurate delineation of the areas or to determine whether the areas are increasing or decreasing in extent. Studies are definitely needed at this time to ascertain whether or not saline water is being drawn toward the heavily pumped areas.

Although it is recognized that much can be done to avoid high-iron water by test drilling and by studies of existing wells in a particular area, it is believed that much benefit will accrue to the State through a study of areas in which high-iron water is common. Such study should seek to determine the horizons that are affected, means that may be utilized to exclude the iron-bearing water from wells, and basic data with respect to the origin and movement of water high in iron content.

IRRIGATED AREAS

Irrigation with ground water requires a combination of the proper soils and adequate water at reasonable cost. The problem is, therefore, both geologic and economic.

Antigo Flats

A report (Harder and Drescher, 1954) has been published on the ground-water conditions in the southwestern part of Langlade County. It was determined that about 5 percent of the total water pumped in the area was used for irrigation. However, with subsequent increases, it is estimated that 10 percent of the total pumpage is now used for irrigation. This amounts to an average of about 120,000 gallons a day for irrigation. It is estimated that the average recharge to the area is about 26 mgd.

Portage County

A detailed study of ground-water conditions in Portage County is in progress. No conclusions have been published but available data indicate that large quantities of ground water are available for irrigation or other purposes.

There are many other areas in the State in which use of ground water for irrigation is increasing, but as yet the data available are insufficient to make more than a rough estimate of the total pumpage. (See table 3.)

GROUND-WATER INVESTIGATIONS

Ground-water investigations fall into two broad categories: those undertaken on a Statewide basis for the collection of basic data, and detailed investigations of areas where problems may exist.

For many years ground-water investigations were made by the Wisconsin Geological Survey. In 1945 the State Legislature authorized the University of Wisconsin to enter into a cooperative agreement with the U. S. Geological Survey to undertake studies of the ground water in the State. The Wisconsin Geological Survey and the U. S. Geological Survey work in close cooperation on all aspects of ground-water studies in order that the work of one may supplement that of the other without conflict or duplication. Both agencies also work closely with the State Board of Health, which is charged by law with the responsibility of insuring that wells are properly constructed and maintained to guard against pollution and of controlling installation of wells of high capacity so as to protect public-water supplies.

The type of work undertaken by the two Surveys may be roughly divided as follows:

1. Well logging and subsurface geology. A knowledge of the formations underlying the surface is the keystone of all ground-water studies. In order to accomplish this, samples of rock from wells, taken at 5-foot intervals, are sent by well drillers to the Wisconsin Geological Survey.

They are carefully examined, bottled, and filed, and a log drawn up in order to provide a permanent record. About 190,000 samples have been examined.

2. Measurement of ground-water levels. About 250 observation wells are maintained throughout the State. Thirty-two of these are equipped with continuous recording devices and others are measured, at regular intervals, by means of a tape. Supervision of this work is by the U. S. Geological Survey.

3. Detailed-areal investigations. Areas to be investigated are selected in collaboration between a University Committee headed by the State Geologist and the U. S. Geological Survey, and the investigations are made by geologists and engineers of the Survey. These investigations are quantitative in nature and require highly trained and specialized personnel. They enable an appraisal to be made of the ground-water resources of the area in question; this not only permits the current problems to be analyzed but, by projecting the effects of ground-water withdrawal into the future, allows future problems to be anticipated. The results of these investigations are published principally by the U. S. Geological Survey.

4. Basic data. The data gathered over the years by the Wisconsin Geological Survey, and more recently by the U. S. Geological Survey, are of inestimable value in providing information to municipalities, industries, well drillers, and consultant engineers on water-supply problems. They are available in open files in the offices of the cooperating agencies in Madison.

In addition to the work done by the Geological Surveys, the Geophysics Section of the University of Wisconsin's Geology Department has been most cooperative in undertaking geophysical exploration for water-bearing horizons in areas where water supplies are critical (Woollard and Hanson, 1954).

GROUND-WATER LAW

Chapter 144 of the Wisconsin Statutes authorizes the State Board of Health to cooperate with the U. S. Geological Survey in collecting information on quality of natural waters and delegates to the Board supervision over the waters of the State insofar as their sanitary condition is concerned. This law also delegates to the Board the control over the installation of wells of high capacity - namely, those pumped at a rate of 100,000 gallons a day or more, in order to protect public-utility wells.

Chapter 162 gives the Board control over all methods of obtaining ground water for human consumption and provides for the registration of well drillers and pump installers.

Section 348.425 prohibits waste or malicious injury of any natural resource within the State. It is believed that this section is applicable to ground water inasmuch as ground water is a natural resource.

Section 88.06(6) requires that the effect of farm drainage on ground-water levels be given consideration in determining the feasibility of a proposed drainage district.

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