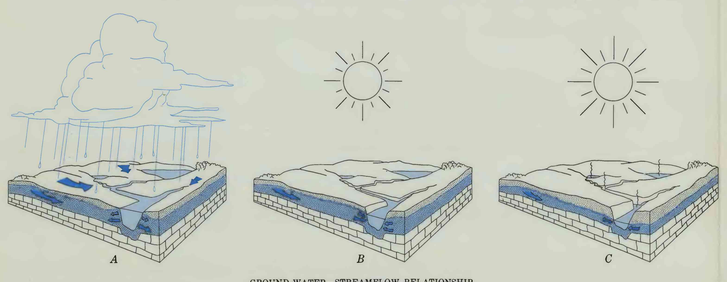
GROUND-WATER—SURFACE-WATER RELATIONSHIPS

Ground and surface water are directly related. Both seasonal and long-term increases or decreases in precipitation also cause corresponding increases or decreases in the ground-water level, streamflow, and lake stage. Natural changes in ground-water level, streamflow, or lake stage cause corresponding changes in the others. Over a long period, natural changes are balanced.

The quality of ground and surface water are usually similar. However, surface-water quality is subject to greater variability because of overland runoff and manmade changes.

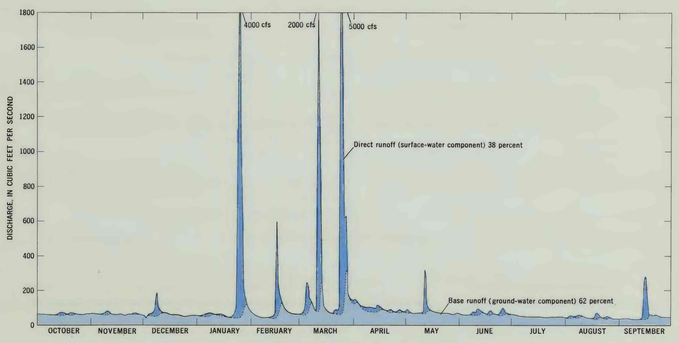
GROUND-WATER CONTRIBUTION TO STREAMFLOW



GROUND WATER—STREAMFLOW RELATIONSHIP

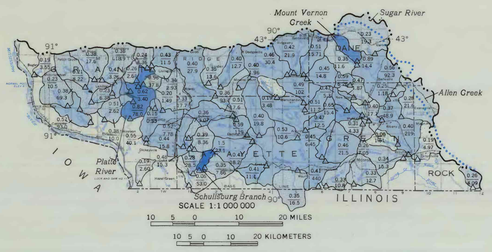
The three sketches above show the general relationship between streamflow and ground water. Streamflow is a combination of surface and ground-water runoff. During rapid snowmelt, and periods of prolonged, heavy precipitation, overland flow is quickly carried off by streams. Water that recharges the shallow ground-water reservoir during these periods is discharged more slowly and maintains streamflow during dry periods.

During periods of heavy rainfall or snowmelt, stream stages and ground-water levels rise (*A*). Water moves into streambanks, raising ground-water levels adjacent to the streams. As stream stages recede, water stored in the streambanks returns to the streams, followed by a general decline in ground-water levels as the ground water is discharged to the streams (*B*). Stream stages and ground-water levels continue to decline (*C*) until the next significant rainfall or snowmelt.



SEPARATION OF STREAMFLOW HYDROGRAPH

The approximate surface and ground-water components of streamflow are shown on the hydrograph of the Grant River at Burton for water year 1967. Snowmelt or precipitation in January, February, and March produced the major high flows during the year. Base runoff was consistent for almost 9 of the 12 months, but was retarded during peak streamflow and increased sharply after passage of each flood crest.



DISTRIBUTION OF LOW-FLOW RUNOFF, SEPTEMBER 16-18, 1969

EXPLANATION

Runoff, in cubic feet per second per square mile of subbasin

- 0.00-0.20
- 0.20-0.40
- 0.40-0.60
- 0.60-0.80
- 0.80-1.0
- 1.0 and above

Boundary of subbasin and streamflow measurement site

Upper number is net gain of runoff, in cubic feet per second per square mile; lower number is discharge in cubic feet per second, September 16-18, 1969

Surface-water divide

Ground-water divide

Low-flow discharge of streams in the study area generally is uniform and consists mainly of ground-water runoff. Low-flow discharge was converted to discharge per unit area (cubic feet per second per square mile) to compare the contribution of the many subbasins of different size. Most subbasins had yields between 0.20 and 0.60 cfs per square mile.

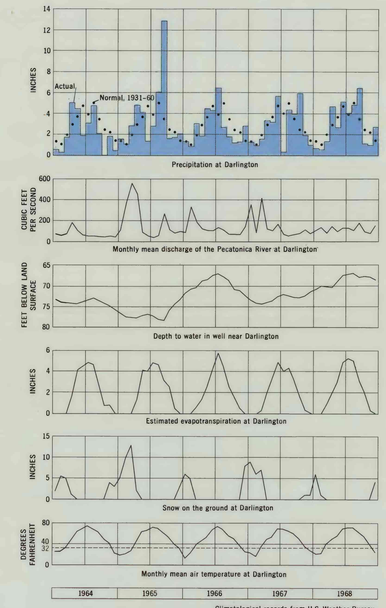
Geologic formation and structure provide the most important control of ground-water runoff rates, with two areas of similar geology having similar runoff rates. The geology of the study area is very uniform. Most streams form in the Galena-Platteville unit and erode down into the St. Peter Sandstone and Prairie du Chien Group in the lower reaches. Because the glacial deposits in the study area are relatively thin, there is no discernible difference in runoff rates between the glaciated and unglaciated areas. The large deposits of outwash in the Sugar River valley do not produce as high a runoff rate as would be expected because much of the outwash has only moderate permeability.

There are a few exceptions to the overall uniform runoff, which can be explained by the characteristics of the individual basins and their physical setting. The very high runoff rate for Mount Vernon Creek is due to a large spring, possibly related to faulting, located a short distance upstream from the measurement site.

A large decrease in ground-water discharge was observed along the mainstem of the Platte River near Lancaster where the Prairie du Chien-Shakopee aquifer is exposed. This anomaly may be caused by either structural control of ground water or by artesian discharge from Cambrian sandstone. A very steep ground-water gradient occurs in this area.

The runoff rate can be artificially controlled, as is the case with the Shullsburg Branch (of the Galena River). Dewatering of mines in this area diverts the natural ground-water movement and artificially augments the flow of the stream.

Differences in area between the ground-water and surface-water basins can account for differences in runoff rates. The upper Sugar River and Allen Creek basins both have ground-water basins smaller than surface-water basins. Because the runoff rate is calculated using surface-water basin area, the rates of runoff for these two areas are lower than would be obtained using just the contributing area.

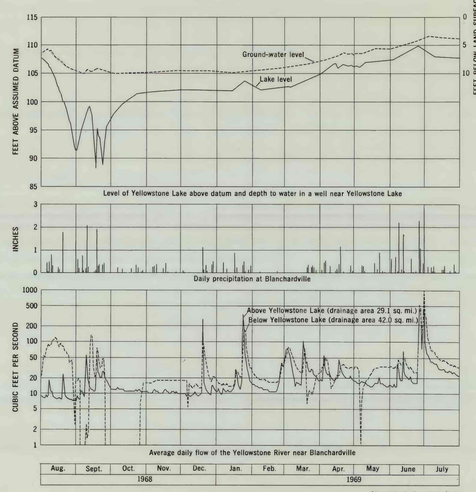


Climatological records from U.S. Weather Bureau. Evapotranspiration estimated using Thornthwaite and Mather (1957)

RELATIONSHIP OF STREAMFLOW AND GROUND-WATER LEVEL TO CLIMATOLOGICAL ELEMENTS

The direct relationship between climatological factors, streamflow, and ground-water levels is shown by a comparison of several years' records. Peak flows of the Pecatonica River are due to increased surface runoff and correlate with snowmelt, precipitation, or a combination of the two. Spring peak flows are primarily from snowmelt that occurs as the air temperature rises above freezing. Spring rains falling on frozen ground, such as occurred in 1965, augment the flow from snowmelt. Heavy precipitation in midsummer may not increase streamflow substantially because evapotranspiration is at a maximum and rain replaces a soil-moisture deficit (see Hydrologic Budget, sheet 1).

Fluctuations in ground-water levels also correspond to precipitation, but because the rate of percolation to the water table is very slow, the response of ground-water levels is much slower and is not as pronounced as the response of streamflow. Month-to-month variations in precipitation are not apparent in the well record, but periods of above and below normal precipitation show clearly.



Climatological records from U.S. Weather Bureau

RELATIONSHIP BETWEEN LAKE LEVEL, GROUND-WATER LEVEL, PRECIPITATION, AND STREAMFLOW

Streamflow, lake levels, and ground-water levels respond not only to climatic conditions but also to artificial regulation. In August 1968 the Wisconsin Department of Natural Resources released water from Yellowstone Lake to lower the lake level. This release was discontinued on September 15 after 19 feet of total drawdown. The lake refilled to about 13 feet above its lowest level by October 25, at which time streamflow from the lake resumed.

Two stream-gaging stations, one above and one below Yellowstone Lake, were installed to monitor the surface-water input and output of the lake. A staff gage was installed in the lake to determine its level, and observations of ground-water levels were obtained at five wells to document changes in water levels, particularly as related to changes in lake levels. Only those wells very near the lake correlated closely with the lake level; the record of one of these wells is shown.

An analysis of the hydrographs shows streamflow into and out of the lake responding to precipitation. Streamflow out of the lake also responds to drainage and refilling of the lake. Outflow during August and September was very high during drainage, and the lake level and water table near the lake fell. There was a 5-day lag in the response of ground-water levels over response of lake levels to precipitation. During the period of drainage, intense precipitation interrupted the trends in the hydrographs.

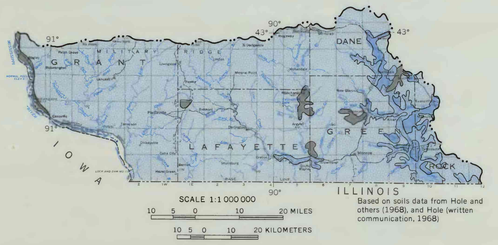
Response of streamflow and water levels to climatic conditions also is clearly shown. Although precipitation has an immediate effect on streamflow, it has a less direct effect on lake levels and an even less distinct effect on ground-water levels.

The effect of reservoir storage on reducing flood peaks is clearly shown by stream hydrographs for the storms in December 1968 and January, March, and April 1969. The lake reduces the peak by storage and slow release of surface runoff.

IRRIGATION

Irrigation is of very little economic importance in the Pecatonica-Sugar River basin. The steep, rugged topography, soil of low permeability, and thin soil cover are the major factors that limit the amount of irrigation in the area.

Nearly all the ground water that is used for irrigation in the study area is applied on municipal and private golf courses. Surface water is used to irrigate about 340 acres of cropland in the Sugar River basin.



Based on soils data from Hole and others (1968), and Hole (written communication, 1968)

EXPLANATION

Suitability	Characteristics	Parent material
Good	Soil is level to gently undulating and permeable; water table is more than 4 ft. below land surface.	Sand and gravel, sand, and silt.
Good to fair if drained	Soil is wet, nearly level, and permeable; water table is within 4 feet of land surface over much of the low land.	Outwash sand and gravel, till, organic material and loess.
Good to fair on few level areas; poor on slopes.	Soil is moderately permeable on gently rolling to undulating glaciated upland and has low permeability on steep slopes and limestone ridges of the "Driftless Area."	Loess
Poor	Mixed soil types have low to moderate permeability on ridges and high permeability on low lands; water table is within 1 foot of surface over much of low land.	Loess, sandstone, and alluvium.

SOIL SUITABILITY FOR IRRIGATION

Most soils suitable for irrigation are found in the Sugar River valley and small level areas throughout the basin. Soil suitability depends upon the topography of the land, the permeability of the soil, and the depth to the water table. The soil suitability shown does not take into account soil fertility or water availability. However, water for irrigation is available everywhere within the basin.

Under the best conditions the topography is level to allow uniform distribution of water and to prevent excessive water runoff; the soil is permeable so that water can infiltrate and percolate to the root zone; and the depth to the water table is 4 feet or more so that plant roots remain in the zone of aerated soil for proper assimilation of oxygen and nutrients. The only large part of the study area that meets these requirements is within the Sugar River valley and, because there is a good supply of both ground and surface water available, its potential for future irrigation is good.

GROUND WATER

Large undeveloped supplies of good quality water are available in the Pecatonica-Sugar River basin from the ground-water reservoir. About 200 billion gallons of ground water discharge to streams and wells each year, which is about 2 million gallons for each person in the study area. Yet this is less than one-half of 1 percent of the total water stored underground.

Aquifers throughout the basin provide water to wells and springs and furnish a perennial base of streamflow by seepage and spring discharge. The amount of water that can be continuously pumped from a well or group of wells, disregarding economic factors, depends upon the aquifer thickness and areal extent, the rate of recharge, the ease with which water moves through the aquifer, and the amount of water in storage.

Ground water will continue to meet domestic, agricultural, municipal, and industrial needs in the study area. Present areas of high pumpage are few, population density within the area is low, and only a small part of the total potential is being utilized. Because ground-water availability is not consistent areally, detailed studies may be needed to guide future large-scale ground-water developments.

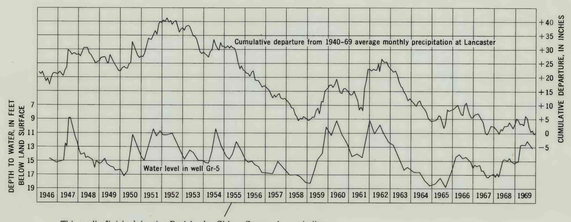
EXPLANATION

Potentiometric contour
Shows altitude of potentiometric surface. Contour interval 100 feet. Datum is mean sea level

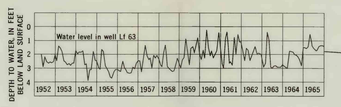
Observation well
Letter is geologic unit tapped by well
G, sand and gravel
P, Galena, Decorah, and Platteville Formations, undifferentiated
S, St. Peter Sandstone
C, Prairie du Chien Group

Surface-water divide

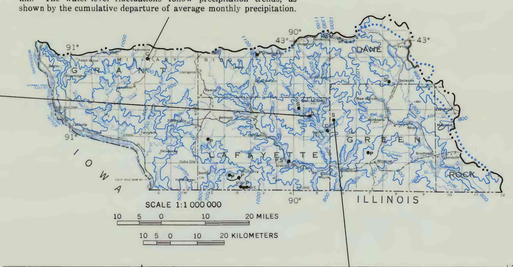
Ground-water divide
(Coincides with surface-water divide where not shown)



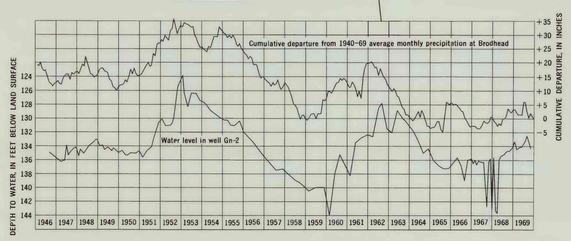
This well, finished in the Prairie du Chien Group, is a shallow water-table well and is located in a discharge area at the base of a hill. The water-level fluctuations follow precipitation trends, as shown by the cumulative departure of average monthly precipitation.



The water level in this water-table well, which is 17 feet deep in sand and gravel, responds rapidly to recharge by precipitation. The hydrograph shows the rise in water level each spring due to snowmelt and rain; the decline in water level during summer dry periods when evapotranspiration is high; and the rise in water level again in the fall, when precipitation increases and evapotranspiration decreases.



The hydrograph of this well, which is finished in St. Peter Sandstone, shows a delayed response to recharge from precipitation as shown by comparison with cumulative departure of precipitation. The well is located on a hilltop, and water-level changes due to precipitation are delayed several months to a year, because water must percolate farther to reach the water table and movement is slow.



POTENTIOMETRIC SURFACE AND OBSERVATION WELL NETWORK

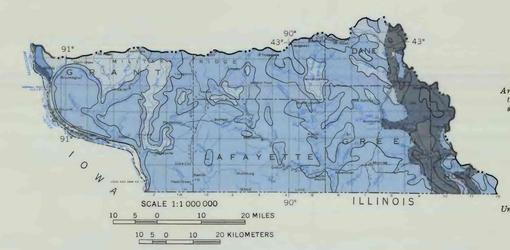
Ground water underlies the entire study area and moves constantly from areas of higher potential (recharge areas) to areas of lower potential (discharge areas)—streams, springs, wells, lakes, and wetlands. This ground-water system, represented by the potentiometric surface, is not truly a single hydrologic system but is a combination of a water-table system and an artesian system. The water-table system is present in all parts of the study area. Within the water-table system there are numerous areas of local confinement that produce artesian systems, so that nearby wells may have very different water levels.

Generally ground-water divides follow surface-water divides; however, in some areas they do not, and the ground-water basin has a different shape and size than the surface-water basin. One example of this is in Dane County, where the ground-water divide is offset to the south and west of the surface-water divide. Pumping from the Madison area is at least partly responsible for this offset (Cline, 1965, p. 31). Ground water within the surface-water basin of the Sugar River is intercepted and discharged into the Yahara River system.

The depth to the water table in the Pecatonica-Sugar River basin ranges from a few feet in valleys and along streams to 200-300 feet below hills in the western part of the basin, where the topographic relief is great. The water table is not static but fluctuates with changes in recharge and discharge. The three well hydrographs illustrate these fluctuations. Each well is in a different area, open to different aquifers, and in a different physical setting, but all show that there has been no long-term trend in water levels within the study area.

Ground water, which is recharged throughout the area, is discharged mainly at streams and through springs. Because of the high relief and barriers to downward movement, this basin has thousands of springs. Reports on springs (Wisconsin Conservation Department, written communication, 1959, 1959) show that there are 144 springs in the basin that have flows greater than 100 gpm (gallons per minute), and 55 of these have flows greater than 200 gpm.

Aquifer	Age	Geologic unit	Thickness (feet)	Maximum yield reported (gpm)	Average high capacity well yield (gpm)	Well depths (feet)
Sand and gravel	Quaternary	Sand and gravel	0-260	1900	Only 2 reported high-capacity wells	10-260
(Not an aquifer)		Maquoketa Shale	0-240	Although not generally classed as an aquifer, a few wells obtain small quantities of water from this unit		68-175
Galena-Platteville	Ordovician	Galena, Decorah, Platteville Formation Undifferentiated	0-350	500	Only 3 reported high-capacity wells	30-452
Sandstone	Cambrian	St. Peter Sandstone	0-400	348	187	17-638
		Prairie du Chien Group	0-250	265	Only 2 reported high-capacity wells	35-435
		Jordon Sandstone	700-1500	1270	404	75-1740
		St. Lawrence Formation				
		Franconia Sandstone				
		Galesville Sandstone				
		Eau Claire Sandstone				
		Mount Simon Sandstone				
(Not an aquifer)	Precambrian	Crystalline rocks	Unknown	No well is known to pump water from this unit		



GROUND-WATER AVAILABILITY

EXPLANATION

Aquifer

Sand and gravel
Area of saturated glacial drift greater than 50 feet thick that contains underlying deposits of permeable sand and gravel

Galena-Platteville
Underlain by the sandstone aquifer

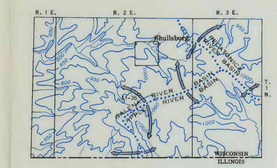
St. Peter Sandstone
Underlain by Cambrian sandstone and generally by the Prairie du Chien Group

Prairie du Chien Group
Underlain by Cambrian sandstone

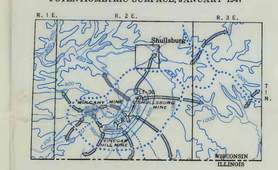
Cambrian sandstone

Aquifer-boundary

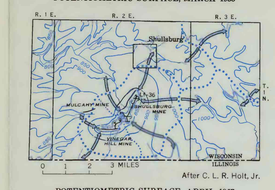
Surface-water divide



POTENTIOMETRIC SURFACE, JANUARY 1947

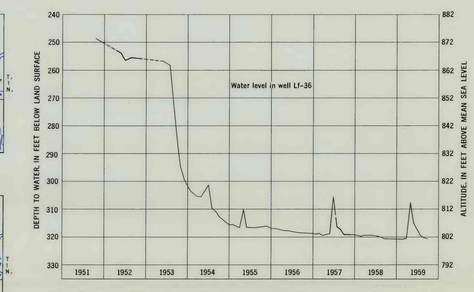


POTENTIOMETRIC SURFACE, MARCH 1955



After C. L. R. Holt, Jr.

POTENTIOMETRIC SURFACE, APRIL 1957



EXPLANATION

Potentiometric contour
Shows altitude to which water would have risen in the Galena-Platteville aquifer. Contour interval 50 feet. Datum is mean sea level

Ground-water divide

Subbasin ground-water divide

General direction of ground-water movement

Underground mine workings

Well and number

EFFECT OF MINE DEWATERING ON THE POTENTIOMETRIC SURFACE OF THE GALENA-PLATTEVILLE AQUIFER IN THE SHULLSBURG AREA

Changes in the potentiometric surface at pumping centers are illustrated during three stages of mine development. In the early 1950's, dewatering of the Galena-Platteville aquifer southwest of Shullsburg, in Lafayette County, began in order to mine the lead and zinc ores found in that formation. Before pumping began the potentiometric surface closely resembled the land surface, and the depth to water ranged from zero at springs to 200 feet beneath ridges. Operations began at the Vinegar Hill mine in 1952, the Shullsburg mine in 1953, and the Mutcahy mine in 1954. The maximum combined pumping rate for the three mines was 6 mgd (C. L. R. Holt, Jr., written commun., 1970). A large cone of depression developed around the mines as a result of this pumpage, and the potentiometric surface dropped more than 250 feet near the mines.

Changes in the location of the ground-water divide and in the direction of ground-water movement are shown for different stages of mine operation. Ground-water movement in January 1947 was natural and was from recharge areas on the divides to discharge areas along streams and in valleys. By March 1955 all three mines were in full operation and pumping water, causing the Galena-Apple River basin divide to split and encircle the resulting cone of depression. Ground-water movement also split, going both toward streams and the mines. Because there were three separate mines pumping independently, there were subbasin divides between the mines with water moving to each mine from the areas between them. In April 1957 the smaller Mutcahy mine ceased operation, and the potentiometric surface near the mine began to recover. Pumpage continued from the remaining two mines, enlarging the cone of depression especially toward the southeast. Ground-water movement continued to be from the divides to streams and, within the cone of depression, to the mines.

The hydrograph of well Lf-36 shows how the operation of the Shullsburg mine affected the potentiometric surface. The immediate decline in water level when pumping started and the constant water level held by the pumps are clearly evident. Four intense storms caused the four sharp partial recoveries in water level, but continued pumpage quickly lowered the water to the previous levels.

GROUND-WATER AVAILABILITY

Ground water is available everywhere within the basin, usually at depths of less than 200 feet. The physical properties of the geologic units control ground-water movement and, hence, yields. Well yields from permeable sand and gravel may be high where saturated thicknesses are more than 50 feet. However, the distribution and permeability of sand and gravel deposits change greatly within short distances, and well yields are difficult to predict. The Prairie du Chien Group and the Galena-Platteville unit are composed mainly of dense dolomitic rock that yields water from fractures and solution channels rather than from intergranular pore spaces, as in sandstone or sand and gravel. Because the distribution of fractures and channels is much less uniform than the distribution of intergranular pore spaces, well yields from dolomitic rocks are even less predictable.

The sand and gravel aquifer constitutes only a minor source of water in the basin because of its limited areal extent. Although yields as high as 1,900 gpm have been obtained from this aquifer, its occurrence is largely confined to deposits within river valleys. Because there are so few wells in the sand and gravel aquifer, the extent and type of deposit is not delineated on the map, and only that part of the glaciated area with saturated thickness of more than 50 feet is shown.

The Galena-Platteville aquifer underlies 89 percent of the basin and is widely used for domestic and farm supplies where it has an adequate saturated thickness. It is estimated that 10-20 gpm can be obtained from this aquifer.

The sandstone aquifer is the most important and extensively used aquifer in the study area. The aquifer consists of the Prairie du Chien Group, the St. Peter Sandstone, and the Cambrian sandstones, but the Cambrian sandstones are the most productive. Yields in most wells depend primarily on the thickness of Cambrian sandstone penetrated; of the Cambrian units, the Galesville and Mount Simon units are commonly the most productive. Of the 44 reported high-capacity wells in the study area, 39 are finished in the sandstone aquifer. Most of the basin wells in the sandstone can yield at least 500 gpm.

The St. Peter Sandstone is missing or is not saturated in some of the deep river valleys, but it is highly productive in the Cuba City-Shullsburg area where it is more than 350 feet thick. The Prairie du Chien Group is saturated wherever it is present but is discontinuous in the study area. Although two high-capacity wells are reported in this unit, yields are generally very low.

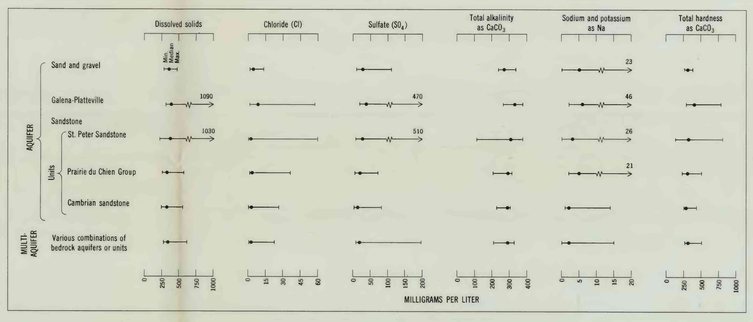
GROUND-WATER QUALITY

Ground water in the study area is generally of good chemical quality and is suitable for most purposes. The water is of the calcium magnesium bicarbonate type, and total dissolved solids usually range from 250 to 400 mg/l (milligrams per liter). These solids are largely carbonate hardness. Most ground water in the basin is very hard (greater than 180 mg/l) and requires softening for many uses.

Locally, highly mineralized water, iron, manganese, and nitrate are problems. The most highly mineralized water occurs in some mining areas; the contributing constituents are mostly Ca^{+2}, Na^{+}, HCO_3^{-}, and SO_4^{-2}. Objectionable quantities of iron occur locally in all aquifers, especially in the sand and gravel deposits. Manganese occurs to a much lesser extent in these deposits. High concentrations of nitrate in ground water are very local, usually depending on the physical condition of well sites and construction.

Bacterial quality was not investigated in this study but is not considered a problem, except where improper well construction may have made individual wells subject to pollution from the surface.

A geochemical spring-water sampling survey to detect bodies of zinc ore was conducted in parts of Grant, Iowa, and Lafayette Counties (De Geoffroy, 1969). The mean overall concentration of zinc in the sampled springs was 0.22 mg/l. A zinc concentration of 0.30 mg/l was used as a criterion to indicate the zinc potential of the different geological formations of the region and to delineate broad areas of interest for mining exploration.



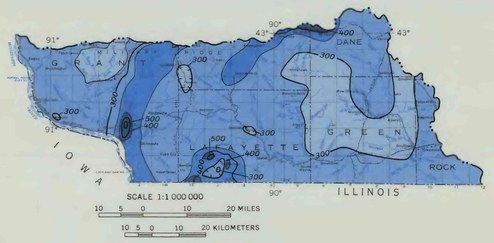
QUALITY OF GROUND WATER BY AQUIFER

Major chemical constituents, characteristics, and properties of water shown in the diagram indicate the similarity of ground-water quality in aquifers within the study area. Quality of ground water differs somewhat between aquifers (compare median values), but there are greater differences within individual aquifers (see maximum and minimum values). All water analyzed has a median dissolved solids content between about 300 and 390 mg/l. Values less than about 250 mg/l largely reflect carbonate hardness, but values more than about 500 mg/l reflect considerable noncarbonate hardness, with sulfate as the contributing anion.

Most of the water in the sand and gravel aquifer in the basin has a total dissolved solids concentration ranging from 275 to 425 mg/l. Dissolved solids concentrations range from 250 to 550 mg/l in the deeper Cambrian sandstone, and they range from 300 to more than 1,000 mg/l in the Galena-Platteville unit.

Water in the Galena-Platteville unit is generally more mineralized than water in the deeper aquifers. Water in the sandstone aquifer is more highly mineralized where the aquifer is overlain by the Galena-Platteville unit, presumably because of recharge through the Galena-Platteville unit.

The multi-aquifer category is included in the figure because most high-capacity wells in the basin are open to more than one water-bearing unit.



DISSOLVED SOLIDS AND HARDNESS IN GROUND WATER

EXPLANATION

Dissolved solids, in milligrams per liter

- *Less than 300*
- *300-500*
- *400-500*
- *Greater than 500*

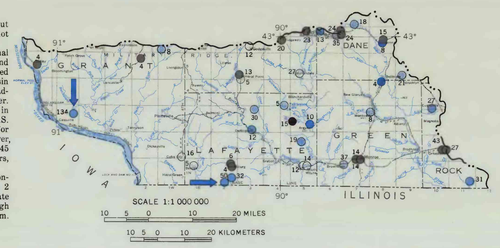
Line of equal hardness
Interval 100 mg/l

Surface-water divide

Small quantities of nitrate are found in ground water throughout the basin. High concentrations of nitrate occur locally but are not common.

Nitrate is commonly derived from human and other animal wastes, agricultural fertilizers, organic decomposition, rainfall, and rocks. Water in shallow, inadequately cased, or poorly constructed wells is particularly susceptible to pollution by wastes. In this basin nitrate concentrations greater than 3 mg/l (as NO_3) suggest degradation of water quality in the well and, possibly, in part of the aquifer. High concentrations of nitrate in water can cause abortion in cattle and methemoglobinemia in infants (Comly, 1945). The U.S. Public Health Service (1962) suggests an upper limit of 45 mg/l for nitrate (NO_3) in water used for human consumption. However, there are recent indications that concentrations much less than 45 mg/l may have deleterious effects on humans (Scalf and others, 1968).

About 130 analyses of well water were studied for nitrate concentrations; 30 exceeded 3 mg/l, 20 exceeded 10 mg/l, but only 2 exceeded 45 mg/l (see map). The modal concentration of nitrate in the basin is about 1.8 mg/l. The isolated occurrence of high nitrates in these wells indicates the very local nature of the problem.



NITRATE IN GROUND WATER

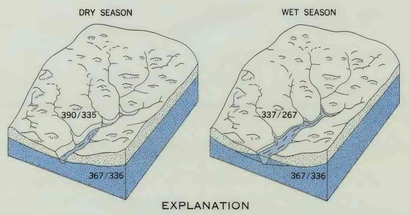
EXPLANATION

Well
Number is nitrate content of water, in milligrams per liter. Arrow indicated nitrate content in excess of 45 milligrams per liter

Geologic unit supplying water to the well

- Sand and gravel
- Galena, Decorah, and Platteville Formations, undifferentiated
- St. Peter Sandstone
- Prairie du Chien Group
- Cambrian sandstone
- Multi-unit
- Unit unknown

Surface-water divide



EXPLANATION

Average dissolved solids (mg/l) — 367/336 — Average total hardness (mg/l as $CaCO_3$)

SEASONAL VARIATION IN WATER QUALITY

The average chemical quality of water in streams differs only slightly from that in the ground. The illustrations compare the concentrations of dissolved solids and hardness of water from these sources during wet and dry seasons. Only water samples from the main streams were analyzed to compute surface-water averages, and they may not represent average values for all parts of the basin.

Surface-water quality changes between wet and dry seasons. Water in streams is less mineralized during wet seasons than during dry seasons because streamflow is mostly overland runoff that has had only brief contact with soils and rocks.

Ground-water quality does not change significantly between wet and dry seasons because it moves through rocks very slowly. However, water quality in some shallow wells in permeable glacial drift may change. Ground water becomes mineralized as soluble minerals in soils and rocks dissolve, and it becomes more mineralized as the time of contact with these soluble materials increases (within the range of solubility potential).

Base from U.S. Geological Survey 1:500,000, 1968

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By
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