Information Circular
Number 17

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The University of Wisconsin

GEOLOGICAL AND NATURAL HISTORY SURVEY

George F. Hanson, State Geologist and Director

FIELD TRIP GUIDEBOOK TO THE HYDROGEOLOGY OF THE ROCK-FOX RIVER BASIN OF SOUTHEASTERN WISCONSIN

Prepared in cooperation with the U.S. Geological Survey
for the Annual Meeting of
THE GEOLOGICAL SOCIETY OF AMERICA
and
ASSOCIATED SOCIETIES
Milwaukee, Wisconsin, 1970

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HYDROGEOLOGY OF THE ROCK-FOX RIVER BASIN

OF

SOUTHEASTERN WISCONSIN 1/

by

C. L. R. Holt, Jr. 2/, R. D. Cotter 2/, J. H. Green 2/, and P. G. Olcott 3/

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INTRODUCTION

On this trip we will examine some hydrogeologic characteristics of glacial features and emphasize ground-water management within the Rock-Fox River basin. Field stops will include the hydrogeology of a classical glacial terrane--the Kettle moraine--and the management of ground-water resources for industrial, municipal, agricultural, and fish-culture purposes. Descriptions of the geology, soils, water availability and characteristics, water quality, water use, and water problems within the basin are given in the accompanying U.S. Geological Survey Hydrologic Atlas (HA-360). This atlas is a product of the cooperative program of University Extension--the University of Wisconsin Geological and Natural History Survey.

An old Indian meaning for Wisconsin, "where the waters gather", was an especially fitting one as the State is rich in water resources. These resources include more than 8,000 lakes, thick and extensive ground-water reservoirs, and more than 9,000 miles of streams. Major drainage divides direct the flow of water in the east and north to Lakes Michigan and Superior and in the rest of the State to the Mississippi River.

Large amounts of water are available in the Rock-Fox River basin in southeast Wisconsin. The average annual precipitation is 31.4 inches, of which about 6.6 inches or 1,500 mgd (million gallons per day) runs off as streamflow.

Ground water is used for all municipal supplies, for most rural supplies, and for most industrial supplies. It is available from four aquifers in the basin: the sandstone aquifer (Cambrian and Ordovician ages), the Platteville-Galena aquifer (Ordovician age), the Niagara aquifer (Silurian age), and the sand and gravel aquifer (Pleistocene age). Any of these aquifers is capable of yielding domestic and stock supplies. The sandstone aquifer commonly yields 1,000 gpm (gallons per minute) or more, as does the sand and gravel in the lower Rock River valley. All municipalities have adequate supplies of ground water available for future growth and development.

The minor water problems in the basin are related to water quality. Both ground and surface water have high natural hardness; high iron content is a local problem in ground water. Some lakes and reaches of streams are polluted by wastes as are very local areas of shallow aquifers.

Figures 1, 2, and 3 are reference material for the field trip and are, respectively, a road map indicating field stops, a glacial geology map of Wisconsin, and a bedrock geology map of Wisconsin. (Note that figs. 2 and 3 contain geologic names that do not correspond to usage by the U.S. Geological Survey.)

ROAD LOG AND DESCRIPTION OF STOPS

Mileage (Milwaukee to Janesville to Madison and return)

0.0 0.0 Trip starts at 5th Street entrance of Schroeder-Sheraton Hotel. Drive south on 5th Street.

0.2 0.2 Turn right (west) on Clybourn Street.

0.3 0.1 Enter cloverleaf turn to Interstate Highway 94 and proceed west.

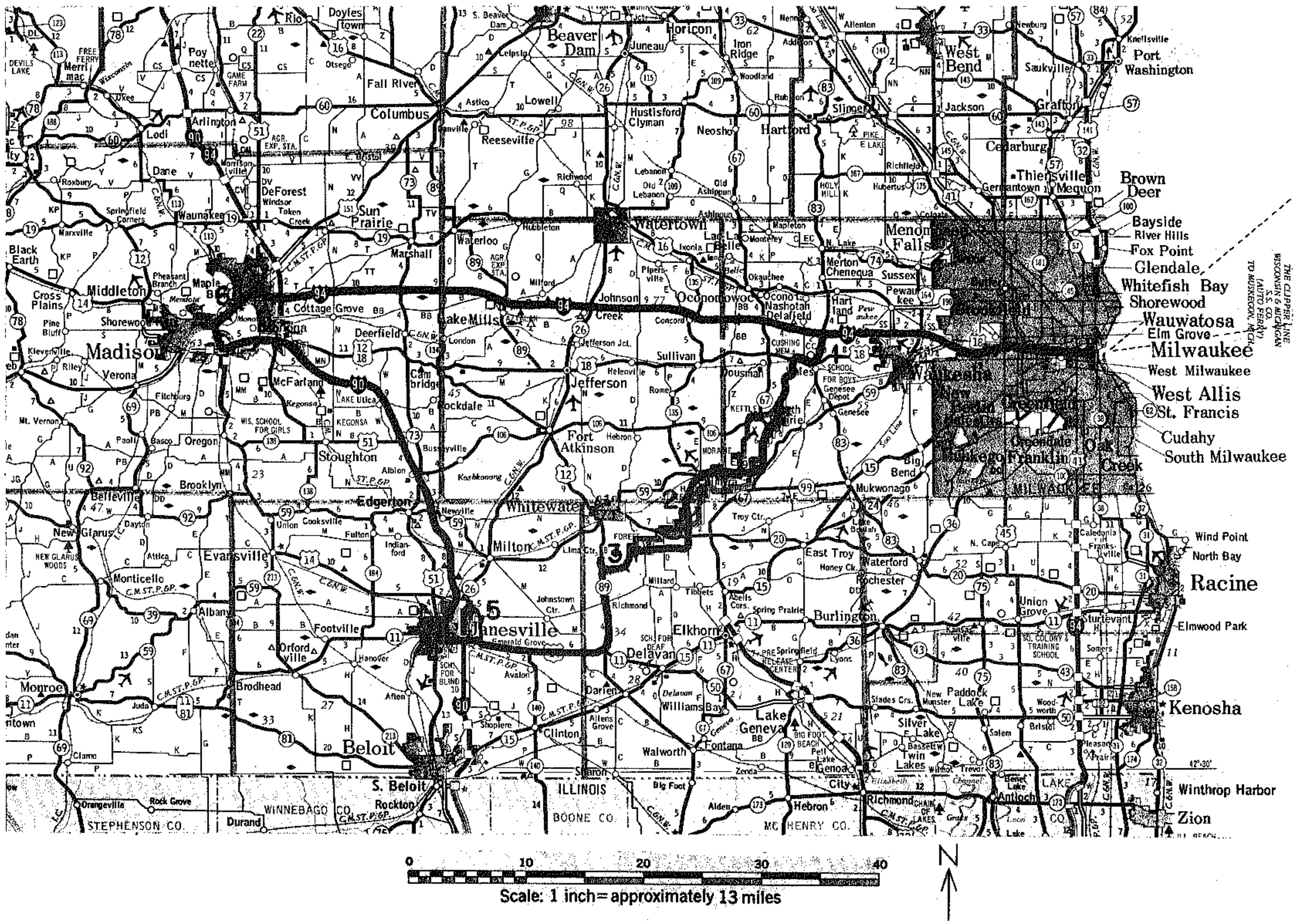
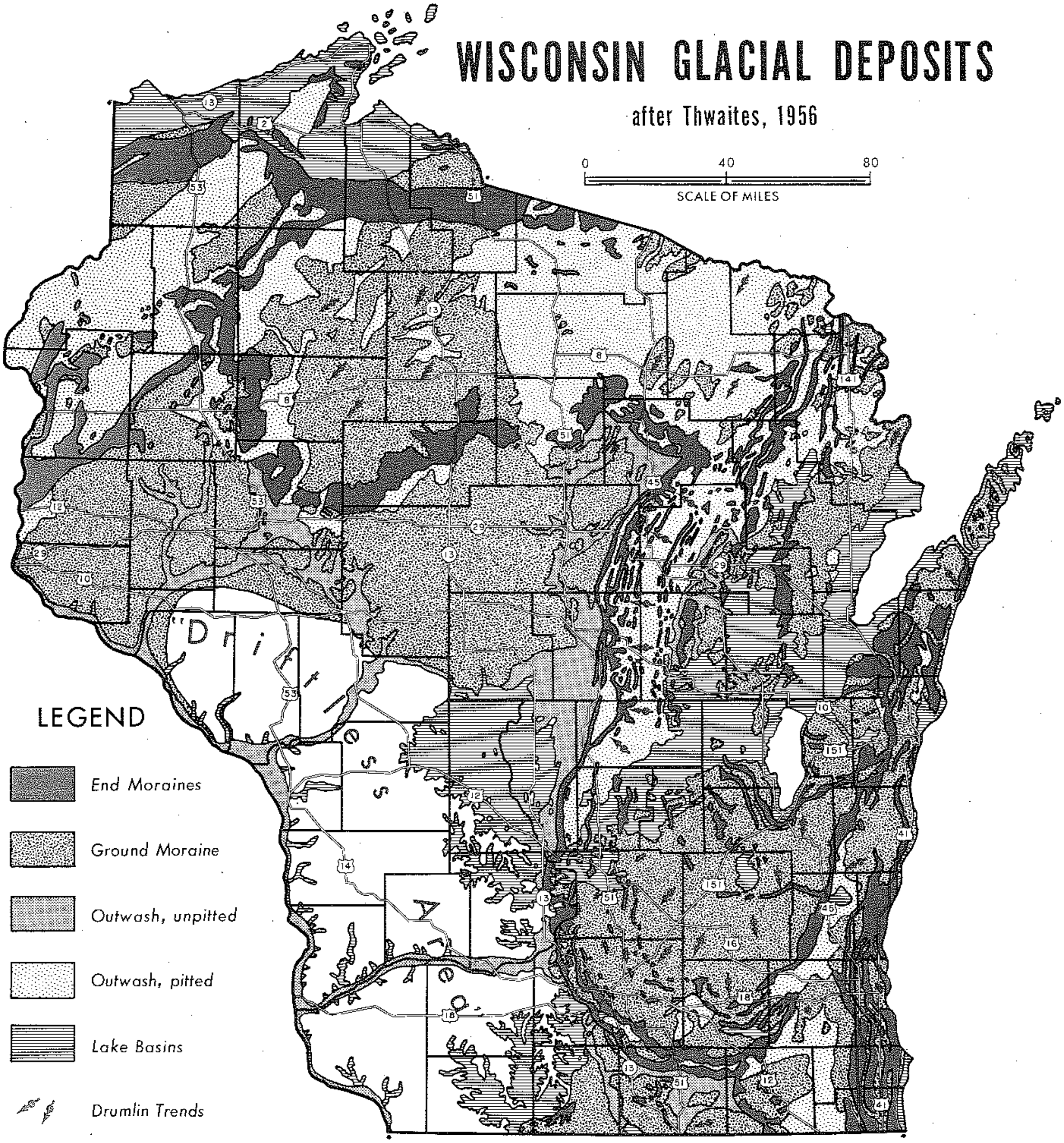


Figure 1. Field trip route.

WISCONSIN GLACIAL DEPOSITS

after Thwaites, 1956



University of Wisconsin

Wisconsin Geological and Natural History Survey

George F. Hanson, Director and State Geologist

SHORT HISTORY OF THE ICE AGE IN WISCONSIN

The Pleistocene Epoch or "Ice Age" began about 1,000,000 years ago which, in terms of geologic time, is a very short time ago. There were four separate glacial advances in the Pleistocene each followed by an inter-glacial period when the ice receded. The fourth glacial stage is called the Wisconsin Stage because it was in this State that it was first studied in detail.

The glaciers were formed by the continuous accumulation of snow. The snow turned into ice which reached a maximum thickness of almost two miles. The ice sheet spread over Canada and part of it flowed in a general southerly direction toward Wisconsin and neighboring states.

The front of the advancing ice sheet had many tongues or "lobes" whose direction and rate of movement were controlled by the topography of the land surface over which they flowed and by the rates of ice accumulation in the different areas from which they were fed.

The ice sheet transported a great amount of rock debris called "drift". Some of this was deposited under the ice to form "ground moraine" and some was piled up at the margins of the ice lobes to form "end moraines". "Drumlins" are elongated mounds of drift which were molded by the ice passing over them and hence indicate the direction of ice movement.

The pattern of end moraines, in red, shows the position that was occupied by four major ice lobes. One lobe advanced down the basin of Lake Michigan, another down Green Bay, a third down Lake Superior and over the northern peninsula of Michigan and yet a fourth entered the state from the northwest corner. The well-known "Kettle Moraine" was formed between the Lake Michigan and Green Bay lobes. As the ice melted the drift was reworked by the running water. Large amounts of sand and gravel were deposited to form "outwash plains"; pits were formed in the outwash where buried blocks of ice melted and many of these are now occupied by lakes.

The action of the ice profoundly modified the landscape, smoothing off the crests of hills and filling the valleys with drift. In some places it changed the course of rivers forcing them to cut new channels such as that of the Wisconsin River at the Dells; elsewhere it dammed the valleys to create lakes such as those of the Madison area.

During recent years there have been intensive studies made of the polar ice caps, and methods have been developed for dating glacial events from the radioactivity of the carbon in wood, bones, etc. which are found in many of the deposits. The results of these studies are causing many previously accepted concepts to be changed or challenged.

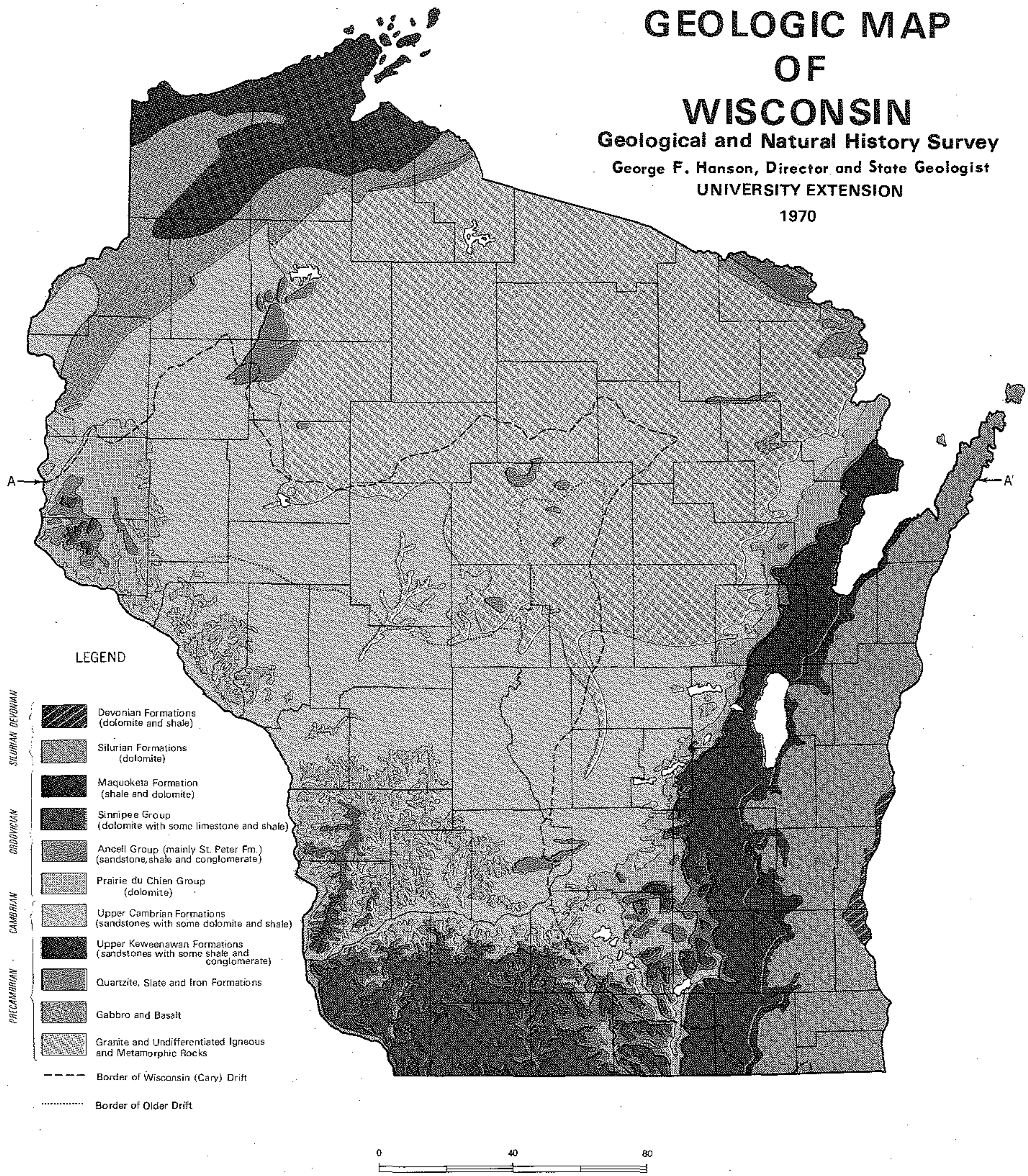
We once thought that there were rather extensive glacial deposits older than Wisconsin age in the State, but age determinations do not support this. It was also thought that the ice left Wisconsin some 20,000 years ago but a forest at Two Creeks in Manitowoc County was buried under an advancing ice tongue only 11,000 years ago. Evidence is accumulating to indicate that ice may have occupied the so-called "Driftless Area" of the southwestern part of the State which hitherto has been held to be unglaciated.

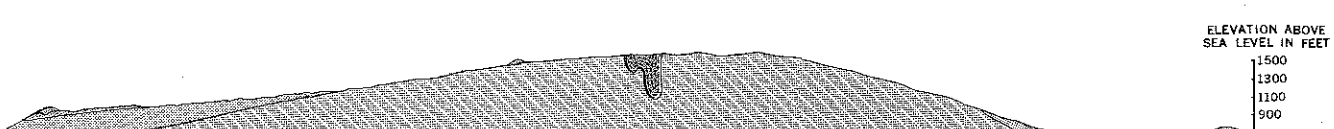
Most scientists now believe that the cause of the Pleistocene "Ice Age" was due to variations in the solar energy reaching the earth, but how these may have occurred is still a matter of conjecture. We are still in the Ice Age and it is anybody's guess whether future millenia will see the melting of the ice caps and the slow drowning of our coastal cities, or the regrowth and once more the inexorable advance of the glaciers.

Prepared by the University of Wisconsin Geological & Natural History Survey, August 1964

GEOLOGIC MAP OF WISCONSIN

Geological and Natural History Survey
George F. Hanson, Director and State Geologist
UNIVERSITY EXTENSION
1970





SHORT GEOLOGIC HISTORY OF WISCONSIN

The bedrock of Wisconsin is separated into two major divisions: (1) older, predominantly crystalline rocks of the Precambrian Era, which were extensively deformed after their deposition by movements of the Earth's crust; and (2) younger flat-lying sedimentary rocks of the Paleozoic.

The Precambrian Era lasted from the time the earth cooled, over 4,000 million years ago, until the Paleozoic Era which began about 500 million years ago. During this vast period of 3,500 million years sediments, some of which were rich in iron and which now form our iron ores, were deposited in ancient oceans, volcanoes spewed forth ash and lava, mountains were built and destroyed, and the rocks of the upper crust were invaded by molten rocks of deep-seated origin. Only a fragmentary record of these events remains but, as tree stumps attest the former presence of forests, the rocky roots tell the geologist of the former presence of mountains.

At the close of the Precambrian Era most of Wisconsin had been eroded to a rather flat plain upon which stood hills of more resistant rocks as those now exposed in the Baraboo bluffs. There were still outpourings of basaltic lava in the north and a trough formed in the vicinity of Lake Superior in which great thicknesses of sandstone were deposited.

The Paleozoic Era began with the Cambrian Period, the rocks of which indicate that Wisconsin was twice submerged beneath the sea. Rivers draining the land carried sediments which were deposited in the sea to form sandstones and shales. Animals and plants living in the sea deposited calcium carbonate and built reefs to form rocks which are now dolomite—a magnesium-rich limestone. These same processes continued into the Ordovician Period during which, as indicated by the rocks, Wisconsin was submerged three more times. Deposits built up in the sea when the land was submerged were partially or completely eroded at times when they were subsequently elevated above sea level. During the close of the Ordovician Period, and in the succeeding Silurian and Devonian periods, Wisconsin is believed to have remained submerged.

There are no rocks outcropping in Wisconsin that are younger than Devonian. Absence of this part of the rock record makes interpretation of post-Devonian geologic history in Wisconsin a matter of conjecture. Available evidence from neighboring areas, where younger rocks are present, indicates that towards the close of the Paleozoic Era, perhaps some 250 million years ago, a period of gentle uplift began which has continued to the present. During this time the land surface was carved by rain, wind and running water.

The final scene took place during the last million years when glaciers invaded Wisconsin from the north and sculptured the land surface. They smoothed the hill tops, filled the valleys and left a deposit of glacial debris over all except the southwest quarter of the State where we may now still see the land as it might have looked a million years ago.

Prepared by U. of W. Geological and Natural History Survey, 1963.

Mileage

The municipal and industrial water supplies for the area come from Lake Michigan, the deep artesian sandstone aquifer (Cambrian and Ordovician ages), the dolomite aquifer (Silurian age), and glacial drift (Pleistocene age). Lake Michigan supplies water for most of the municipalities near the lake and within the lake's drainage basin. More than 160 mgd of water was pumped in 1969 to supply the Milwaukee area. The deep sandstone aquifer is used by industries throughout the area and by municipalities that are primarily inland from the Lake Michigan drainage divide. The dolomite and glacial drift aquifers yield water for domestic, farm, municipal, and industrial uses in the area. Inland lakes and streams are used only for a small amount of irrigation and stock watering.

Concentrated, heavy pumpage from the sandstone aquifer caused about 350 feet of decline of the potentiometric surface in the Milwaukee-Waukesha area since 1930. Since 1950 ground-water pumpage has decreased in the central Milwaukee area, and water levels have risen slightly as the use of water from Lake Michigan replaced that of ground water (Green and Hutchinson, 1965). Wisconsin's water law prohibits diversion of surface water from a drainage basin and, therefore, ground-water use is expected to increase as urbanization expands westward. Present increases in pumpage are causing increasing water-level declines in the Waukesha area.

1.4 1.1 The Milwaukee Harbor on the left (south) consists of several miles of the channels near the mouths of the Milwaukee, Menomonee, and Kinnickinnic Rivers. From 6,000 to 7,000 major cargo ships use this harbor each year.

2.3 0.9 The three glass domes on the left (south) contain the Mitchell Park Conservatory, which has assemblages of plants from desert, tropical, and local environments.

3.0 0.7 Miller Brewery is on the right (north). This is one of the many breweries that have made Milwaukee the beer capitol of the nation. The Milwaukee County Stadium is on the left (south), the home of the Milwaukee Brewers baseball team.

5.4 2.4 Wisconsin State Fair Grounds on left (south). We are traveling over ground moraine and recessional moraines of the Lake Michigan lobe of Wisconsin Glaciation. The route is due west and parallel to the direction of ice movement. The till is largely boulder clay. Terraces of outwash occur in glacial drainageways between several of the moraines. Over much of this area the glacial deposits are more than 100 feet thick and overlie dolomite of Silurian age.

7.0 1.6 Milwaukee County Zoo on right (north).

9.0 2.0 We are crossing the major divide between Lake Michigan and Mississippi River drainage and entering the Fox River basin (HA-360, Cotter and others, 1969).

10.4 1.4 Brookfield Square Shopping Center to right (north). This generally flat terrane is ground moraine (clay till). An east-west trending drumlin is west of the shopping center.

13.8 3.4 Blue Mound Road, U.S. Highway 18 to Waukesha. The city of Waukesha, a few miles to the left (south), uses ground water from the sandstone aquifer (HA 360, sheet 3).

At the turn of the century Waukesha was famous for its "mineral" springs, which were reported to have curative powers for most illnesses. The spring water is of the calcium magnesium bicarbonate type and typifies the quality of water in the shallow aquifer. The first springs were discovered near the Fox River where ground water seeped out of the permeable glacial drift overlying the Niagara Dolomite. Shortly afterward, numerous "improved springs" (wells) were dug into the shallow drift aquifer. Because of declining interest in mineral springs and pollution of the shallow aquifer, only two commercial "springs" remain in operation today.

14.8 1.0 We are now in the valley of the Fox River (HA 360, sheet 2). Outwash terraces, which parallel the valley, are important sources of aggregate. Flood damages to residences and businesses in Waukesha in 1960 were approximately $100,000. However, they would have been higher except that much of the flood plain has been developed for recreation or is occupied by railroads.

15.7 0.9 We are approaching the Pewaukee River, a tributary to the Fox River. The gravel pit on the left (south) is in an outwash terrace. Along the Fox River valley in the Waukesha area Niagara Dolomite is quarried for building stone, crushed rock, and the production of lime.

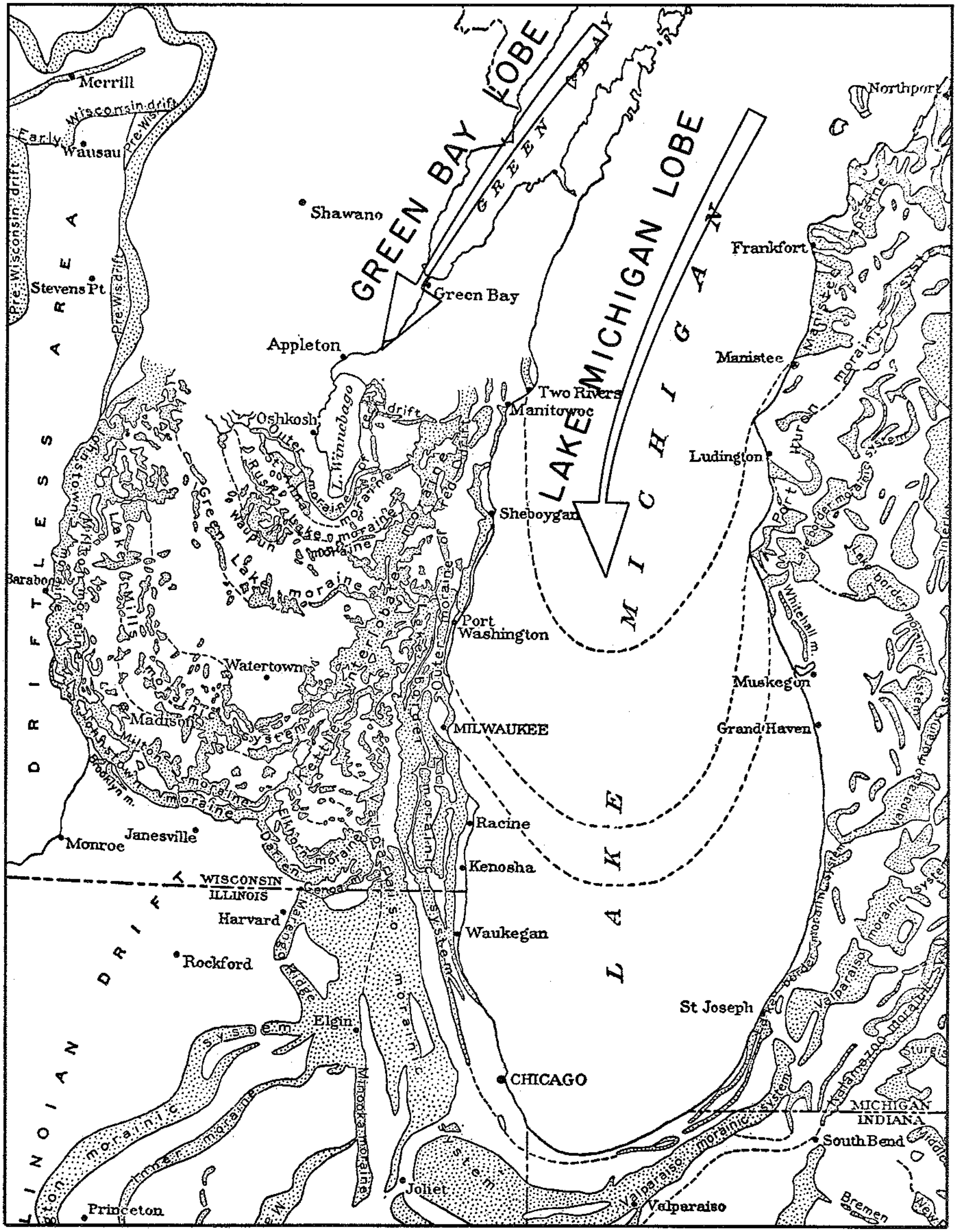
18.0 2.3 On the right (north) are outwash terraces of sand and gravel, deposited by melt water draining to the south.

18.2 0.2 U.S. Highway 16 to Milwaukee.

18.7 0.5 A large drumlin field may be observed to your left (south) for the next 3 miles. The axis of the drumlins trend west. Further west and south drumlins gradually assume a general southwest trend. The drumlins are composed largely of sandy clay till with numerous boulders.

22.0 3.3 Ground moraine deposits are very thin in this area. Niagara Dolomite is exposed at several places on the golf course, and striae indicate ice movement was west and southwest.

We are approaching the terminal moraine of the Lake Michigan lobe, which is in juxtaposition with the terminal moraine of the Green Bay lobe of Wisconsin Glaciation (HA 360, sheet 1). The two moraines form the interlobate moraine, much of which has been set aside as the southern Kettle Moraine State Forest. The interlobate moraine extends over 130 miles in a north-northeast direction from Walworth County in the south to Kewaunee County in the north (fig. 4).



From Alden (1918)
Plate 23

Figure 4. Relation of moraines of Lake Michigan and Green Bay lobes.

Mileage
23.3 1.3 Pewaukee Lake on the right (north) is typical of kettle lakes formed during the period of ice wastage.

24.2 0.9 Turn right off of Interstate Highway 94 to State Highway 83.

24.3 0.1 STOP SIGN. Turn left (south) on State Highway 83. Note the remnant of the high outwash terrace on left (east), deposited by glacial streams draining to the south (fig. 5).

STOP NO. 1

24.7 0.4 STOP NO. 1. Park on right (west) side of road. Assemble across road on terrace overlooking a small gravel pit.

GLACIAL DRAINAGE OF THE KETTLE MORAINE

The Kettle moraine has the most distinctive topographic features in the Rock-Fox River Basin. Its "knob and kettle" surface consists of conical hills and irregular ridges, which are 100 feet or more high; deep irregular or round depressions; and remnants of numerous terraces. Lapham Peak, a high point of the moraine marked by a radio tower, is about 300 feet above the valley north of STOP NO. 1.

The material comprising the moraine is extremely variable and consists of coarse gravel, sand, boulders, and some stony till (Alden, 1918, p. 270), most of which is derived from the Niagara Dolomite. Crystalline rock makes up the remainder. Much of the material is water sorted and consists of kame and outwash deposits (Chamberlin, 1878, p. 210).

The Kettle moraine marks a junction of the Lake Michigan and Green Bay lobes. These ice sheets, pushing from nearly opposite directions, accumulated drift at their margins. Chamberlin (1877), recognizing the special character of this moraine, applied the name Kettle interlobate moraine.

The preglacial escarpment of the Niagara Dolomite may have locally retarded the eastward thrust of the Green Bay lobe. From STOP NO. 1 south about 14 miles to Eagle the Kettle moraine lies close or upon the crest of the Niagara escarpment (fig. 1). The Green Bay lobe pushed east to this escarpment and overrode it for a short distance. South of Eagle the moraine does not extend to the escarpment. North of Waukesha County the Kettle moraine overlies the Niagara Dolomite upland.

Protracted melting, probably alternated with intermittent stages of advancement, contributed large volumes of melt water to the restricted interlobate area. The flow of this melt water carried sediments from the glaciers and washed the drift in the end moraines. Early deposits in the interlobate area consisted of poorly sorted gravel and cobbles filling crevasses and holes in the ice and the valleys between ice masses. R. F. Black describes the development of these glacial features in "Glacial geology of northern Kettle Moraine State Forest, Wisconsin" (1969).

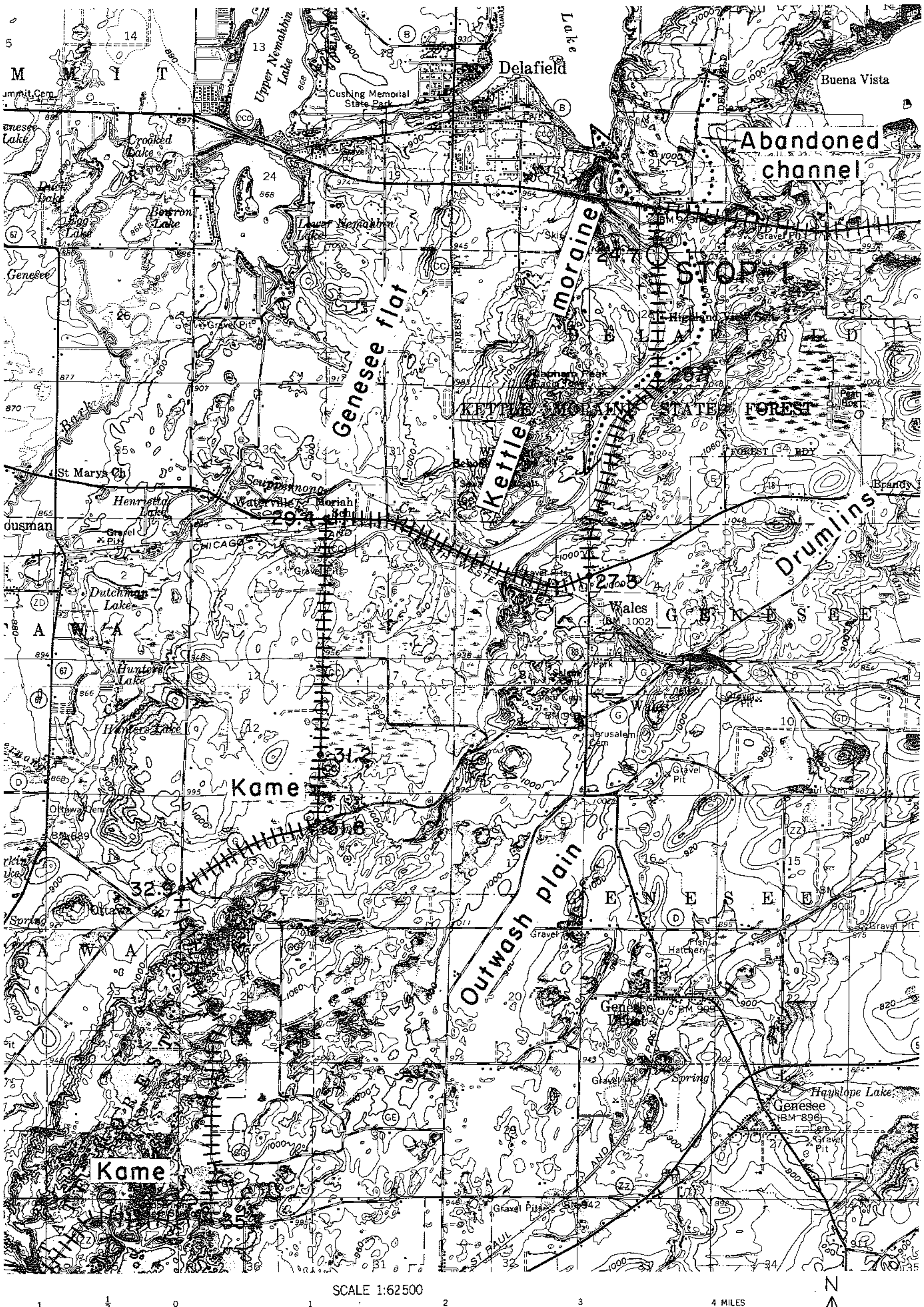


Figure 5. Topography of Kettle moraine, Genesee area.

As the glaciers melted, channels were cut by melt-water streams, ice masses were buried in sediment, and obstacles to flow were removed by erosion of drift and the melting of ice. As each successive obstacle was cut away, drainage outlets were developed at lower elevations, new channels were eroded, and terraces were left. Channels were abandoned as the melt water found an easier path to follow. As each sediment-buried ice block melted, a depression, or kettle, remained. Some of these new kettles intercepted and altered the flow of the melt water.

At STOP NO. 1 you can see many of the erosion and deposition features described above, as well as discern the general sequence of changes in the drainage pattern during development of the interlobate area. The highest parts of the Kettle moraine, such as Lapham Peak and the crests of hills to the west, are composed of washed till and poorly sorted gravel deposited when the interlobate area was restricted by ice and melt water drained to the south (fig. 6a). The terrace on which you are standing is a part of one of many terraces that was left by successively lower drainage channels as the glacier melted. About one-fourth of a mile northwest of STOP NO. 1 is a higher terrace. Homes on Hillside Drive are built on this terrace. In the small gravel pit at STOP NO. 1 you can see the very coarse and poorly sorted character of sediments in the terrace.

This deposit (STOP NO. 1) was the floor of a wide valley that was draining glacial melt water from the reentrant angle that was expanding as the Lake Michigan lobe wasted to the east and north. The water from this valley flowed along the east side of the Kettle moraine to Wales and then spread out in a broad south-sloping outwash plain. The communities of North Prairie and Eagle are situated on this plain.

The extensive deposits of sand and gravel bordering the east side of the Kettle moraine are about 100 feet above the sand, gravel, and marsh deposits bordering the west side of the moraine (fig. 5). This difference in the altitudes of the deposits bordering the moraine is attributed to differences in bedrock topography and to near-moraine melting of the Lake Michigan lobe while the Green Bay lobe was in contact with the west side of the moraine. The surface of the bedrock (Niagara Dolomite) underlying 60-150 feet of sand and gravel on the east side of the moraine is about 200 feet above the surface of the bedrock (Galena Dolomite) west of the moraine.

The abandoned drainage channel, located about 1,000 feet east of STOP NO. 1, conducted the last melt water that drained south along this part of the interlobate area (fig. 5). During this period the reentrant between the glaciers expanded and moved north as the ice wasted. Remnants of the Lake Michigan lobe occupied Pewaukee Lake, and part of the Green Bay lobe occupied Nagawicka Lake. Melt water drained south in the one-fourth mile wide valley until it reached the Wales area, where the stream cut through the Kettle moraine and flowed west (fig. 6b). This channel through the moraine may have

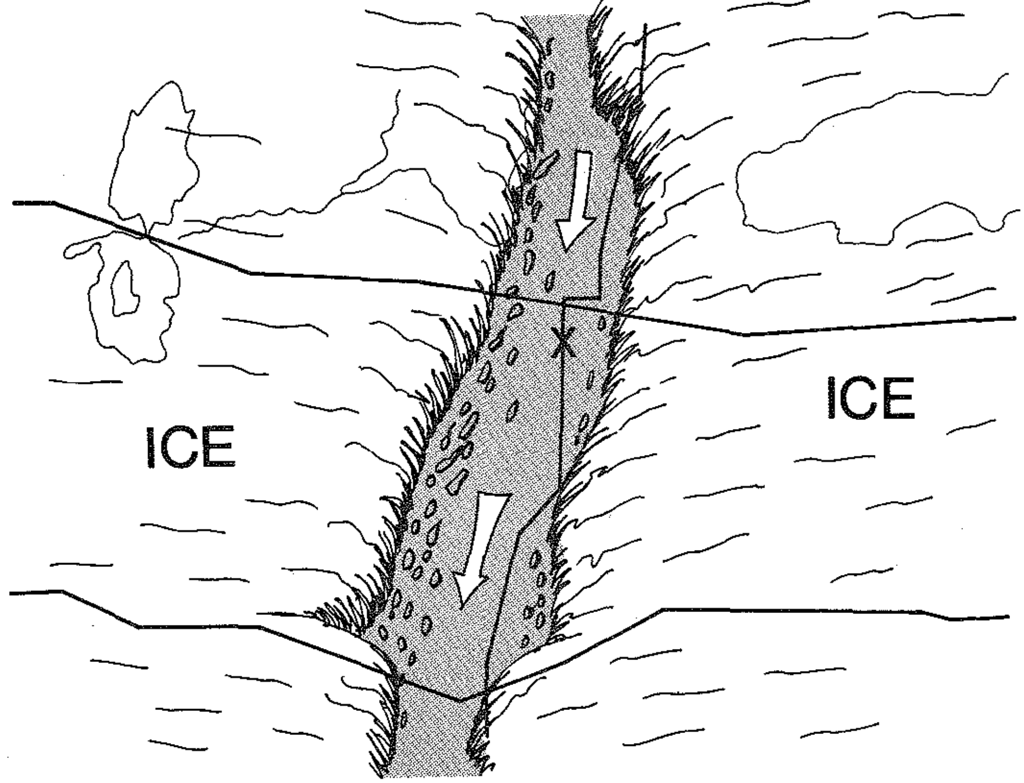


Figure 6a. Glacial drainage channel in interlobate area--early stage.

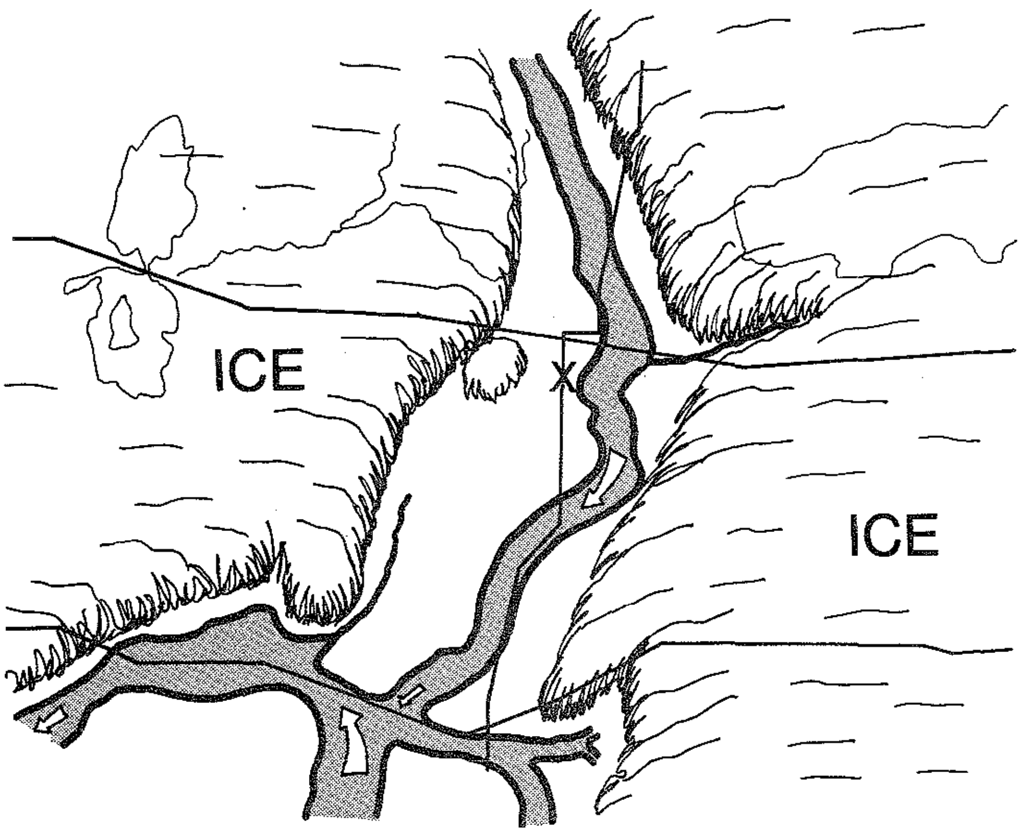


Figure 6b. Glacial drainage channel in interlobate area--and diversion to Genesee flat.

Mileage developed by stream piracy resulting from headward erosion through a depression developed by a melting ice block. This westward discharge contributed sediment from the Lake Michigan lobe to a broad and southwest-sloping outwash plain now called the Genesee flat (fig. 5).

The south drainage through the channel east of STOP NO. 1 was terminated abruptly when a new and lower channel was developed about one-fourth mile to the north (fig. 7a). Melting of the ice that had occupied the Nagawicka Lake area created an easier path of flow to the Genesee flats and Bark River. This new stream rapidly eroded to a new gradient, leaving the previous channel cut off and perched about 50 feet higher than the new channel (fig. 5). The melt waters supplying this stream were draining from the Lake Michigan lobe side of the Kettle moraine. The reentrant angle between the glaciers was north of the area.

As the glaciers continued to waste to the north and east, melting of the ice that had occupied Pewaukee Lake created an eastward path of flow to the Fox River. This diversion removed the last glacial melt water from the area.

The present drainage system to the Bark River is only slightly influenced by the large glacial channel (fig. 7b). Because of the highly permeable moraine deposits and the associated outwash, recharge to ground water is rapid and overland runoff is very small. Erosion has not significantly altered the area since glacial water was diverted from the area.

Ground water moves from east to west, flowing under the abandoned channels seen to the east and north, and discharges to the Genesee flat, the Bark River, and the chain-of-lakes (fig. 8). A ground-water divide does not underlie the Kettle moraine, as might be assumed by looking at the topography (fig. 9). Instead, the ground-water divide is 1.5 miles east of STOP NO. 1 in an area of drumlins and an extensive bog. The abandoned channel to the east intercepts the water table about 1.5 miles to the south, and springs commence the flow of a small creek draining to the Genesee flat.

Pollution of the shallow ground water may be the major management concern. In the highly developed areas around Pewaukee Lake and Nagawicka Lake, numerous wells tapping shallow sand and gravel have been reported to be polluted. In addition, both lakes have large growths of weeds and algae. Sewerage systems have been proposed to replace the numerous septic tanks.

24.9 0.2 Crossing the terrace we examined at STOP NO. 1.

25.4 0.5 The road leaves the kame terrace and crosses abandoned drainage channel.

This 0.2 mile wide, flat-bottomed, drainageway channeled melt water from the Lake Michigan lobe southwestward through the Kettle moraine and to the Genesee flat. Assuming that the glacial stream

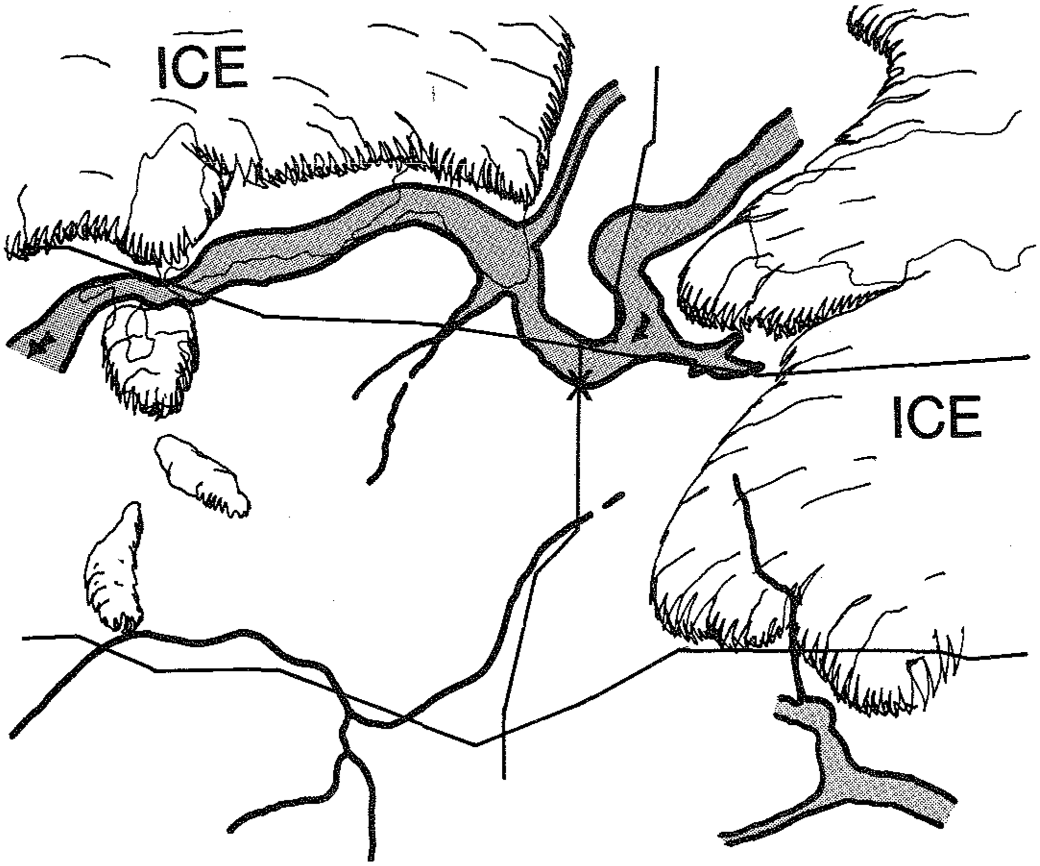


Figure 7a. Glacial drainage channel diverted to Bark River.

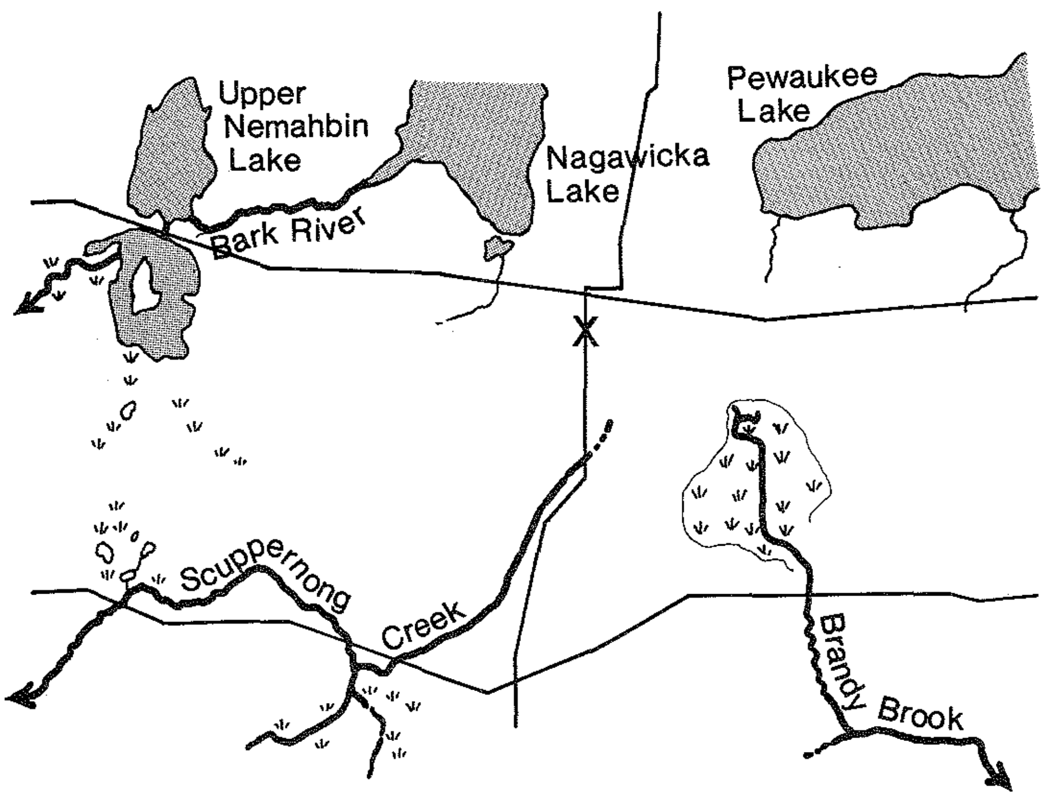


Figure 7b. Present drainage in area of Stop No. 1.

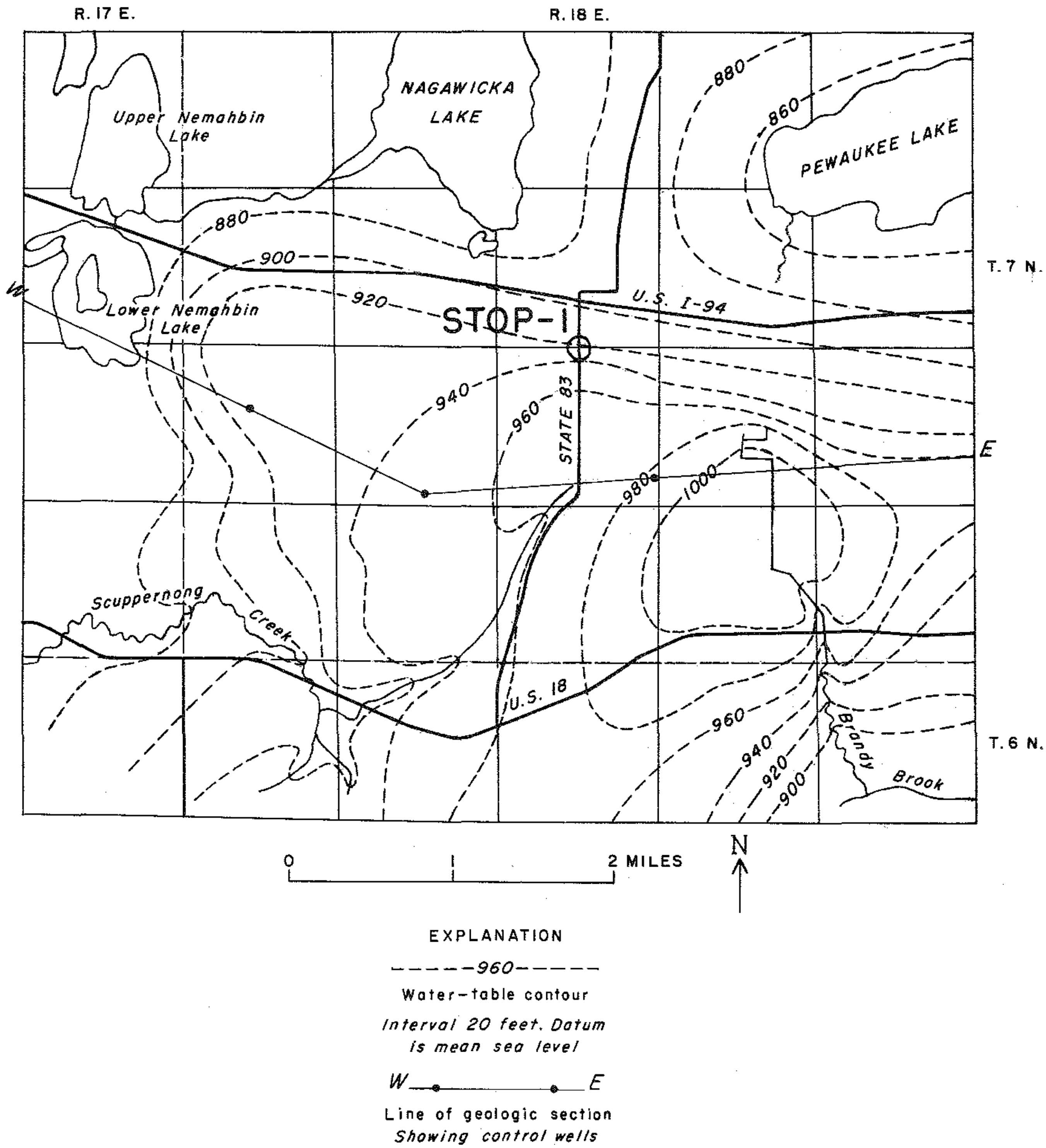


Figure 8. Potentiometric surface in glacial deposits in Kettle moraine area near Stop No. 1.

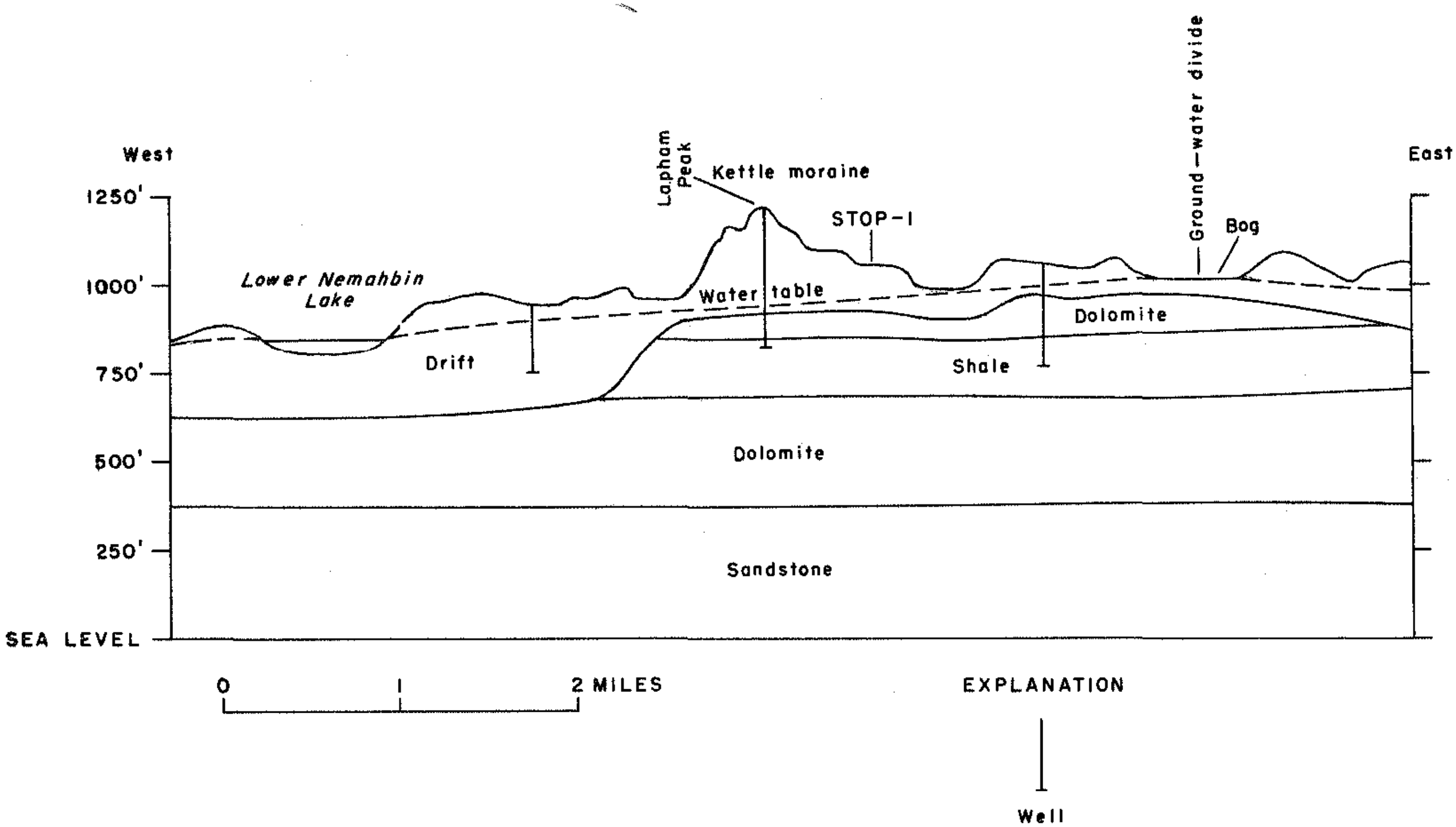


Figure 9. Geologic section through Kettle moraine near Stop No. 1.

Mileage was 20 feet in depth, the flow could have been 200,000 cfs (cubic feet per second). The channel intersects the ground-water table just above this road crossing, and springs commence the flow of a small creek. Note the present underfit character of the creek.

26.1 0.7 Road parallels the Genesee drainageway. Lapham Peak (see radio tower to right--west) marks the highest point (1,250 feet altitude) of the interlobate moraine. The channel altitude is 950 feet.

27.3 1.2 STOP SIGN. Turn right on U.S. Highway 18.

You are now on an outwash terrace that is a continuation of the terrace visited at STOP NO. 1. This terrace widens and slopes to the south (fig. 5). We will view the further continuation of this terrace when we reach Eagle.

27.6 0.3 Gravel pit on right (north) in terrace. You have left the Lake Michigan lobe side of the Kettle moraine and are crossing through a gap in the moraine (fig. 5).

29.4 1.8 Turn left (south) on County Highway CC (Kettle Moraine Scenic Drive).

29.5 0.1 Cross railroad tracks. Note large gravel pit in the terrace.

29.8 0.3 Gravel pit on the left (east) is a solid-waste disposal site for Wales.

30.2 0.4 Travel south on terrace on the Green Bay lobe side of the Kettle moraine.

31.2 1.0 The conical hill of drift to your right (west) is a moulin kame (fig. 5). The wetlands to the east mark the water table.

31.5 0.3 Note pits in terrace.

31.8 0.3 STOP SIGN. Junction with County Highway G. Turn right (west) and continue on the Kettle Moraine Scenic Drive.

32.2 0.4 The northwest face of the Kettle moraine rises abruptly on your left (south) from marshes and nearly flat plains. The steep slope, which extends from Waterville south to STOP NO. 2 near Palmyra, was an ice-contact face of the Green Bay lobe. These lowlands on the west side of the moraine are about 100 feet below the extensive outwash terraces on the east side of the moraine (fig. 5).

32.9 0.7 Junction of County Highways C, D, and G. Turn left (south) on County Highway G--Kettle Moraine Scenic Drive.

33.2 0.3 Reentering the Kettle moraine.

33.6 0.4 Note knob and kettle topography typifying the stagnant ice conditions (fig. 5).

Mileage		
34.8	1.2	We are now on the high terrace on the Lake Michigan lobe side of the Kettle moraine.
35.3	0.5	Junction with County Highway GG--continue on County Highway G.
35.7	0.4	STOP SIGN. Junction with County Highway ZZ--turn right (west). Note large kettles on left (south).
36.4	0.7	Scuppernong Ranger Station. A moulin kame is 0.2 mile west of the station (fig. 5).
37.0	0.6	Picnic area on left (south).
37.3	0.3	STOP SIGN. Junction of State Highway 67 and County Highway ZZ. Turn left (south on State Highway 67 (Kettle Moraine Scenic Drive).
37.5	0.2	Kettle Lake on right. Springs enter pond on the south side. Pond drains west through extensive wetlands to Scuppernong Creek, a tributary of the Rock River.
38.3	0.8	McClintock's spring pond on the left (east) is a tributary to the Scuppernong River (fig. 10). The spring, a discharge point for ground water moving west from the Kettle moraine area, has an average flow of 390 gpm. Since May 1967 the flow has ranged from 260 to 610 gpm. The water temperature averages approximately 10°C (50°F) at the spring and ranges from 4°C (39°F) to 17°C (86°F) at the pond outlet. The water is a calcium magnesium bicarbonate type, similar to the chemical quality of ground water in other parts of the Kettle moraine area (HA 360, sheet 3).
38.6	0.3	Road parallels Kettle moraine on left (east). Scuppernong marsh to right.
39.8	1.2	Junction of County Highway GN. Continue south on State Highway 67.
41.4	1.6	STOP SIGN. Junction with State Highway 59. Turn right (west) on State Highway 59, following Kettle Moraine Scenic Drive.
		Eagle is situated on the west edge of the same south-sloping outwash terrace we viewed near Wales and which, in turn, was a continuation of the kame terrace visited at STOP NO. 1 (fig. 10). A 15-carat diamond was found in a well dug on the moraine near Eagle.
42.1	0.7	Recrossing the Kettle moraine after leaving the Lake Michigan lobe side.
42.4	0.3	Paradise Springs Resort and trout pond to the north. Numerous springs discharge from the Kettle moraine to Scuppernong marsh on your right (northwest) (fig. 9). Lake clays overlie outwash sand in some parts of the marsh.
43.2	0.8	Attractive springs and unsightly junk yard at junction with County Highway S.

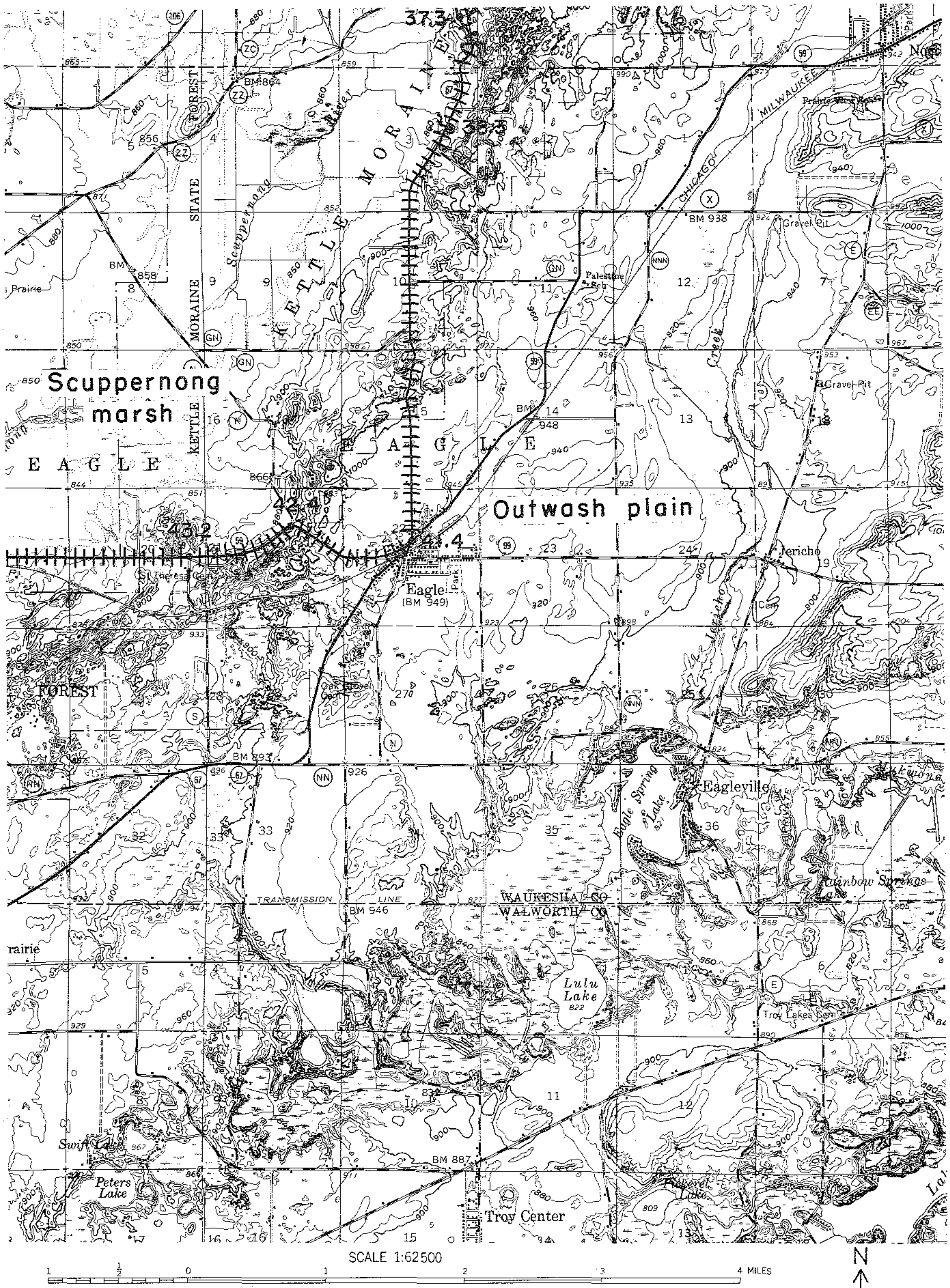


Figure 10. Topography of Kettle moraine, Scuppernong area.

Mileage

44.8 1.6 Crossing outwash plain. Kettle moraine hills to left (south).

45.2 0.4 Junction with County Highway Z.

46.7 1.5 Palmyra city limits. Spring Lake on left.

47.6 0.9 Center of Palmyra. Junction of State Highway 59 and County Highway H.

47.9 0.3 CAUTION. Railroad.

49.6 1.7 Blue Spring Lake outlet to left (east). The lake occupies a kettle adjacent to the interlobate moraine seen to the east (fig. 11). This headwaters lake is fed by springs along the eastern and southeastern shores. The springs discharge ground water recharged in the moraine and outwash several miles to the east. The lake drains west to Scuppernong Creek and to the Rock River.

50.1 0.5 Turn right (west) to Rushing Waters Trout Farm.

Mileage

STOP NO. 2

50.4 0.3 STOP NO. 2. Disembark from buses to tour Rushing Waters Trout Farm.

This farm is privately owned and raises rainbow and golden rainbow trout for sale to fee-fishing ponds in Illinois, Michigan, Indiana, and Wisconsin. The ponds produce about 100,000 lbs. of fish per year. About 300,000 trout are now being reared in the ponds. A 6-8-inch trout in November will increase to 11 inches (market size) by spring. Forty-eight rearing ponds are fed by three large springs and by 3 flowing wells, 130-200 feet in depth, tapping the Platteville-Galena aquifer (HA 360, sheet 3). Total discharge is about 1,500 gpm.

Water temperature and dissolved oxygen (DO) content are critical factors for fish culture. Water temperature is maintained below 70°F for trout by continuous flow of 50°F ground water through the ponds. The amount of ground water limits the total volume of the ponds.

Trout need 6-8 mg/l of DO for normal activity and greater amounts for health and maximum growth. Ground water from wells has a DO content of 4-6 mg/l. Various types of aerators are used to increase the DO content in the water and thereby increase the productivity of the trout ponds. In the northeastern group of 16 ponds a production of 40,000 fish in 1968 was increased to 56,000 in 1969.

50.7 0.3 Return to County Highway H. Turn right (south).

51.1 0.4 Kettle moraine on the left (east).

51.3 0.2 Jefferson-Walworth County line. We are now on the interlobate moraine. Drift here is 200-300 feet thick.

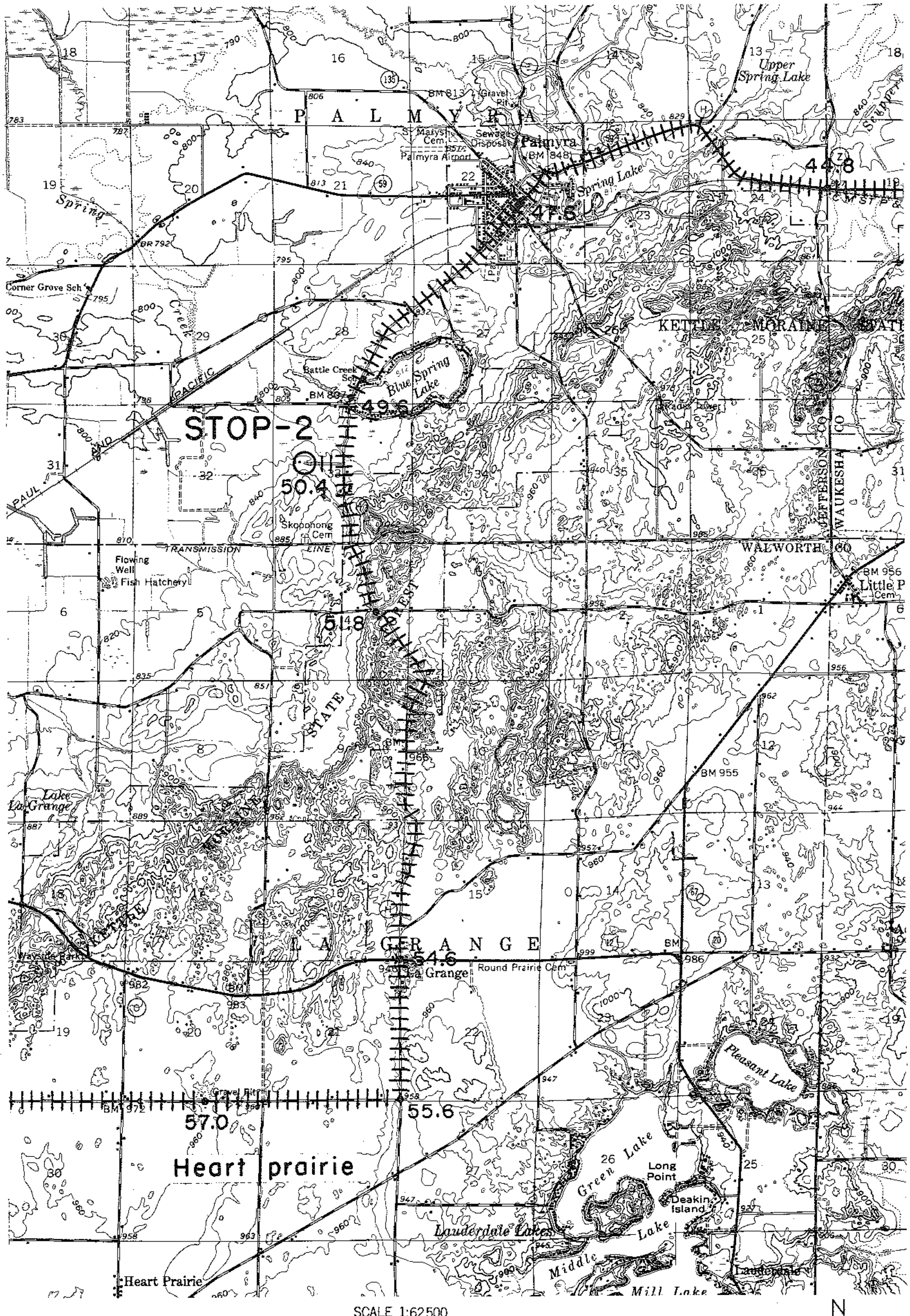


Figure 11. Topography of Kettle moraine near Stop No. 2.

Mileage		
51.8	0.5	Crossing through center of interlobate moraine. The 40-foot road cut on left exposes sand and gravel as well as large boulders.
52.3	0.5	Deep kettles and steep knobs typify the moraine topography.
52.5	0.2	LaGrange Public Park.
53.1	0.6	Pits in outwash terrace on the Lake Michigan lobe side of the Kettle moraine.
53.6	0.5	On the right (west) is a large bog occupying a kettle. Note the dark colored leatherleaf ringed by buff colored sedge and reed-canary grass.
54.6	0.8	STOP SIGN. Junction with U.S. Highway 12. Continue south on County Highway H.
55.6	1.0	Turn right on Kettle Moraine Scenic Drive.
55.7	0.1	We are now on the Heart Prairie, a high pitted outwash plain southwest of the Kettle moraine (figs. 11 and 12). It consists principally of outwash from the Green Bay lobe, which was deposited behind the Darien moraine after the Lake Michigan lobe had receded to the position of the Elkhorn moraine (Alden, 1918, p. 258). The ground water in Heart Prairie moves northwest, under the Kettle moraine, and discharges as springs and flowing wells in the wetland area between the Milton moraine and Whitewater (fig. 13). Preglacial drainage was toward Lake Michigan. A buried bedrock valley called the Troy Valley begins in the Lauderdale Lake area, trends northeast into Waukesha County, and then east to Lake Michigan. Although surface drainage no longer follows this direction, the trend of the buried valley is indicated by numerous lakes and wetlands. The valley is filled with as much as 500 feet of saturated glacial material that could yield large supplies of ground water (Green, 1968, p. 135).
57.0	1.3	Gravel pit on right in the outwash terrace. As much as 6 feet of silt fills depressions in the outwash surface.
57.6	0.6	STOP SIGN. Junction with County Highway O. Continue west on Kettle Moraine Scenic Drive.
57.8	0.2	Note flat surface and gentle south slope of the outwash, as well as the small pits.
58.9	1.1	Reenter Kettle moraine with its distinctive knob and kettle topography.
59.5	0.6	STOP SIGN. Junction of Kettle Moraine Scenic Drive and County Highway P. Continue straight on Kettle Moraine Scenic Drive.
60.5	1.0	Road divides--turn left (south).

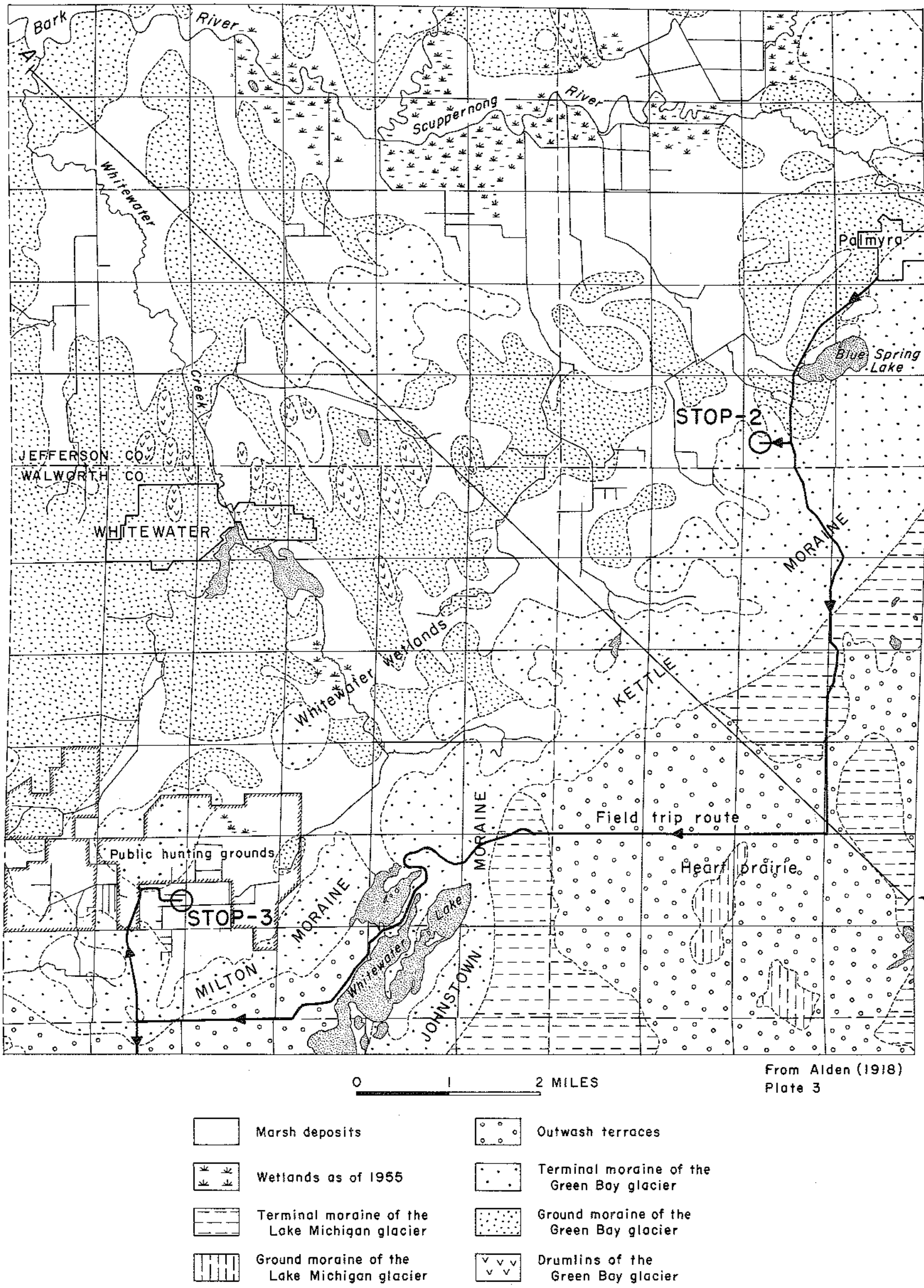


Figure 12. Glacial geology of the Whitewater area.

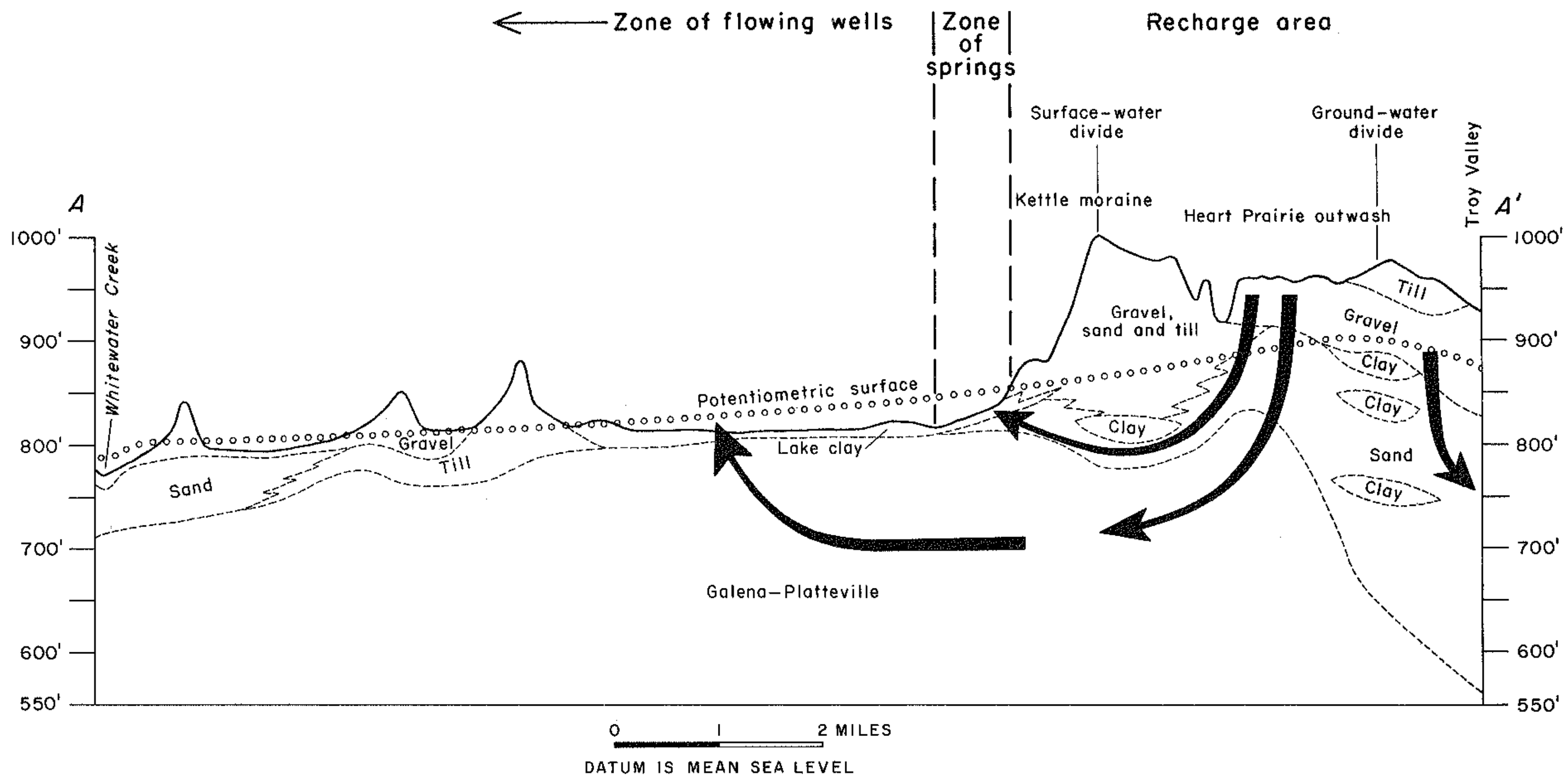


Figure 13. Hydrogeologic section through Whitewater area.

Mileage		
61.1	0.6	Road divides. Stay on right fork--Ridge Road on left. You are driving on top of a crevasse filling, which separates Rice Lake on the right (north) from Whitewater Lake on the left (south) (fig. 14).

Ground water moves through this lake area from the southeast to the northwest and supplies the base flow to Whitewater Creek. The picturesque ridge on your left, a crevasse filling, nearly divides Whitewater Lake. This ridge is more than a mile long, as much as 90 feet above the lake, and less than 500 feet in width. Most of the ridge has been developed for summer cottages and permanent homes.

The shallow depth and small size of these lakes greatly influence their eutrophication processes. Lakes such as these are sensitive to the inflow of nitrates from fertilizers and septic tanks, which create leafy weed growth and algal blooms.

61.8	0.7	Crossing stream that joins the two lakes--the stage of Whitewater Lake is 6 feet above Rice Lake.
62.3	0.5	STOP SIGN. Turn left (south).
62.8	0.5	Following Whitewater Lake on left.
62.9	0.1	Turn right (west) on Town Line Road.
64.5	1.6	Crossing an outwash terrace between the Johnston moraine on the left (south) and the Milton moraine on the right (north) (fig. 12 and 14).
65.2	0.7	STOP SIGN. Turn right (north) on State Highway 89.
65.8	0.6	Crossing the Milton moraine.
66.2	0.4	We are now in the plain of a glacial lake formed behind the Milton moraine after the Green Bay ice lobe receded to the north (fig. 4). This is an area of numerous springs and flowing wells first described by Chamberlin (p. 162) in 1877. Fifty to 75 feet of lake clays, which overlie sand and gravel, partly confine water moving north from the Kettle moraine. Flowing wells and springs discharge from both the Platteville-Galena aquifer (HA 360, sheet 3) and the overlying sand and gravel. Ground water and streams drain to Whitewater Creek.

STOP NO. 3

66.7	0.5	STOP NO. 3. Get off bus and tour the Vander Veen Farm (fig. 14).

HYDROGEOLOGY OF VANDER VEEN FARM AREA

This farm is an example of optimum use and management of the water resource in a wetland area. The farm occupies part of an extensive and flat area north of the Milton moraine that was

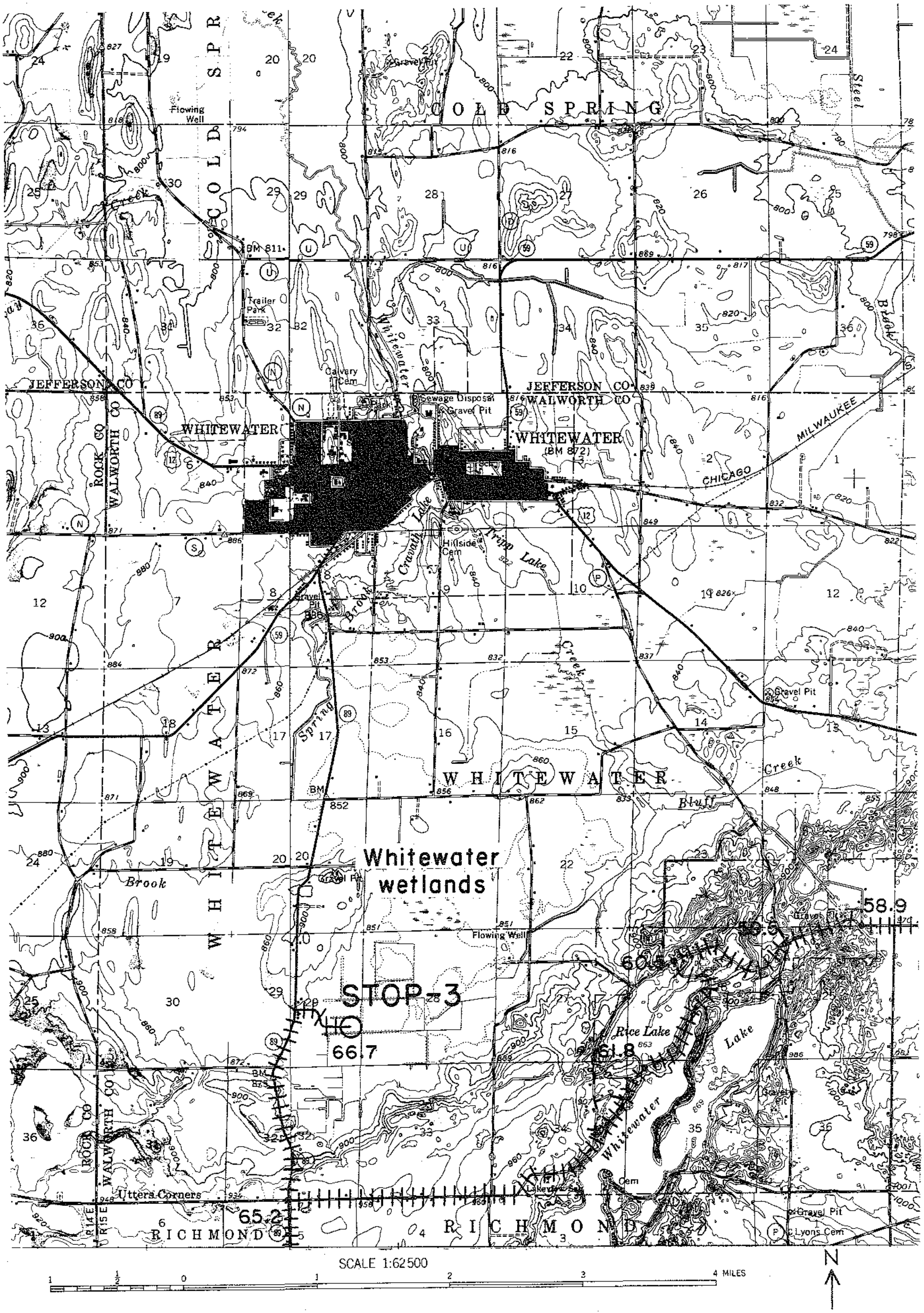


Figure 14. Topography of Whitewater-wetlands area.

formerly almost entirely wetlands used primarily for hunting and harvesting marsh grass. These Whitewater wetlands are a southern part of the belt of wetlands that lies on the west and northwest side of the Kettle moraine and the Milton moraine and includes the Genesee flat and the Scuppernong marsh. The lake clays that form this flat plain overlie dolomite of the Galena-Platteville unit. About 4 feet of peat overlies nearly 40 feet of lake clays here.

The Whitewater wetlands are the discharge point for a shallow ground-water system, which begins with recharge to the Heart Prairie and to the outwash terrace south of the Milton moraine (fig. 13). The top of the saturated zone below the Heart Prairie and related outwash terraces is about 60 feet higher than the discharge area (wetlands).

Ground water moves northwest from the recharge area, through sand and gravel and the underlying dolomite of the Galena-Platteville unit. Part of the ground water enters Whitewater Lake as springs and seeps along the southeast shore and reenters the ground on the northwest side of the lake, rejoining ground water moving northwest to the Whitewater marsh.

As ground water moves from the moraine northwest to the Whitewater wetlands, shallow ground water discharges as springs from the edge of the moraine. Some of the springs are from gravel and sand in the moraine, and some are from fractures in the dolomite.

A spring pond in the southern part of the Vander Veen Farm is being developed for recreation. It is at the foot of the moraine, and the water source is the sand and gravel underlying the lake clays exposed on the hill side of the pond. Note sand boils at the point of emergence.

Ground water also moves under the wetlands, flowing through the dolomite and discharging slowly upwards through the lake clays to ditches and creeks and through wells tapping the dolomite.

Water control is very important to the successful farming of wetlands. Ditches and tile drains must be spaced close enough to lower the water table adequately for crop growth. On the Vander Veen Farm, east-west ditches spaced about one-quarter mile apart are supplemented by buried tile drains normally spaced 70-100 feet apart. Inadequate drainage because of too wide spacing of drains has been a farming problem. Near the base of the Kettle moraine ground-water seepage is much greater, and tiles must be spaced closer together.

Water levels are maintained within a few feet of the land surface by dams. This reduces irrigation requirements of the sod and prevents excessive oxidation of the organic soils.

Draining of these wetlands has changed the properties of the soils, particularly peat and muck. An anaerobic environment generally exists in organic soils that are saturated with water. When drainage

Mileage lowers water levels and the peat is exposed to air, subsidence occurs caused by oxidation, drying, and compaction (Phillips, 1970). Aerobic decay of the peat may also cause lowering of the pH of the ground water.

When organic soils are exposed to air, some nitrogen is leached out and carried away in the drainage water (Phillips, 1970). The supply of nitrogen in drained wetlands diminishes with time, and fertilizers are added.

During the growing season about 2 mgd of water is pumped for the irrigation of sod and peppermint. Water is pumped from the drainage ditches and spread by a sprinkler system. A flowing well tapping bedrock supplies 25 gpm, which is used for makeup water for the peppermint distillation. Flow from the farm is about 2 cfs. Peppermint is grown in partial rotation with sod. The mint is harvested the latter part of August and loaded into trailer-mounted pressure cookers. In the refining shed steam is passed into the cooker, vaporizing the oil in the peppermint plants. The vapor and steam come out of the cooker at the top and pass into water tanks, which condense both oil and steam. The floating oil is then skimmed off and shipped out in 400 lb. drums.

The ditches and drains only locally dewater the wetlands. Wetlands used as public hunting grounds are maintained north, east, and west of the farm (fig. 12).

69.3 2.6 Leave Vander Veen Farm. Turn left and proceed south on State Highway 89.

70.9 1.6 You have now gained 100 feet in altitude after leaving the lake plain (altitude 850 ft.) and are reentering the pitted outwash plain (altitude 950 ft.) lying between the Milton and Johnstown moraines of the Green Bay lobe.

73.3 2.4 Crest of Johnstown moraine (altitude 1,010 ft.).

74.0 0.7 CAUTION! Dangerous intersection with County Highway A. Continue south on State Highway 89.

You are now in the area where the interlobate Kettle moraine separates into the Johnstown moraine of the Green Bay lobe and the Darien moraine of the Lake Michigan lobe (fig. 2). For the next 4½ miles we will travel along the west edge of the Darien moraine.

75.1 1.1 We are now crossing an abandoned drainageway, which carried melt water from the stagnating ice westward to Turtle Creek.

78.6 3.5 STOP SIGN. Junction of Stage Highway 89 and U.S. Highway 14. Turn west on U.S. Highway 14.

We are now on outwash deposited in front of the Darien moraine. This plain extends west to Janesville and Beloit. Related outwash extends discontinuously along the front of the Johnstown moraine for more than 40 miles.

Mileage

81.9 3.3 We are now crossing an inlier of ground moraine within the outwash plain. The outwash plain is visible to the north.

86.1 4.2 Emerald Grove village limits.

87.1 1.0 We are now returning to the flat outwash plain.

HYDROGEOLOGY OF THE ROCK RIVER VALLEY

Bedrock in the Rock valley area consists of sandstone and dolomite of Cambrian and Ordovician ages (HA 360, sheet 1). Maximum thickness of the Ordovician rocks in the area is about 500 feet. The total thickness of the sandstones of Cambrian age averages about 1,100 feet. The rocks dip southeast at about 14 feet per mile.

The bedrock surface in the Rock valley area has been deeply dissected by preglacial erosion. A major feature is the preglacial Rock River valley, which attains a maximum known depth of 396 feet below land surface about 5 miles north of Janesville. Figure 15 shows the general configuration and geologic section of the buried valley. Note that the present drainage conforms generally with the buried valley but crosses bedrock ridges in many places.

Ground moraine covering the southern and western parts of the area (HA 360, sheet 1) are the oldest glacial deposits and consist of a thick clayey till.

Large quantities of ground water are available in the Rock River valley from both glacial outwash and the bedrock aquifer. Outwash in the valley yields as much as 5,450 gpm for 24 hours with only 7 feet of drawdown (city of Janesville). An aquifer performance test at Beloit indicated the transmissivity of the outwash to be about 1,200,000 gpd per ft. (gallons per day per foot) (LeRoux, 1963). The thick saturated section of sandstones underlying the outwash yields as much as 1,200 gpm to wells and has a transmissivity of about 33,000 gpd per ft. Only a very small part of the water available from these two aquifers is developed.

Movement of water in both the bedrock and glacial drift aquifers is toward the Rock River valley. A composite potentiometric map of the two aquifers is shown in figure 16. The low gradient and poorly developed drainage in the outwash covered areas between Rock River and Turtle Creek and in the area north of Janesville and east of the Rock River indicate high permeability of the outwash. Steeper gradients in the terminal and ground moraines west of the Rock River and southeast of Turtle Creek indicate lower permeability.

Turtle Creek loses water as it leaves clayey morainal deposits and enters the plain formed by the Rock valley outwash deposits (fig. 15) (HA 360, sheet 2).

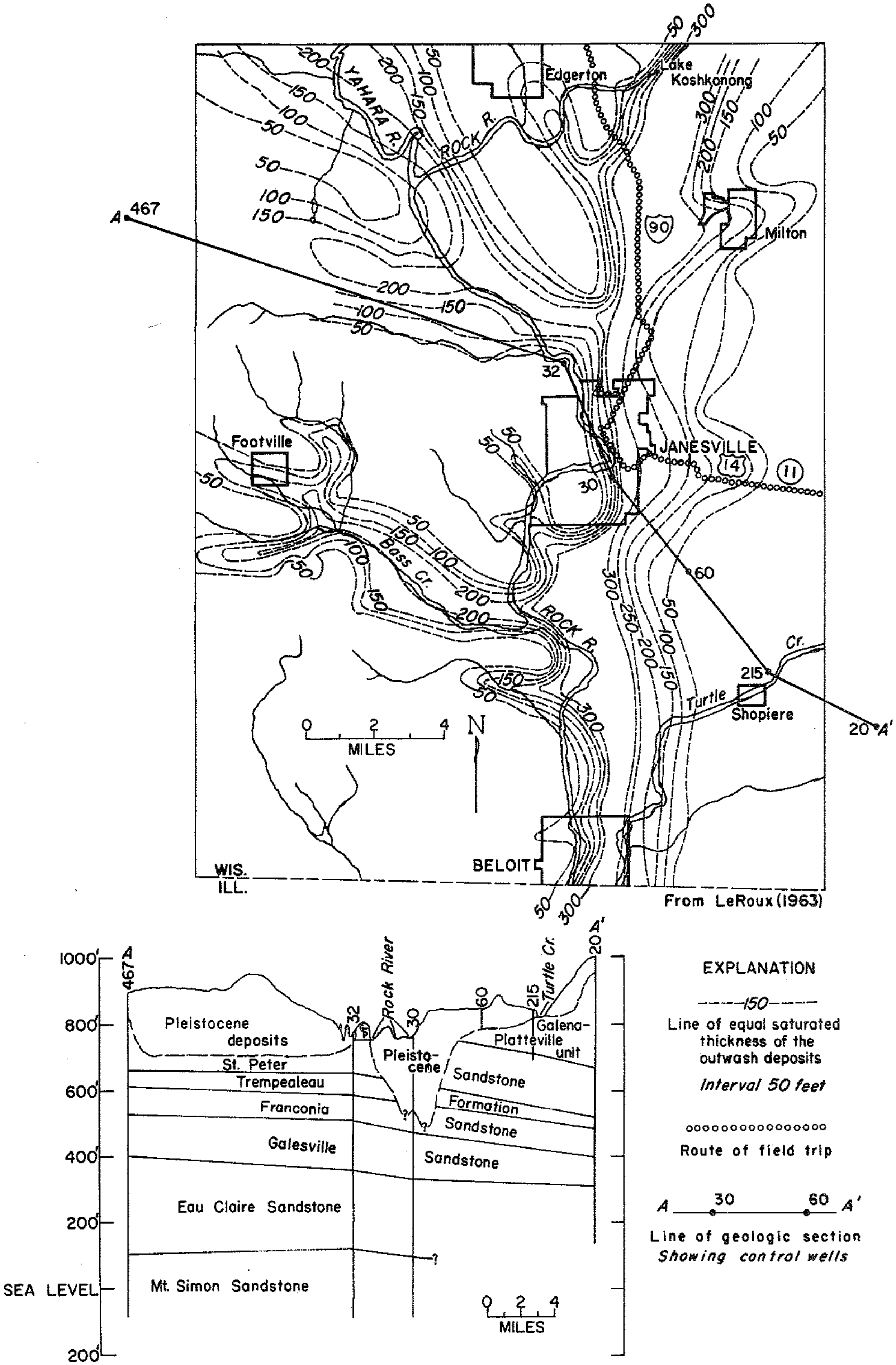


Figure 15. Saturated thickness of outwash deposits in the Rock River valley, Janesville area.

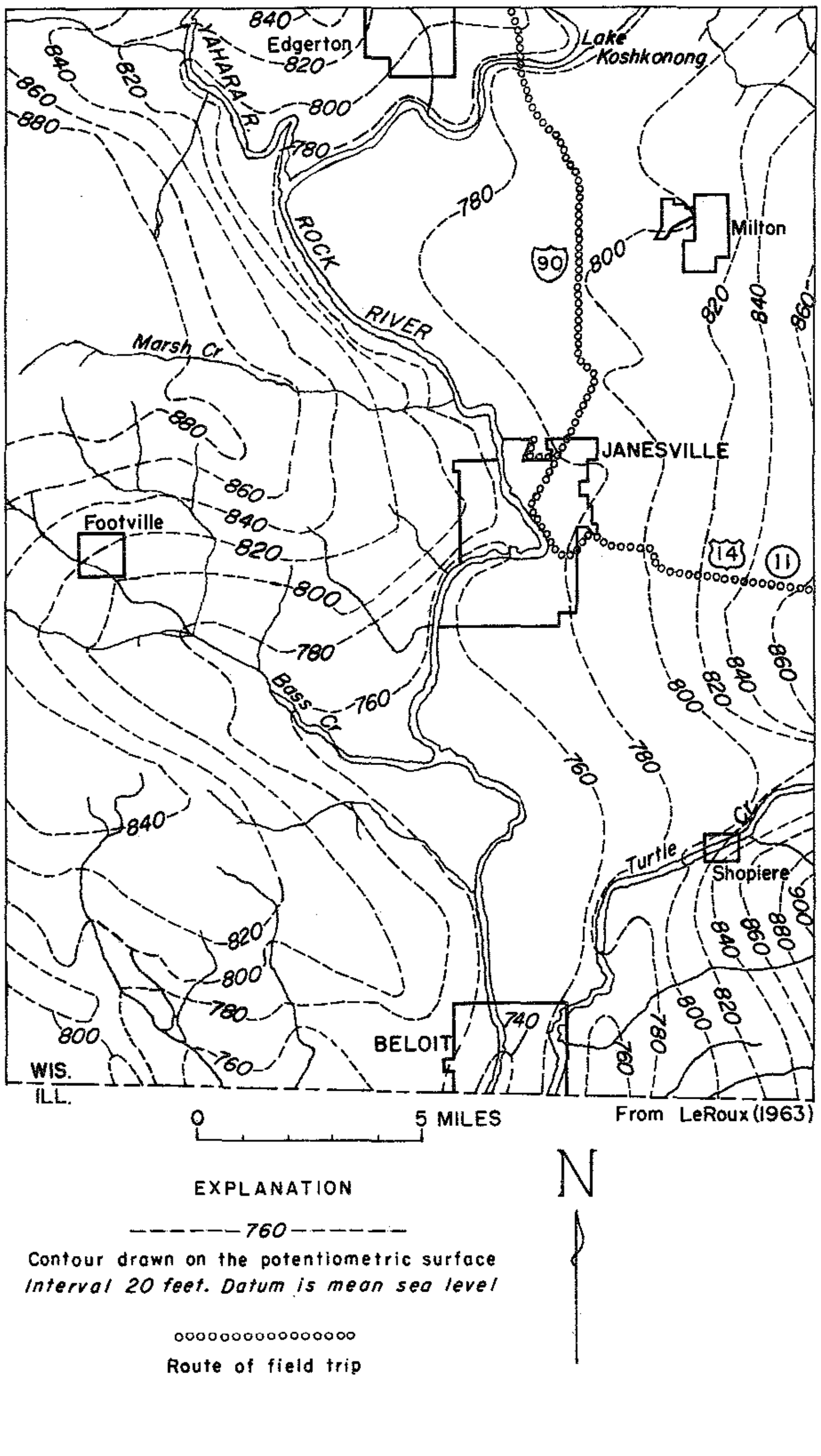


Figure 16. Potentiometric surface of the Rock River valley, Janesville area, 1958.

Mileage

Chemical quality of ground water from outwash of the Rock River valley and from bedrock aquifers is very similar. The water is a hard calcium magnesium bicarbonate type and is slightly alkaline (table 1). The high bicarbonate concentrations reflect the predominance of carbonate rocks (dolomite) in the aquifers.

90.4 3.3 Junction of U.S. Highway 14 and Janesville City Highway 14. Turn left (west) on City Highway 14.

91.8 1.4 Junction of City Highway 14 and Interstate Highway 90.

92.3 0.5 Janesville city limits.

92.4 0.1 Junction of City Highway 14 and Palmer Drive. Turn left (southwest) on Palmer Drive.

We are now following a southwest sloping glacial drainageway that is being used by the city of Janesville for recreation and water management (fig. 17). The valley floor was acquired by the city, thereby restricting housing development to the terraces. Both sewer and water lines are laid along the valley with laterals extending to houses on the terraces. The flat valley floor also provides park and recreation areas for the city, as evidenced by the Blackhawk Golf Course and a swimming area.

Storm runoff from the housing areas is directed to the valley where it infiltrates rapidly to the ground-water reservoir. The grassy valley floor prevents erosion and the highly permeable outwash allows rapid recharge. Municipal wells located in the valley benefit from this local recharge. Several new test wells have been drilled in the valley. The city is continuing to purchase land in the valley as it becomes available.

93.1 0.7 Swimming area and lagoon on right were developed by reclaiming a 30-year old sand pit. Another nearby sand pit has been planted with trout and pan fish and is used for fishing.

93.5 0.4 Junction of Palmer Drive and South Main Street. Turn right (north) on South Main Street.

City well number 4, located at this junction, is 105 feet deep and penetrates gravel with some sand. The well is 26 inches in diameter and is cased to 45 feet with screen and gravel pack from 45 to 105 feet. The well is pumped regularly at a rate of 5,200 gpm. The specific capacity determined during a test pumping was 780.

94.3 0.8 Rock River on left.

94.8 0.5 Junction of South Main Street and State Highway 26 (East Centerway). Turn right (east) on State Highway 26.

96.5 1.7 Junction of State Highway 26 and Black Bridge Road. LUNCH STOP at Family Kitchen Restaurant on corner.

Table 1.--Chemical analyses of water from Janesville city wells and shallow ground water

Source	Date	Well Depth Feet	Aquifer	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrite (NO_2)	Nitrate (NO_3)	Phosphorus (PO_4)	Total solids	Hardness as $CaCO_3$	pH	*Analysis by
Rock County Hospital, Janesville	6/62			.05	.03	52	36	349	2	1.5	--	--	0.0	.89	304	280	7.3	WSLH
City of Janesville																		
Well #1	10/63	1,087	SS	.05	.04	69	40	359	14	3.5	0.0	--	19	--	362	--	7.6	WSLH
Well #2	10/63	1,125	SS	.24	.04	64	--	454	5.5	0.0	0.0	--	.4	--	380	360	7.5	WSLH
Well #3	8/66	100	Q	.03	.03	76	31	337	26	3.8	.2	.01	18	--	366	318	7.5	WSLH
Well #4	10/63	105	Q	.29	.04	72	34	327	28	1.5	0.0	--	21	--	372	320	7.3	WSLH
Well #5	6/66			.03	.03	78	37	337	30	8.5	.2	.01	25	--	414	349	7.7	WSLH
Janesville Dump																		
Shallow pond	8/69	--	Q	3.9	.31	--	--	200	23	4.0	.0	.00	4.1	.12	214	190	7.7	USGS
Well	8/69	4	Q	.45	.03	--	--	112	25	8.0	.3	.00	.3	.07	290	100	8.7	USGS
Janesville Sand & Gravel Co. Pit																		
Pond	8/69	--	Q	.10	.17	--	--	346	31	8.0	1.1	.10	5.4	.01	338	322	7.9	USGS

*WSLH, Wisconsin State Laboratory of Hygiene; USGS, U.S. Geological Survey. The analyses by the USGS are in Milligrams per liter while those of the WSLH are in parts per million. The units are essentially equivalent.

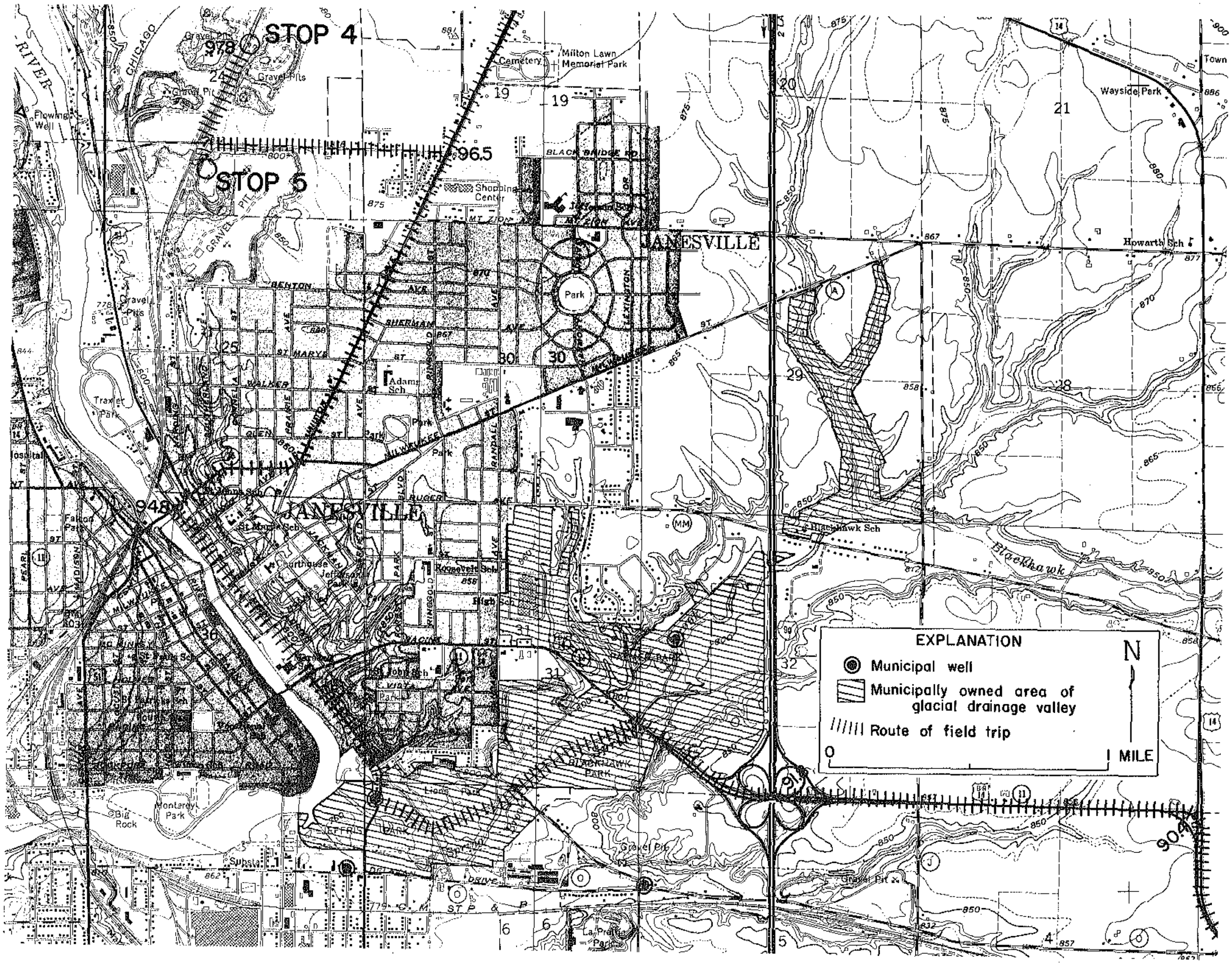


Figure 17. Glacial drainage valley and gravel pits, Janesville.

Mileage
97.4 0.9 Proceed west on Black Bridge Road to Janesville Sand and Gravel Company. BE CAREFUL OF TRUCKS AND HEAVY EQUIPMENT. Turn right to parking area.

STOP NO. 4

97.8 0.4 STOP NO. 4. The Janesville Sand and Gravel Company, which has been operating since 1907, produces sand and gravel from this pit as well as from several other pits in southern Wisconsin. The company estimated in 1963 that the total sand and gravel removed from their workings would fill a train reaching from New York to Los Angeles!

The pits are 90 feet deep and are excavated to within 2-3 feet of the water table. Large reserves of sand and gravel below the water table could be developed if economically feasible. A small bedrock exposure in the northwestern part of this pit is the west wall of the buried bedrock valley, and the sand and gravel thicken eastward (fig. 15).

Water for washing is pumped from a deepened part of the gravel pit. At full operation water is pumped at a rate of about 1,000 gpm 24 hours per day, with a resulting drawdown of about 30 inches. After use the silt and sand-laden water is discharged to another part of the pit to be recharged to the water table. Part of this water recirculates back to the pumping pit.

The company produces all sizes of concrete and bituminous agregates, sized-washed gravel, sand, and unwashed sand and gravel. Major markets are in Madison, Milwaukee, and Chicago. Decorative exposed aggregate for precast concrete panels is shipped as far as Ohio, Missouri, Kansas, and Nebraska.

98.1 0.3 Leave gravel pit and proceed to abandoned pit and city dump.

STOP NO. 5

The city of Janesville acquired this abandoned gravel pit from the Janesville Sand and Gravel Company for disposal of refuse. This dump has been operated since 1963, but another nearby site was used from 1950 to 1963. The base of the dump is the gravel pit floor, which is about at the water table. Refuse is covered daily with dirt fill.

From the management standpoint, the gravel pit is ideal for refuse disposal. The site is concealed, it is in an industrial area, cover material is readily available, and the land is of questionable value for other uses. These advantages have made abandoned pits a favorite dumping ground. However, the use of these pits for refuse disposal is questionable from the standpoint of ground-water pollution.

Mileage

A hole augered to a depth of 30 feet in the dump, nearly the total thickness of refuse, showed the material to be well drained and in a good state of preservation. The leachate from the dump entering the ground-water reservoir is diluted by the water moving through this permeable aquifer. Movement of water at the dump site is nearly due west to the Rock River where it is discharged. The river is about 0.5 mile from the disposal site (fig. 17). One industrial well using ground water for air conditioning is located between the dump and the river.

Chemical analyses of shallow ground water immediately adjacent to the east side of the refuse site (upgradient) are shown on table 1. Concentrations of dissolved minerals, except iron, were lower at the refuse site than in water from the Janesville city wells, probably because of dilution from local recharge. Iron, possible from leaching of the refuse, was higher in the refuse site samples.

98.6 0.5 Intersection of Black Bridge Road and State Highway 26. Turn left (east) on State Highway 26.

99.2 0.6 Intersection of U.S. Highway 14 and State Highway 26. Proceed straight on State Highway 26

99.7 0.5 Intersection of State Highway 26 and Interstate Highway 90. Turn (west) on Interstate Highway 90 (under bridge and to the right).

100.7 1.0 Leave Rock River valley outwash plain and enter the Johnstown moraine.

103.3 2.6 Leave Johnstown moraine and enter intermorainal outwash plain.

106.1 2.8 Leave intermorainal outwash plain and reenter Milton moraine.

107.4 1.3 Rock River.

109.5 2.1 Leave Milton moraine, enter area of ground moraine and marsh deposits with associated drumlins, kames, and recessional moraines. This terrane continues into Madison (HA 360, sheet 1).

110.6 1.1 U.S. Highway 51 south and State Highways 73 and 106 exit. Continue on Interstate Highway 90.

113.7 3.1 Drumlins can be seen to the right (east) in the distance.

114.1 0.4 U.S. Highway 51 north exit. Continue on Interstate Highway 90.

126.7 12.6 Yahara Hills Golf Course on right. Complex faulting in this area severly restricts the yield of the regionally productive sandstone aquifer.

128.1 1.4 Intersection of U.S. Highways 12 and 18 and Interstate Highway 90. Turn left (west) off Interstate Highway 90 onto U.S. Highways 12 and 18.

Mileage

131.2 1.4 Cross the Yahara River, a tributary of the Rock River.

132.1 0.9 Village of Monona well on left. The well penetrated 180 feet of glacial drift over sandstones of Cambrian age and reached crystalline rock at a depth of 775 feet. The well was test pumped $3\frac{1}{2}$ hours at 1,506 gpm with 90.8 feet of drawdown, for a specific capacity of 15.1.

132.8 0.7 Intersection of U.S. Highways 12 and 18 and Olin Avenue (County Highway MC). Turn right (northwest) at Olin Avenue.

132.9 0.1 Lake Monona on right (north).

133.3 0.4 Dane County Coliseum and grounds on left have been built on sanitary landfill. Two lagoons are dug adjacent to the sanitary landfill site and discharge ground water to Murphys Creek, which empties into Lake Monona. A recent study of this area has shown water in the lagoon to be only slightly contaminated by the landfill. Quality of water in the lagoon is very similar to the quality of water in Murphys Creek and the ground water in the area (oral communication, Robert F. Kaufmann, University of Wisconsin).

133.5 0.2 Intersection of Olin Avenue and John Nolen Drive. Continue straight on John Nolen Drive.

134.2 0.7 Causeway across Lake Monona. Wisconsin State Capitol can be seen on the right (north).

134.7 0.5 End causeway. Proceed right (northeast) on North Shore Drive.

135.6 0.9 Intersection of North Shore Drive, Wilson Street, and Blair Street (stop light). Proceed left (northwest) on Blair Street.

135.8 0.2 Intersection of Blair Street and East Washington Avenue. Proceed straight on Blair Street.

136.1 0.3 Intersection of Blair Street and Gorham Street. Turn left (southwest) on Gorham Street

STOP NO. 6

136.2 0.1 STOP NO. 6. City of Madison Main Station (M. Starr Nichols Pumping Plant). Turn left on Hancock Street and into parking lot.

HYDROGEOLOGY OF THE MADISON AREA

The water resources of the Madison area include a sanstone aquifer, 700-1,000 feet thick which underlies the entire area, and a chain of large lakes.

The sandstone aquifer in the Madison area is considered a single water-yielding unit that consists of five formations of Cambrian age.

Precambrian crystalline rocks underlie the Madison area at depths ranging from about 700 to 1,000 feet.

The Madison municipal water supply is obtained from 24 wells in the sandstone aquifer. Most of the city wells are between 700 and 1,000 feet deep and penetrate the full thickness of the aquifer. Rated capacities of the wells range from 450 to 2,600 gpm, and the average is about 1,700 gpm.

The pumpage of water at Madison has increased from about 1.5 mgd in 1905 to about 26 mgd in 1968 (fig. 18). Since 1950 the pumpage has increased at a rate that has doubled in 18 years. The doubling of pumpage in 18 years, compared to the doubling of the population in 22 years, reflects an increased per capita usage from 115 gpd in 1950 to 146 gpd in 1968. At the present rate (1950-68) of increase, Madison's pumpage may be near 45 mgd in 1980 and near 70 mgd in 1990.

A major effect of the municipal pumpage has been to intercept ground water that formerly moved toward the lakes. As a result, several large springs near the lakeshores have ceased flowing. Cones of depression due to pumping are shallow, generally less than 60 feet, and extensive (HA 360, sheet 3) (Cline, 1965). Although the water-level decline has not been large, the potentiometric surface is below the levels of Lakes Mendota and Monona throughout much of the city area, and recharge probably is being induced from the lakes.

Municipal water pumped from wells is not returned to the stream and lake system in the Madison area in order to protect the quality of the downstream lakes. Treated sewage effluent is diverted around the chain of four lakes through a canal and Badfish Creek.

The Madison well-development plan has changed several times during the growth of the city. Originally all city wells were drilled near the Nichols pumping station. Later the system was expanded to an east-west line of wells spaced about 1 mile apart. At that time it was believed that the sandstone aquifer was being recharged near Wisconsin Dells (about 45 miles north of Madison), and that the water moved generally southward under the Madison area. New wells were drilled transverse to this supposed movement to intercept the moving water.

Continued expansion of the city and an increased knowledge of hydrology led to the development of the well field as it exists today. The wells were spaced areally at intervals of 1 mile or more to avoid excessive drawdown of the water levels.

Madison's newest plan, based on 1964 and 1969 recommendations by an engineering firm, is primarily economic rather than hydrologic in its approach. Basically the plan calls for extension of new or improved water mains into developed areas and areas of expected development, and new wells will be drilled near the new mains. Individual wells will serve units of the city, with the largest water mains located near the wells. Interconnections between mains will allow temporary shutdown of individual wells. This plan is due for completion by 1980.

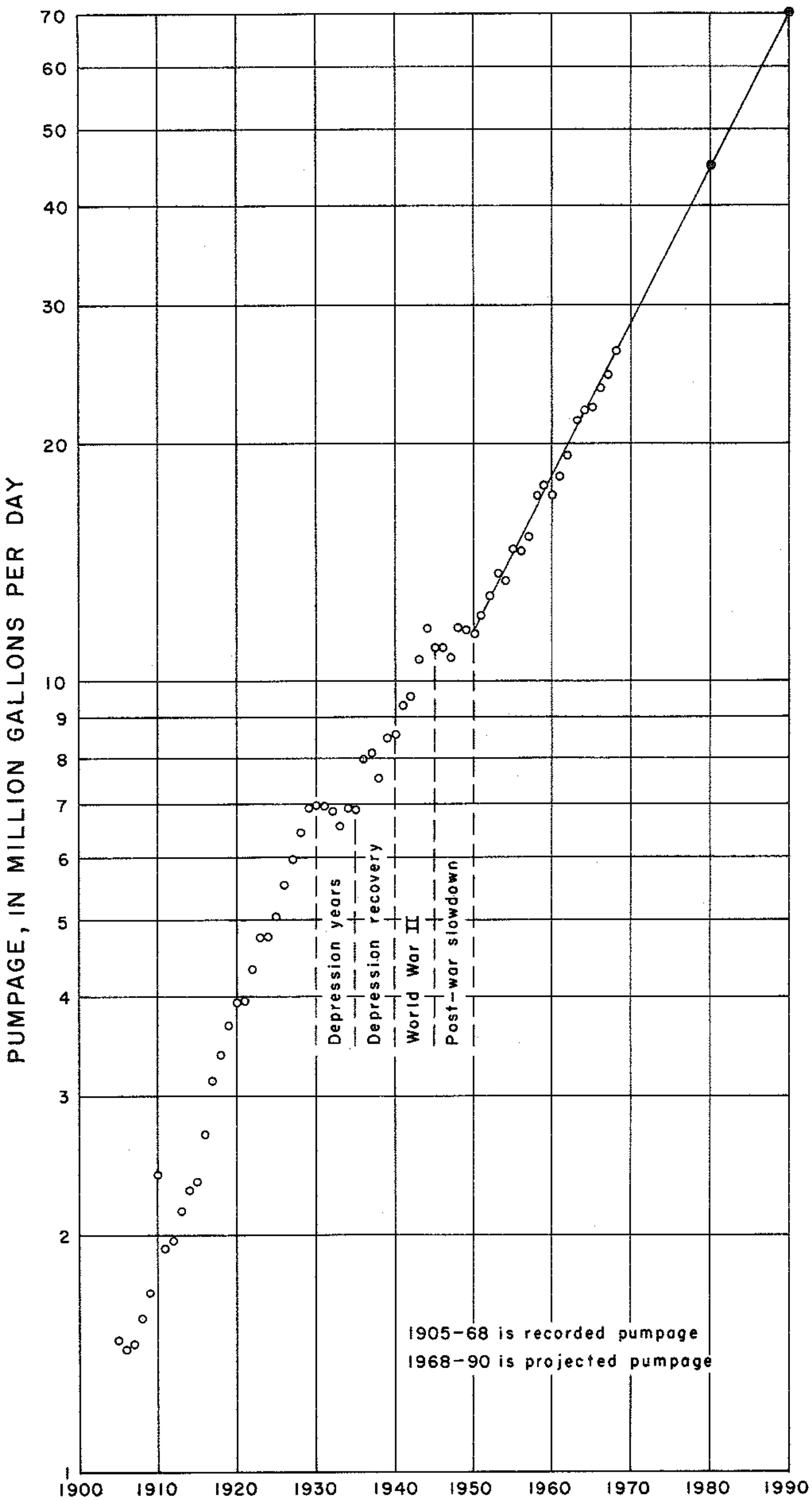


Figure 18. Madison municipal pumpage.

An analog model of Madison and the surrounding area was built to supplement the new economic plan. Because the economic plan is to be in progress for another 10 years, the analog model is expected to aid in the selection of new well sites and probably will influence the size and location of new or improved water mains.

MADISON AREA ANALOG MODEL

The purpose of the Madison area analog model is to assist the city of Madison in appraising alternative proposals for developing ground water to meet the expected increase in future demand.

The area represented by the Madison analog model is approximately 800 square miles (about 30 miles east to west and 26 miles north to south). The ground distance between node junctions in most of the model is 2,000 feet, but in the central part, the area that denotes the city of Madison, the nodes are 1,000 feet apart. The real hydrologic system simulated by the model extends beyond the analog model limits in all directions. The continuity of the real system is simulated in the model by the use of termination strips.

The transmissivity and storage coefficients in the sandstone aquifer in the Madison area are fairly uniform, being generally about 40,000 gpd per foot and 0.0004, respectively.

Recharge to the aquifer is by direct infiltration of precipitation, by vertical leakage in the cone of depression from the overlying saturated glacial deposits, and by induced infiltration of surface water within the cone of depression. The most important of these processes in the Madison area probably is vertical leakage from the surficial deposits. The aquifer system is modeled as a leaky artesian aquifer in which there is little significant change in storage in the overlying glacial deposits.

The coefficient of vertical leakage, P'/m' in gpd per cubic foot, ranges significantly in the Madison area because of the wide range of saturated thickness and types of glacial materials. [P' is the coefficient of vertical permeability in gpd per sq ft; m' is the saturated thickness, in feet, of the confining bed.] The coefficient of leakage is simulated in the model by resistors vertically attached to each node.

To verify the Madison area analog model, the distribution and rate of historical pumpage through April 1960 was prepared. These data were introduced into the model. The drawdown response of the analog model to the electrical stimulation was read out on the oscillograph, and the results compared to the actual potentiometric surface map resulting from pumping the real aquifer. The model is used to determine the effects of future increased demands on the aquifer, optimum well spacings, and assisting the determination of the most economic operating procedure.

Mileage		
138.9	2.7	Leave M. Starr Nichols Pumping Station. Proceed northeast on East Johnson Street to East Washington Avenue. Turn left (east) on East Washington Avenue and change to right traffic lane.
139.2	0.3	Turn right (east) on State Highway 30.
140.4	1.2	U.S. Highway 51 crossing. Continue east through area of ground moraine and drumlins oriented generally northeast-southwest.
142.1	1.7	Interstate Highway 90 crossing and junction with Interstate Highway 94. Continue east on Interstate Highway 94 toward Milwaukee.
144.5	2.4	Green Bay lobe of recessional moraine. This recessional moraine lies about 17.5 miles northeast of the farthest southwest advance of the Green Bay glacier. Moraine orientation is about northwest-southeast. The moraine is the fifth recession moraine behind the terminal moraine.
146.6	2.1	County Highway N crossing.
146.9	0.3	Green Bay lobe ground moraine and outwash. Much of the ground moraine has been covered by very flat deposits of outwash, and numerous drumlins are completely surrounded by outwash. The road continues through these mixed deposits for the next 12.6 miles. Drumlin orientation along this strip is generally south-southwest.
148.1	1.2	Koshkonong Creek.
148.3	0.2	Baxter Road crossing.
149.0	0.7	Dips in road. Here the Interstate Highway has settled and has been repaired several times because of the unstable base of organic material. Note numerous sod farms in valley.
151.1	2.1	Road cut through a large drumlin.
152.5	1.4	State Highway 73 crossing.
153.3	0.8	More uneven road over organic base, associated with lake deposits behind another recessional moraine of the Green Bay lobe. Many large drumlins for the next one-half mile.
156.2	2.9	Jefferson County line.
159.3	3.1	County Highway OB crossing.
159.5	0.2	Green Bay lobe recessional moraine. This recessional moraine is about 27 miles north-northeast of the farthest advance of the Green Bay lobe near Janesville. Moraine orientation is approximately northwest-southeast. For the next 4.8 miles the road is on two recessional moraines. County Highway A is very near the division of the moraines. Although nearly indistinct along the Interstate, the moraines can be differentiated easily about 3 or 4 miles southeast of Lake Mills. Between Rock Lake and the Crawfish River end moraine topography is evident to the south, whereas ground moraine and drumlins are evident to the north.

Mileage		
160.8	1.3	Rock Lake and Lake Mills on the right (south).
161.8	1.0	State Highway 89 crossing.
164.3	2.5	Aztalan Road crossing.

Return to area of mixed Green Bay lobe ground moraine and outwash for the next 13.2 miles. Through this area the glacier moved nearly due south; drumlin orientation changes from south-southwest to south and, finally, to south-southeast. Drumlins are very dense in the area for about 4 miles past the Rock River. Many are more than 1 mile long, and some exceed 2 miles.

164.9	0.6	Crawfish River.
165.6	0.7	County Highway QB crossing.
166.5	0.9	Drumlin on the south with barn in saddle.
167.5	1.0	Rock River.
168.4	0.9	State Highway 26 crossing. Extensive drumlin field.
173.6	5.2	County Highway P crossing.
173.7	0.1	Road cut through drumlin.
174.6	0.9	County Highway WW crossing.

A long (9 miles) but discontinuous esker crosses the road near this point. The esker runs north-northwest nearly to Watertown, but parts of it have been removed for gravel.

176.5	1.9	Green Bay glacier recessional moraine for the next 3.2 miles. This is approximately the 6th recessional moraine behind the farthest ice advance about 12 miles to the southeast. Moraine orientation is approximately northeast-southwest. Moraine is somewhat hard to see in this area because of erosion by the Oconomowoc River and the presence of marshes associated with kettle lakes.
177.3	0.9	State Highway 135 crossing. You may turn off here to explore the esker and recessional moraine.
179.7	2.4	Area of mixed outwash from Green Bay and Lake Michigan lobes for next 2.3 miles.
180.0	0.3	Waukesha County line.
182.0	2.0	Green Bay lobe recessional moraine for the next 0.5 mile. Moraine orientation is approximately northeast-southwest. This is approximately the 4th recessional moraine behind the farthest ice advance about 8 miles to the southeast.

Mileage		
182.5	0.5	Area of mixed outwash from Green Bay and Lake Michigan lobe for the next 3.4 miles.
183.6	1.1	State Highway 67 (Summit Avenue) crossing.
185.6	2.0	Upper Nemahbin Lake on left (north) and Lower Nemahbin Lake on right (south). Lakes are associated with the damming of glacial drainage by the Green Bay terminal moraine. Lake drainage now is toward the west.
185.9	0.3	Green Bay lobe terminal moraine and Kettle interlobate moraine for the next 3 miles. Moraine orientation is approximately north-south. The glacier stopped advancing in this area because it met the Lake Michigan lobe that was advancing from the east.
188.8	2.9	State Highway 83 and abandoned drainage channels.
212.6	23.8	Continue on Interstate Highway 94 to Milwaukee. Turn right (north) at 6th Street exit.
212.8	0.2	Turn right (east) at Wisconsin Avenue.
212.9	0.1	Schroeder-Sheraton Hotel.

END OF TRIP

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