HYDROGEOLOGY OF SOUTHWESTERN SHEBOYGAN COUNTY, WISCONSIN, IN THE VICINITY OF THE KETTLE MORAINE SPRINGS FISH HATCHERY

By T.D. Conlon

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To Obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	4,047	square meter
square mile (mi^2)	2.590	square kilometer
inch per year (in/yr)	25.4	millimeter per year
foot per day (ft/d)	0.3048	meter per day
foot squared per day[1] (ft^2/d)	0.09290	meter squared per day
cubic foot per day (ft^3/d)	0.02832	cubic meter per day
gallon per minute (gal/min)	0.06309	liter per second
pound (lb)	453.6	gram

Temperature can be converted to degrees Celsius (°C) or degrees Fahrenheit (°F) by the equations:

$$°C = 5/9\ (°F - 32)$$

$$°F = 9/5\ (°C + 32)$$

[1]The standard unit for transmissivity (T) is cubic foot per day per square foot times foot of aquifer thickness $[(ft^3/d)/ft^2]ft$. This mathematical expression reduces to foot squared per day (ft^2/d).

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

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Abstract

This report describes the hydrogeology of the dolomite aquifer of Silurian age and its relation to springs in a study area in southwestern Sheboygan County, Wisconsin. The study was conducted at the Kettle Moraine Springs fish hatchery in cooperation with the Wisconsin Department of Natural Resources.

The dolomite aquifer is overlain by more than 60 feet of glacial deposits. Fine-grained glacial deposits confine the dolomite aquifer in the lowland at the hatchery. Thicker, coarse-grained glacial deposits overlie the dolomite aquifer on the hills surrounding the hatchery. The coarse-grained deposits are in good hydraulic connection with the aquifer.

The transmissivity and storage coefficient of the dolomite aquifer are 1,220 feet squared per day and 0.0007, respectively. Pumping from the aquifer results in drawdown in wells open to the aquifer and the effects of this pumping will decrease the greater the distance between wells. The amount of drawdown caused by pumping was estimated by means of distance-drawdown curves.

Five springs and two wells open to the dolomite aquifer supply water to the hatchery. Ground-water withdrawals from fish hatchery wells affect the water level in an observation well near the springs and probably decrease the flow from the springs to the hatchery. Additional pumping from the aquifer probably will further decrease flow from the springs.

INTRODUCTION

Ground water from the glacial sand and gravel aquifer and the dolomite aquifer of Silurian age supply most domestic and municipal water needs in southwestern Sheboygan County, Wis. In places, springs flow from hillsides where the sand and gravel aquifer is exposed near the ground surface and the water level in the aquifer is greater than the ground surface. The U.S. Geological Survey (USGS), in cooperation with the Wisconsin Department of Natural Resources (WDNR) Bureau of Fisheries Management, collected hydrogeologic data in 1991 and 1992 to determine flow and hydrologic characteristics of the dolomite aquifer, its relation to springs, and the effects of pumping from the aquifer at the headwaters of Melius Creek where the WDNR operates a fish hatchery (fig. 1).

The hatchery, when started in 1955 as a private business, used nearby springs for water supply. In 1979, the hatchery produced 20,000 lb of fish using water from the springs and one well. The WDNR purchased the hatchery in 1979 and drilled a second well to augment the hatchery's water supply. In 1992, the hatchery produced more than 40,000 lb (Randy Link, Kettle Moraine Springs fish hatchery, oral commun., 1992) using water from five springs and two wells (fig. 2). The total flow from five tiled springs is approximately 730 gal/min. Pumpage from hatchery wells 1 and 2 (fig. 2) averaged 230 gal/min during 1992.

Purpose and Scope

This report describes the ground-water resources at a site in southwestern Sheboygan County where springs and the sand and gravel and

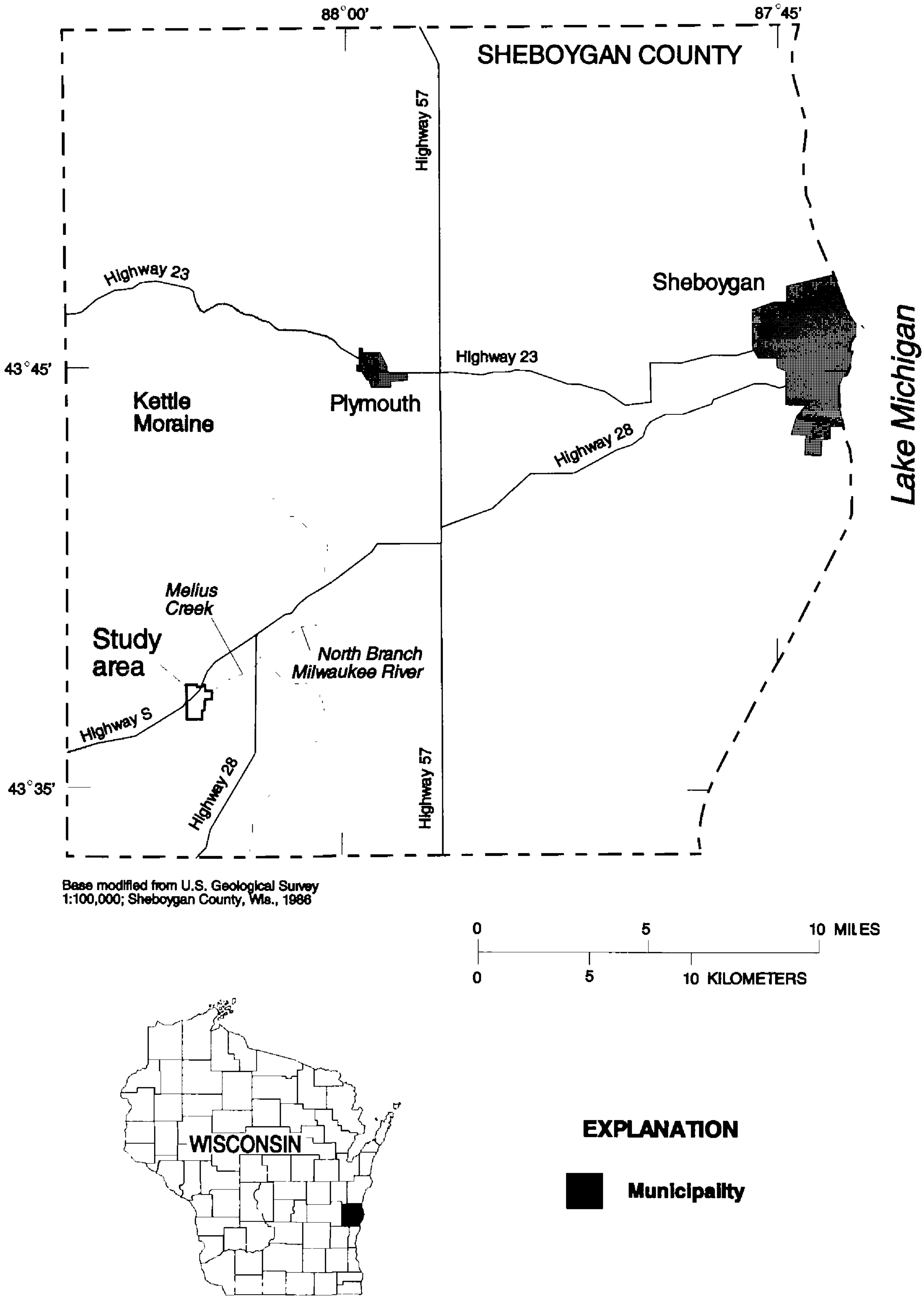

Figure 1. Location of study area in southwestern Sheboygan County, Wisconsin.

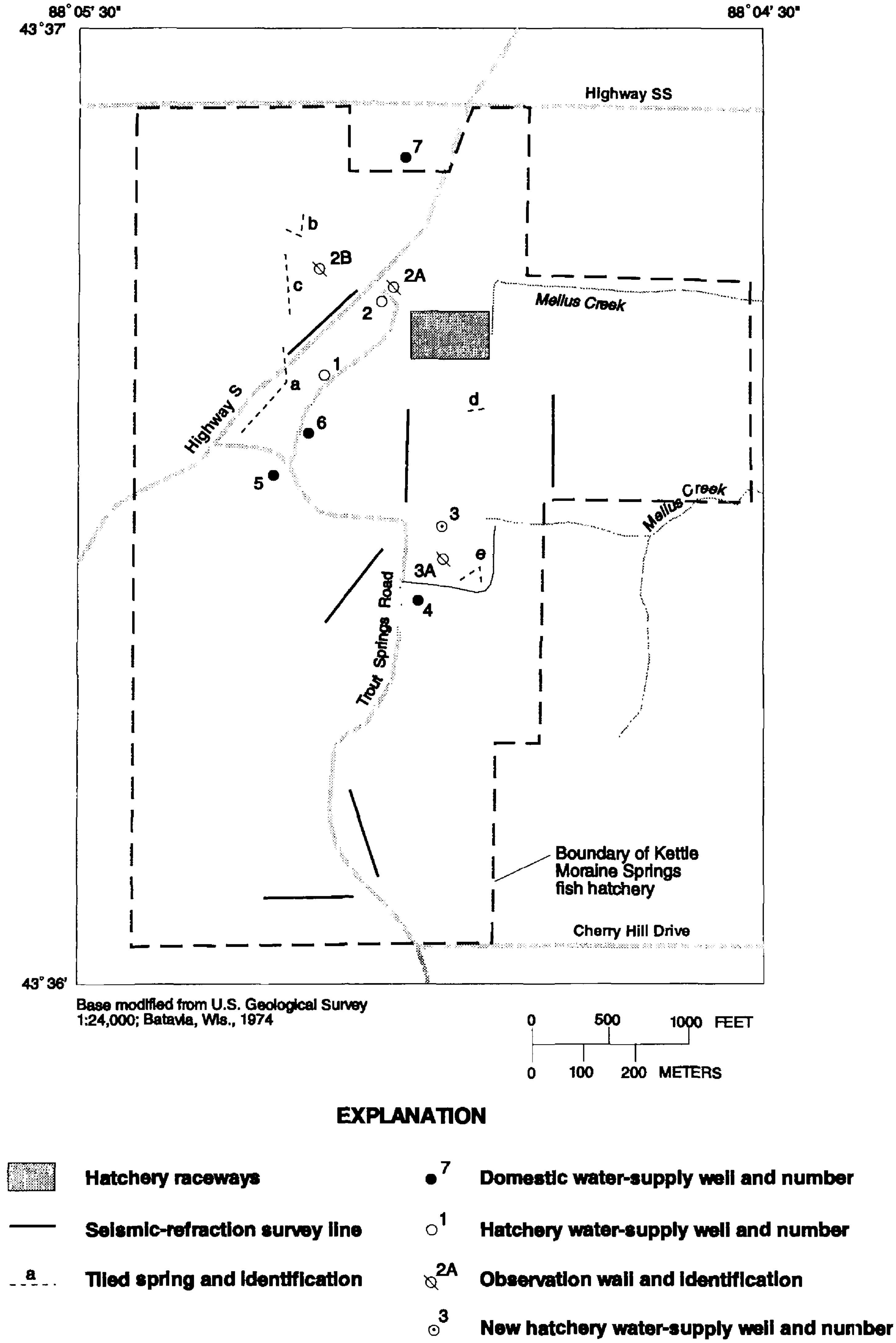

Figure 2. Approximate extent of hatchery property and location of wells, springs, and seismic-survey lines at the Kettle Moraine Springs fish hatchery, Sheboygan County, Wisconsin.

dolomite aquifers are present, and evaluates the relation between the dolomite aquifer and springs. The report includes interpretations of the (1) thickness of unconsolidated glacial deposits, (2) altitude of the bedrock surface, (3) hydraulic properties of the dolomite aquifer, and (4) potential effects of pumping ground water from future wells on nearby springs and wells. The study is limited to evaluating the water resources of the dolomite aquifer. Evaluation of a deeper sandstone aquifer at the study site is beyond the scope of the study.

Location and Physical Setting

The study area is located at the Kettle Moraine Springs fish hatchery (fig. 1) in southwestern Sheboygan County, Wisconsin. The hatchery land is on the southeastern edge of a hilly area called the Kettle Moraine, a topographic high trending north-south in the eastern quarter of the State. The hills of the Kettle Moraine west of the hatchery reach an altitude of approximately 1,100 ft above sea level. Adjacent to the hatchery are lower, mostly wooded hills to the north, west, and south. The valleys are cultivated to raise crops for dairy farms.

The altitude of the land surface in the study area ranges from approximately 850 ft above sea level near Melius Creek to approximately 1,000 ft west of well 2B (fig. 2). Melius Creek drains the hatchery area, flows northeastward through a wetland, and joins with the North Branch of the Milwaukee River approximately 2.5 mi northeast of the hatchery. The study was confined to an area including the fish hatchery and a few private residences near the hatchery. The study area (fig. 2) consists of approximately 360 acres of forested and cultivated areas. The hatchery buildings and raceways occupy approximately 20 acres. The areas where springs are active have been tiled to maximize water collection and minimize contamination.

Methods

Drillers' well construction reports for wells drilled prior to this study, available from the Wisconsin Geological and Natural History Survey, were compiled and used to determine the thickness of the glacial deposits and altitude of the bedrock surface. Where well data were unavailable, the thickness of glacial deposits and bedrock surface altitude were determined using the seismic-refraction method. Thickness and bedrock altitude were interpreted from arrival times of refracted seismic waves along six survey lines (fig. 2) using a time-delay and iterative ray-tracing program (Scott and others, 1972).

The thickness and texture of glacial deposits were interpreted by visually inspecting cuttings from three test holes drilled during the study. Wells 2A, 3, and 3A (fig. 2) were installed in the test holes by seating 6-inch steel casing into the surface of the dolomite. These wells are open to dolomite only. In addition to the these wells, one well, well 2B (fig. 2), was installed by driving a well point screened over a 3-ft interval into the glacial deposits 4 ft below land surface.

Aquifer tests were conducted by recording water levels in an observation well at a known distance from a well continuously pumping at a constant rate. Water levels were recorded with pressure transducers and confirmed with steel tape measurements prior to, during, and after aquifer tests. The flow rate for pumping was determined by dividing the known volume of a container by the time to fill the container with water. Drawdown, or the decline in water levels from pumping, was plotted as a function of time since pumping began. Transmissivity and storage coefficient were calculated by matching the drawdown curves to type curves (Lohman, 1979).

Cation and anion concentration data for spring and well water, collected by hatchery staff in 1989 and available at the hatchery, were compiled to determine if spring water and ground water from the dolomite aquifer were chemically similar. The data were plotted and compared using a trilinear diagram (Hem 1989, p. 178-180).

Acknowledgments

Staff at the Kettle Moraine Springs fish hatchery measured flow from wells and springs, and adjusted their schedules to accommodate the aquifer tests. Hatchery staff also provided water-quality data for water samples from springs and wells.

HYDROGEOLOGY

Understanding the hydrogeology of the area requires knowledge of aquifers and confining units. Two aquifers, the sand and gravel and dolomite aquifers, are present in southwestern Sheboygan County. The extent of the sand and gravel aquifer may be discontinuous in some areas where sand and gravel layers grade into finer-grained deposits. Within the study area, only observation well 2B and domestic water-supply well 7 (fig. 2), located on a hillside north of the hatchery, are screened in the sand and gravel aquifer. The sand and gravel aquifer is not present in the lowlands near the hatchery and its extent under the hillsides is not known. In the lowlands, fine-grained glacial deposits overlie and confine the dolomite aquifer. The following discussion focuses on the characteristics of the springs, the dolomite aquifer, and their interrelations.

Geologic Setting

The geology of the study area was shaped by two important events: the subsidence of the Michigan Basin to the east, which resulted in the preservation of a sequence of sedimentary rocks of Cambrian to Silurian age in the area; and the advance of the continental glaciers which left behind a variety of glacial deposits and shaped the landscape in the study area.

Bedrock Geology

Sedimentary rocks in Sheboygan County, located on the western side of the Michigan Basin, dip gently to the east. The youngest rock beneath the study area is the Niagara Dolomite of Silurian age, which consist of fine- to medium-grained dolomite with vertical and bedding plane joints, sometimes enlarged by solution (Devaul, 1975). The thickness of the dolomite in this area is estimated to be 400 ft (Olcott, 1992, p. J19), although some boreholes east of the study area have penetrated more than 500 ft of dolomite. No boreholes penetrate the entire thickness of the dolomite in the study area.

Regionally, the top of the Niagara Dolomite slopes to the east. Within the study area, the surface of the dolomite was eroded by glaciation, resulting in an uneven bedrock surface (fig. 3). The altitude of the top of the dolomite beneath the study area ranges from approximately 700 ft at well 2 to approximately 850 ft at well 5 based on information from six seismic lines and seven well logs (fig. 3, table 1).

Glacial Geology

The occurrence and thickness of the unconsolidated deposits are a result of the glacial processes that were at work in the study area approximately 15,000 years ago. A major glacial feature is the Kettle Moraine west of the study area (fig. 1). This hilly region was formed where two advancing glacial lobes of ice met. These were the Lake Michigan Lobe that moved west from present-day Lake Michigan and the Green Bay Lobe that moved southwest down a trough underlying present-day Green Bay and Lake Winnebago. The study area lies in the area glaciated by the Lake Michigan Lobe. The glacial deposits consist of outwash and till (Skinner and Borman, 1973).

The thickness of the glacial deposits ranges from approximately 60 ft in the southern part of the study area to more than 150 ft at wells 2 and 7 (fig. 4). The thickness of glacial deposits may be greater beneath the hills surrounding the hatchery than in the lowlands at the hatchery.

A general interpretation of the distribution of fine- and coarse-grained glacial deposits (fig. 5) is based on cuttings from three testholes and outcrops of glacial deposits in nearby road cuts and gravel pits. The hillsides are interpreted to be underlain by coarse-grained deposits because outcrops of glacial deposits on the hillsides consist of sand and gravel. The lowlands are interpreted to be underlain by fine-grained glacial deposits because the three testholes penetrated fine sand, silt, and clay. Even where gravel was encountered in the testholes, the matrix material was predominantly fine silt and clay. The fine-grained deposits are inferred to pinch out near the base of the hillsides.

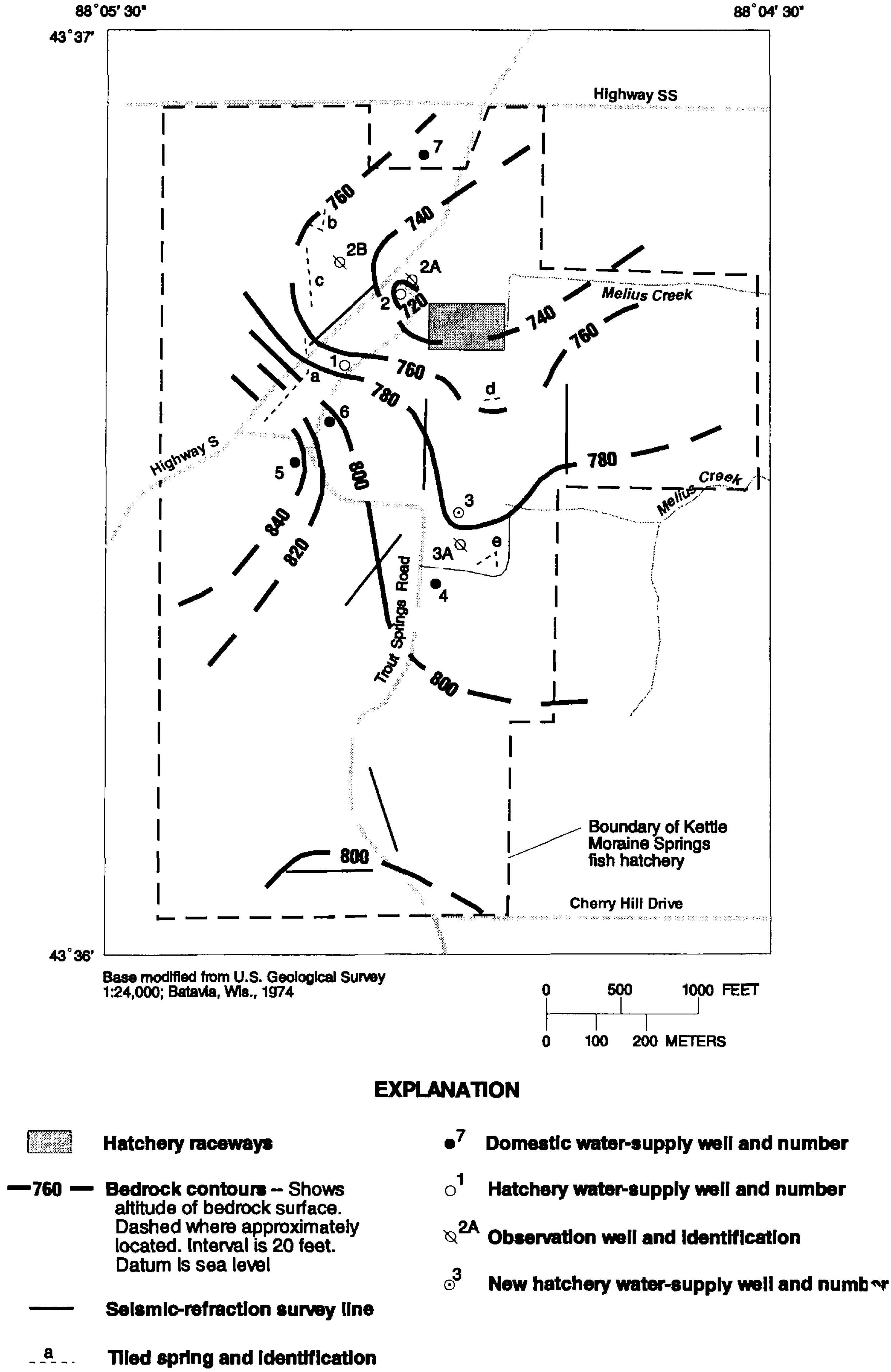

Figure 3. Altitude of bedrock surface at the Kettle Moraine Springs fish hatch·ry, Sheboygan County, Wisconsin.

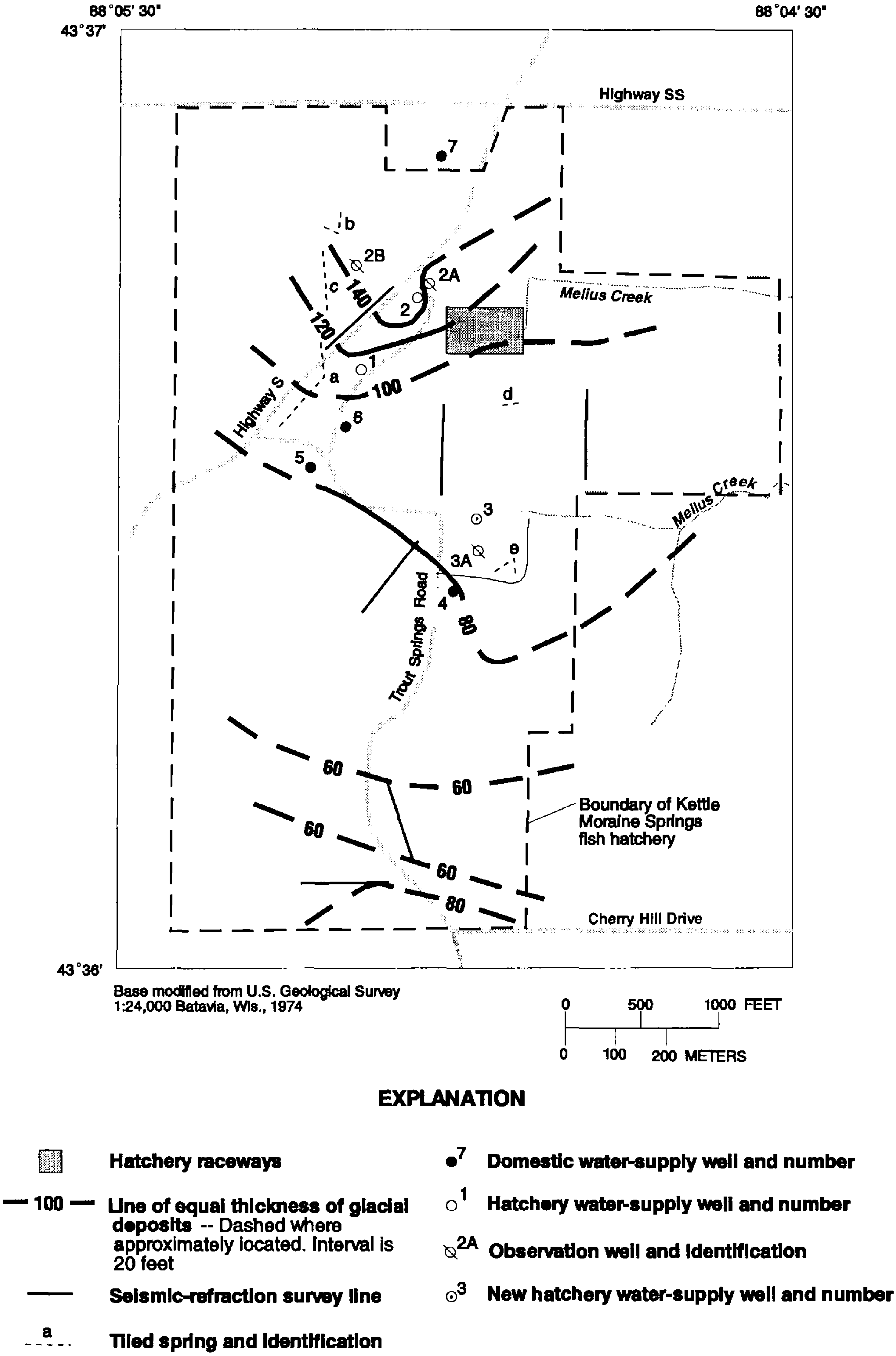

Figure 4. Thickness of glacial deposits at the Kettle Moraine Springs fish hatchery, Sheboygan County, Wisconsin.

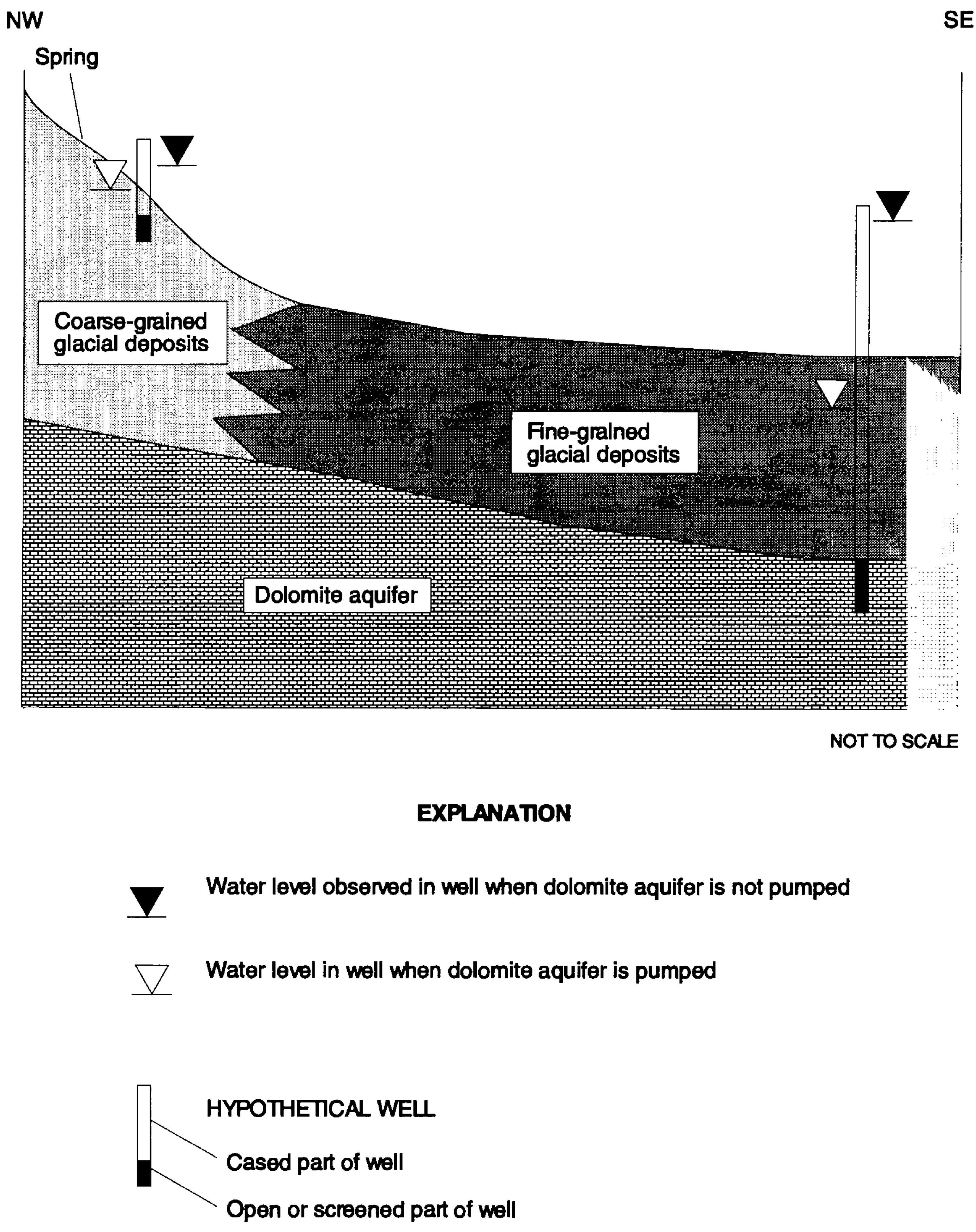

Figure 5. Diagrammatic section showing lithology and water levels in wells with and without pumping from the dolomite aquifer, Kettle Moraine Springs fish hatchery, Sheboygan County, Wisconsin.

Table 1. Lithologic logs for all wells in the study area

[Location of wells shown in figure 2]

Well 2: Altitude of land surface, 870 feet above sea level. Date drilled 1/12/88.
Depth to static water level (negative values are height above land surface), not available.

Lithology	Depth interval (feet)
Sand and gray clay	0-18
Gray clay	19-70
Fine sand	71-110
Fine sand and gravel	111-158
Dolomite	159-175

Well 2A: Altitude of land surface, 860 feet above sea level. Date drilled 7/15/92.
Depth to static water level (negative values are height above land surface), -6.8 feet.

Lithology	Depth interval (feet)
Clay	0-45
Fine sand	46-120
Gravel with clay	121-131
Dolomite	132-175

Well 3: Altitude of land surface, 860 feet above sea level. Date drilled 10/31/92.
Depth to static water level (negative values are height above land surface), -8.0 feet.

Lithology	Depth interval (feet)
Clay	0-60
Clay and gravel	61-70
Gravel	71-88
Dolomite	89-180

Well 3A: Altitude of land surface, 868 feet above sea level. Date drilled 7/17/92.
Depth to static water level (negative values are height above land surface), -1.0 foot.

Lithology	Depth interval (feet)
Fine sand	0-15
Sand and clay	16-20
Clay	21-35
Gravel and clay	36-60
Fine sand	61-80
Gravel	81-89
Dolomite	90-180

Well 5: Altitude of land surface, 950 feet above sea level. Date drilled 10/13/77.
Depth to static water level (negative values are height above land surface), 38 feet.

Lithology	Depth interval (feet)
"Hard pan" (reported by driller)	0-60
Clay and gravel	61-82
Dolomite	83-102

Table 1. Lithologic logs for all wells in the study area--Continued

Well 6: Altitude of land surface, 890 feet above sea level. Date drilled 8/21/80.
Depth to static water level (negative values are height above land surface), 15 feet.

Lithology	Depth interval (feet)
Fine sand	0-15
Sand and gravel	16-35
Sand	36-60
Gravel and clay	61-70
Sand and gravel	71-95
Dolomite	96-125

Well 7: Altitude of land surface, 900 feet above sea level. Date drilled 5/30/74.
Depth to static water level (negative values are height above land surface), 15 feet.

Lithology	Depth interval (feet)
Sand and gravel	0-47
Clay	48-110
Clay and gravel	111-146
Gravel	147-153

Springs

Springs are an important source of water to ponds and streams in southwestern Sheboygan County. Flow from springs is used by public and private fish hatcheries in the area. The following sections discuss the source and discharge of the springs at the Kettle Moraine Springs fish hatchery and the effect of pumping from the dolomite aquifer on spring flow.

Source and Discharge

The springs flow from the sand and gravel aquifer where there is no fine-grained confining unit above the aquifer and the altitude of the potentiometric surface of the sand and gravel aquifer is greater than the altitude of the ground surface. The springs supply water to the hatchery at a rate of approximately 730 gal/min (table 2). The source of the water flowing from the springs is precipitation which infiltrates into the sand and gravel and dolomite aquifers west of the hatchery. The area over which precipitation must fall to maintain a flow of 730 gal/min can be estimated if the rate of water recharging the aquifer is known. A recharge rate of approximately 4 in/yr was estimated using base-flow measurements in streams near the hatchery reported by Skinner and Borman (1973). Given this recharge rate, the area necessary to maintain a spring flow of 730 gal/min is approximately 5.7 mi^2. An area of 5.7 mi^2 would capture water as far away as the Kettle Moraine highlands west of the hatchery and require flow paths of up to 4 mi in length.

Table 2. Average flow rates for springs and average pumping rates for wells at Kettle Moraine Springs fish hatchery, Sheboygan County, Wisconsin, 1992

[Location of wells and springs are shown in figure 2; gal/min, gallons per minute]

Well or spring identifier	Type	Flow rate (gal/min)
1	Well	70
2	Well	160
Total average pumping well rate		230
a	Spring	125
b	Spring	200
c	Spring	170
d	Spring	80
e	Spring	155
Total average spring flow rate		730
Total flow		960

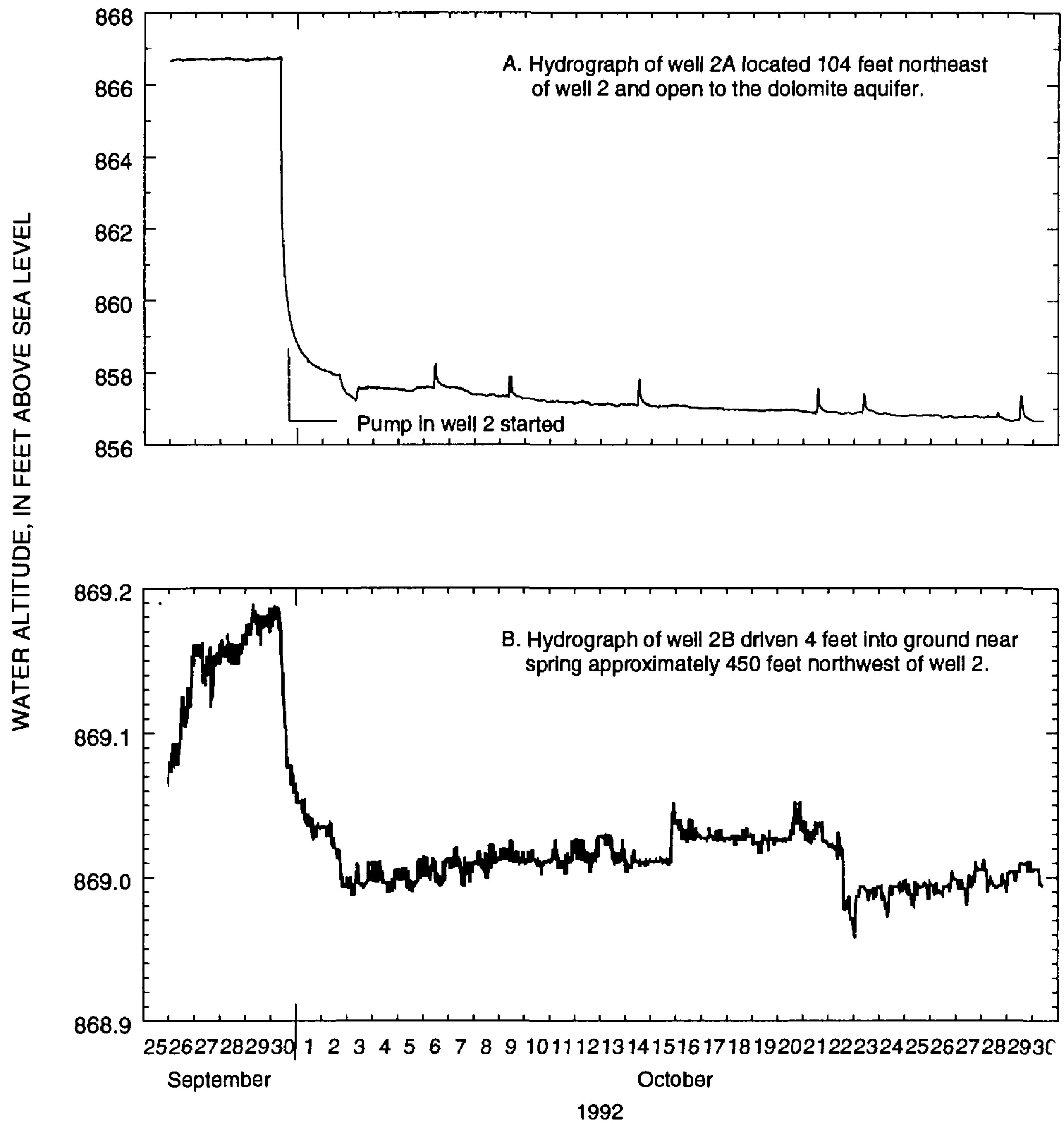

Figure 6. Hydrographs showing effects of pumping from the dolomite aquifer on water levels in (A) well 2A and (B) well 2B, September 25-October 30, 1992, Kettle Moraine Springs fish hatchery, Sheboygan County, Wisconsin.

Response of Spring Flow to Pumping from the Dolomite Aquifer

Determining the response of spring flow to pumping from the dolomite aquifer requires an understanding of the hydraulic connection between the pumped dolomite aquifer, and the sand and gravel aquifer from which the springs flow. Evidence that suggests that there is a good hydraulic connection between the aquifers includes the response of water levels in a well open to sand and gravel deposits next to a spring, the estimated length of the flowpath in the aquifer of ground water flowing from the springs, and the similarity of chemistry of spring water and ground water from the dolomite aquifer.

The hydrographs in figure 6 show that water levels in well 2B near spring b and in well 2A, which is open to the dolomite aquifer, declined in response to pumping water from well 2, which is also open to the dolomite aquifer. Because well 2B is screened in the shallow sand and gravel aquifer near the spring, the decline in the water level in this well indicates that there is a good hydraulic connection between the sand and gravel and dolomite aquifers. A diagrammatic section (fig. 5) shows the response of water levels measured in the sand and gravel aquifer near a spring and the dolomite aquifer to pumping and nonpumping conditions.

Flow paths of up to 4 mi in length are estimated for ground water flowing to the springs. This relatively long flow path indicates that ground water flowing from the springs is in a deep flow path from a regional flow system. A deep flow path increases the possibility that ground water flows between the sand and gravel and dolomite aquifers, and supports the concept of a good hydraulic connection between the aquifers.

Water-quality data also support the concept of a good hydraulic connection between the spring and dolomite aquifer system. Analysis of cation and anion concentration data for water samples collected from springs and wells indicates that the water from these two sources is chemically similar and is a calcium magnesium bicarbonate type.

Because of the good hydraulic connection between the dolomite and sand and gravel aquifers, pumping from the dolomite aquifer decreases the water levels near the springs, and probably decreases flow from the springs. The effect of pumping from the dolomite aquifer on spring flow could not be quantified because spring flow was not measured during the aquifer tests performed for this study.

Dolomite Aquifer

The dolomite aquifer underlies most of southwestern Sheboygan County including the fish hatchery. The top of the aquifer is considered to be the top of the dolomite bedrock (fig. 3), which lies directly beneath unconsolidated glacial deposits. Many wells in the area penetrate less than 100 ft of the dolomite aquifer because sufficient water supplies may be obtained at shallow depths. Wells 2, 5, and 6 (fig. 2, table 1), which were installed prior to this study, are known to be open to the dolomite aquifer. Wells 2A, 3, and 3A (fig. 2, table 1), which were installed during this study, also are open to the dolomite aquifer. Static water levels in wells 2A, 3, and 3A are above the land surface. The static water-level for well 2 was not measured but must be above the land surface because water naturally flows from the well. A sulfur odor, which was noted while drilling through the dolomite at well 2A, suggests that sediment from an anoxic environment may have filled the dolomite fractures. Sediment-filled fractures may account for the high iron concentration in some well water reported by the hatchery staff.

Hydraulic Properties

Aquifer tests were conducted with wells open to the dolomite aquifer to determine the transmissivity and storage coefficient of the aquifer. Transmissivity (T) is expressed as the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. The storage coefficient (S) is defined as the volume of water an aquifer releases from or takes into storage per unit surface area per unit change in water level. The quantity of water available to a well is proportional to the transmissivity and storage coefficient of the aquifer.

The aquifer-test data were analyzed using the type-curve method originally developed by Theis (1935). This method assumes horizontal ground-water flow, and observation and production wells of infinitesimal diameter fully penetrating a confined aquifer of infinite extent with homogeneous and isotropic properties. Previous authors (Sherrill, 1978, p. 20; Bradbury, 1982, p. 34-35, 44) have suggested that the primary and secondary porosity of the upper part of dolomite aquifer may be considered equivalent to a porous medium, the medium on which Theis' method was based. The clay and silt deposits overlying the dolomite confine the aquifer in the lowlands where the observation and production wells are located. The assumption of horizontal flow is justified for this study because many fractures are horizontal bedding fractures. The diameters of the wells are small (6-8 in.) relative to the distance between wells (greater than 100 ft) and the extent of the aquifer (greater than 5 mi). Although the wells do not fully penetrate the total thickness of the dolomite, which is approximately 400 ft thick near the fish hatchery, it is assumed that using the type-curve method will provide an adequate approximation of the transmissivity for the purposes of this study.

Water-level corrections for the effects of barometric pressure on water levels measured in wells were not made because changes in water levels did not correlate with changes in barometric pressure. No correction was made to measured water levels for trends in water levels because hydrographs showed no trend in water-level changes prior to pumping from September 25 to September 30, 1992 (fig. 6A).

Three aquifer tests were conducted using two pumped wells. Two tests involved pumping from well 2 and observing water levels in well 2A. The first test on August 17, 1992 was a planned 24-hour test. The data for the second test from September 30, 1992 to December 10, 1992 was recorded when the hatchery started pumping from well 2 for fish production in the winter. The third test on December 10, 1992 involved pumping from well 3 and observing water levels in well 3A.

For the aquifer test conducted on August 17, 1992, and from September 30 to December 10, 1992, well 2 was pumped at a rate of 115 gal/min. Water levels in well 2 stabilized after 2 hours at a depth of approximately 100 feet below land surface. The drawdown curve for observation well 2A for the August 17, 1992 test is similar to the drawdown curve (fig. 7) for the September 30 to December 10, 1992 test. The hydrograph for observation well 2A (fig. 6A) shows that water levels were stable prior to pumping from well 2 and that 80 percent of the total drawdown was reached after several days of pumping. The perturbations in the hydrograph after October 4, 1992, were caused by turning the pump in hatchery water-supply well 1 (fig. 1) off for maintenance about once per week. These relatively small perturbations in water levels, which lasted less than a day and did not occur on the day pumping began at well 2, did not affect the analysis of the drawdown curves.

The drawdown curve (fig. 7) for observation well 2A for the September 30 to December 10, 1992 aquifer test was matched to a type curve (Lohman, 1979) and a transmissivity of 1,220 ft^2/d and a storage coefficient of 0.0007 were calculated. The slope of the observed drawdown curve decreases with time relative to the type curve, which suggests that the cone of depression (the depression in the altitude in the water-level surface) formed by pumping intersects a recharge boundary–an area that can supply a sufficient quantity of water to equal the quantity pumped from the well. This recharge boundary may represent leakage of water from the sand and gravel deposits overlying the dolomite aquifer near the hillside.

For the aquifer test conducted in December 1992, well 3 was pumped at 185 gal/min, and water levels were measured in observation well 3A. Water levels in well 3 stabilized after 3 hours of pumping at a depth of 33 ft below land surface. The transmissivity could not be computed from drawdown data because the pump was briefly stopped after the first 3 minutes of pumping. The transmissivity of the dolomite aquifer near well 3 is larger than that calculated from the aquifer test using well 2 because the interval of dolomite to which well 3 is open (90 ft) is greater than that to which well 2 is open (16 ft).

The small storage coefficient from the aquifer test at well 2 indicate that the dolomite aquifer is a confined aquifer (Freeze and Cherry, 1979, p. 60). The aquifer is confined locally by the fine-grained sediment overlying the dolomite in the lowlands near the wells at the hatchery.

Response of Water Levels in Dolomite Aquifer to Pumping from Dolomite Aquifer

Pumping from one well may interfere with pumping from or cause drawdown in a nearby well. Interference may be objectionable if the pumping from one well causes water levels to decline below the level of the pump in the nearby well. If this is the case, the pump in the nearby well would need to be lowered, which may require a pump with a greater lift capacity and the deepening of the well. Drawdown in wells open to the pumped aquifer generally increase with decreasing distance from

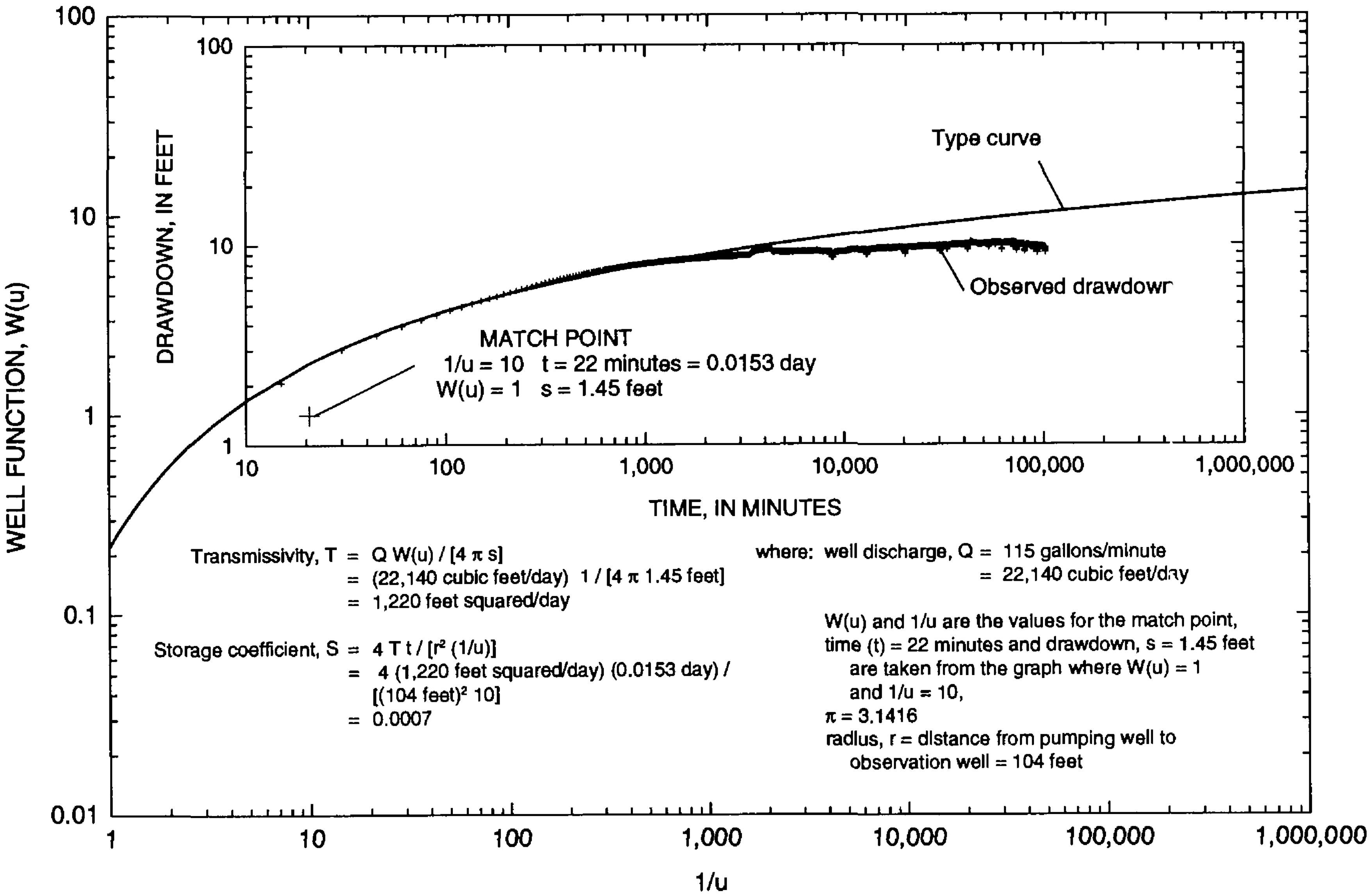

Figure 7. Time-drawdown plot of observation well 2A matched to type curve, September 30-December 10, 1992, Kettle Moraine Springs fish hatchery, Sheboygan County, Wisconsin.

the pumped well. Therefore, the distance between wells is critical in maximizing the yield from each well and minimizing the drawdown in nearby wells. When multiple wells are used to increase the water supply, drawdown in a well may be greater due to interference from other wells. However, the drawdown in any one well of the multiple wells would be less than if the increased water supply were obtained from a single well. The goal is to minimize the drawdown in nearby wells by placing multiple wells at sufficient distance from each other.

Drawdown can be estimated at any distance from a pumped well by means of distance-drawdown curves if the transmissivity, storage coefficient, and time since pumping began are known. Several assumptions must be made to prepare the distance-drawdown curves. The same assumptions apply in developing distance-drawdown curves as in computing transmissivity and storage coefficients using the type curves. One such assumption requires that the dolomite aquifer, whether its permeability is from fractures, intergranular pores or a combination, respond as a porous medium, such as sand or a poorly cemented sandstone. If the wells derive most of their water from a few discrete fractures instead of many small fractures distributed throughout the dolomite, the Theis method used for calculating transmissivity and drawdown will not be valid. The distance-drawdown curves shown in figure 8 were developed assuming a transmissivity of 1,220 ft^2/d and a storage coefficient of 0.0007. Use of a transmissivity of 1,220 ft^2/d in developing the distance-drawdown curves resulted in a greater estimated drawdown in nearby wells than did use of a larger transmissivity representing hydraulic properties near wells 3 and 3A.

The distance-drawdown curves (fig. 8) show drawdown at various distances from a single well pumping at a rate of 100 gal/min. Several distance-drawdown curves are plotted to show drawdown at specific times since pumping began. The curves were developed assuming no recharge boundary and, therefore, the distance-drawdown curves estimate greater drawdown than actually would occur. Distance-drawdown curves may be used to compute the drawdown from several wells. The estimated drawdown in a well near several pumped wells is the sum of the drawdown from each of the pumping wells.

Effects of Future Withdrawals of Ground Water from the Dolomite Aquifer on Ground-Water Levels

Additional water may be withdrawn from the dolomite aquifer in the area by deepening existing wells or drilling more wells. Deepening wells or drilling new wells so that the well is open to a large thickness of the dolomite aquifer will reduce drawdown based on aquifer tests at wells 2 and 3. Well 3 was pumped at a greater rate and resulted in a smaller drawdown than that at well 2. Drawdown is less in well 3 because the transmissivity is greater at well 3. Transmissivity is greater at well 3 than at well 2 because well 3 is open to a greater thickness of the aquifer.

The estimated effect of pumping from hatchery well 3 on domestic well 4, which is located at a residence 500 ft south of well 3 (fig. 2), is calculated as an example and demonstrates the utility of distance-drawdown curves. If well 3 is pumped at 100 gal/min and no recharge boundary is encountered, the additional drawdown in well 4 would be approximately 7.7 ft after 30 days. Pumping a shorter amount of time, 3 days, would result in a smaller estimated drawdown, approximately 4.9 ft. If a recharge boundary is encountered, the drawdown in well 4 would be less. If the pumping rate were doubled, the drawdown would double. If a second well were drilled 800 ft from domestic well 4 and each well were pumped at 100 gal/min, the total additional drawdown at domestic well 4 after 30 days would be 14.3 ft, or the sum of the drawdown (7.7 ft) resulting from pumping well 3 and the drawdown (6.6 ft) resulting from pumping the well 800 ft from domestic well 4. Distance-drawdown curves may be used in this way to evaluate many possible configurations of pumped wells.

SUMMARY AND CONCLUSIONS

Two aquifers are the primary source of water for southwestern Sheboygan County. The upper aquifer is the sand and gravel aquifer consisting of coarse-grained glacial deposits. The aquifer is discontinuous because the coarse-grained deposits grade into fine-grained deposits of relatively low permeability. The dolomite aquifer is a bedrock aquifer and is continuous throughout the area. Springs flow from the sand and gravel aquifer where there is no fine-grained confining unit above the aquifer and the altitude of the potentiometric surface of the sand and gravel aquifer is greater than the altitude of the ground surface.

The hydrogeology of the dolomite aquifer and its relation to springs was studied at the Kettle Moraine Springs fish hatchery in southwestern Sheboygan County. Springs flowing from the hillsides to the north, west, and south supply water to the hatchery before entering Melius Creek. Two wells also provide water to the hatchery.

The depth to the dolomite aquifer beneath glacial deposits near the hatchery ranges from about 60 to more than 150 ft below land surface. The glacial deposits overlying the dolomite are fine grained in the lowland near the hatchery and act as a confining unit to the dolomite aquifer. Although the dolomite aquifer is more than 400 ft thick in the study area, most wells are open to only the uppermost 100 ft of the aquifer.

Springs flow from the hillsides where the confining fine-grained glacial deposits are absent. The springs represent discharge areas for a ground-water-flow system that receives recharge from approximately 4 mi to the west near the Kettle Moraine highlands. The springs are assumed to be in good hydraulic connection with the dolomite aquifer on the basis of (1) the response of water levels in a well open to the sand and gravel aquifer

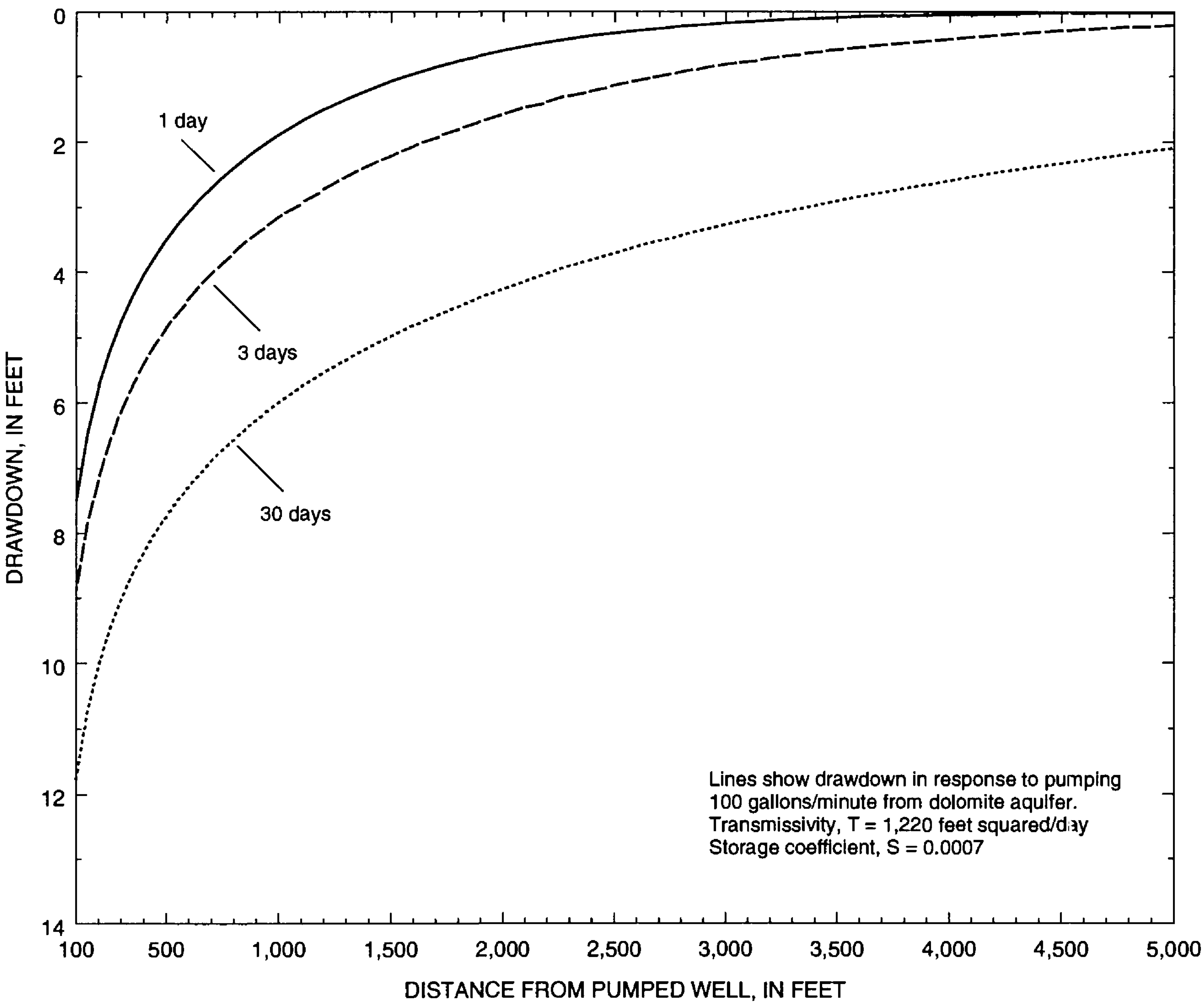

Figure 8. Distance-drawdown curves for dolomite aquifer, Kettle Moraine Springs fish hatchery, Sheboygan County, Wisconsin.

located near a spring to pumping from the dolomite aquifer, (2) the long flowpath (about 4 mi) of ground water flowing from the recharge area to the spring, and (3) the similarity of the chemistry of water from springs and the dolomite aquifer.

The transmissivity and storage coefficient of the dolomite aquifer are 1,220 ft^2/d and 0.0007, respectively, based on aquifer tests performed near well 2. Water levels reached steady state within 1 day in pumping wells and approximated steady state within 3 days in observation wells. The transmissivity of the dolomite aquifer near well 3 could not be determined but is probably greater than 1,220 ft^2/d. Using a transmissivity of 1,220 ft^2/d, a storage coefficient of 0.0007, and a pumping rate of 100 gal/min, distance-drawdown curves were calculated to estimate the drawdown at distances from pumping wells. Use of the curves may overestimate drawdown because they were calculated assuming no recharge boundary was encountered and only 16 ft aquifer is penetrated.

The curves may be used to calculate the effects of pumping from future hatchery wells on nearby wells open to the dolomite aquifer. Use of the curves shows that the effects of pumping decrease the greater the distance between wells.

Additional pumping from the dolomite aquifer will increase the drawdown in wells open to the dolomite aquifer. The magnitude of the increased drawdown may be estimated using distance-drawdown curves. Several wells sufficiently spaced may provide the hatchery with additional water and minimize interference between wells. Additional pumping from the dolomite aquifer probably will decrease the flow from the tiled springs because of the hydraulic connection between the dolomite aquifer and the springs.

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