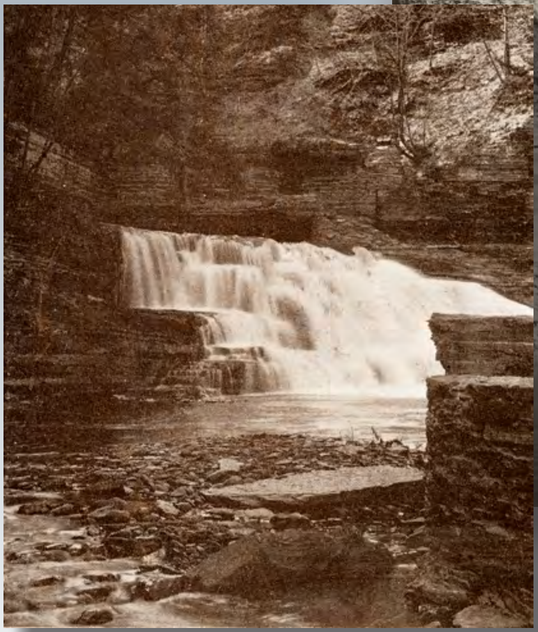
Prepared in cooperation with the Town of Enfield and the Tompkins County Planning Department

Geohydrology and Water Quality of the Unconsolidated Aquifers in the Enfield Creek Valley, Town of Enfield, Tompkins County, New York



Scientific Investigations Report 2019–5136
Version 1.1, May 2020

U.S. Department of the Interior
U.S. Geological Survey

Cover. Left: Devil's Parlor Falls at Robert H. Treman (Enfield Glen) State Park, Enfield, New York. Middle: Lucifer Falls (Enfield Falls) at Robert H. Treman (Enfield Glen) State Park, Enfield, New York. Right: Lucifer Falls (Enfield Falls) at Robert H. Treman (Enfield Glen) State Park, Enfield, New York. Historical photographs courtesy of Bill Hecht.

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DAVID BERNHARDT, Secretary

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Contents

Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
gallon (gal)	3.785	cubic decimeter (dm^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as

$$°F = (1.8 \times °C) + 32.$$

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L).

Abbreviations

EPA	U.S. Environmental Protection Agency
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
NWQL	National Water Quality Laboratory
NYSDOH	New York State Department of Health
SC	specific conductance
SMCL	secondary maximum contaminant level
USGS	U.S. Geological Survey

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By Benjamin N. Fisher, Paul M. Heisig, and William M. Kappel

Abstract

From 2013 to 2018, the U.S. Geological Survey, in cooperation with the Town of Enfield and the Tompkins County Planning Department, studied the unconsolidated aquifer in the Enfield Creek Valley in the town of Enfield, Tompkins County, New York. The valley will likely undergo future development as the population of Tompkins County increases and spreads out from the metropolitan areas. The Town of Enfield, Tompkins County, and the New York State Departments of Health and Environmental Conservation need geohydrologic information to help planners develop a more comprehensive approach to water-resource management in Tompkins County.

The Enfield Creek Valley is underlain by an unconfined aquifer that consists of saturated alluvium, alluvial-fan deposits, and ice-contact (kame) sand and gravel. A confined aquifer of discontinuous ice-contact sand and gravel overlies bedrock. Depth to bedrock in the valley ranges from about 50 feet below land surface from just north of the Enfield Creek divide in the northern part of the aquifer to the confluence of Fivemile Creek to at least 140 feet below land surface from Fivemile Creek to where the valley orientation changes from north-south to northwest-southeast. Depth to bedrock is much shallower from the valley orientation change to the southeastern part of the aquifer because Enfield Creek has carved through overlying sediments into bedrock as the creek drops 450 feet into the Cayuga Inlet Valley. A small buried valley running south to north was identified within the Fivemile Creek drainage along the western edge of the town. However, the valley fill consists of glacial till, and no sand-and-gravel aquifer is present.

The unconfined aquifers are recharged by direct infiltration of precipitation, surface runoff, and shallow subsurface flow from hillsides, and by seepage loss from streams overlying the aquifer. The confined aquifers are recharged mostly by precipitation that enters the adjacent valley walls, by groundwater flowing from bordering till or bedrock, and by flow from the bottom of the valley. Also, some recharge may be occurring where confining units are absent or from confining units with sediments of moderate permeability.

Groundwater discharges to Enfield Creek, its tributaries, and wetlands and is lost through evapotranspiration from the water table or is withdrawn from domestic, commercial, and agricultural wells. About 700 individual well owners depend on the unconsolidated aquifers for their water supply. An estimated 28,300,000 gallons per year are withdrawn.

Groundwater samples were collected from eight test wells drilled for this study, and six surface-water samples were collected from five locations on Enfield Creek. Of the eight wells sampled, two were finished in unconfined sand-and-gravel aquifers, two were finished in confined sand-and-gravel aquifers, and four were finished at or near the shale bedrock surface.

Water quality in the study area generally met State and Federal drinking-water standards. However, some samples exceeded maximum contaminant levels for barium (25 percent of samples) and secondary maximum containment levels for chloride (25 percent), dissolved solids (25 percent of samples), iron (70 percent of samples), and manganese (75 percent of samples). Groundwater from 75 percent of the wells sampled for methane had concentrations greater than the Office of Surface Mining Reclamation and Enforcement recommended action level of 10 to 28 milligrams per liter. The two deepest wells sampled, TM1075 and TM1077, had the highest specific conductance, chloride, and sodium concentrations of all wells sampled. The chloride/bromide ratios of these samples suggest the source may represent a mixture of saline formation waters with shallow dilute groundwater and may receive recharge contribution from two tributaries overlying bedrock to the west and southwest of the aquifer. In general, the highest yields are from wells completed within about 50 feet below land surface, which may tap either type of aquifer.

Introduction

The Town of Enfield relies on groundwater as its sole source for drinking water. Unconsolidated aquifers like those that underlie the study area are susceptible to contamination from manmade and natural sources. Elevated concentrations of sodium, chloride, total dissolved solids, and methane in groundwater are of local concern.

In 2000, the U.S. Geological Survey (USGS) mapped the extent of the unconsolidated (sand-and-gravel) aquifer systems in Tompkins County, New York (Miller, 2000). From 2000 to 2002, the USGS, in cooperation with the Tompkins County Planning Department, used this information to plan more detailed studies to better understand these unconsolidated aquifers. The purpose of these studies is to provide town and county planners information to manage, maintain, and protect their groundwater resources as a drinking-water source. A list of 17 unconsolidated-aquifer reaches (fig. 1) was compiled, and a plan to study them over the following years was developed. The extent of the stratified-drift unconsolidated aquifers was based mostly on natural hydrologic boundaries, but, in some cases, political boundaries were used as well. Between 2013 and 2018, the Enfield Creek Valley was the fifth (Miller and Karig, 2010; Miller and Bugliosi 2013; Bugliosi and others, 2014; Miller, 2015) aquifer study to be investigated for this county-wide program.

The objective of this study is to improve the understanding of the geohydrology of the unconsolidated aquifer in the Enfield Creek Valley. Specifically, the study provides information regarding the (1) extent and thickness of geohydrologic units, (2) hydraulic conditions in the aquifer (whether the units are under confined [artesian] or unconfined conditions), (3) extent of groundwater/surface-water interaction, (4) groundwater use (type and amount of groundwater withdrawal), (5) water levels in the geohydrologic units, and (6) general water quality of Enfield Creek and the aquifer.

The study may benefit Federal, State, and county governments and the residents in the study area by advancing knowledge of the regional geohydrologic framework of these types of valley-fill systems, by increasing the understanding of hydrologic processes in unconsolidated aquifer systems in the glacial northeast, and by contributing data to national databases that are used to advance the understanding of the regional and temporal variations in hydrologic systems. Additionally, the information provides local government, water managers, businesses, and homeowners with groundwater information to help ensure that the drinking-water supply will be safe, water will be available for economic development, and aquatic environments will be healthy. The study builds upon the USGS data-collection efforts in New York State and on the interpretation of the Nation's water availability.

Purpose and Scope

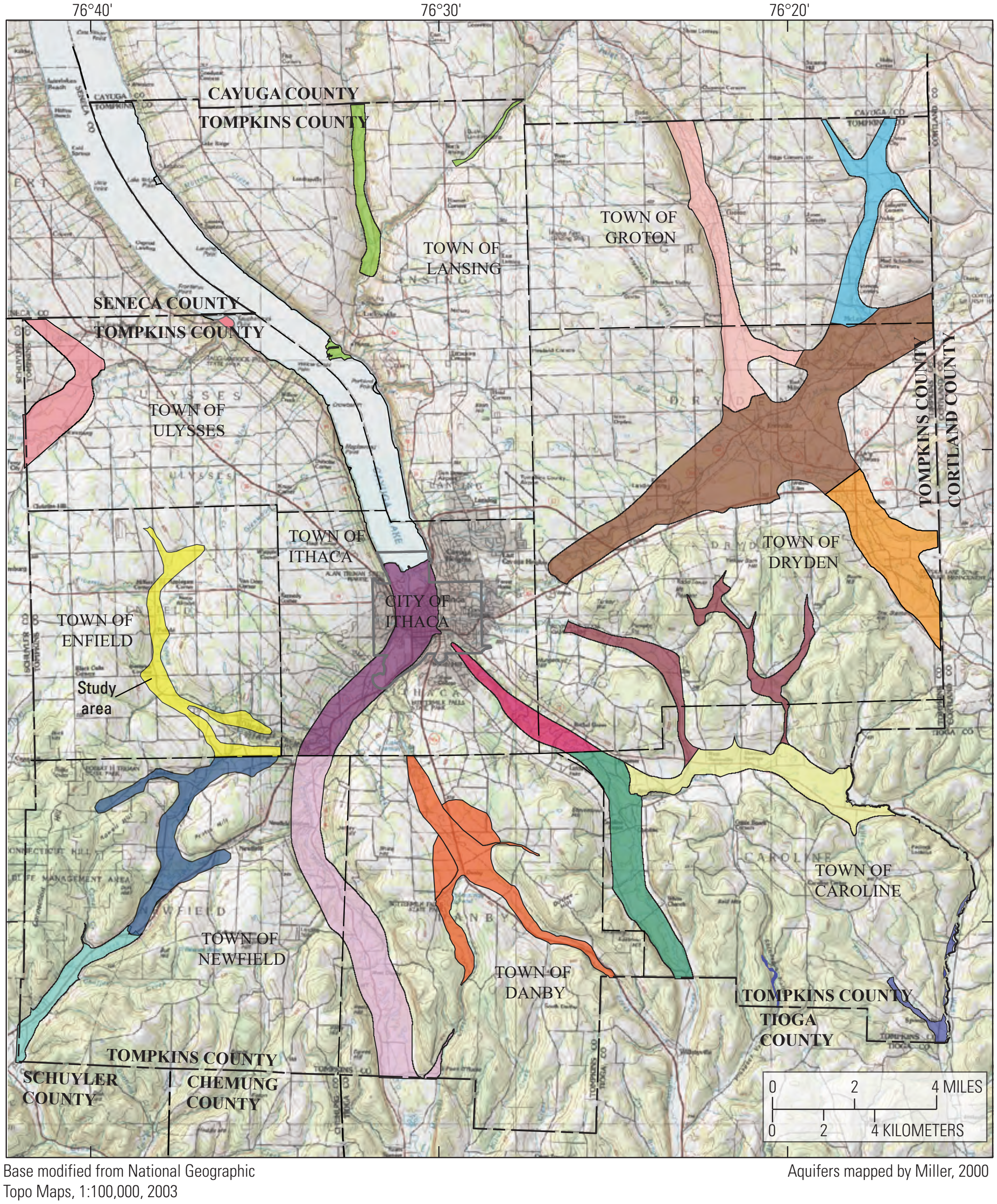
This report describes the geohydrology of the unconsolidated aquifer in the Enfield Creek Valley in the town of Enfield, Tompkins County, New York. The report describes and illustrates (1) the geology of the study area, including the geologic framework of the unconsolidated aquifers and geohydrologic sections; (2) the groundwater-flow system, including information about groundwater levels, groundwater/surface-water interaction, and recharge and discharge conditions; and (3) groundwater and surface-water quality, including information about concentrations of common inorganic ions, inorganic forms of nitrogen and phosphorus (collectively, nutrients), trace elements, dissolved gasses, and chlorofluorocarbons.

Evaluating, developing, and protecting these unconsolidated aquifers requires information on the aquifer geometry (the three-dimensional extent and distribution of glacial sediments including aquifers and confining units), on sources of recharge and discharge, and on aquifer water quality. Aquifer geometry was determined from test wells drilled for the study, driller's logs from existing wells, topographic maps, light detection and ranging coverage, passive-seismic soundings, field surveys, and field observations from previous studies in the area. The types of recharge were delineated, and streamflow measurements were made along Enfield Creek and its tributaries to determine where the aquifer was being recharged from the overlying streams. Groundwater withdrawals were estimated using values from USGS water-use reports (Horn and others, 2008; Dieter and others, 2018) and from U.S. Census Bureau (2012b) data and have been rounded to three significant figures.

Stream samples were collected to characterize the quality of surface water under base-flow conditions (when the flow is mostly from groundwater discharging into stream channels) and to determine whether there are similarities in water quality between surface water and groundwater. Groundwater samples were collected from wells that are finished in unconfined and confined aquifers to compare water-quality conditions. Samples were collected from wells to characterize the quality of groundwater and to determine if the concentrations of any constituents exceeded standards for drinking-water quality.

Description of Study Area

The town of Enfield is in the Appalachian Plateau physiographic province of central New York at the transition between highly eroded, smooth interfluve areas of low relief between deeply eroded Finger Lake valleys and the dissected plateau areas of moderate relief to the south (fig. 2). Relief between valley bottoms and adjacent hills at the northern end of town is about 200 feet (ft); local relief just upvalley from Enfield Glen at the southern end of town is about 600 ft. The topography of the plateau reflects millions of years of dissection by streams and subsequent modification by several periods of glaciation. Enfield is underlain by gently southward dipping sedimentary



EXPLANATION
Aquifer reach names

- Cascadilla Creek Valley and upland Sixmile Creek Valley
- Enfield Creek Valley
- Lower Cayuga Inlet trough
- Lower Fall Creek Valley
- Lower Sixmile Creek trough (towns of Dryden and Ithaca)
- Owasco Inlet Valley
- Pony Hollow Valley
- Salmon Creek and Locke Valleys and Myers Point
- Taughannock Creek Valley and Taughannock delta
- Upper Buttermilk Creek and Danby Creek Valleys
- Upper Cayuga Inlet trough
- Upper Fall Creek Valley
- Upper Sixmile Creek and West Branch Owego Creek Valleys
- Virgil Creek Valley
- West Branch Cayuga Inlet and Fish Kill Valleys
- West Branch Owego Creek Valley and tributaries
- Lower Sixmile Creek and Willseyville Creek trough

Figure 1. The location of 17 stratified-drift (unconsolidated) aquifer reaches in Tompkins County, New York.

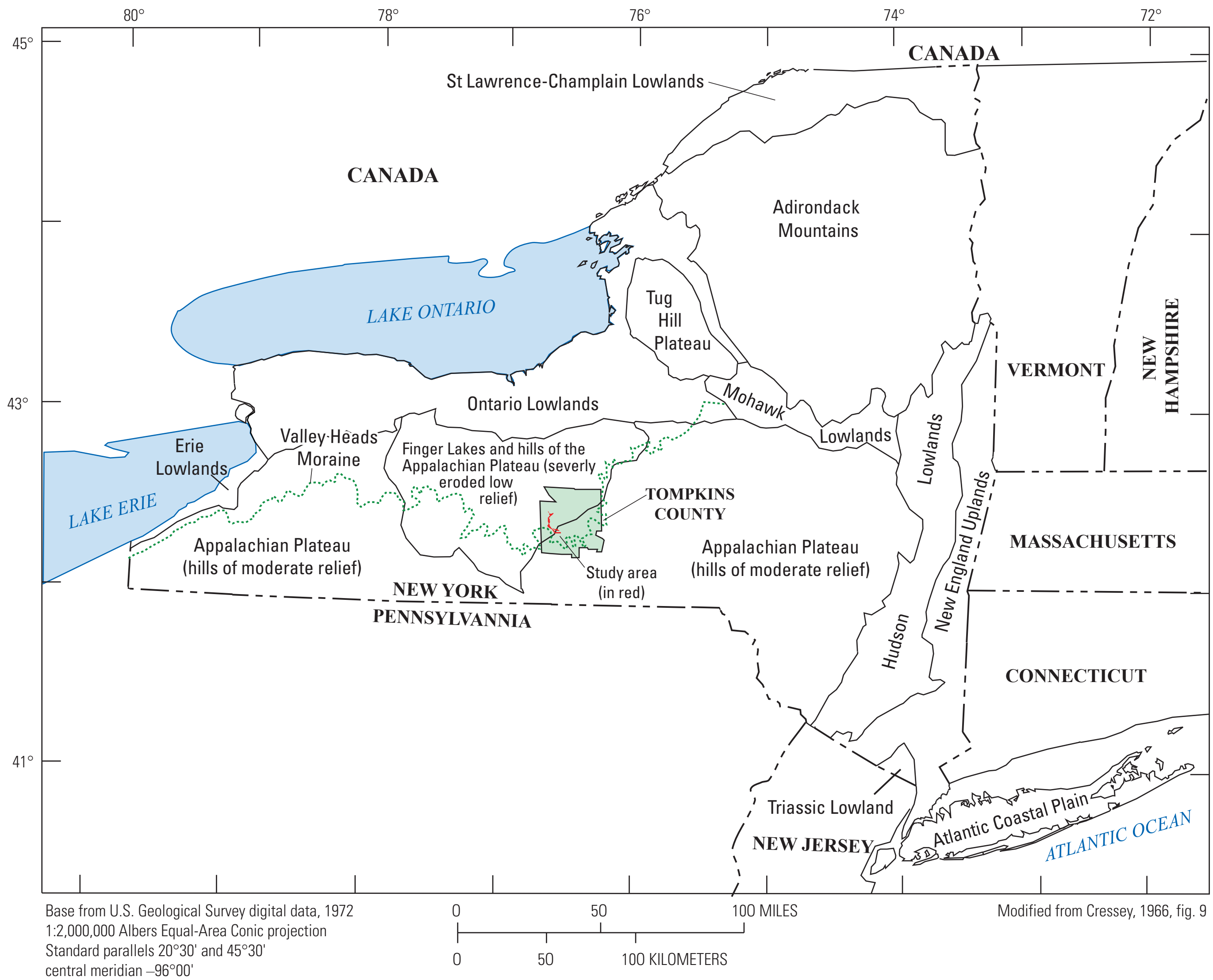


Figure 2. Physiographic features of New York and location of the Enfield Creek Valley study area in the town of Enfield, Tompkins County, New York.

bedrock that primarily consists of shale and siltstone of the Sonyea Group and the underlying Genesee Group (exposed in Enfield Glen), which are of Upper Devonian age (Rickard and Fisher, 1970).

Enfield Creek begins at a watershed divide at the northern edge of town just northeast of the intersection of County Route 170 (Halseyville Road) and County Route 139 (Hayts Road). Just downstream, Enfield Creek is joined by its main tributary, Fivemile Creek, as Enfield flows southward, then eastward through the main valley to Robert H. Treman State Park. At the park, Enfield Creek has incised through unconsolidated deposits and into bedrock as it descends 400 ft through Enfield Glen on the west wall of the Cayuga Inlet Valley. Enfield Creek joins Cayuga Inlet and flows north into Cayuga Lake, which is part of the Oswego River Basin and the Lake Ontario watershed (Michigan Sea Grant, 2019). The Enfield Creek drainage area is 30.6 square miles. Elevations in the study area range from about 1,990 ft above the North American Vertical Datum of 1988 on Buck Hill, which is in the southwest corner of the town of Enfield, to about 600 ft at the base of Enfield Glen in the southeast corner of town (fig. 3).

Methods of Investigation

Data used for analysis in this study were collected through geologic mapping, test drilling, passive-seismic soundings, measuring groundwater levels, and surface-water and groundwater-quality sampling; and through compiling existing data, including driller well records, and past geologic, soil, surficial- and bedrock-deposit maps and reports, which are described in the following sections.

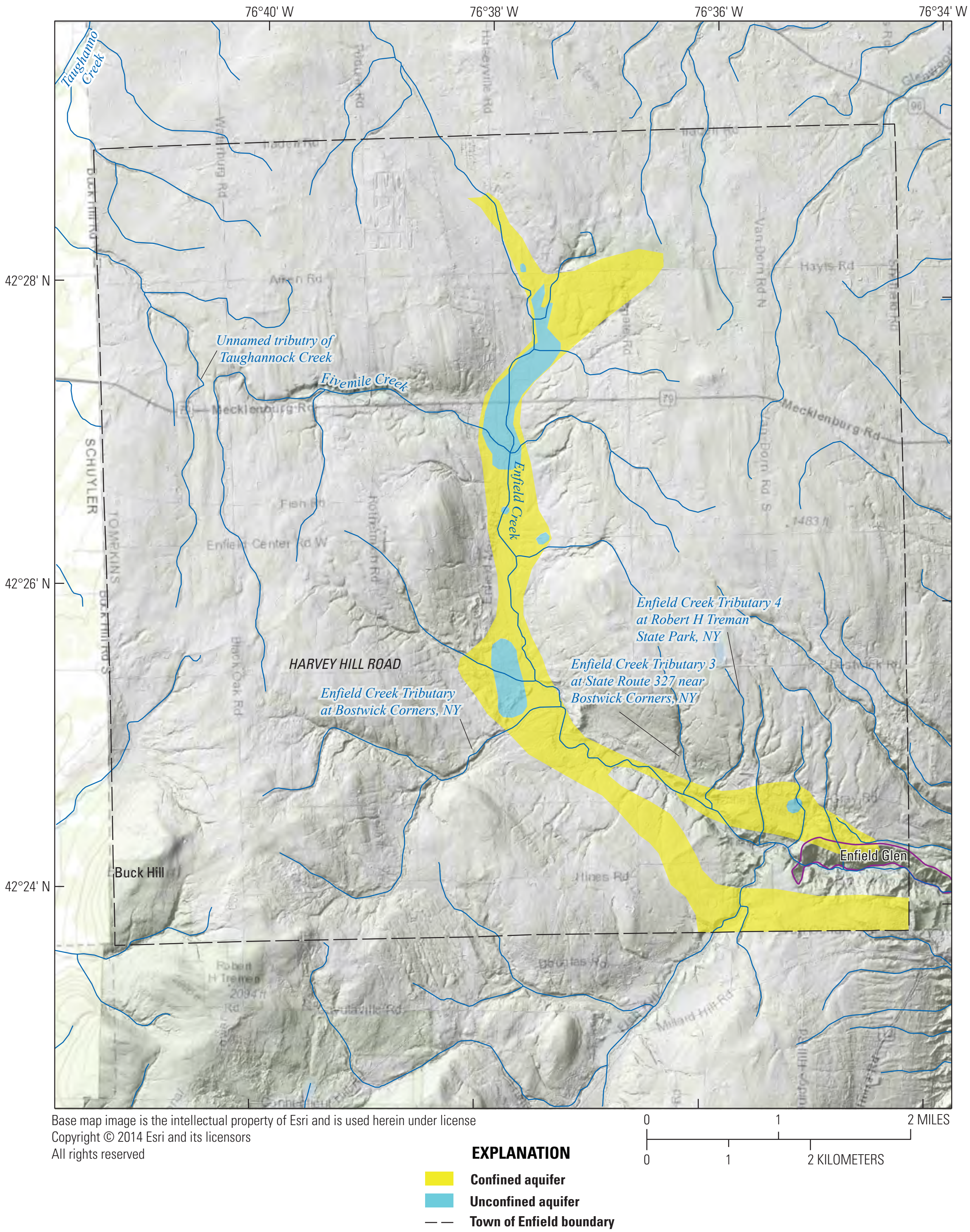


Figure 3. Extent of unconfined and confined aquifers in the Enfield Creek Valley, town of Enfield, Tompkins County, New York. See also Fisher and others (2020).

Well Inventory, Test Drilling, and Water-Level Measurements

Well records (306 in total) within and outside the unconsolidated aquifer were collected and compiled within the town of Enfield. Sources of well data include previous USGS groundwater studies, the USGS National Water Information System, and well records obtained from the New York State Department of Environmental Conservation Water Well Contractor Program. These data are available from Fisher and others (2019b, 2020).

Eight test wells were drilled in the town of Enfield and village of Enfield, New York, as part of the project (app. 1):

- Well TM1075 is at the Town of Enfield Highway Department and was drilled 142 ft into gray and black shale bedrock and cased to 136 ft in sand and gravel.
- Well TM1076 is next toTM1075 and was drilled 60 ft into sand and gravel and cased to 53 ft in sand and gravel.
- Well TM1077 is behind an apartment complex in the village of Enfield and was drilled 106 ft into gray and black shale and cased to 93 ft in sand and gravel.
- Well TM1078 is next to well TM 1077 and was drilled 60 ft into sand and gravel and cased to 56 ft in sand and gravel.
- Well TM1079 is off Hayts Road and was drilled 61 ft into gray and black shale bedrock and cased 48 ft in sand and gravel.
- Well TM1080 is next to TM1079 and was drilled 12 ft into sand and gravel and cased to 9 ft in sand and gravel.
- Well TM1081 is on a private farm off Enfield Main Road and was drilled 142 ft into gray and black shale and cased to 138 ft in sand and gravel;
- Well TM1082 is next to TM 1081 and was drilled 51 ft into sand and gravel and cased to 42 ft in sand and gravel.

Soil and rock samples were obtained with depth during the drilling to help determine the underlying aquifer material. All wells, except for well TM1081, were completed as open holes. The casing of well TM1081 was perforated from 77 to 79 ft deep and sealed at the bottom of the hole. Water-level and water-temperature data were collected at all eight USGS test wells during the study period after completing the test drilling. Water-level data loggers were installed in each of these wells to monitor seasonal water-level fluctuation. As the well data loggers were sealed, a barometric pressure data logger in the USGS New York Water Science Center, Ithaca office was used to compensate for barometric pressure changes recorded at each well. The loggers were set to record water-level and water-temperature data every 4 hours, from which graphical representations of changes in water level and water temperature were made (app. 2).

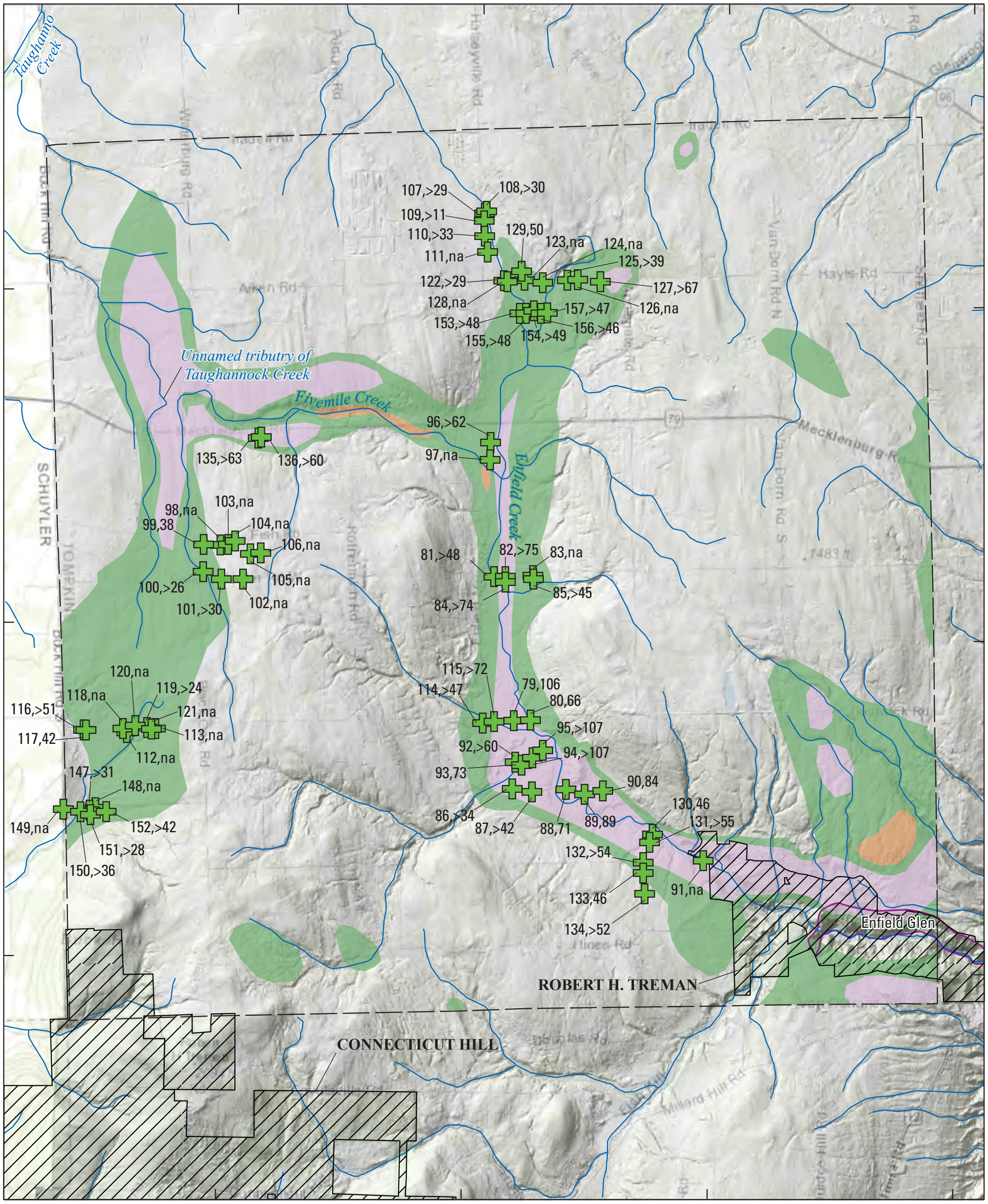
Land-surface elevations at wells were estimated using light detection and ranging technology with a horizontal accuracy of 1.000 meter root mean square error and a vertical accuracy of 0.185 meter root mean square error. Also used were 1:24,000-scale topographic contour maps that were accurate to 5 ft. Depths to water below the measuring points were then converted to water-level elevations by subtracting water level from land-surface elevation.

Horizontal-to-Vertical Spectral Ratio Seismic Sounding Surveys

The horizontal-to-vertical spectral ratio or passive-seismic method measures ambient seismic noise to determine sediment thickness overlying bedrock. This method uses a single, broad-band three-component seismometer to record the ambient seismic noise. The averaged horizontal-to-vertical frequency spectrum is used to determine a resonance frequency that can then be interpreted using regression equations to estimate sediment thickness and depth to bedrock (Lane and others, 2008). Measurements were taken at 69 locations (fig. 4) to refine aquifer geometry as determined from the data collected and described above. These data are available as a separate USGS data release (Fisher and others, 2019a) and are shown on figure 4. This method works best when the shear wave velocities of bedrock and the unconsolidated deposits differ; stratified sediments over bedrock generally work best. Dense glacial till over shale typically provides a weak peak or no peak, which results in either underestimated bedrock depth or unusable data and no estimate. The results of these analyses are noted with a “greater than” depth estimate or “na,” meaning no analysis was possible. Results are still useful because they indicate that the unconsolidated deposits above bedrock are probably till. There were several passive-seismic soundings collected in till-dominated areas to the west and southwest of the study area valley. These soundings were collected to investigate a possible buried valley thought to extend from the southwest to the northeast and terminate at the Fivemile Creek Valley. Well logs in the area indicated the existence of a buried valley filled in with till, which explains why the passive-seismic soundings in the area were largely unable to estimate the bedrock depth.

Surficial Geologic Map

The surficial geologic map of Muller and Cadwell (1986) was modified using information from topographic maps, orthophotographs, soils maps, and well logs (Neeley, 1961). Horizontal-to-vertical spectral ratio seismic surveys were used to determine the thickness of the unconsolidated deposits and bedrock-surface elevation to help refine the surficial geologic map.



0 1 2 MILES

0 1 2 KILOMETERS

EXPLANATION

[HVSR, horizontal-to-vertical spectral ratio]

- State park
- Town of Enfield boundary
- HVSR seismic survey location
- 90,84 HVSR seismic sounding number with estimated thickness of unconsolidated sediments

Thickness of unconsolidated deposits

- Less than 40 feet
- Greater than or equal to 40 feet
- 80 to 140 feet

Figure 4. Thickness of unconsolidated deposits and locations of horizontal-to-vertical seismic soundings, town of Enfield, Tompkins County, New York. See also Fisher and others (2020).

Streamflow Measurements

Synoptic streamflow measurements (Rantz and others, 1982) were performed during base flow, or sustained low-flow conditions in the absence of direct surface runoff, at 12 sites along Enfield Creek and its tributaries to determine if streams were losing water to or gaining water from the aquifer (fig. 5; table 1). The streamflow measurements for discharge (stream width, stream depth, and stream velocity) were made at intervals along a longitudinal profile based on locations of tributaries entering the main stem using a SonTek acoustic Doppler velocimeter. These streamflow measurements were collected on September 17, 2015.

Measurements at all locations, except for sites 04233090 and 04233100, were made twice and averaged together for the final discharge value. The two locations mentioned above, with only one measurement collected, have greater uncertainty because of the lack of a verification (or second) measurement. In general, there may be relative uncertainty between all measurements made because of equipment uncertainty, possible human error in depth and width readings, and the absence of uniform flows in the streams.

Water-Quality Sampling and Analysis

Samples for this study were collected from surface water and groundwater. Water samples, including replicates and blanks, were collected in accordance with the USGS national field manual for the collection of water-quality data (U.S. Geological Survey, variously dated). Surface-water and groundwater samples were analyzed at the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado, for physical properties, nutrients (Fishman, 1993; Patton and Truitt, 2000; Patton and Kryskalla, 2011), major ions, and trace elements (Fishman and Friedman, 1989; Fishman, 1993; Garbarino, 1999; Garbarino and others, 2005; American Public Health Association, American Water Works Association, and Water Environment Federation, 1998). Groundwater samples were also analyzed at the USGS Groundwater Dating Laboratory in Reston, Virginia, for dissolved gases, chlorofluorocarbons (CFCs), and age dating (Busenberg and Plummer, 2008, U.S. Geological Survey, 2018).

Physical properties were measured in the field at the time of sampling, aside from well depth. Well depth was determined during the test well drilling. The physiochemical properties (dissolved oxygen, pH, and water temperature) were obtained using a YSI 6920 V2 multiparameter water-quality sonde. Specific conductance (SC) values were reported from the laboratory.

Surface-water samples were collected on September 17, 2015. Samples were collected along Enfield Creek overlying the aquifer boundaries and were collected at the same time as the discharge measurements that were performed for the streamflow synoptic. One replicate (or quality-control) sample was collected—to ensure reproducibility in sample collection method—for six surface-water samples.

Groundwater samples were collected on June 15, 2016, at all eight USGS test wells. One blank quality-control sample was collected for nine groundwater samples. Wells were purged until properties (temperature, SC, pH, and dissolved oxygen) stabilized. Stability criteria allow variation between five or more sequential field-measurement values. Stability criteria for each property are as follows: temperature is plus or minus (±) 0.2 degree Celsius (°C; thermistor); SC is ±5 percent of SC less than 100 microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C) and ±3 percent for SC greater than 100 µS/cm; pH is ±0.1 units (±0.05 units if instrument displays two or more digits to the right of the decimal); and dissolved oxygen is ±0.2 milligram per liter (mg/L; U.S. Geological Survey, variously dated).

Depositional History and Framework of Glacial and Postglacial Deposits

The Finger Lakes region has been subject to several periods of glaciation separated by interglacial periods during the Pleistocene Epoch, from about 2.6 million years ago until about 12,000 years ago (Fullerton, 1980). Since then, the glacial deposits locally have been subject to erosion and redeposition as postglacial deposits including alluvium and alluvial-fan deposits and colluvium (not mapped as a separate unit in this study).

The town of Enfield occupies a high-elevation upland area (interfluve) between the two deepest valleys in the region—the Cayuga Lake and Seneca Lake troughs. The main valley within the town, occupied by Enfield Creek, ranges from about 800 to 200 ft above the level of Cayuga Lake, which lies 6 miles to the northeast.

Bedrock Surface and Thickness of Glacial Deposits

Unconsolidated deposits in the study area overlie bedrock that has been eroded during glacial and interglacial periods. Bedrock primarily consists of shale and siltstone of the Sonyea Group and the underlying Genesee Group (exposed in Enfield Glen), which are of Upper Devonian age (Rickard and Fisher, 1970). Williams and others (1909) recognized that glacial erosion of bedrock was most pronounced in the deepest valleys where the ice was thickest and where valleys were aligned with regional ice movement, such as the Cayuga Lake and Cayuga Inlet Valleys. The depth to bedrock in the Inlet Valley south of Ithaca is at least 350 ft and probably as much as 450 ft below land surface (Lawson, 1977). Erosion by glacial ice was least effective in upland areas or areas close to the ice margin (where ice was thinnest and flow weakest), and in valleys oriented perpendicular to regional ice flow. The north-south-oriented section of Enfield Creek Valley was parallel to ice flow (figs. 6 and 7), and although depth to bedrock is about 50 ft just south of the northern through-valley divide

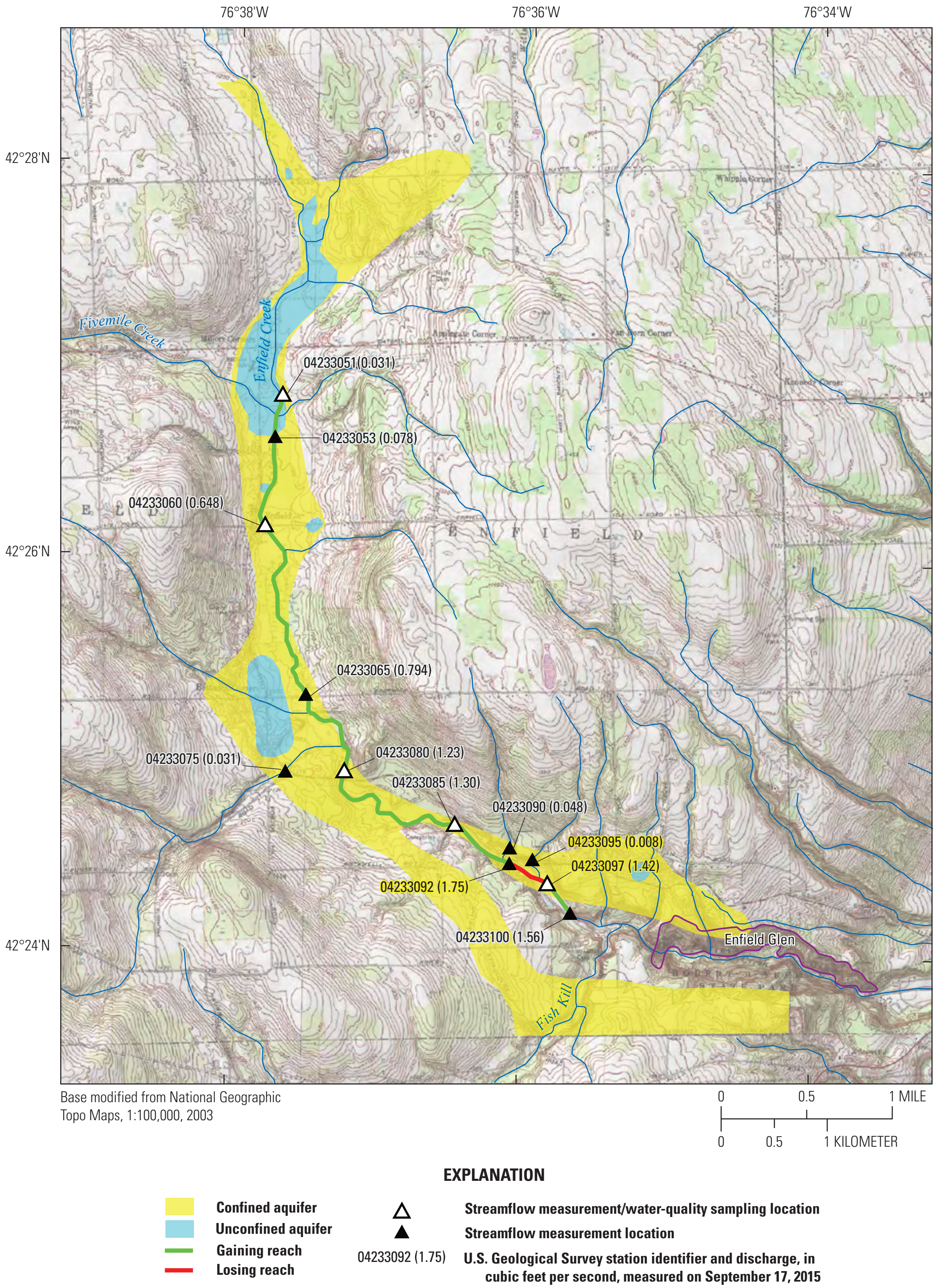


Figure 5. Streamflow and surface-water quality sampling locations, town of Enfield, Tompkins County, New York. See also Fisher and others (2020).

Table 1. Streamflow sites and associated discharge measurements, town of Enfield, Tompkins County, New York.

[ft^3/s, cubic foot per second; mi^2, square mile; Cr, Creek; Rd, Road; °, degree; ′, minute; ″, second; N., north; W., west]

Station identification number	Station name	Discharge (ft^3/s)	Drainage area (mi^2)	Latitude	Longitude
04233051	Enfield Creek above Fivemile Creek at Millers Corners, New York	0.031	2.86	42°26′43.7″ N.	76°37′43.6″ W.
04233053	Enfield Creek below Fivemile Cr at Millers Corners, New York	0.078	7.47	42°26′41.8″ N.	76°37′43.4″ W.
04233060	Enfield Creek at Enfield Center Road 3 at Enfield, New York	0.648	8.43	42°26′09.6″ N.	76°37′47.6″ W.
04233065	Enfield Creek at Bostwick Road at Bostwick Corners, New York	0.794	10.2	42°25′17.9″ N.	76°37′28.0″ W.
04233075	Enfield Creek Tributary at Bostwick Corners, New York	0.031	2.94	42°24′54.3″ N.	76°37′36.5″ W.
04233080	Enfield Creek above State Route 327 at Bostwick Corners, New York	1.23	15.0	42°24′54.8″ N.	76°37′11.4″ W.
04233085	Enfield Creek at Hines Rd near Bostwick Corners, New York	1.30	16.5	42°24′39.4″ N.	76°36′27.3″ W.
04233090	Enfield Creek Tributary 3 at State Route 327 near Bostwick Corners, New York	0.048	0.40	42°24′29.4″ N.	76°36′06.5″ W.
04233092	Enfield Creek below Tributary 3 near Bostwick Corners, New York	1.75	17.4	42°24′28.6″ N.	76°36′04.6″ W.
04233095	Enfield Creek Tributary 4 at Robert H. Treman State Park, New York	0.008	0.28	42°24′22.9″ N.	76°35′51.3″ W.
04233097	Enfield Creek below Tributary 4 near Robert H. Treman State Park, New York	1.42	17.8	42°24′22.2″ N.	76°35′50.2″ W.
04233100	Enfield Creek at Robert H. Treman State Park, New York	1.56	17.9	42°24′12.9″ N.	76°35′39.2″ W.

of Enfield Creek, it increases to at least 140 ft within 1 mile downvalley (at the confluence with Fivemile Creek). This 140-ft depth is maintained at least until the valley orientation changes from north-south to northwest-southeast toward the Cayuga Inlet Valley. Reported depths to bedrock downgradient from this point are shallower because Enfield Creek has incised through overlying sediments into bedrock as it descends 450 ft into the Cayuga Inlet Valley. Tributary valleys of the Cayuga Inlet Valley are termed “hanging valleys” because glaciation has eroded the bedrock floor of the Inlet Valley far below the bedrock floors of the tributary valleys. For example, Enfield Creek, before it starts to incise into the valley fill, is greater than 600 ft higher than the Cayuga Inlet flood plain at their confluence; the difference in elevation of the bedrock floors is greater still. Such differences in elevation have resulted in the development of a system of gorges along the Cayuga Inlet Valley during interglacial intervals (Williams and others, 1909; Miller, 2015; Miller and Karig, 2010; Karig, 2015). The gorges were buried by sediment deposited during subsequent glacial advances and have been re-excavated to varying degrees during the past 12,000 years. In the study area, Enfield Creek has partially re-excavated a buried interglacial gorge and incised farther into bedrock at Enfield Glen (within Robert H. Treman State Park in the southeast corner of the town of Enfield; figs. 4 and 7*B*, *C*).

The upland areas in Enfield are mostly mantled by thin (0–40 ft) glacial till of low permeability. Thick till (as much as 125 ft) primarily underlies the drainages of Fivemile Creek and an unnamed tributary of Taughannock Creek within the northwest quadrant of the town (fig. 4). Adjacent areas of thin till may indicate that some thick till areas cover buried interglacial gorges.

Glacial and Postglacial History

Most glacial deposits within the study area are derived from two primary Laurentide ice sheet advances and retreats during the Late Wisconsinan substage at the end of the Pleistocene Epoch. Both advances completely covered the town of Enfield. These include the maximum Late Wisconsinan ice advance that extended as far south as Pennsylvania (Nissouri Stade, about 23,000 to 16,500 years before present [2019]; Muller and Calkin, 1993), and the Valley Heads re-advance (Fairchild, 1932), which deposited moraines mostly in the form of outwash heads in valleys immediately south of Enfield (in the town of Newfield; Denny and Lyford, 1963; Bugliosi and others, 2014) and across much of western New York (Port Bruce Stade, starting about 15,500 years before present [2019] until ice retreated from the area about 14,400 years ago; Karrow, 1984; Cadwell and Muller, 2004). As a result, two tills (or more) are common in valleys north of the Valley Heads moraine (for example, Miller, 2015). Earlier glacial or interglacial deposits have been noted within the region, most commonly as gorge fillings (for example, Karig, 2015).

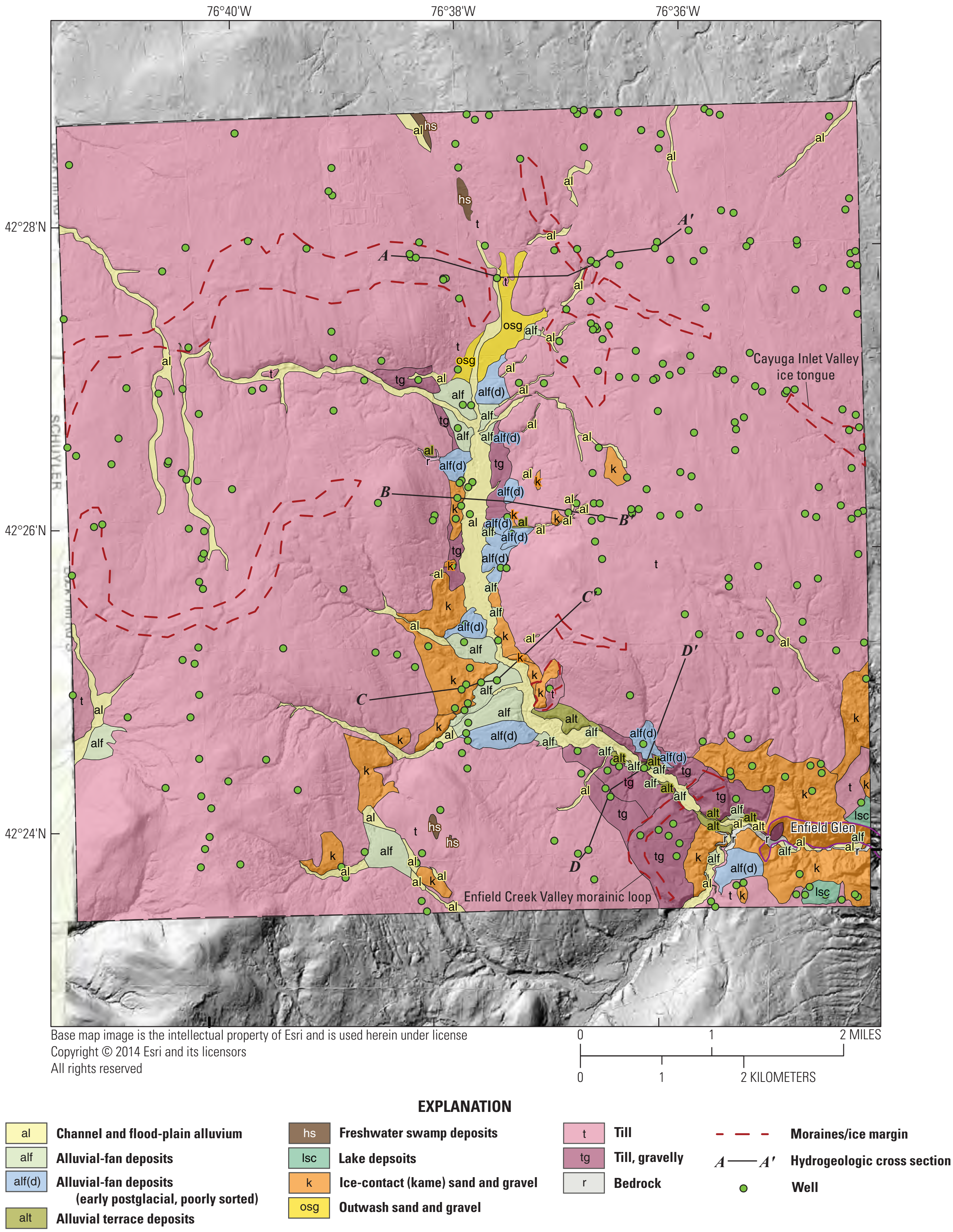
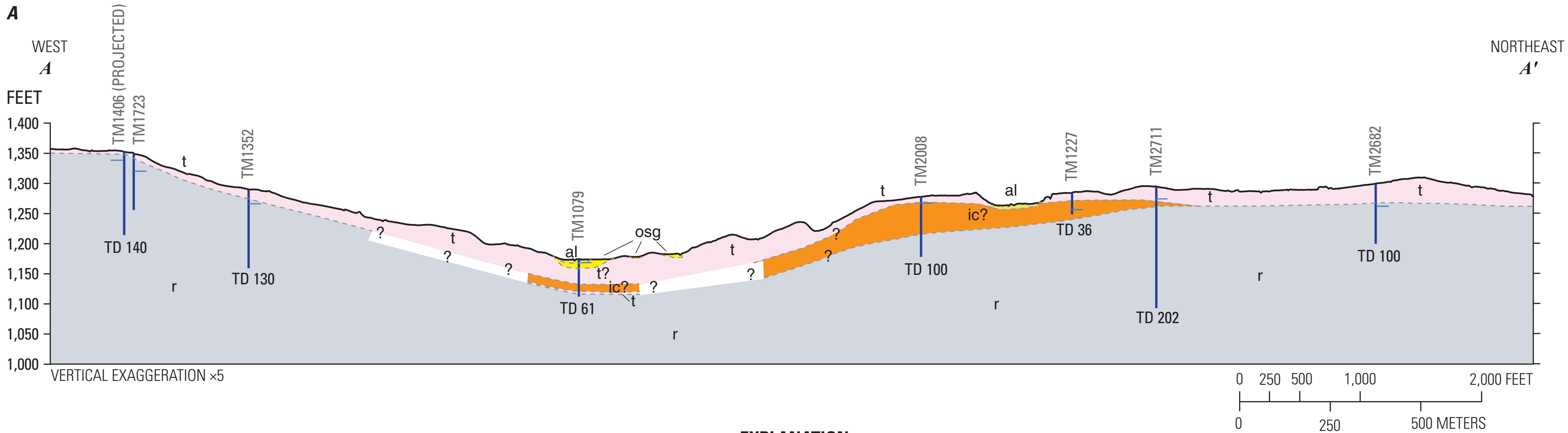


Figure 6. Surficial geology of Enfield Creek Valley, town of Enfield, Tompkins County, New York. See also Fisher and others (2020).



EXPLANATION

Postglacial deposits of Holocene age

al — Channel and flood-plain alluvium—Stream-deposited gravel, sand, silt, and clay

Glacial deposits of late Wisconsin age

ic, k — Ice-contact (kame) sand and gravel—Stratified gravel, sand, and silt deposited by meltwater beneath, within, atop, or adjacent to glacial ice. At land surface, in the form of kames and on map, labeled "k." In sections, labeled "ic." Ranges from well-sorted units to poorly sorted "dirty gravels" reported in driller's logs and some silty to clayey layers. Contorted or faulted bedding is common, caused by meltout of nearby ice. Locally, the ice-contact sediments are overlain by till or resedimented till as thick as 15 feet

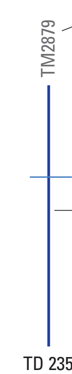
osg — Outwash sand and gravel—Silty sand and gravel deposited by meltwater drainage away from the ice. In Enfield, the flow and sediment source was weak from ice at high-elevation drainage divides

t — Till—Poorly sorted clayey to silty matrix with embedded stones deposited by glacial ice. At land surface, includes a layer of colluvium. Till may overlie stratified material along valley edges where oversteepened slopes have resulted in downslope movement of the till. In upland areas, mostly compact and dense lodgment till with subangular to angular clasts (fine pebbles to boulders) of local shale and siltstone embedded in a sandy to clayey matrix. Referred to as hardpan or till by local drillers. Forms a confining unit, where present

Consolidated deposits

r — Bedrock—Mostly Devonian-age shale and siltstone. Beds are gently folded and dip south from 20 to 50 feet per mile

Wells



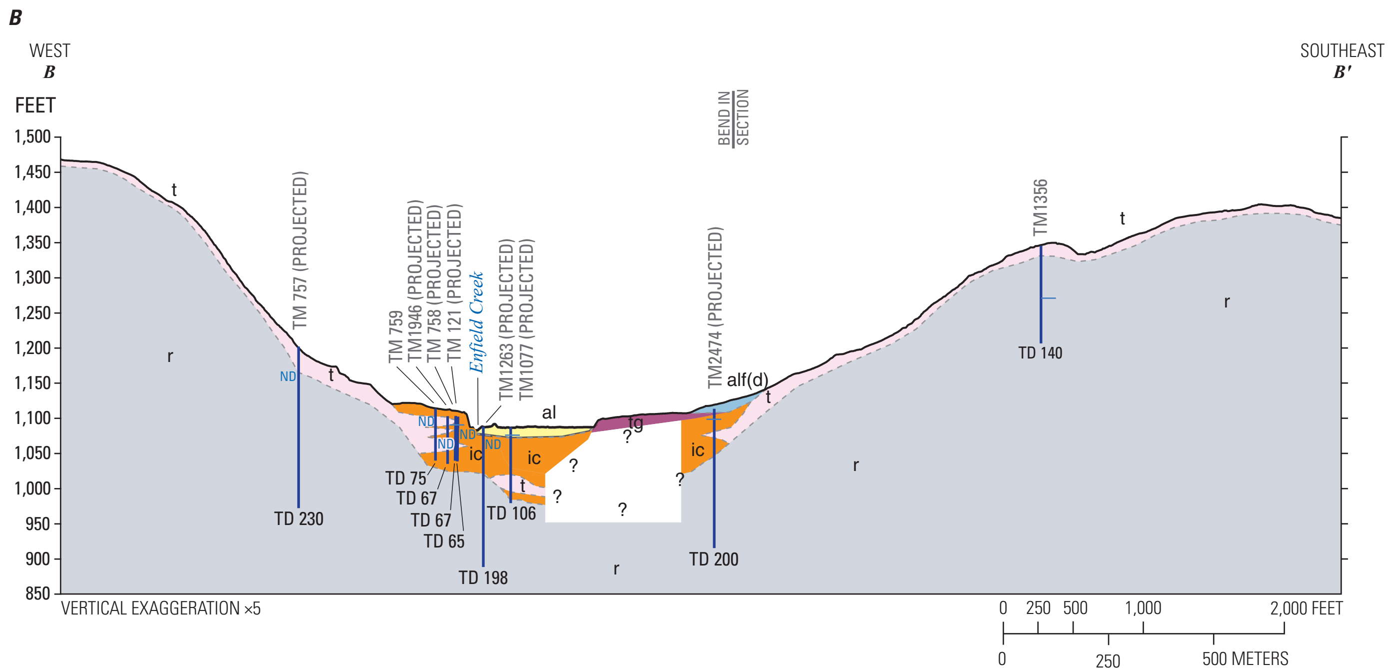
Well number—Number is assigned by U.S. Geological Survey. Well data are in the U.S. Geological Survey National Water Information System

Water-level marker

Well

Total depth of well, in feet

Figure 7. Hydrogeologic sections across the Enfield Creek Valley, town of Enfield, Tompkins County, New York. *A*, Cross section *A–A′*. *B*, Cross section *B–B′*. *C*, Cross section *C–C′*. *D*, Cross section *D–D′*.



EXPLANATION

Postglacial deposits of Holocene age

al — Channel and flood-plain alluvium—Stream-deposited gravel, sand, silt, and clay

alf(d) — Alluvial fan deposits—Gravel, sand, silt, and clay deposited as fans by upland tributaries where they join larger valleys. Some driller's logs describe these deposits as hardpan or dirty gravel. Fan development began as soon as valley floors became ice free. Easily erodable glacial deposits on unstable, unvegetated slopes provided an abundant sediment supply for late-glacial meltwater discharges and runoff from early deglacial precipitation. These conditions favored debris-flow-dominated early fan development. Fans with small ice-free watershed areas that were fed by glacial meltwater largely ceased development once ice left the area and have uneven, somewhat lobate surfaces and are designated as alf(d)

Glacial deposits of late Wisconsin age

ic, k — Ice-contact (kame) sand and gravel—Stratified gravel, sand, and silt deposited by meltwater beneath, within, atop, or adjacent to glacial ice. At land surface, in the form of kames and on map, labeled"k." In sections, labeled "ic." Ranges from well-sorted units to poorly sorted "dirty gravels" reported in driller's logs and some silty to clayey layers. Contorted or faulted bedding is common, caused by meltout of nearby ice. Locally, the ice-contact sediments are overlain by till or resedimented till as thick as 15 feet

t — Till—Poorly sorted clayey to silty matrix with embedded stones deposited by glacial ice. At land surface, includes a layer of colluvium. Till may overlie stratified material along valley edges where oversteepened slopes have resulted in downslope movement of the till. In upland areas, mostly compact and dense lodgment till with subangular to angular clasts (fine pebbles to boulders) of local shale and siltstone embedded in a sandy to clayey matrix. Referred to as hardpan or till by local drillers. Forms a confining unit, where present

tg — Till, gravelly—Commonly referred to in driller's logs as "hardpan with gravel layers" or "gravelly till." Soil survey commonly indicates till parent material. May include flow till, till that has moved down valley hillsides as debris flows, slumps, or other mass movements soon after deglaciation, or poorly sorted ice-contact sediments. Late glacial to postglacial

Consolidated deposits

r — Bedrock—Mostly Devonian-age shale and siltstone. Beds are gently folded and dip south from 20 to 50 feet per mile

Wells

TM2879 — Well number—Number is assigned by U.S. Geological Survey. Well data are in the U.S. Geological Survey National Water Information System

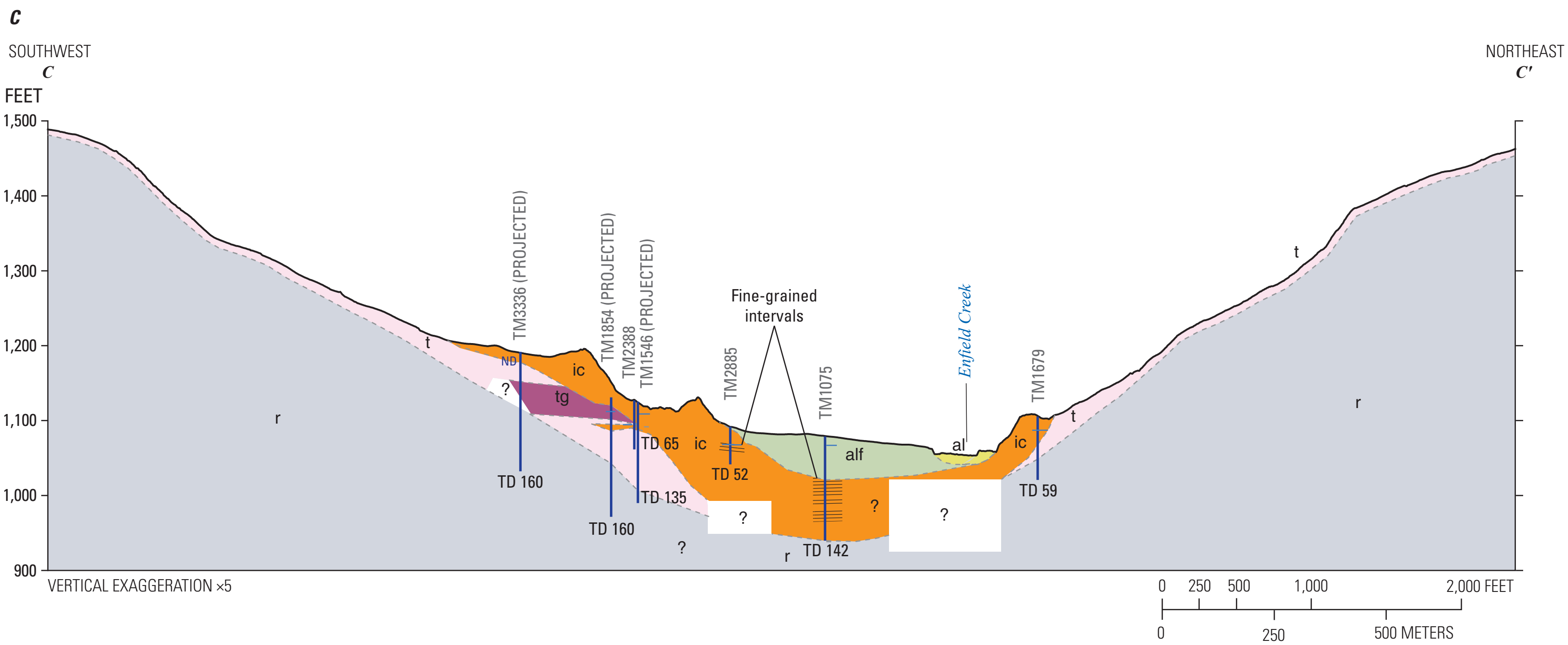
Water-level marker

Well

TD 235 — Total depth of well, in feet

ND — No data

Figure 7. Hydrogeologic sections across the Enfield Creek Valley, town of Enfield, Tompkins County, New York. *A*, Cross section *A–A′*. *B*, Cross section *B–B′*. *C*, Cross section *C–C′*. *D*, Cross section *D–D′*.—Continued



EXPLANATION

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Glacial deposits of late Wisconsin age

ic, k — Ice-contact (kame) sand and gravel—Stratified gravel, sand, and silt deposited by meltwater beneath, within, atop, or adjacent to glacial ice. At land surface, in the form of kames and on map, labeled "k." In sections, labeled "ic." Ranges from well-sorted units to poorly sorted "dirty gravels" reported in driller's logs and some silty to clayey layers. Contorted or faulted bedding is common, caused by meltout of nearby ice. Locally, the ice-contact sediments are overlain by till or resedimented till as thick as 15 feet

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Consolidated deposits

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Wells

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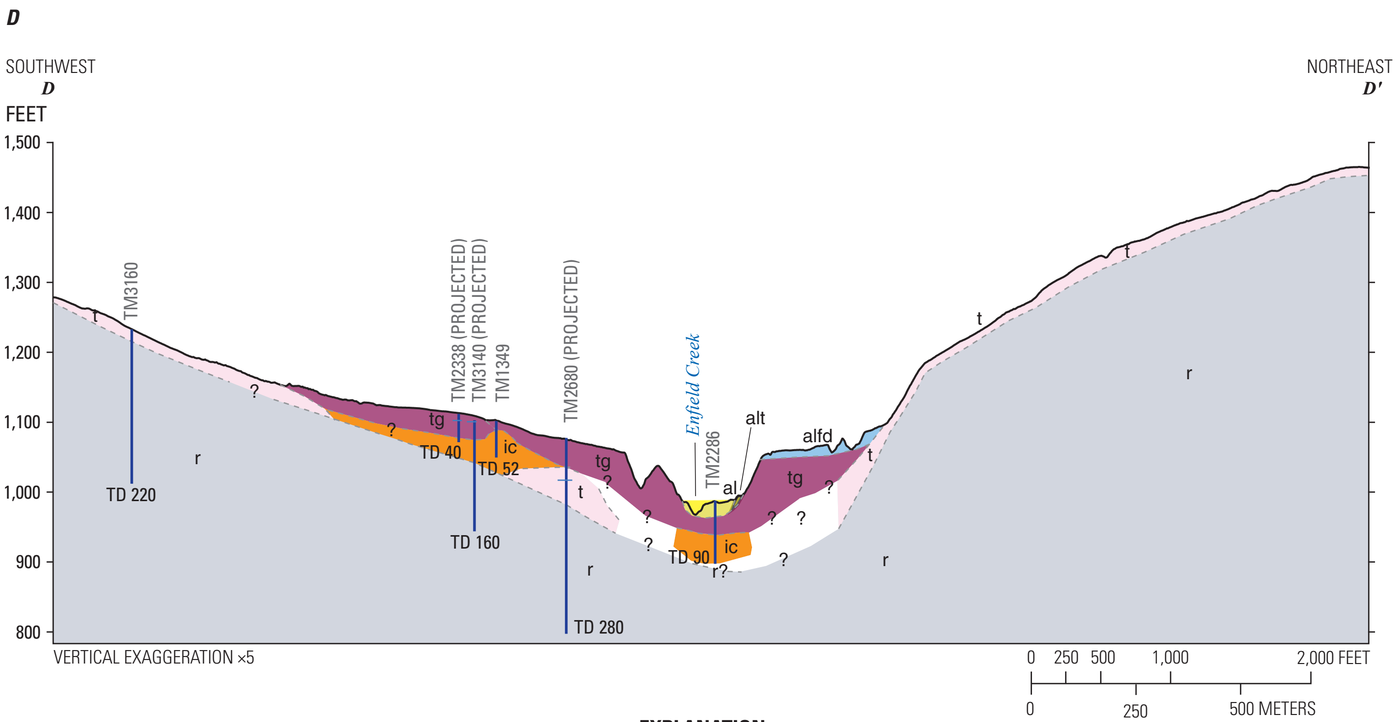
Water-level marker

Well

TD 235 — Total depth of well, in feet

ND — No data

Figure 7. Hydrogeologic sections across the Enfield Creek Valley, town of Enfield, Tompkins County, New York. *A*, cross section *A–A′*. *B*, cross section *B–B′*. *C*, cross section *C–C′*. *D*, cross section *D–D′*.—Continued



EXPLANATION

Postglacial deposits of Holocene age

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alt — Alluvial terrace—Remnants of early postglacial alluvial deposits of gravel, sand, silt, and clay in the form of terraces as the stream continued to downcut it's channel

Glacial deposits of late Wisconsin age

ic, k — Ice-contact (kame) sand and gravel—Stratified gravel, sand, and silt deposited by meltwater beneath, within, atop, or adjacent to glacial ice. At land surface, in the form of kames and on map, labeled"k." In sections, labeled "ic." Ranges from well-sorted units to poorly sorted "dirty gravels" reported in driller's logs and some silty to clayey layers. Contorted or faulted bedding is common, caused by meltout of nearby ice. Locally, the ice-contact sediments are overlain by till or resedimented till as thick as 15 feet

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Wells

TM2879 — Well number—Number is assigned by U.S. Geological Survey. Well data are in the U.S. Geological Survey National Water Information System

Water-level marker

Well

TD 235 — Total depth of well, in feet

ND — No data

Figure 7. Hydrogeologic sections across the Enfield Creek Valley, town of Enfield, Tompkins County, New York. *A*, cross section *A–A′*. *B*, cross section *B–B′*. *C*, cross section *C–C′*. *D*, cross section *D–D′*.—Continued

The major unconsolidated depositional features in Enfield (fig. 6) are the result of early deglacial deposition of ice-contact deposits (kames) during final ice retreat from the Valley Heads position, of limited late glacial meltwater drainage from ice-marginal positions within and at the northern edge of the Enfield Creek drainage, and of erosion of the recently deglaciated landscape through mass wasting and runoff along with deposition of flood-plain alluvium, alluvial fans, and organic deposits (see Randall, 2001, p. B12, ”The Universal Three Depositional Facies”).

The mode of deglaciation from the Valley Heads position in much of Enfield seems to have been an active retreat of the ice; pauses or re-advances are marked by small moraines. Northward ice retreat is indicated by two moraines, and ice retreat to the east, towards the ice tongue in the Cayuga Inlet Valley, is indicated by a morainic loop in the lower Enfield Creek Valley (fig. 6).

Poorly sorted ice-contact deposits, till, and gravelly or resedimented till (flow till, debris flow, or slump deposits) are the primary glacial deposits within the Enfield Creek Valley (figs. 6 and 7). These deposits are the result of small amounts of meltwater flow and sorting in this high-elevation valley, with drainage away from the ice margin. Little meltwater was impounded in the valley. The most extensive ice-contact deposits are on the west side of the valley just before it turns to the southeast and on each side of the lowermost valley at Enfield Glen (fig. 6). Lacustrine deposits are mostly limited to the lower Enfield Creek Valley, where drainage was toward the ice tongue in the Cayuga Inlet Valley. Elsewhere within the valley fill, deposits that could be interpreted as lacustrine are thin and discontinuous (fig. 7*C*). The only outwash deposits in Enfield Creek Valley are present near the through-valley drainage divide at the north end of the town, where little meltwater from the ice margin entered the valley (fig. 6; Williams and others, 1909).

As the Enfield area became ice free more than 13,000 years ago (Miller and Karig, 2010; table 1), erosion of unvegetated glacial deposits began, principally by water action and gravity-driven mass movement of unstable slopes. Sediments deposited by running water formed alluvial fans and alluvial flood plains. Organic deposits (freshwater swamp deposits) accumulated in poorly drained areas (fig. 6). Subsequent decreases in sediment load and lowering base level has incised the flood plain and created alluvial terraces immediately upvalley from Enfield Glen. Erosion and deposition continue to the present day but at slower rates because of vegetative cover.

Alluvial fans are common within the study area and are divided into two classes on the basis of morphology: “alf(d)” indicates irregular and somewhat lobate fans, generally of high slope that were formed by water-poor, debris-flow deposits as the area became ice free (Church and Ryder, 1972), and “alf” indicates regular-shaped fans of generally low slope that reflect water-rich fluvial deposition (fig. 6). Debris-flow-dominated fans have intermittent confined permeable zones within less permeable deposits whose parent material was mostly till. Soil surveys indicate till parent material. Fluvially dominated fans or parts of fans are generally silty gravels with some cleaner zones.

The debris-flow-dominated fans are indicative of early deglacial conditions (Church and Ryder, 1972), and their presence indicates that fluvial action since then has not been enough to alter their morphology. In Enfield, alf(d) deposits most commonly have upgradient drainages that are disproportionately small relative to fan size or even fan development (fig. 6). This may indicate that some early fan development depended on meltwater flow across cols (a gap in a hillside) from a nearby ice margin. Because meltwater contributions ceased, local runoff from the small drainage areas has been insufficient to substantially modify the fans. Fans with relatively large drainage areas have developed more regular fluvial-dominated fan morphology during postglacial time.

Glacial Aquifers

Glacial aquifers in the Enfield area are a modest groundwater resource, present within ice-contact and outwash stratified drift and in alluvial fan deposits (fig. 6) primarily within the Enfield Creek Valley (fig. 3). Ice-contact deposits can vary greatly in grain size and degree of sorting over short distances. Alluvial fan (alf) deposits may likewise have silty confining zones, silty gravels, and less commonly cleaner sand-and-gravel beds. Shallow intervals of these deposits form unconfined aquifers, and deeper deposits form semiconfined or confined aquifers within the valley fill (fig. 3). Alluvium is generally too thin to form an unconfined aquifer unless it is underlain by other permeable deposits. Confined aquifer conditions are widespread but mostly consist of multiple, relatively thin, silty sand-and-gravel beds isolated to varying degrees by intervening, poorly sorted beds. Ice-contact deposits are most probably thinly saturated and thus of limited aquifer potential where the Enfield Creek Valley joins the Cayuga Inlet Valley because deep incision has lowered the base level at Enfield Glen. The most favorable area for groundwater resources is within ice-contact and alluvial fan deposits just north of where the Enfield Creek Valley turns to the southeast in the unconfined and shallower confined zones (fig. 7*C*).

Driller-reported well yields from wells completed in glacial aquifers across the town range from 0 to 40 gallons per minute (gal/min; Fisher and others, 2019b). In general, the highest yields are from wells completed within about 50 ft of land surface, which may tap either type of aquifer. Deeper productive confined or semiconfined aquifer intervals intersected during the USGS drilling effort yielded as much as 20 gal/min. Higher yields from both types of aquifer would be expected if wells are constructed with screened intervals; most domestic-water wells are typically completed with an open-ended well casing.

Groundwater Recharge, Discharge, and Withdrawals

Groundwater recharge, discharge, and withdrawals are characterized in the following sections. Groundwater recharge from the overlying Enfield Creek was estimated by collecting synoptic streamflow measurements commonly known as a seepage run. Several water temperature and water level loggers were installed in two test wells drilled for this study to help determine where major sources of surface water may be recharging the aquifer. Groundwater withdrawal rates were compiled from reported or estimated data to determine the amount of groundwater being withdrawn from domestic and production wells in the town of Enfield.

Groundwater Recharge

Unconfined aquifers are primarily recharged by the infiltration of precipitation, either by rain or snowmelt, on the land surface. The confined aquifers are recharged mostly by areas where upland runoff meets deposits on the valley floor in hydraulic connection with the confined aquifer, by groundwater flow from bordering till or bedrock, and by flow from the bottom of the valley. Also, some recharge may be occurring where confining units are absent or from confining units with sediments of moderate permeability. Understanding groundwater recharge is essential to determine the long-term availability of the groundwater in a specific aquifer system.

Aquifer recharge mostly occurs at two periods during the year: March through April and mid-October through mid-December. These are the primary recharge periods because vegetation is dormant during these times, which decreases evapotranspiration, allowing more aquifer recharge and storage. During the growing season, which occurs from May through mid-October, the rate of evapotranspiration is typically greater than the rate of precipitation, causing a net decrease in water levels and storage. During the study period, substantial recharge occurred during July 2017 from large summer storms. Other sources of recharge included unchannelized runoff from hills that border the aquifer and seepage losses that occurred when overlying streams drained into the aquifer.

Streamflow measurements were collected on September 17, 2015 (fig. 5; table 1), at 12 locations along Enfield Creek to determine where surface water was potentially losing water to or gaining water from the aquifer. Measurements at every location indicated streamflow gains along Enfield Creek, except for the stretch between Enfield Creek below Tributary 3 near Bostwick Corners, New York (04233092), and Enfield Creek below Tributary 4 near Robert H. Treman State Park (04233097) where Enfield Creek recharges 0.33 cubic foot per second (ft^3/s) to the aquifer (fig. 5; table 1).

In March 2016, two of the eight drilled test wells (TM1075 and TM1077) were instrumented with water-temperature loggers at multiple depths to determine the timing of aquifer recharge and how groundwater temperature fluctuates in the unconsolidated aquifer at these locations. Well TM1075 is near the Village Department of Public Works garage in the southern part of the aquifer. Well TM1077 is about 1.5 miles north of well TM1075 and is near the middle, between the north and south ends, of the aquifer and is adjacent to Enfield Creek (fig. 8). Well TM1075 was equipped with seven temperature loggers at depths of 10, 20, 45, 65, 85, 100, and 134 ft. Well TM1077, which is shallower, was equipped with five temperature loggers at depths of 10, 25, 50, 75, and 90 ft. The temperature graphs are provided in appendix 3.

In comparing the two sets of temperature logs, it is interesting to note that in the middle part of the aquifer at well TM1077, groundwater temperatures fluctuated seasonally down to about 25 ft and did not change at greater depths; the shallower depths were more reactive to temperature change (app. 3) because of recharge. In well TM1075, the zone of more constant seasonal water temperature was encountered below 70 ft (app. 3). These temperature profiles, especially in well TM1075 in the southern part of the aquifer, seem to indicate an appreciable amount of groundwater recharge.

In viewing the topography of the two contributing areas to these wells (fig. 8), well TM1077 only receives water from the valley walls and from farther upvalley. Well TM1075 receives water from these same sources but also seems to be affected by a large tributary entering the Enfield Valley off the west valley wall near Harvey Hill Road and an even larger tributary (Enfield Creek Tributary at Bostwick Corners, N.Y.) that enters the valley from the southwest toward this well (fig. 3).

The orientation of these tributary streams mimics the structural framework of the underlying bedrock. The stream channels have either a northwest-southeast trend or a northeast-southwest trend, both of which are typical for central New York. These tributaries contribute surface-water recharge to the unconfined aquifer along their channels and could potentially provide recharge to the unconfined aquifer (Miller, 2015). The orientation of the tributary valleys is further enhanced by preferential glacial erosion and subsequent deposition of glacial sediments in these valleys and into the Enfield Creek Valley. The water quality in these tributaries has a direct bearing on the usefulness of the aquifer as a water resource.

A. **All quadrangles**

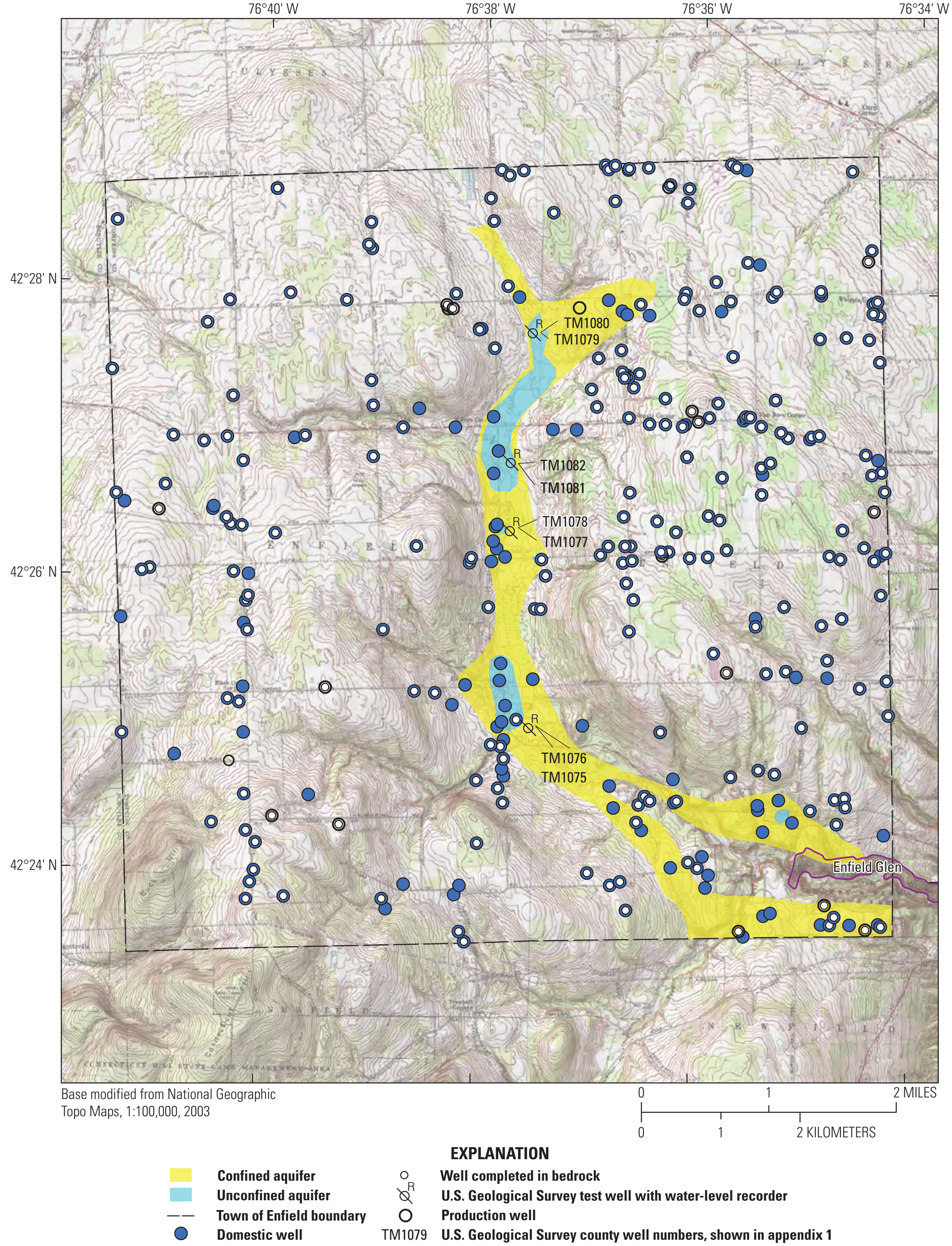
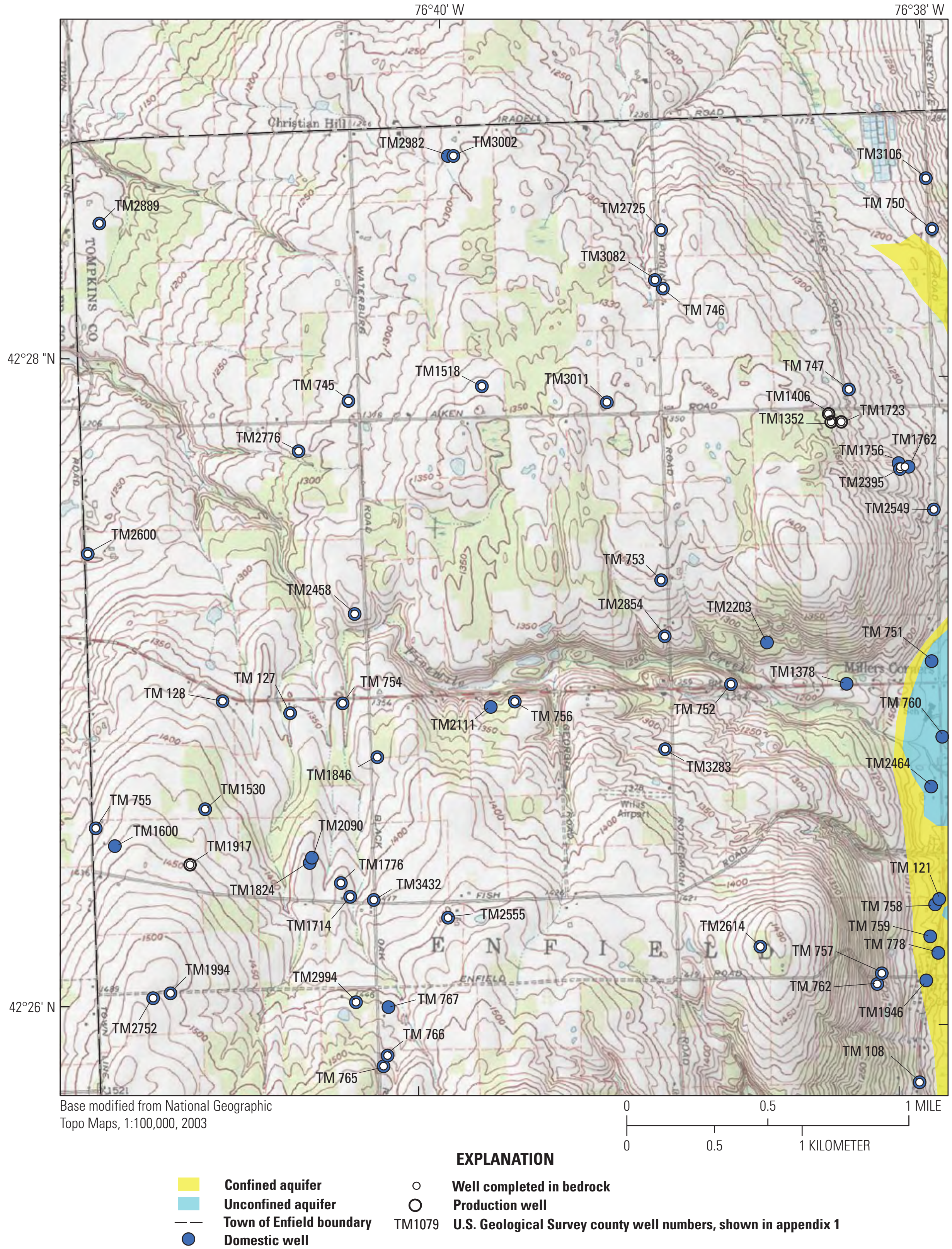


Figure 8. Locations of domestic, test, and production wells in the town of Enfield, Tompkins County, New York. *A*, All quadrangles; *B*, Northwest, *C*, Northeast, *D*, Southwest, and *E*, Southeast quadrangles. See also Fisher and others (2020).

B. **Northwest quadrangle**



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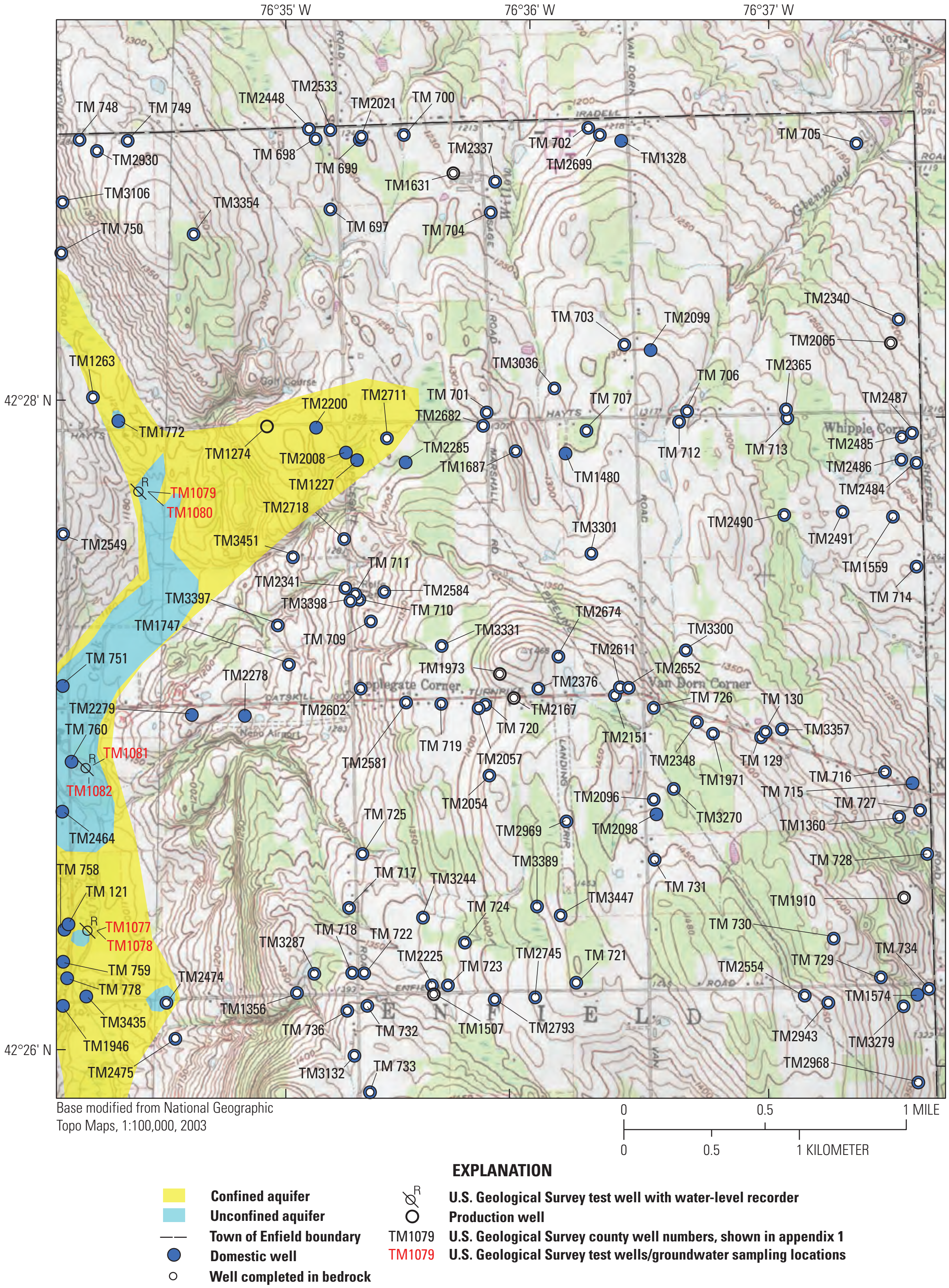
C. **Northeast quadrangle**



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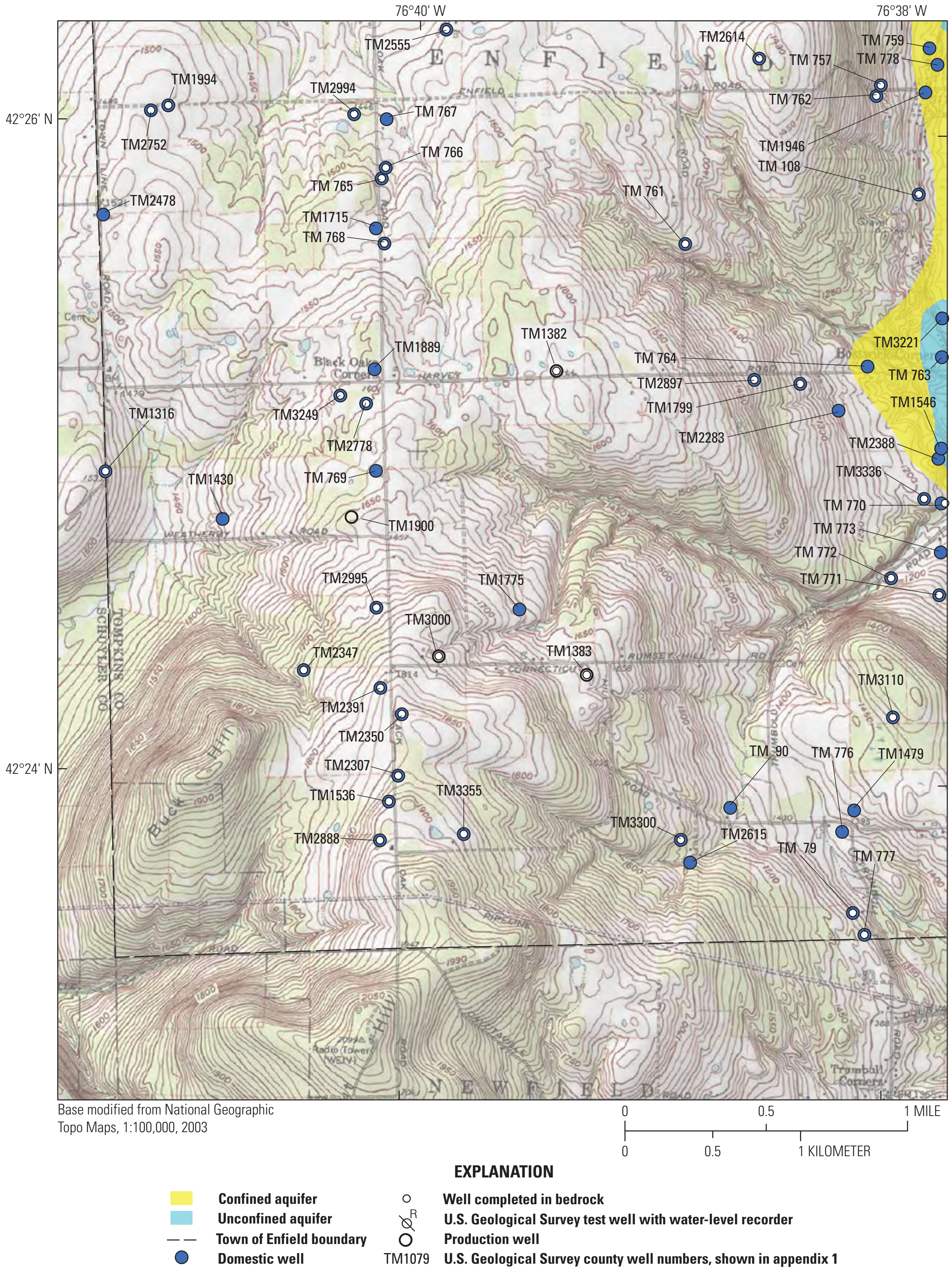
D. **Southwest quadrangle**



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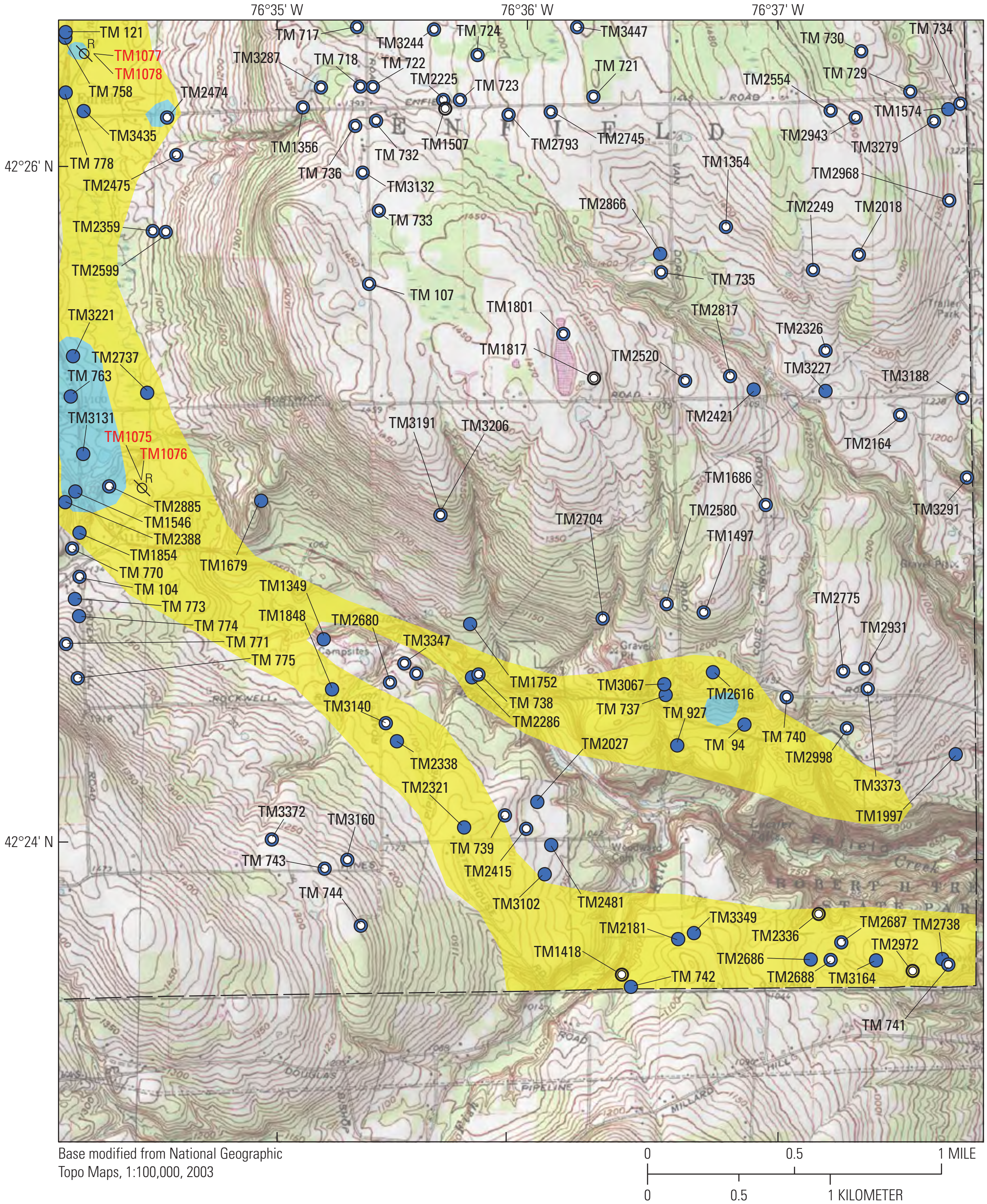
—Continued

E. **Southeast quadrangle**



Base modified from National Geographic
Topo Maps, 1:100,000, 2003

EXPLANATION

- **Confined aquifer**
- **Unconfined aquifer**
- **Town of Enfield boundary**
- **Domestic well**
- **Well completed in bedrock**
- **U.S. Geological Survey test well with water-level recorder**
- **Production well**
- TM1079 **U.S. Geological Survey county well numbers, shown in appendix 1**
- TM1079 **U.S. Geological Survey test wells/groundwater sampling locations**

Figure 8. Locations of domestic, test, and production wells in the town of Enfield, Tompkins County, New York. *A*, All quadrangles; *B*, Northwest, *C*, Northeast, *D*, Southwest, and *E*, Southeast quadrangles. See also Fisher and others (2020).—Continued

Groundwater Discharge

Groundwater discharges to Enfield Creek, its tributaries, and local wetlands; and groundwater discharge is removed by evapotranspiration from the water table or is withdrawn by domestic, commercial, and agricultural wells. During the nongrowing season from mid-October through April, the rate of recharge to the aquifer is greater than discharge, which is reflected by an increase in aquifer storage and groundwater levels. During the growing season from May through mid-October, the rate of discharge from the aquifer is greater than the rate of recharge, which is reflected by a decrease in aquifer storage and groundwater levels.

Groundwater Withdrawals

Groundwater withdrawals were estimated at locations where withdrawal data were not available or provided. The total estimated annual withdrawal from the aquifer was 28.3 million gallons (Mgal).

Domestic wells (n=218) that tap the unconsolidated aquifer by homes and farms overlying the aquifer boundaries were estimated using orthoimagery and tax parcels to do a visual count. Because the U.S. Census Bureau did not have a population count for the town of Enfield, the number of wells was multiplied by the average household size for the neighboring town of Newfield, which is 2.45 residents (U.S. Census Bureau, 2012a), to obtain the estimated number of people withdrawing water from the aquifer. In Enfield, that estimated number was 534 persons; this number was then multiplied by 75 gallons per day (gal/d), which is the average use per person (Dieter and others, 2018), to determine the estimated withdrawal (40,000 gal/d), The estimated withdrawal was then multiplied by 365 days to determine the estimated annual withdrawal of 14.6 Mgal from residences overlying the aquifer boundary. Water use for the only mobile home park overlying the aquifer was calculated similarly as above. About 70 households withdraw water from 1 well serving the mobile home community. The estimated daily and annual withdrawals from the mobile home park are 12,800 and 4,670,000 gallons (gal), respectively. This estimation (4,670,000 gal) plus the visual count estimation above (14,600,000 gal) equal an annual withdrawal of 19,300,000 gal from domestic wells (table 2).

Water use, in gallons per day, at a commercial store, a commercial business, and Enfield Elementary School were estimated using median water demand estimates for commercial establishments and schools (Horn and others, 2008). The daily withdrawals are 40, 132, and 234 gal/d, respectively, and annual withdrawals are 14,600, 48,200, and 85,400 gal, respectively. Water use for a golf course overlying the aquifer along the northeastern boundary was estimated in 2015 using data from Dieter and others (2018) based on other golf course data. The estimated daily use is 23,700 gal/d, and annual use is 8,650,000 gal, respectively. Water use from a well, which overlies the aquifer, at the Upper Park at Robert H. Treman State Park was provided by the park manager for 2016 (Robert H. Treman State Park park manager, oral commun., April 2018). The estimated annual withdrawal from that well for 2016 was 242,000 gal. The sum of withdrawals from production wells equals a total annual withdrawal of 9,040,000 gal (table 2).

Table 2. Estimated groundwater withdrawals by users that reside over the unconsolidated aquifer in the Enfield Creek Valley, town of Enfield, Tompkins County, New York.

[—, no data]

Users	Estimated number of wells that tap the unconsolidated aquifer[1]	Average household size[2]	Estimated number of people using water from unconsolidated aquifer	Average use per person, in gallons[3]	Estimated daily withdrawal, in gallons	Estimated annual withdrawal, in gallons
Domestic wells	288	2.45	706	75	52,900	19,300,000
Production wells[3–5]	—	—	—	—	—	9,040,000
Total	—	—	—	—	—	28,300,000

[1]The estimated number of wells that tap the unconsolidated aquifer were determined by a visual count of homes and farms overlying the aquifer area using orthoimagery and tax parcels.

[2]Data from U.S. Census Bureau (2012b).

[3]Data from Dieter and others (2018).

[4]Data from Horn and others (2008).

[5]Estimate provided by Robert H. Treman State Park park manager (oral commun., April 2018).

Water Quality of the Unconsolidated Aquifers in the Enfield Creek Valley

Surface-water quality samples were collected on September 17, 2015, during base-flow conditions at five locations along Enfield Creek. Base-flow conditions occur when flow in a stream is sustained by groundwater discharge and no direct runoff. The surface-water quality samples were analyzed for physical properties, common inorganic ions, nutrients, and trace elements at the USGS NWQL in Denver, Colo. Results for chemical analyses of surface-water samples are presented in this section.

Comparisons of results are often made to State and Federal contaminant levels and goals. U.S. Environmental Protection Agency (EPA) maximum contaminant levels and secondary maximum contaminant levels (MCLs and SMCLs, respectively) are enforceable standards and represent the highest level of a contaminant allowed in drinking water. Maximum contaminant level goals (MCLGs) are nonenforceable public health goals for drinking-water quality. Treatment techniques are primary drinking-water regulations created in lieu of an MCL and used instead of an MCL if an MCL would be too difficult or too costly to comply with (U.S. Environmental Protection Agency, 2012). The New York State Department of Health (NYSDOH) MCLs similarly set state regulation on levels of contaminants in drinking water (New York State Department of Health, 2019).

Surface Water

Surface-water quality samples were collected from Enfield Creek and select tributaries in the town of Enfield during base-flow conditions to obtain a general baseline of the water quality overlying the aquifer (fig. 5). The results of the chemical analyses are presented in table 3.

Physical Properties

Temperature values ranged from 11.8 to 19.5 °C. pH values ranged from 7.35 to 8.45 standard units. Specific conductance values ranged from 459 to 472 µS/cm at 25 °C. Dissolved-oxygen concentrations ranged from 7.60 to 10.3 mg/L. Temperature, pH, and dissolved oxygen trend upward in values moving downstream. This trend may be attributed to a change in groundwater chemistry from the addition of water from other tributaries downstream. Additionally, air temperature over the course of sampling changed by 20 °C and may also provide some context to the increasing physical properties (National Oceanic and Atmospheric Administration, 2019).

Common Inorganic Ions

Common inorganic ion constituent results were relatively similar at each site along Enfield Creek. In general, alkalinity, calcium, chloride, hardness, silica, sodium, and dissolved solids all slightly trended downward in concentration as the sampling moved downstream. A similar downward trending pattern can also be seen for specific conductance. Conversely, fluoride, magnesium, potassium, and sulfate trended slightly upward in concentration as sampling moved downstream. As mentioned above, these trends may also be attributed to the effect of groundwater contribution higher up in the basin. Concentrations of all common inorganic ion constituents were below State and Federal drinking-water standards.

Nutrients

Most results for nutrient concentrations either were below the detection limit or had low concentrations that did not show any trend. Nitrate plus nitrite, however, did show a clear trend of high to low concentrations moving downstream in the system, which may be attributed to the presence of agriculture closer to the upstream parts of Enfield Creek. Another possible source of high nitrate concentration upstream could be related to septic systems because there are a greater number of houses closer to Enfield Creek in the upstream part (fig. 5) of the study area. All constituent concentrations were below drinking-water standards (table 3).

Trace Elements

Overall, trace-element concentrations were low; several constituents (beryllium, cadmium, silver, and zinc) were below the detection limit at all stream locations. All constituent concentrations were below drinking-water standards (table 3).

Table 3. Physical properties and concentrations of inorganic major ions, nutrients, and trace elements in surface-water samples from Enfield Creek, town of Enfield, Tompkins County, New York.

[Values in **bold** indicate maximum values where three or more different values are present; values in *italics* indicate minimum value where three or more different values are present. p code, U.S. Geological Survey National Water Information System parameter code; ft^3/s, cubic foot per second; mg/L, milligram per liter; µS/cm, microsiemens per centimeter; °C, degree Celsius; FNU, formazin nephelometric unit; $CaCO_3$, calcium carbonate; N, nitrogen; <, less than; P, phosphorus; µg/L, microgram per liter]

Constituent	P code	Unit of measurement	Station name (and identification number; fig. 5)						Drinking-water standard
			Enfield Creek above Fivemile Creek at Millers Corners, New York (04233051)	Enfield Creek at Enfield Center Road 3 at Enfield, New York (04233060)	Enfield Creek above State Route 327 at Bostwick Corners, New York (04233080)	Enfield Creek at Hines Road near Bostwick Corners, New York (04233085)	Enfield Creek below tributary 4 near Robert H. Treman State Park, New York (04233097)	Enfield Creek below tributary 4 near Robert H. Treman State Park, New York (04233097; replicate sample)	
Physical properties									
Discharge[a]	00061	ft^3/s	*0.031*	0.648	1.23	1.30	**1.42**	**1.42**	—
Dissolved oxygen (field)	00300	mg/L	*7.60*	9.59	8.72	**10.3**	9.56	9.56	—
pH (field)	00400	standard units	*7.35*	7.93	7.93	8.39	**8.45**	**8.45**	6.5–8.5[a,b]
Specific conductance (lab)	90095	µS/cm at 25 °C	**573**	471	472	479	*459*	*459*	—
Temperature (field)	00010	°C	*11.8*	14.8	17.9	18.3	**19.5**	**19.5**	—
Turbidity (field)	63680	FNU	0.0	0.0	0.0	0.0	0.0	0.0	—
Common inorganic ions									
Alkalinity, filtered, as $CaCO_3$	29801	mg/L	**185**	*156*	175	178	166	165	—
Bromide, filtered	71870	mg/L	0.043	*0.032*	0.04	**0.053**	0.049	0.045	—
Calcium, filtered	00915	mg/L	**61.0**	*51.2*	56.1	55.0	51.5	52.3	—
Chloride, filtered	00940	mg/L	**61.2**	44.8	*37.4*	38.9	38.7	38.4	250[a]
Dissolved solids, dried at 180 °C	70300	mg/L	**322**	266	264	272	*258*	264	500[a,b]
Fluoride, filtered	00950	mg/L	*0.05*	*0.05*	0.06	**0.07**	**0.07**	**0.07**	2.2[a]–4[c,d]
Hardness, filtered, as $CaCO_3$	00900	mg/L	**192**	*164*	182	179	172	174	—
Magnesium, filtered	00925	mg/L	9.5	*8.76*	10.2	10.2	**10.6**	**10.6**	—
Potassium, filtered	00935	mg/L	*1.45*	1.59	1.65	1.63	1.71	**1.72**	—
Silica, filtered	00955	mg/L	6.5	6.67	**6.79**	6.09	5.83	*5.81*	—
Sodium, filtered	00930	mg/L	**36.9**	25.7	*21.4*	22.1	22.4	22.6	60[e]
Sulfate, filtered	00945	mg/L	*9.45*	11.5	12.3	14.5	**15.7**	15.5	250[a,b]

Table 3. Physical properties and concentrations of inorganic major ions, nutrients, and trace elements in surface-water samples from Enfield Creek, town of Enfield, Tompkins County, New York.—Continued

[Values in **bold** indicate maximum values where three or more different values are present; values in *italics* indicate minimum value where three or more different values are present. p code, U.S. Geological Survey National Water Information System parameter code; ft^3/s, cubic foot per second; mg/L, milligram per liter; µS/cm, microsiemens per centimeter; °C, degree Celsius; FNU, formazin nephelometric unit; $CaCO_3$, calcium carbonate; N, nitrogen; <, less than; P, phosphorus; µg/L, microgram per liter]

Constituent	P code	Unit of measurement	Station name (and identification number; fig. 5)						Drinking-water standard
			Enfield Creek above Fivemile Creek at Millers Corners, New York (04233051)	Enfield Creek at Enfield Center Road 3 at Enfield, New York (04233060)	Enfield Creek above State Route 327 at Bostwick Corners, New York (04233080)	Enfield Creek at Hines Road near Bostwick Corners, New York (04233085)	Enfield Creek below tributary 4 near Robert H. Treman State Park, New York (04233097)	Enfield Creek below tributary 4 near Robert H. Treman State Park, New York (04233097; replicate sample)	
Nutrients									
Ammonia (NH_3+NH_4^+), as N, filtered	00608	mg/L	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	2.0[a]
Ammonia plus organic nitrogen, as N, filtered	00623	mg/L	0.12	*0.11*	0.12	**0.14**	0.12	0.12	—
Nitrite, as N, filtered	00613	mg/L	*0.002*	**0.004**	0.003	*0.002*	*0.002*	*0.002*	1[a,c,d]
Nitrate plus nitrite, as N, filtered	00631	mg/L	**1.96**	1.26	0.384	0.194	0.105	*0.1*	10[a,c,d]
Orthophosphate, as P, filtered	00671	mg/L	*<0.004*	**0.005**	0.004	0.004	*<0.004*	*<0.004*	—
Trace elements									
Aluminum, filtered	01106	µg/L	8.5	*<3.0*	3.5	3.1	*<3.0*	**12.3**	50–200[b]
Antimony, filtered	01095	µg/L	*0.036*	0.058	**0.096**	0.065	0.068	0.087	6[a,c,d]
Arsenic, filtered	01000	µg/L	*0.14*	0.21	0.41	0.4	**0.45**	**0.45**	0[e]–10[a,c,f]
Barium, filtered	01005	µg/L	*29.1*	30.3	42.0	**43.4**	40.4	40.4	2,000[a,c,d]
Beryllium, filtered	01010	µg/L	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	4[a,c,d]
Boron, filtered	01020	µg/L	**26.0**	20.0	*17.0*	*17.0*	*17.0*	*17.0*	—
Cadmium, filtered	01025	µg/L	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	5[a,c,d]
Chromium, filtered	01030	µg/L	<0.3	0.83	<0.3	<0.3	<0.3	<0.3	100[a,c,d]
Cobalt, filtered	01035	µg/L	0.101	0.073	0.12	*0.058*	*0.058*	**0.133**	—
Copper, filtered	01040	µg/L	**1.4**	*0.8*	0.97	1.1	0.91	1.3	1,000[b]–1,300[d,f]
Iron, filtered	01046	µg/L	*<4.0*	**9.9**	7.2	*<4.0*	*<4.0*	*<4.0*	300[a,b]
Lead, filtered	01049	µg/L	**0.63**	0.109	0.116	0.463	*0.084*	0.105	0[d]–15[f]
Lithium, filtered	01130	µg/L	0.72	*0.67*	1.59	1.02	**1.65**	1.26	—
Manganese, filtered	01056	µg/L	*0.51*	**10.4**	6.78	5.07	1.03	1.26	50[b]–300[a]
Molybdenum, filtered	01060	µg/L	*0.099*	0.232	0.266	0.393	0.466	**0.469**	—

Table 3. Physical properties and concentrations of inorganic major ions, nutrients, and trace elements in surface-water samples from Enfield Creek, town of Enfield, Tompkins County, New York.—Continued

[Values in **bold** indicate maximum values where three or more different values are present; values in *italics* indicate minimum value where three or more different values are present. p code, U.S. Geological Survey National Water Information System parameter code; ft^3/s, cubic foot per second; mg/L, milligram per liter; µS/cm, microsiemens per centimeter; °C, degree Celsius; FNU, formazin nephelometric unit; $CaCO_3$, calcium carbonate; N, nitrogen; <, less than; P, phosphorus; µg/L, microgram per liter]

Constituent	P code	Unit of measurement	Station name (and identification number; fig. 5)						Drinking-water standard
			Enfield Creek above Fivemile Creek at Millers Corners, New York (04233051)	Enfield Creek at Enfield Center Road 3 at Enfield, New York (04233060)	Enfield Creek above State Route 327 at Bostwick Corners, New York (04233080)	Enfield Creek at Hines Road near Bostwick Corners, New York (04233085)	Enfield Creek below tributary 4 near Robert H. Treman State Park, New York (04233097)	Enfield Creek below tributary 4 near Robert H. Treman State Park, New York (04233097; replicate sample)	
Trace elements—Continued									
Nickel, filtered	01065	µg/L	**0.4**	0.37	0.39	0.4	*0.36*	0.39	—
Selenium, filtered	01145	µg/L	<0.05	<0.05	0.05	<0.05	<0.05	<0.05	50[a,c,e]
Silver, filtered	01075	µg/L	*<0.02*	<0.03	<0.04	<0.05	<0.06	**<0.07**	100[a,b]
Strontium, filtered	01080	µg/L	114	*101*	104	**127**	123	124	—
Uranium, natural, filtered	22703	µg/L	0.225	*0.207*	0.31	0.362	**0.39**	0.389	0[e]–30[a,c,f]
Zinc, filtered	01090	µg/L	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	5,000[a,b]

[a]New York State Department of Health maximum contaminant level.

[b]U.S. Environmental Protection Agency secondary maximum contaminant level.

[c]U.S. Environmental Protection Agency maximum contaminant level.

[d]U.S. Environmental Protection Agency maximum contaminant level goal.

[e]U.S. Environmental Protection Agency drinking-water advisory taste threshold.

[f]U.S. Environmental Protection Agency treatment technique.

Groundwater

Groundwater-quality samples were collected to better understand the water quality of the confined and unconfined parts of the Enfield Creek Valley unconsolidated aquifer. Results from the sampling are tabulated in table 4.

Physical Properties

Temperature ranged from 7.2 to 10.9 °C. pH values ranged from 7.7 to 8.4 standard units. Specific conductance values ranged from 369 to 3,100 µS/cm at 25 °C. Dissolved-oxygen concentrations ranged from of 0.1 to 3.8 mg/L.

Common Inorganic Ions

Most common inorganic ion concentrations were relatively similar at each well except for two wells: TM1075 and TM1077 (fig. 8*E*). TM1075 is on the town highway department grounds, and TM1077 is within the village. These wells were finished near bedrock and although they are likely pulling water mostly from the overlying sand and gravel, they are confined and there may be more inorganic constituents resulting from the underlying bedrock because they have had time to accumulate in the slower moving groundwater.

Wells TM1075 and TM1077 exceeded the NYSDOH MCL for chloride (250 mg/L) with values of 830 and 789, respectively. Concentrations of chloride above 250 mg/L have aesthetic effects on the water quality such as odor and taste, giving the water a salty taste (U.S. Environmental Protection Agency, 2012). The NYSDOH MCL and EPA SMCL for dissolved solids (500 mg/L) was exceeded at these wells with values of 1,880 and 1,970 mg/L, respectively. The EPA drinking-water advisory taste threshold for sodium (60 mg/L) was exceeded at these wells with values of 384 and 429 mg/L, respectively. High concentrations of total dissolved solids can cause hardness, deposits, colored water, staining, and a salty taste. Oral doses of sodium above 60 mg/L may cause nausea, vomiting, inflammation of the gastrointestinal tract, thirst, muscular twitching, convulsions, and possibly death (U.S. Environmental Protection Agency, 2003). The source of high chloride and sodium (which contributed to high specific conductance values) can be inferred by looking at the chloride-bromide (Cl^-/Br^-) ratios (Williams and Kappel, 2015). Road salt sources of chloride generally have high chloride-bromide ratios, when chloride is elevated but bromide is not, whereas chloride-bromide ratios of around 100 indicate a mixture of saline formation waters with shallow dilute groundwater (Williams and Kappel, 2015). The chloride-bromide ratios for wells TM1075 and TM1077 are 90 and 94, respectively, which indicates that these high chloride and sodium values represent a mixture of saline formation waters with shallow dilute groundwater.

Nutrients

Many of the results for nutrient concentrations were at or near the method reporting limit for each constituent (table 4). Although each constituent was detected at several wells, no constituents came close to or exceeded any drinking-water standard.

Groundwater Age and Gasses

Dissolved gases were only collected at wells drilled to bedrock: TM1075, TM1077, TM1079, and TM1081. Each well was analyzed for methane, dissolved nitrogen gas, argon, carbon dioxide, and dissolved-oxygen gas (table 4). All four samples had elevated concentrations of methane that decreased from south to north. Wells TM1075, TM1077, TM1079, and TM1081 had methane concentrations of 52.2, 29.4, 16.7, and 7.79 mg/L, respectively. As groundwater enters a well at atmospheric pressure, methane can be released from the water, which can cause a column of gas to form above the water surface in the well or be released within a pressure tank, at faucets inside a home, or in structures enclosing the well, where it can become flammable or explosive as a result (Eltschlager and others, 2001). Methane reaches saturation in water at 28 mg/L at 1 atmosphere of pressure and temperature of 15 °C and becomes flammable in air at about 5 percent by volume (Eltschlager and others, 2001). The Office of Surface Mining Reclamation and Enforcement recommends that methane concentrations greater than 28 mg/L in well water should be addressed immediately by removing any potential ignition source and venting the gas away from confined spaces (Eltschlager and others, 2001). The Office of Surface Mining Reclamation and Enforcement also recommends that methane concentrations ranging from 10 to 28 mg/L in water (or 3 to 5 percent by volume in air) signify an action level where the situation should be closely monitored, and if the concentration increases, the area should be vented to prevent methane gas buildup. Concentrations of methane less than 10 mg/L in water (or 1 to 3 percent by volume in air) are not as great a concern, but the gas should be monitored to observe if the concentrations increase over time (Kappel and Nystrom, 2012).

CFCs were analyzed in water collected from wells TM1075, TM1077, TM1079, and TM1081. All four wells were drilled to bedrock but finished in a confined sand-and-gravel aquifer. CFC concentrations in the sample from well TM1075 indicated that the recharge age of the water (time that groundwater was isolated from the atmosphere) was from the early 1960s or younger. More information on the methods used to determine groundwater age can be found in Busenberg and Plummer (2008). The sample from TM1077 showed a range in age from the mid- to late 1960s or younger. The sample from TM1079 ranged in age from early 1950 or younger. The sample from TM1081 ranged in age from the mid-1950s or younger (table 4).

Table 4. Physical properties and concentrations of inorganic major ions, nutrients, trace elements, dissolved gasses, and chlorofluorocarbons in groundwater samples from stratified-drift aquifers in the town of Enfield, Tompkins County, New York.

[Values that are underlined indicate drinking water standard exceedance (footnote "b," maximum contaminant level goal excluded); values in **bold** indicate maximum value where three or more values are present; values in *italics* indicate minimum value where three or more values are present. p code, U.S. Geological Survey National Water Information System parameter code; S&G, sand and gravel; conf, confined aquifer; unconf, unconfined aquifer; mg/L, milligram per liter; —, no data or not available; µS/cm, microsiemens per centimeter; °C, degree Celsius; ft, foot; $CaCO_3$, calcium carbonate; <, less than; e, estimated; N, nitrogen; P, phosphorus; µg/L, microgram per liter; pg/kg, picogram per kilogram; CFC, chlorofluorocarbon; EPA, U.S. Environmental Protection Agency; USGS, U.S. Geological Survey]

Constituent	P code	Unit of measurement	Site name (fig. 8), station identification number, and aquifer type								Drinking-water standard
			TM1075 422504076373001 S&G, conf	TM1076 422504076373002 S&G, unconf	TM1077 422623076374501 S&G, conf	TM1078 422623076374502 S&G, conf	TM1079 422744076373401 S&G, conf	TM1080 422744076373402 S&G, unconf	TM1081 422653076374601 S&G, conf	TM1082 422653076374602 S&G, conf	
Physical properties											
Dissolved oxygen (field)	00300	mg/L	*0.1*	**3.8**	*0.1*	0.2	*0.1*	0.7	*0.1*	0.2	—
pH (field)	00400	units	8.1	7.7	8.1	8.2	8.1	*7.4*	**8.4**	8.3	6.5–8.5[a,b]
Specific conductance (field)	00095	µS/cm at 25 °C	**3,100**	*369*	3,000	570	471	584	573	556	—
Water temperature (field)	00010	°C	7.5	*7.2*	10.5	9.7	9.3	**10.9**	9.9	9.2	—
Well depth of open-ended casing	—	ft	136	53	93	56	48	9	77-79[c]	42	—
Common inorganic ions											
Alkalinity, filtered, as $CaCO_3$	29801	mg/L	*129*	137	*129*	145	226	**241**	162	181	—
Bromide, filtered	71870	mg/L	**9.12**	*<0.01*	8.44	0.893	0.051	0.035	0.845	0.681	—
Calcium, filtered	00915	mg/L	**152**	49.7	116	46.6	51.8	83.4	*42.1*	42.2	—
Chloride, filtered	00940	mg/L	**830**	23.8	789	89.1	*17.1*	40.7	81.3	66.0	250[a]
Dissolved solids, dried at 180 °C	70300	mg/L	1,880	*214*	**1,970**	331	292	338	317	313	500[a,b]
Fluoride, filtered	00950	mg/L	[e]0.06	0.05	**0.42**	0.24	0.23	*0.03*	0.30	0.33	2.2[a]–4[d,e]
Hardness, filtered, as $CaCO_3$	00900	mg/L	**538**	160	413	179	183	273	*157*	170	—
Magnesium, filtered	00925	mg/L	**36.8**	*8.75*	28.0	14.9	12.8	15.5	12.4	15.6	—
Potassium, filtered	00935	mg/L	2.48	*0.97*	**2.85**	1.40	1.44	1.47	1.65	1.77	—
Silica, filtered	00955	mg/L	8.13	*5.42*	7.30	**12.1**	8.11	8.26	8.50	10.4	—
Sodium, filtered	00930	mg/L	384	*14.4*	**429**	43.3	35.0	18.1	57.5	48.6	60[f]
Sulfate, filtered	00945	mg/L	*0.1*	**15.1**	<0.24	0.61	5.37	14.4	0.67	2.22	250[a,b]

Table 4. Physical properties and concentrations of inorganic major ions, nutrients, trace elements, dissolved gasses, and chlorofluorocarbons in groundwater samples from stratified-drift aquifers in the town of Enfield, Tompkins County, New York.—Continued

[Values that are underlined indicate drinking water standard exceedance (footnote "b," maximum contaminant level goal excluded); values in **bold** indicate maximum value where three or more values are present; values in *italics* indicate minimum value where three or more values are present. p code, U.S. Geological Survey National Water Information System parameter code; S&G, sand and gravel; conf, confined aquifer; unconf, unconfined aquifer; mg/L, milligram per liter; —, no data or not available; µS/cm, microsiemens per centimeter; °C, degree Celsius; ft, foot; $CaCO_3$, calcium carbonate; <, less than; e, estimated; N, nitrogen; P, phosphorus; µg/L, microgram per liter; pg/kg, picogram per kilogram; CFC, chlorofluorocarbon; EPA, U.S. Environmental Protection Agency; USGS, U.S. Geological Survey]

Constituent	P code	Unit of measurement	Site name (fig. 8), station identification number, and aquifer type								Drinking-water standard
			TM1075	TM1076	TM1077	TM1078	TM1079	TM1080	TM1081	TM1082	
			422504076373001	422504076373002	422623076374501	422623076374502	422744076373401	422744076373402	422653076374601	422653076374602	
			S&G, conf	S&G, unconf	S&G, conf	S&G, conf	S&G, conf	S&G, unconf	S&G, conf	S&G, conf	
Nutrients											
Ammonia (NH_3+NH_4^+), as N, filtered	00608	mg/L	0.16	*0.01*	**0.43**	0.09	0.11	*0.01*	0.12	0.11	2.0[a]
Ammonia plus organic nitrogen, as N, filtered	00623	mg/L	0.21	*<0.07*	0.47	0.09	0.18	*<0.07*	**0.53**	0.18	—
Nitrite, as N, filtered	00613	mg/L	0.002	**0.010**	0.001	*<0.001*	0.003	*<0.001*	0.001	0.001	1[a,d,e]
Nitrate plus nitrite, as N, filtered	00631	mg/L	<0.040	0.75	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	10[a,d,e]
Orthophosphate, as P, filtered	00671	mg/L	<0.004	<0.004	<0.004	0.015	<0.004	<0.004	<0.004	<0.004	—
Trace elements											
Aluminum, filtered	01106	µg/L	<6	10.6	<6	3.1	*<3*	**18.1**	*<3*	*<3*	50–200[b]
Antimony, filtered	01095	µg/L	0.078	0.038	0.067	*<0.027*	0.373	0.218	0.698	**1.1**	6[a,d,e]
Arsenic, filtered	01000	µg/L	0.2	*<0.1*	**5.2**	0.47	0.29	1.2	0.54	1.8	0[e]–10[a,d,g]
Barium, filtered	01005	µg/L	3,470	*25.9*	**3,930**	729	248	103	126	245	2,000[a,d,e]
Beryllium, filtered	01010	µg/L	<0.04	<0.02	<0.04	<0.02	<0.02	<0.02	<0.02	<0.02	4[a,d,e]
Boron, filtered	01020	µg/L	31	*9*	**187**	53	131	18	96	112	—
Cadmium, filtered	01025	µg/L	<0.06	<0.03	<0.06	<0.03	<0.03	<0.03	<0.03	<0.03	5[a,d,e]
Chromium, filtered	01030	µg/L	<0.6	<0.3	<0.6	<0.3	<0.3	<0.3	<0.3	<0.3	100[a,d,e]
Cobalt, filtered	01035	µg/L	0.356	*0.125*	0.185	<0.05	0.153	**0.7**	0.203	0.526	—
Copper, filtered	01040	µg/L	<1.6	<0.8	<1.6	<0.8	<0.8	<0.8	<0.8	<0.8	1,000[b]–1,300[e,g]
Iron, filtered	01046	µg/L	5,210	396	3,030	1,210	**5,960**	*180*	2,720	3,070	300[a,b]

Table 4. Physical properties and concentrations of inorganic major ions, nutrients, trace elements, dissolved gasses, and chlorofluorocarbons in groundwater samples from stratified-drift aquifers in the town of Enfield, Tompkins County, New York.—Continued

[Values that are underlined indicate drinking water standard exceedance (footnote "b," maximum contaminant level goal excluded); values in **bold** indicate maximum value where three or more values are present; values in *italics* indicate minimum value where three or more values are present. p code, U.S. Geological Survey National Water Information System parameter code; S&G, sand and gravel; conf, confined aquifer; unconf, unconfined aquifer; mg/L, milligram per liter; —, no data or not available; µS/cm, microsiemens per centimeter; °C, degree Celsius; ft, foot; $CaCO_3$, calcium carbonate; <, less than; e, estimated; N, nitrogen; P, phosphorus; µg/L, microgram per liter; pg/kg, picogram per kilogram; CFC, chlorofluorocarbon; EPA, U.S. Environmental Protection Agency; USGS, U.S. Geological Survey]

Constituent	P code	Unit of measurement	Site name (fig. 8), station identification number, and aquifer type								Drinking-water standard
			TM1075	TM1076	TM1077	TM1078	TM1079	TM1080	TM1081	TM1082	
			422504076373001	422504076373002	422623076374501	422623076374502	422744076373401	422744076373402	422653076374601	422653076374602	
			S&G, conf	S&G, unconf	S&G, conf	S&G, conf	S&G, conf	S&G, unconf	S&G, conf	S&G, conf	
Trace elements											
Lead, filtered	01049	µg/L	<0.08	*<0.04*	<0.08	*<0.04*	*<0.04*	**0.04**	*<0.04*	*<0.04*	0[e]–15[g]
Lithium, filtered	01130	µg/L	271	*1.37*	**277**	20.0	27.6	5.35	20.4	20.6	—
Manganese, filtered	01056	µg/L	150	*32.6*	110	42.2	176	122	**224**	101	50[b]–300[a]
Molybdenum, filtered	01060	µg/L	2.93	*0.192*	**10.90**	2.28	3.54	0.599	6.45	6.96	—
Nickel, filtered	01065	µg/L	1.0	0.45	0.5	*<0.2*	0.58	0.49	1.8	**6.0**	—
Selenium, filtered	01145	µg/L	**0.28**	*<0.05*	0.26	0.07	*<0.05*	*<0.05*	0.05	*<0.05*	50[a,d,e]
Silver, filtered	01075	µg/L	<0.04	<0.02	<0.04	<0.02	<0.02	<0.02	<0.02	<0.02	100[a,b]
Strontium, filtered	01080	µg/L	5,070	*75.5*	**5,320**	676	436	160	593	590	—
Uranium, natural, filtered	22703	µg/L	<0.028	0.126	0.031	*<0.014*	0.049	**0.497**	0.156	*<0.014*	0[e]–30[a,d,g]
Zinc, filtered	01090	µg/L	<4.0	*<2.0*	<4.0	*<2.0*	<3.0	<4.0	<5.0	**<6.0**	5,000[a,b]
Dissolved gases and chlorofluorocarbons											
Argon, unfiltered	82043	mg/L	*0.498*	—	0.557	—	0.774	—	**0.829**	—	—
Carbon dioxide, unfiltered	00405	mg/L	**3.27**	—	*0.396*	—	2.78	—	1.37	—	—
Dissolved nitrogen gas, unfiltered	00597	mg/L	*13.3*	—	13.8	—	22.9	—	**25.7**	—	—
Dissolved oxygen gas, unfiltered	62971	mg/L	0.463	—	**0.480**	—	0.378	—	*0.347*	—	—
Methane, unfiltered	85574	mg/L	**52.2**	—	29.4	—	16.7	—	*7.79*	—	10–28[h]

Table 4. Physical properties and concentrations of inorganic major ions, nutrients, trace elements, dissolved gasses, and chlorofluorocarbons in groundwater samples from stratified-drift aquifers in the town of Enfield, Tompkins County, New York.—Continued

[Values that are underlined indicate drinking water standard exceedance (footnote "b," maximum contaminant level goal excluded); values in **bold** indicate maximum value where three or more values are present; values in *italics* indicate minimum value where three or more values are present. p code, U.S. Geological Survey National Water Information System parameter code; S&G, sand and gravel; conf, confined aquifer; unconf, unconfined aquifer; mg/L, milligram per liter; —, no data or not available; µS/cm, microsiemens per centimeter; °C, degree Celsius; ft, foot; $CaCO_3$, calcium carbonate; <, less than; e, estimated; N, nitrogen; P, phosphorus; µg/L, microgram per liter; pg/kg, picogram per kilogram; CFC, chlorofluorocarbon; EPA, U.S. Environmental Protection Agency; USGS, U.S. Geological Survey]

Constituent	P code	Unit of measurement	Site name (fig. 8), station identification number, and aquifer type								Drinking-water standard
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			S&G, conf	S&G, unconf	S&G, conf	S&G, conf	S&G, conf	S&G, unconf	S&G, conf	S&G, conf	
Dissolved gases and chlorofluorocarbons—Continued											
CFC–11[i]	50281	pg/kg	15.97	—	**79.21**	—	10.22	—	*9.73*	—	—
CFC–12[i]	50282	pg/kg	14.64	—	**45.26**	—	*6.10*	—	16.87	—	—
CFC–113[i]	50283	pg/kg	3.93	—	**10.80**	—	*2.56*	—	5.17	—	—
CFCs[i]	50281 50282 50283	years	Early 1960s or younger	—	Mid- to late 1960s or younger	—	Early 1950 or younger	—	Mid 1950s or younger	—	—

[a]New York State Department of Health maximum contaminant level.

[b]U.S. Environmental Protection Agency secondary maximum contaminant level.

[c]Water enters at perforations in the casing at a depth of 77 to 79 feet.

[d]U.S. Environmental Protection Agency maximum contaminant level.

[e]U.S. Environmental Protection Agency maximum contaminant level goal.

[f]U.S. Environmental Protection Agency drinking-water advisory taste threshold.

[g]U.S. Environmental Protection Agency treatment technique.

[h]Action level recommended by the Office of Surface Mining Reclamation and Enforcement.

[i]CFCs are used to estimate groundwater age; concentration values represent the median derived from three values reported by U.S. Geological Survey Groundwater Dating Laboratory.

Trace Elements

Concentrations of arsenic, lead, and (or) uranium in all wells were above the EPA MCLG, which all have a contaminant level goal of 0 microgram per liter (µg/L). Arsenic, lead, and uranium were below the NYSDOH MCL, EPA treatment technique, and EPA MCL of 10, 15, and 30 µg/L, respectively. No groundwater samples exceeded the EPA MCL or NYSDOH MCL for arsenic. One sample at well TM1077 had an arsenic level 5 to 10 times higher than the other values (table 4).

Two samples exceeded the EPA and the NYSDOH MCL for barium (2,000 µg/L) at wells TM1075 and TM1077 with values of 3,470 and 3,930 µg/L, respectively. The potential health effect from long-term exposure above the MCL for barium is an increase in blood pressure (U.S. Environmental Protection Agency, 2012).

Concentrations of iron in all but one well (TM1080) exceeded the NYSDOH MCL and the EPA SMCL threshold of 300 µg/L. High values of iron above the SMCL have noticeable effects in the water such as a rusty color, sediment, metallic taste and reddish or orange staining (U.S. Environmental Protection Agency, 2012).

Six of the wells sampled (TM1075, TM1077, TM1079, TM1080, TM1081, and TM1082) had values of manganese above the EPA SMCL threshold of 50 µg/L with values of 150, 110, 176, 122, 224, and 101 µg/L, respectively. No samples exceeded the NYSDOH MCL of 300 µg/L. High values of manganese above the SMCL have noticeable effects in the water such as a black to brown color, black staining, and a bitter metallic taste (U.S. Environmental Protection Agency, 2012).

Comparison of Groundwater and Surface-Water Chemistry

Waters sampled in this study can be categorized as surface water, unconfined aquifer groundwater, or confined aquifer groundwater (fig. 9). The overall trend is an increase in major ion and trace-metal concentrations with depth and a shift from oxic to reducing environments with depth. The chloride-bromide ratios indicate surface-water and unconfined groundwater chloride concentrations are associated with halite sources, such as road-salt leachate and water-softener discharges, whereas confined aquifer groundwater chloride, major ion, and trace-element chemistry is mostly derived from mixing of freshwater with small amounts of saline formation waters.

Surface and unconfined groundwater samples have similar concentrations of major ions and trace elements but differ in reduction-oxidation (redox)-sensitive species (fig. 9). Surface-water samples are well oxygenated (high dissolved oxygen), with more nitrate and less iron and manganese (filtered) than either unconfined or confined groundwaters.

Unconfined groundwater samples are less oxygenated than surface-water samples because of reducing conditions in the soil and aquifer resulting from a combination of land-use practices (for example, septic influences) and natural conditions (such as microbial activity; fig. 9). Dissolved oxygen and nitrate concentrations are lower, and iron and manganese (filtered) concentrations are higher than in surface-water samples. Sulfate concentrations are about the same.

Confined aquifers can be characterized based on potability, which is reflected in the depth and hydrogeology of the wells sampled. Shallow and deep confined aquifer sample concentrations of most major ions and all trace elements (fig. 9) are consistently higher than unconfined aquifer and surface-water samples. Differences in chloride and sodium concentrations were greatest among the major ions—shallow confined chloride and sodium were as high as 90 and 60 mg/L, respectively, and deep confined samples were about 800 and 300 mg/L, respectively. The greater effect of mixing with saline formation waters and shallow dilute groundwater in the deepest, and farthest downvalley confined aquifer water makes it unpotable. Among major ions, calcium is an exception in that shallow confined-aquifer concentrations are typically lower than surface-water or unconfined-aquifer concentrations. This exception is likely a result of cation exchange of calcium for sodium on clay minerals over time in the confined aquifer (for example, see Back and others, 1993).

Confined-aquifer samples indicate a reducing (anoxic) groundwater environment (fig. 9). Oxic species such as dissolved oxygen and nitrate are virtually absent, and sulfate concentrations are all less than 6 mg/L. Species consistent with a reducing environment in these samples include ammonia, manganese, iron, and methane (7.8 to 52 mg/L). In south-central New York, methane and high specific conductance (mineral content) in well water is most closely associated with confined sand-and-gravel and fractured bedrock aquifers in valley settings (Heisig and Scott, 2013).

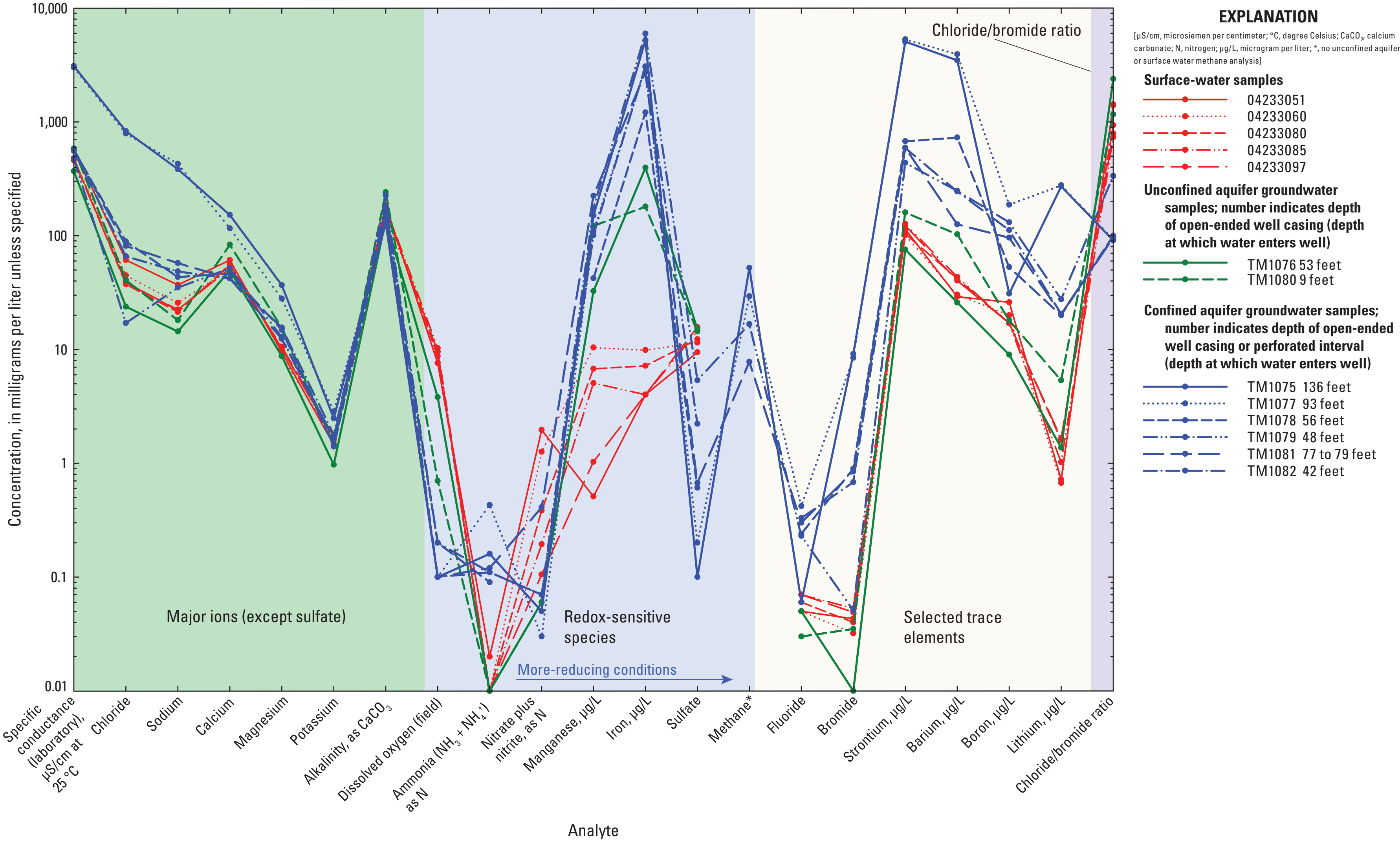

Figure 9. Water chemistry for surface-water and groundwater samples for the town of Enfield, Tompkins County, New York.

Summary

This report presents new and existing data collected to better understand the geohydrology and water quality of the Enfield Creek Valley unconsolidated aquifer in the town of Enfield, Tompkins County, New York. The report describes the methods used to collect all the data, the geological and glacial history of the area, sources of groundwater discharge and recharge, and water quality of Enfield Creek and the underlying groundwater aquifers.

Eight test wells were drilled to determine the underlying surficial material, to monitor continuous water-level and water-temperature changes using data loggers, and to collect water-quality data at different depths and locations within the boundary of the aquifer. Discharge measurements were made along Enfield Creek and its major tributaries to determine stream gains to and losses from the aquifer. Horizontal-to-vertical sounding seismic surveys were collected to assist in determining the aquifer geometry. Water-quality samples were collected at five locations along Enfield Creek and at all eight test wells drilled for the study.

The glacial history and surficial geology were summarized using past reports, orthoimagery, light detection and ranging, test wells, horizontal-to-vertical spectral ratio, and a large well inventory from the New York State Department of Environmental Conservation Water Well Drillers Registration Program. The confined and unconfined aquifers were identified, mostly in the valley. The confined aquifer consists of a discontinuous sand-and-gravel layer overlying bedrock. The unconfined aquifer consists of ice-contact sand and gravel, and alluvial silt, sand, and gravel, all of which were deposited during and after the last glacial recession. There are also unconfined aquifers where several large tributary streams deposited alluvial fans in the valley.

The main source of groundwater recharge is from the infiltration of rainfall or snowmelt onto the land surface overlying the aquifer. Other sources of groundwater recharge include unchannelized runoff from hills that border the aquifer and seepage losses that occur when overlying streams drain into the aquifer. Groundwater is discharged in four main ways: (1) stream gains when water from the aquifer loses to Enfield Creek, (2) losses to wetlands overlying the aquifer, (3) evapotranspiration, and (4) groundwater withdrawals from domestic and production wells.

Groundwater withdrawals were calculated using several sources of information including information from a mobile home park and business owners, the U.S. Geological Survey water-use circular, and from an estimated visual count using orthoimagery and tax parcels. Withdrawals from wells overlying the aquifer accounted for an estimated 28.3 million gallons per year.

Six surface-water quality samples, including one replicate sample, were collected for physical properties, common inorganic ions, nutrients, and trace elements at five locations along Enfield Creek overlying the aquifer boundary. Groundwater-quality samples were collected for physical properties, common inorganic ions, nutrients, groundwater age and gasses, and trace elements at all eight test wells, including one blank sample for quality control. Water quality in surface and groundwater generally met State and Federal drinking-water standards; however, some constituents (chloride, dissolved solids, barium, iron, manganese, and methane) did exceed these standards. In general, the highest yields and best water quality are from wells completed within about 50 feet of land surface, which may tap either type of sand-and-gravel aquifer.

Water-chemistry data from U.S. Geological Survey test wells within the northern two-thirds of the Enfield Creek Valley (wells TM1075, TM1077, TM1079, and TM1081) indicate a downvalley decrease in oxidized chemical species (dissolved oxygen, nitrate, and sulfate), an increase in mineral content (evidenced by increases in specific conductance and dissolved solids), and an increase in methane that is consistent with a confined-aquifer system with relatively slow groundwater movement and mixing with more highly mineralized bedrock groundwater containing methane and saline formation waters mixed with shallow dilute groundwater. The groundwater quality at wells TM1075 and TM1077 is unpotable without treatment and is a limitation of the resource.

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Appendixes 1–3

Appendix 1. Well Logs of Test Wells Drilled in the Enfield Creek Unconsolidated Aquifer, Town of Enfield, Tompkins County, New York

This appendix contains the well logs showing specific material and well information for the eight test wells drilled for the aquifer study.

Table 1.1. Site identification and well logs for test wells drilled for the study in the Enfield Creek Valley, town of Enfield, New York.

[Data in the “link to well log” column link to the relevant available data. USGS, U.S. Geological Survey; no., number]

USGS local well site no. (fig. 8)	USGS station identification no.	Link to well log
TM1075	422504076373001	Log 30083
TM1076	422504076373002	Log 30084
TM1077	422623076374501	Log 30085
TM1078	422623076374502	Log 30086
TM1079	422744076373401	Log 30087
TM1080	422744076373402	Log 30088
TM1081	422653076374601	Log 30089
TM1082	422653076374602	Log 30090

U.S. Geological Survey test wells TM1075 and TM1076

Town of Enfield Highway Department, Town of Enfield, New York

Site name: TM1075 and TM1076
Site identifier: 422504076373001, 422504076373002
Latitude: 42°25′04.28″
Longitude: 076°37′29.89″

Date completed: 11/11 and 12/2015
Drilling contractor: Frey Well Drilling, Alden, N.Y.
6-inch diameter steel casings
Casing above ground=3.1 feet Casing above ground=3.7 feet

Latitude and longitude measurement made by Global Positioning System (NAD 83)

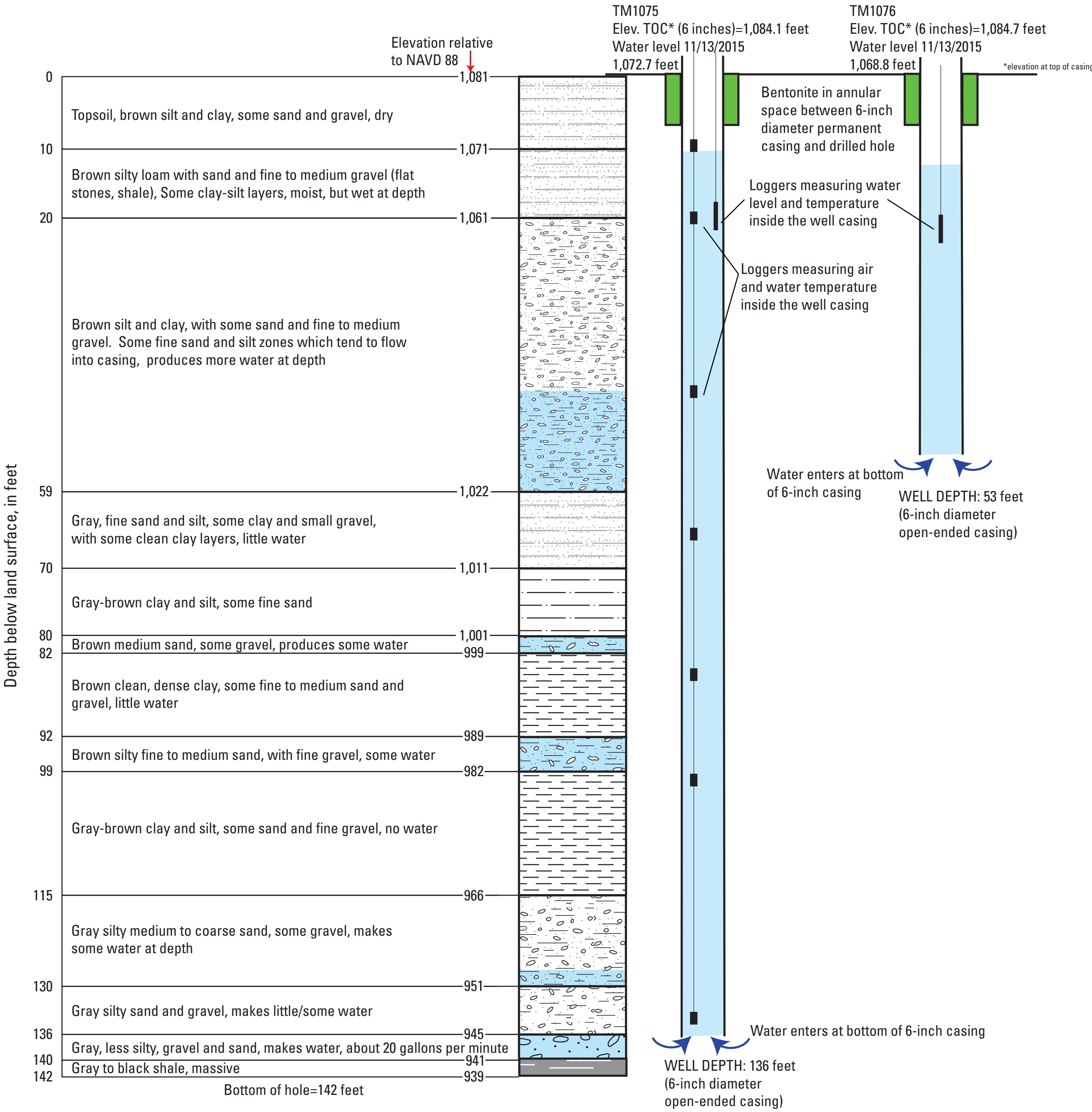

Figure 1.1. Well logs for U.S. Geological Survey test wells TM1075 and TM1076.

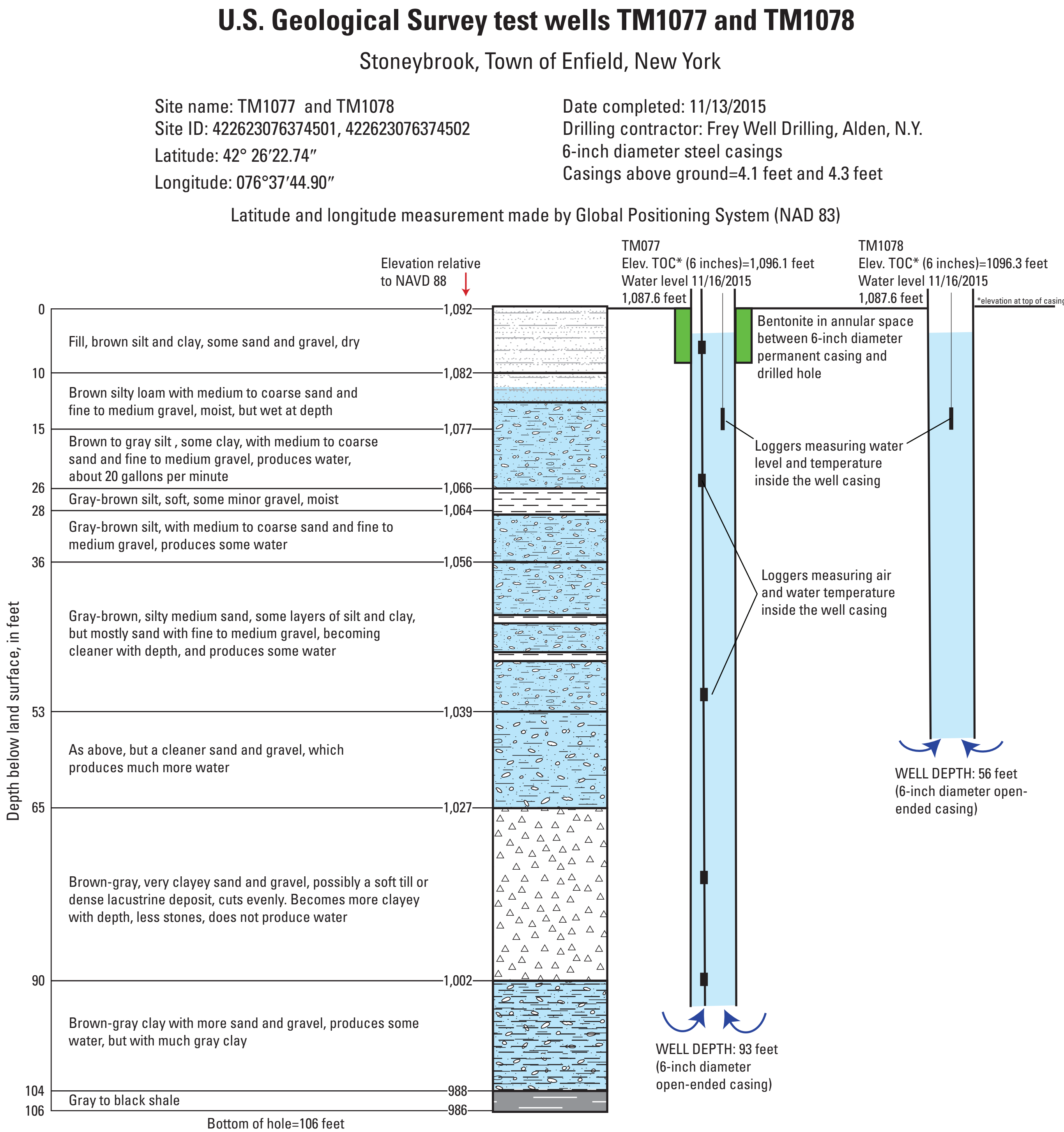

Figure 1.2. Well logs for U.S. Geological Survey test wells TM1077 and TM1078.

U.S. Geological Survey test wells TM1079 and TM1080

Hayts Road, Town of Enfield, New York

Site name: TM1079 and TM1080
Site ID: 422744076373401, 422744076373402
Latitude: 42°27′43.72″
Longitude: 076°37′33.94″

Date completed: 11/16/2015
Drilling contractor: Frey Well Drilling, Alden, N.Y.
6-inch diameter steel casing
Casings above ground=3.1 feet and 3.2 feet

Latitude and longitude measurement made by Global Positioning System (NAD 83)

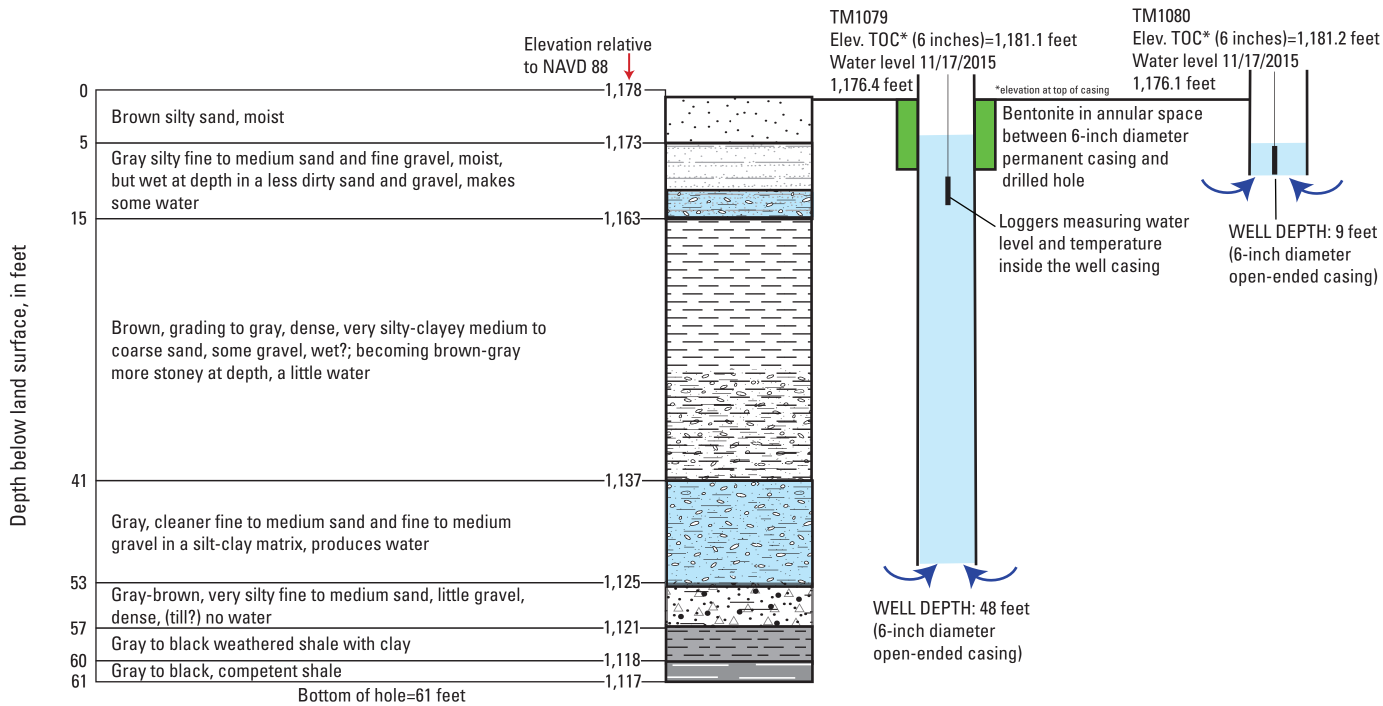

Figure 1.3. Well logs for U.S. Geological Survey test wells TM1079 and TM1080.

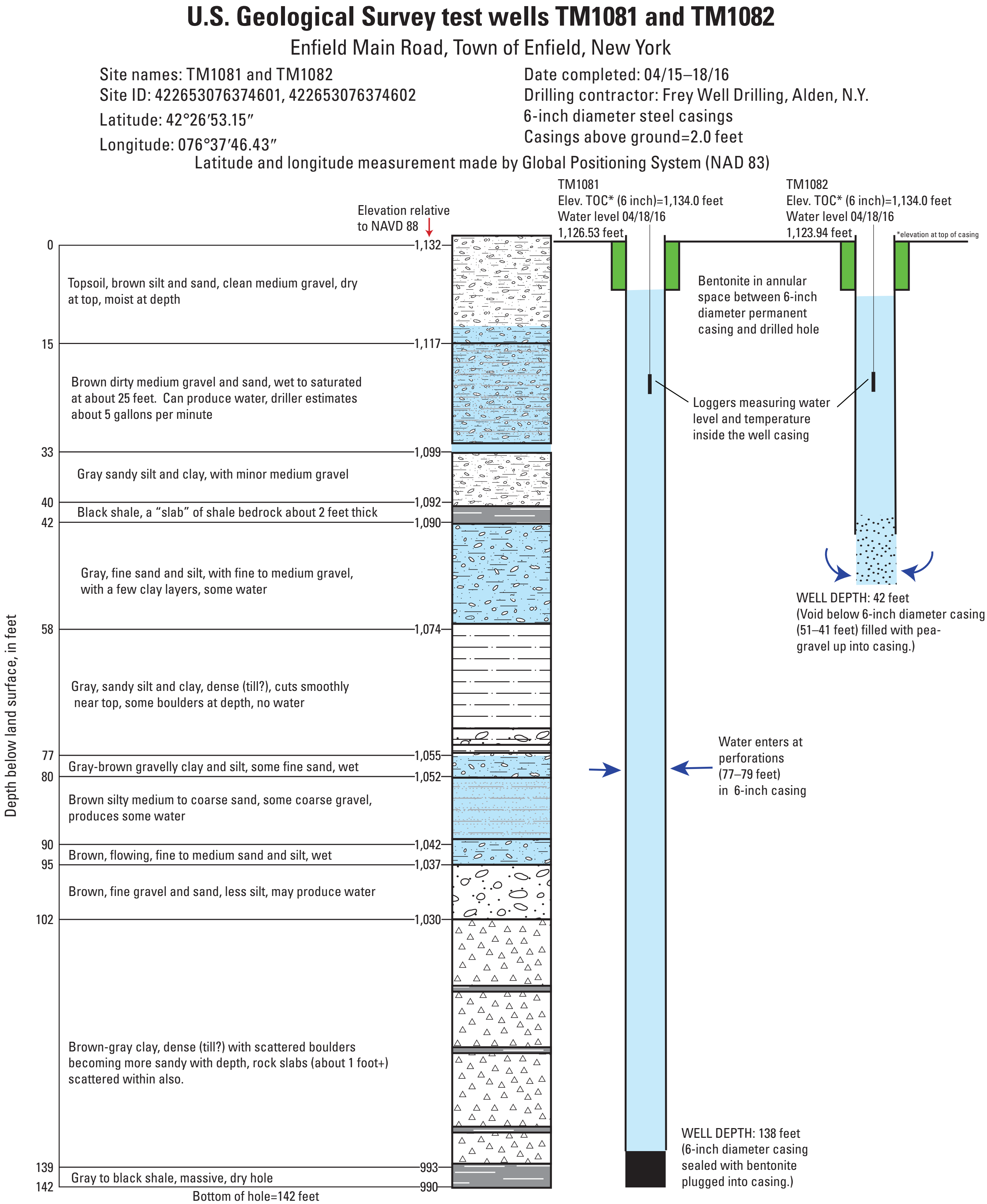

Figure 1.4. Well logs for U.S. Geological Survey test wells TM1081 and TM1082.

Appendix 2. Test-Well Hydrographs in the Enfield Creek Unconsolidated Aquifer, Town of Enfield, Tompkins County, New York

This appendix contains the hydrographs created for data collected from the eight test wells drilled for the unconsolidated groundwater aquifer study in the town of Enfield, New York. These hydrographs show water level and water temperature from November 7, 2015, to April 25, 2018.

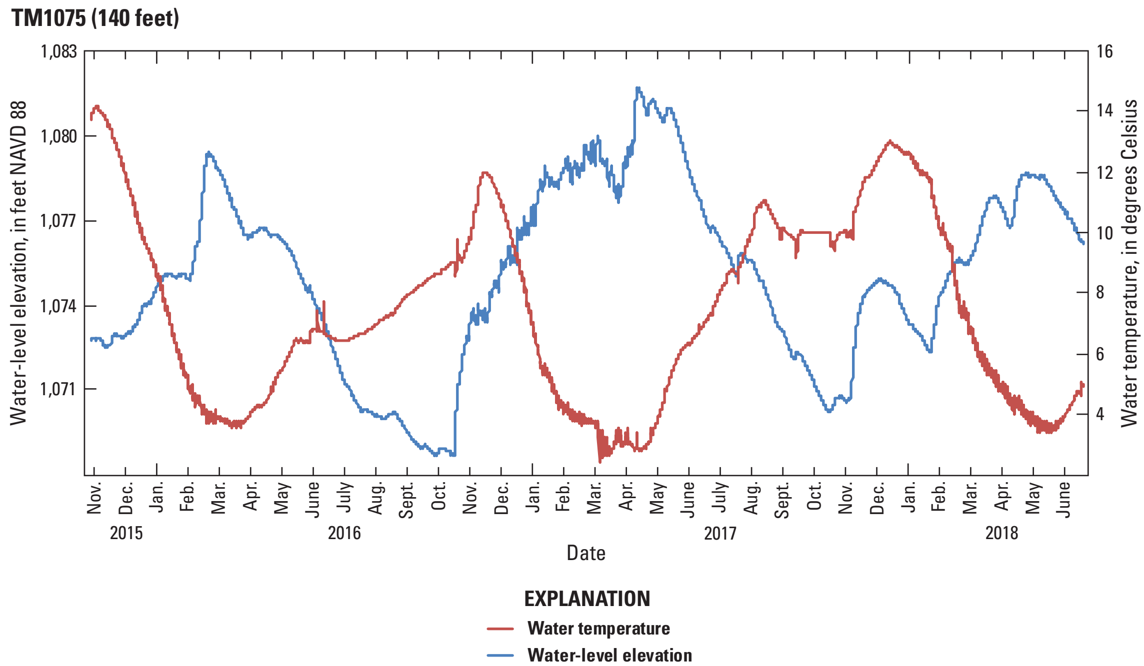

Figure 2.1. Test-well hydrograph for U.S. Geological Survey test well TM1075.

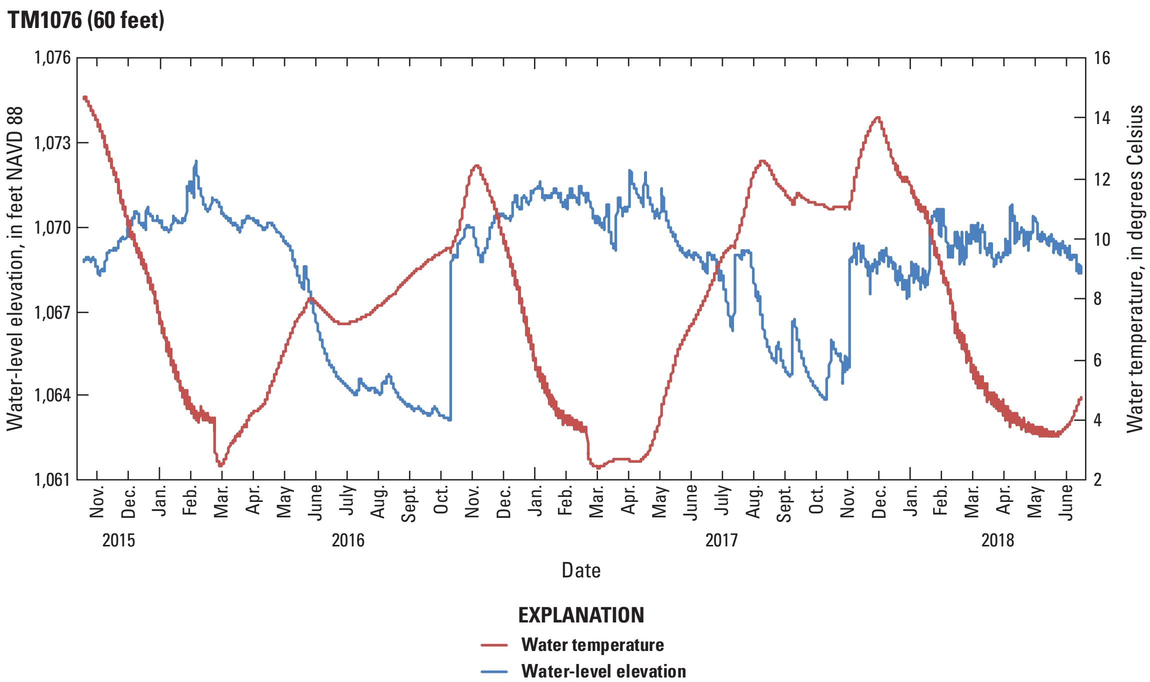

Figure 2.2. Test-well hydrograph for U.S. Geological Survey test well TM1076.

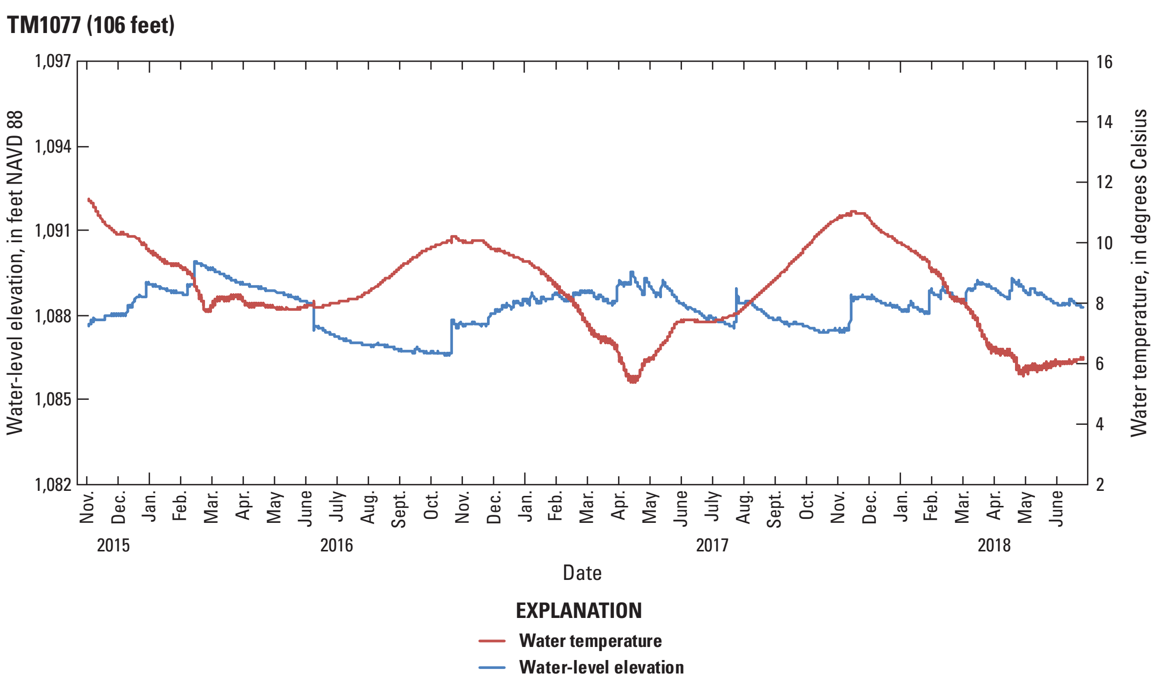

Figure 2.3. Test-well hydrograph for U.S. Geological Survey test well TM1077.

TM1078 (60 feet)

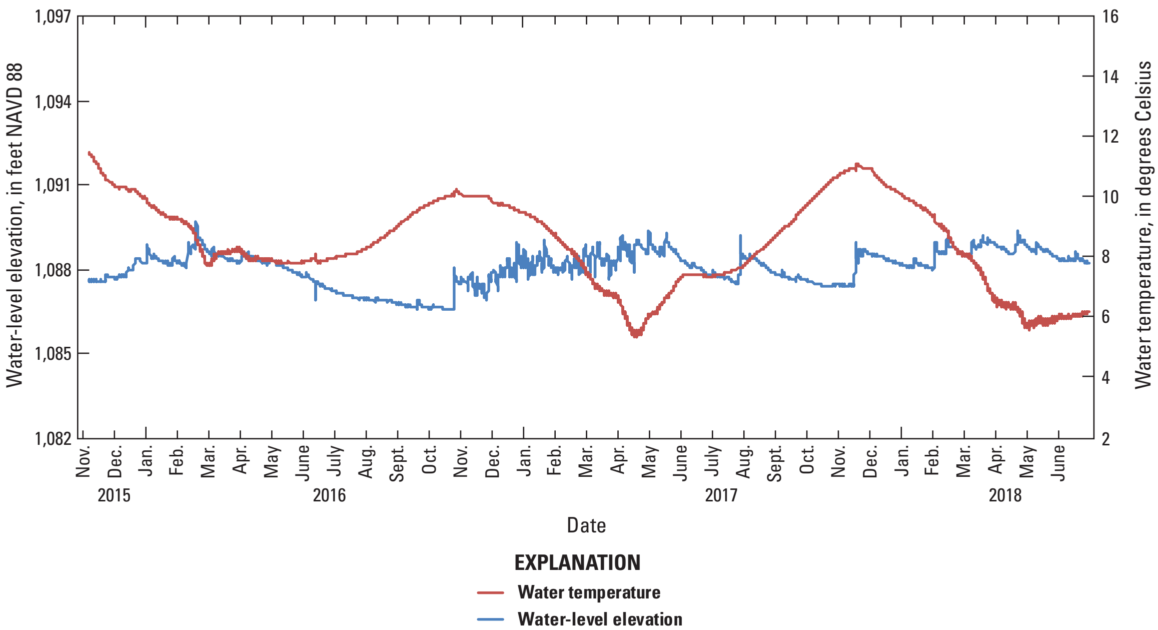

Figure 2.4. Test-well hydrograph for U.S. Geological Survey test well TM1078.

TM1079 (61 feet)

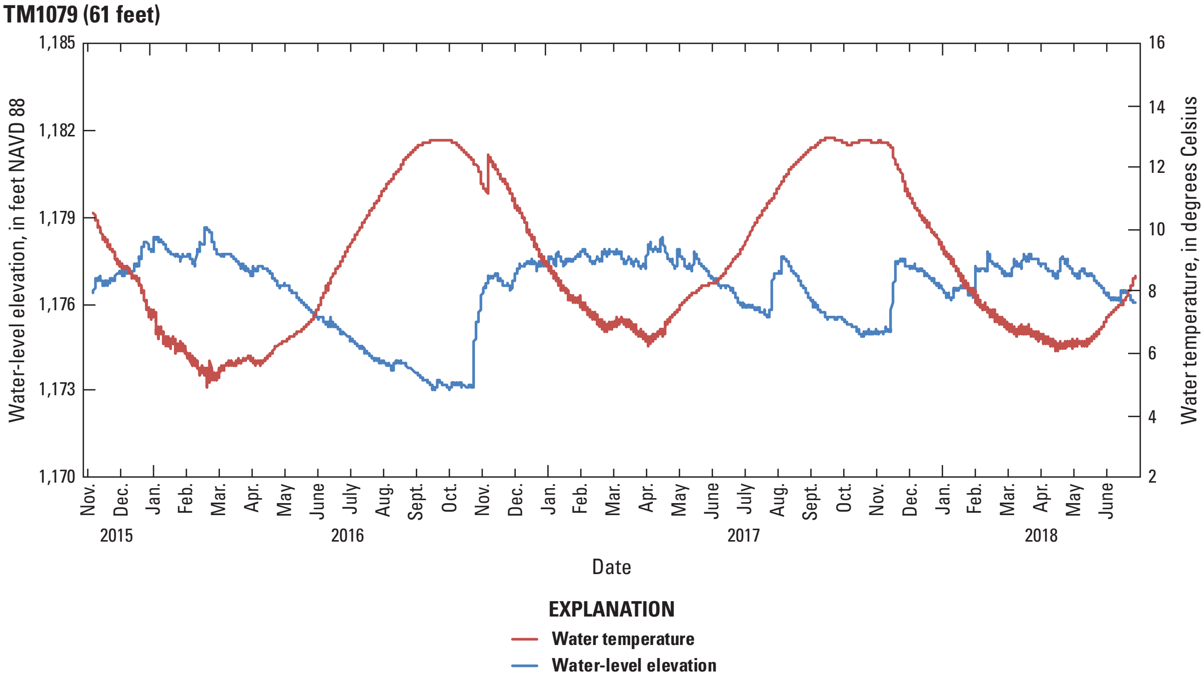

Figure 2.5. Test-well hydrograph for U.S. Geological Survey test well TM1079.

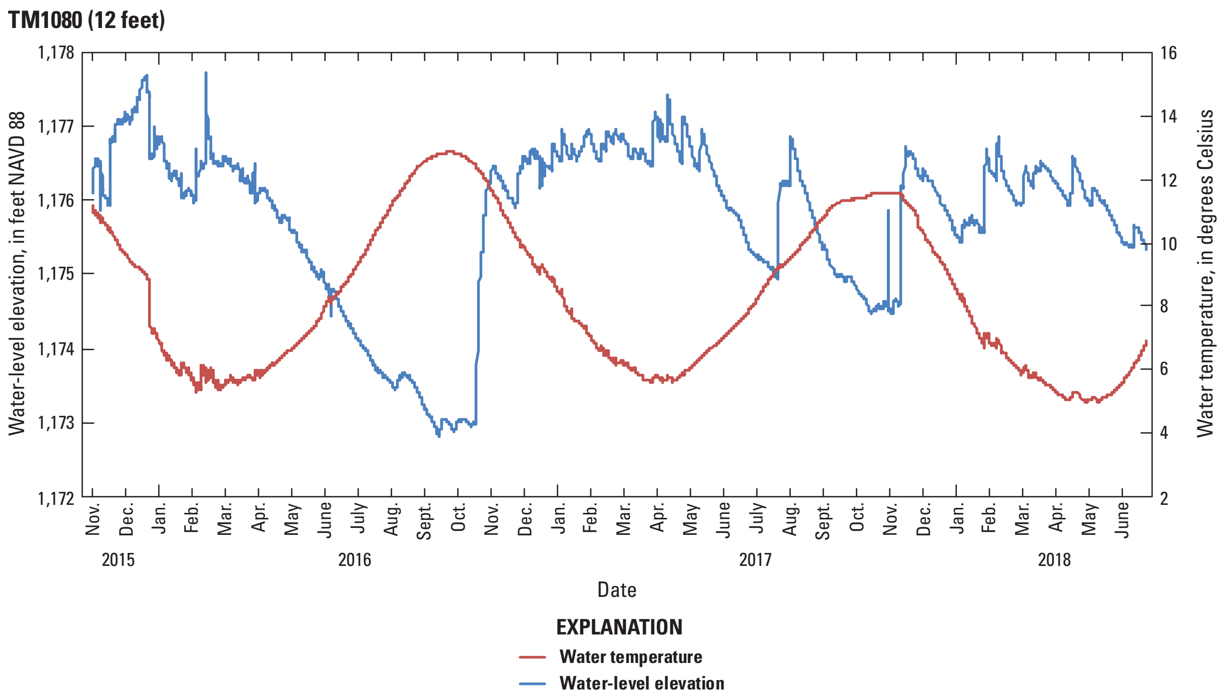

Figure 2.6. Test-well hydrograph for U.S. Geological Survey test well TM1080.

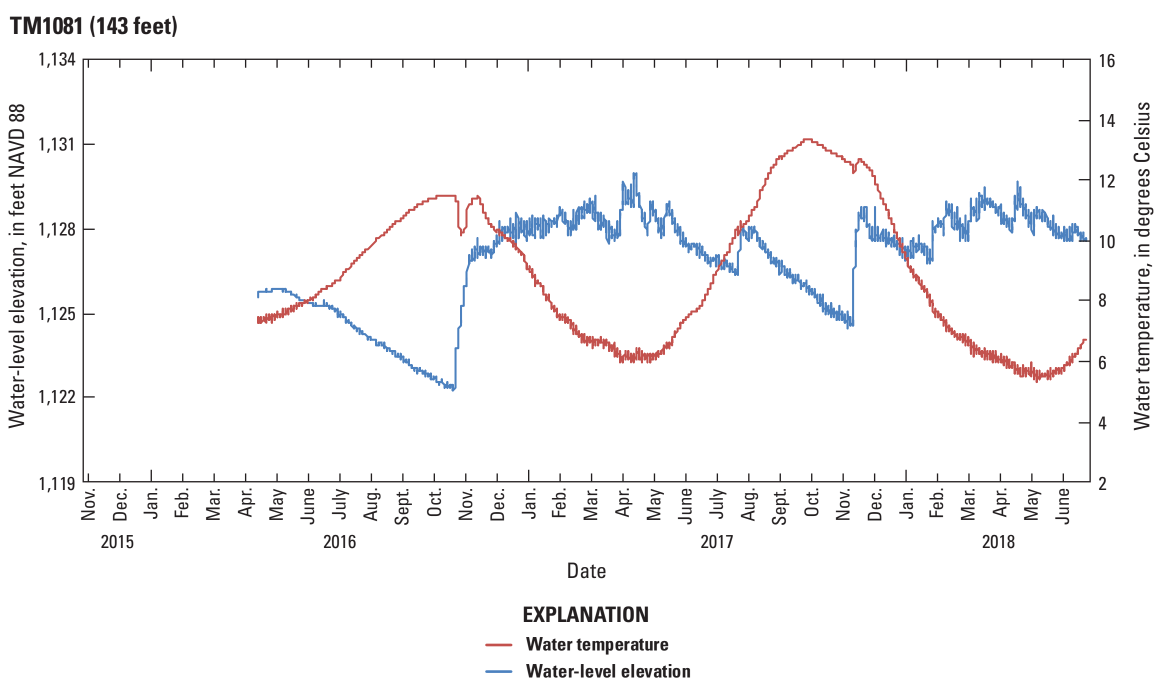

Figure 2.7. Test-well hydrograph for U.S. Geological Survey test well TM1081.

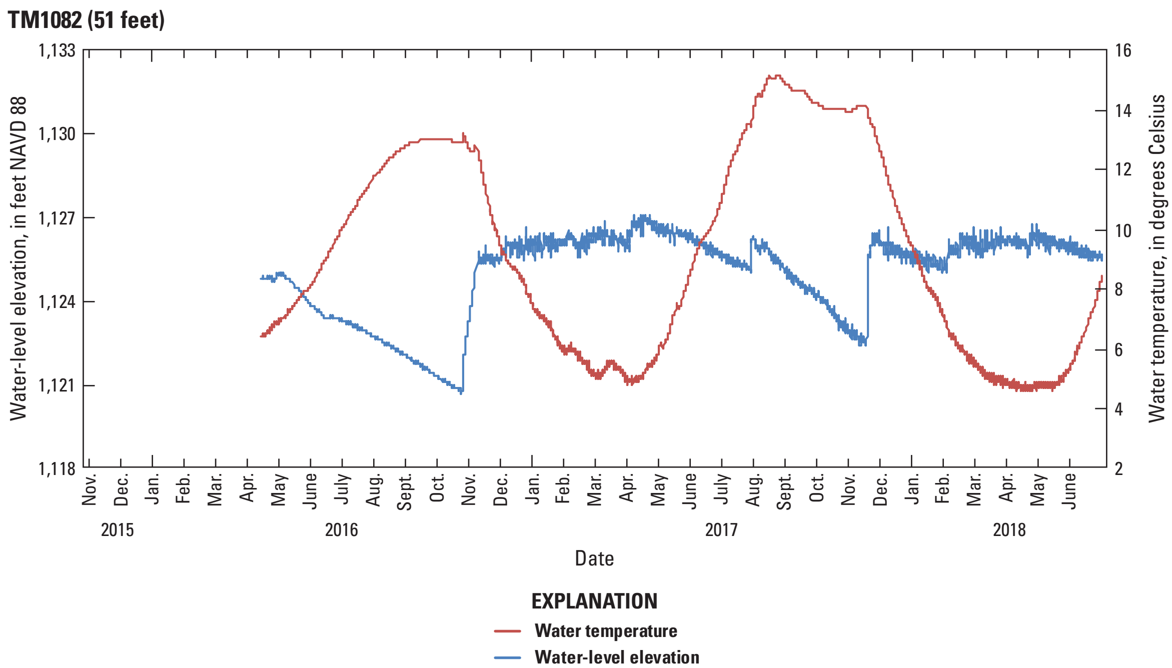

Figure 2.8. Test-well hydrograph for U.S. Geological Survey test well TM1082.

Appendix 3. Air and Water Temperatures by Depth at Test Wells TM1075 and TM1077 in the Enfield Creek Unconsolidated Aquifer, Town of Enfield, Tompkins County, New York

This appendix contains two graphs showing ambient air and groundwater temperature at multiple depths in the water column at test wells TM1075 and TM1077.

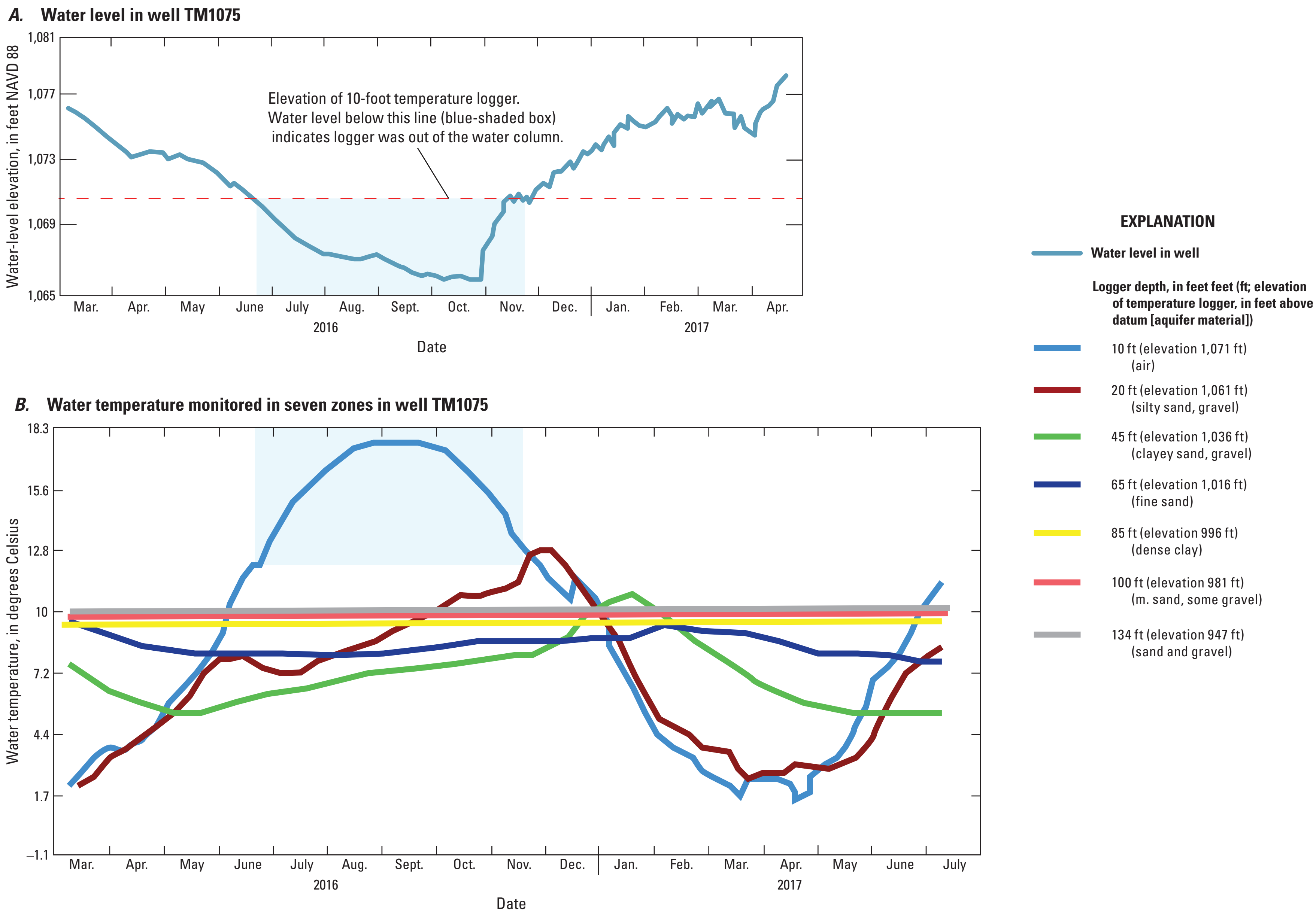

Figure 3.1. Graph showing ambient air and groundwater temperature at multiple depths in the water column at U.S. Geological Survey test well TM1075.

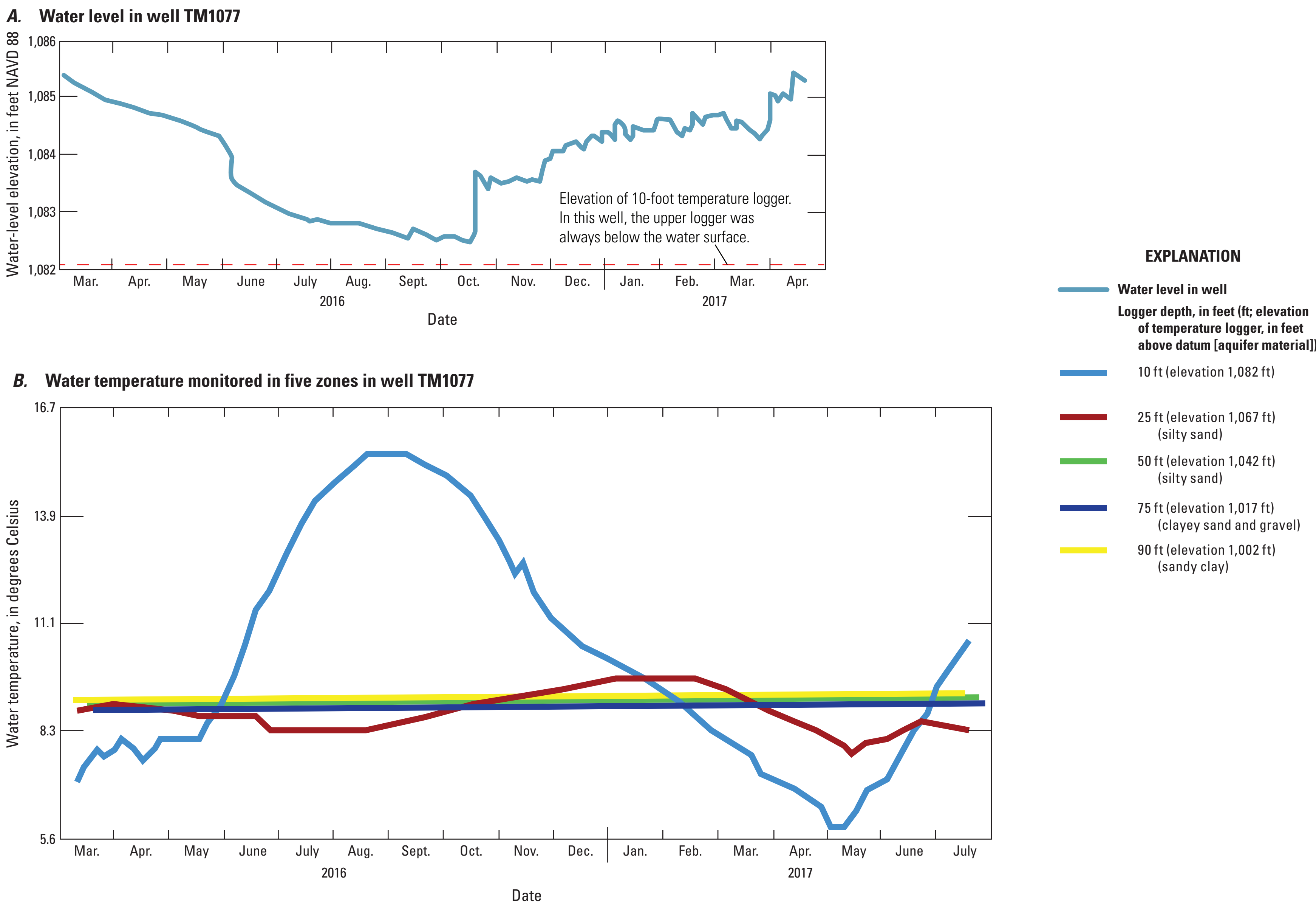

Figure 3.2. Graph showing ambient groundwater temperature at multiple depths in the water column at U.S. Geological Survey test well TM1077.

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