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Hydrogeology and Water Quality of the Unconsolidated Aquifer System in the Lower Fall Creek Valley, Tompkins County, New York

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Abstract

The U.S. Geological Survey, in cooperation with Tompkins County and the Town of Dryden, conducted a hydrogeologic investigation of the lower Fall Creek unconsolidated aquifer system in Tompkins County, New York. This study is part of an ongoing effort to characterize major valley-fill aquifers in the region to support sustainable groundwater management. The lower Fall Creek valley, encompassing the Village of Freeville, the unincorporated communities of Etna, and the hamlets of McLean and Varna, has experienced moderate development and relies heavily on groundwater for residential, agricultural, and commercial use.

The study area spans approximately 51 square miles along the boundary of the Allegheny Plateau and North Rim of the Allegheny Plateau physiographic provinces. The aquifer system, composed primarily of glacially derived sand and gravel deposits, includes both unconfined and confined aquifer units. For the approximately 2,300 people who live over the aquifers, groundwater is the sole source of drinking water. In some areas, such as the Village of Freeville, artesian conditions exist, with potentiometric heads exceeding 25 feet above land surface.

This report describes the hydrogeologic framework, aquifer distribution, groundwater-flow dynamics, and water quality of the lower Fall Creek aquifer system. Groundwater is generally hard and contains elevated concentrations of redox-sensitive constituents, such as iron and manganese relative to U.S. Environmental Protection Agency secondary maximum contaminant levels. Arsenic was not detected above the U.S. Environmental Protection Agency maximum contaminant level during this study but remains a regional concern due to past detections in the study area and nearby aquifers. The findings provide data for local planners and resource managers to use in understanding and protecting this water resource.

Introduction

In 2000, the U.S. Geological Survey (USGS) published a map highlighting the extents of 17 unconsolidated aquifer systems in Tompkins County, New York (Miller, 2000). During the early 2000s, plans were developed to map the aquifers in greater detail to help planners and homeowners better understand, manage, and protect these water resources. The lower Fall Creek unconsolidated aquifer system is the most recent of these aquifer systems to be investigated (Bugliosi and others, 2014; Fisher and others, 2019; Fisher and others, 2021; Miller, 2009, 2015; Miller and Bugliosi, 2013; Miller and Karig, 2010).

In 2019, the USGS, in cooperation with Tompkins County and the Town of Dryden, began a study of the lower Fall Creek unconsolidated aquifer system, which includes the Village of Freeville, unincorporated communities of Etna, and the hamlets of McLean and Varna (figs. 1 and 2). This area was selected for study because there has been moderate development during the last several decades over the aquifer in the lower Fall Creek valley. In this area, population centers, rural homeowners, many businesses, and dairy and other agricultural farms typically pump water from wells that tap sand and gravel aquifers in the valley. Hydrogeologic information is needed to help planners develop a more comprehensive approach to water-resources management in Tompkins County. Recent (2016) drought conditions along Fall Creek (fig. 2)—a major tributary to Cayuga Lake (fig. 1), which supplies drinking water to nearly 100,000 residents—highlighted the need to improve understanding of the groundwater and surface-water interaction within the watershed (New York State Department of Environmental Conservation [NYSDEC], 2022).

Figure 1. Map showing the lower Fall Creek study area, associated watersheds, areas of adjacent aquifer mapping studies, nearby Finger Lakes, and physiographic regions (also referred to as hydrophysiographic provinces in other publications), Tompkins and Cortland Counties, New York.

Figure 2. Map showing the study area, population centers, U.S. Geological Survey (USGS) Tunison Laboratory of Aquatic Science, and extent of the unconsolidated aquifer system and general surface water flow direction in the lower Fall Creek valley in Tompkins and Cortland Counties, New York (DeMott and others, 2026b).

Arsenic concentrations exceeded the U.S. Environmental Protection Agency (EPA) maximum contaminant level (MCL) of 10 micrograms per liter ($\mu\text{g/L}$) (EPA, 2025) in 8 percent of groundwater samples collected by the Tompkins County Water Resources Council in Tompkins County and the USGS during a 2000–2012 sampling campaign in the major valley-fill aquifers in Tompkins County, which highlighted a known concern in the area (Aquifer Committee of the Tompkins County Water Resources Council, 2014).

Purpose and Scope

To evaluate and protect the lower Fall Creek aquifer system in Tompkins County and in a small part of Cortland County, New York, information is needed regarding the aquifer framework, hydraulic properties, and water quality of the aquifer. This report describes (1) the geology and glacial history of the study area, including the hydrogeologic framework of the unconsolidated aquifer system; (2) aquifer types and distribution; (3) the groundwater-flow system, including groundwater levels, groundwater and surface-water interaction, direction of groundwater flow, groundwater use, and well yields; and (4) the water quality of the study area for both surface water and groundwater, including concentrations of common inorganic ions and

nutrients. Also included are (1) hydrogeologic sections; (2) maps and diagrams depicting well locations, surficial geology, groundwater levels, and aquifer extents; (3) tables of well records and water-quality data; and (4) results from horizontal-to-vertical spectral ratio (HVSR) passive-seismic surveys. All associated geospatial and HVSR data are available in DeMott and others (2026a and 2026b).

Description of Study Area

The study area encompasses approximately 51 square miles along the lower Fall Creek valley. Most of the study area is in the North Rim of the Allegheny Plateau physiographic province, with a small area in the eastern part that is in the Allegheny Plateau region (Randall, 2001) (fig. 1). The study area includes the Village of Freeville, the unincorporated communities of Etna, and the hamlets of McLean and Varna (fig. 2) and has an estimated total population of ~2,300 residents. Land cover across the study area is predominantly agriculture (45 percent) and forests (33 percent), followed by wetlands (12 percent) and developed land (9 percent), and the remainder (1 percent) is shrublands, barren land, and open water (Dewitz, 2023). The region receives approximately 42 inches of precipitation each year and has a mean temperature of 46 degrees Fahrenheit (PRISM Group, 2020).

The drainage divide between the Oswego River and Susquehanna River Basins (basins not shown in any figure) marks the northeastern boundary of lower Fall Creek watershed (fig. 1). In this area, just east of the Tompkins-Cortland County border (fig. 2), morainal deposits of the Valley Heads Moraine extend across the valley. Multiple springs discharge from the backside of the moraine and contribute to the headwaters to Fall Creek. To the southwest, the unconsolidated aquifer thins and eventually ends where the lower Fall Creek valley is floored by thin till and (or)

bedrock and Fall Creek becomes a hanging tributary that cascades down waterfalls and then drains into Cayuga Lake.

Adjacent Aquifer Systems and Previous Investigations

The lower Fall Creek aquifer system is adjacent to three aquifer systems that have been studied in detail and have important implications for the current study (figs. 1):

1. Owasco Inlet (Heisig, 2023)
2. Cortland County (Miller and others, 1998)
3. Virgil Creek and Dryden Lake Valleys (Miller and Bugliosi, 2013)

The Owasco Inlet study area lies approximately half a mile north of the Village of Freeville and is contiguous to the northern boundary of the lower Fall Creek aquifer. Heisig (2023) proposed the presence of a glacially eroded “through valley” connecting the two regions. However, current data are insufficient either to determine whether a groundwater connection exists through the glacial deposits or to define the depth and extent of this feature.

The Cortland County study area borders the end-moraine region of the lower Fall Creek valley, where the headwaters of Beaver Creek originate. A groundwater-flow model developed by Miller and others (1998) indicates that groundwater west of the regional groundwater divide within the Cortland study area flows southwestward, exiting the area as underflow into the lower Fall Creek valley. This underflow is estimated at approximately 40,500 cubic feet per day, or ~0.5 cubic feet per second. Some part of this subsurface flow may contribute to surface-water discharge into Beaver Creek, which has a relatively high unit discharge ($[\text{ft}^3/\text{s}]/\text{mi}^2$) compared to other tributaries within the lower Fall Creek Basin (USGS, 2024b).

The Virgil Creek and Dryden Lake Valley study area is 2.3 miles southeast of the Village of Freeville (Miller and Bugliosi, 2013) and is contiguous to the Fall Creek valley-fill aquifer. The Dryden aquifer model, which extends slightly northwest of the Town of Dryden, identifies three confined aquifers—upper, middle, and lower—separated by lacustrine confining units at the downstream end of the model domain. Although the extent to which these aquifers continue into the lower Fall Creek aquifer is uncertain due to the lack of depth-to-bedrock data along Virgil Creek. However, evidence presented in this report indicates that at least the middle and lower confined aquifers are likely to extend into the lower Fall Creek valley near Freeville. Hydraulic connection with these aquifers may be responsible for the flowing artesian conditions observed within the Village of Freeville.

Finally, the upper Fall Creek watershed is north of the hamlet of McLean (figs. 1 and 2) and drains from the till-mantled bedrock uplands surrounding the hamlet of McLean. This part of the Fall Creek watershed encompasses approximately 40 square miles (USGS, 2024a).

Data Sources and Methods

The USGS collected, compiled, and analyzed multiple types of information to characterize the hydrogeology and water quality of the study area. This information included geologic maps of unconsolidated deposits, well and test-boring records, stream-discharge measurements, passive-seismic surveys, groundwater monitoring, and analyses of groundwater and surface-water quality.

Geologic Mapping

This report presents an updated surficial geologic map of the study area that builds upon the work from the New York State Geological Survey (Backhaus and others, 2019; Leone and

Backhaus, 2018) and work from other researchers (Karig, 2022). Geologic data were gathered through a combination of passive-seismic surveys, field reconnaissance, and interpretations from topographic maps, orthophotos, and digital elevation maps derived from light detection and ranging (lidar). Additionally, existing geologic reports, soil maps, and well and test-boring records and logs were reviewed.

Well and Test-Boring Records

Records from approximately 475 wells and borings were analyzed to characterize the aquifer system; data from the records include well and casing depths, water levels, yields, and lithologic logs. Most of these well records were provided by the NYSDEC water-well drillers' registration program. Additional records are from well and test-boring data in the USGS National Water Data for the Nation (WDFN) database (USGS, 2024b), test boring data from the New York State Department of Transportation, and data from wells at the USGS Tunison Laboratory of Aquatic Science (fig. 3).

Figure 3. Map of well and test-boring sites in the lower Fall Creek unconsolidated aquifer system, in Tompkins and Cortland Counties, New York. NYSDEC, New York State Department of Environmental Conservation; NYSDOT, New York State Department of Transportation; WDFN; USGS Water data for the nation; USGS; U.S. Geological Survey (DeMott and others, 2026b).

Streamflow Measurements

Stream discharge was measured at 24 sites in lower Fall Creek (fig. 4) and in selected tributary streams under base-flow conditions on November 15, 2023 and according to published techniques (Rantz and others, 1982). Stream discharge was measured to identify where and to what degree groundwater was discharging to lower Fall Creek and conversely where the creek

may be losing water to the surrounding aquifer. In addition to stream discharge data, three water-quality samples were collected in lower Fall Creek and analyzed for chemical constituents outlined in the “Water Quality” section.

Figure 4. Streamflow-measurement, groundwater-level monitoring, and groundwater- and surface-water-quality sampling sites in the lower Fall Creek valley study area, Tompkins and Cortland Counties, New York. Many streamflow-measurement sites overlap on the map (DeMott and others, 2026; USGS 2024b).

Passive-Seismic Surveys

HVSR passive-seismic surveys were completed at 72 sites in the study area (fig. 5) and were used to estimate total sediment thickness of the unconsolidated aquifer system. Quality control checks were conducted to ensure that the two seismometers used in this study were functioning properly; quality control checks included three side-by-side check measurements and six bedrock control measurements at four locations next to wells with known bedrock depths (TMHVSR167, TMHVSR175A&B, CHVSR9A&B, TMHVSR212; DeMott and others, 2026a). HVSR data were collected for a minimum of 30 minutes at each site with a Tromino TEP-3C1 three-component seismometer. These data were processed with Grilla (2018, release 8.0) software to (1) normalize the spectral traces, (2) remove anthropogenic background noise, (3) transform time-domain data to frequency domain data, (4) calculate spectral ratio curves, and (5) determine the resonance frequency (Heisig and Fleisher, 2022).

Figure 5. Map showing passive-seismic survey sites and hydrogeologic sections A–A' to D–D' within the lower Fall Creek unconsolidated aquifer system in Tompkins and Cortland Counties, New York (DeMott and others, 2026b).

The HVSR passive-seismic method uses a single broadband three-component (x , y , and z directions) seismometer to record ambient seismic noise (frequencies). The ratio of the averaged horizontal (x , y) to vertical (z) component is used to produce a spectral ratio curve and determine a peak resonant frequency (f) for each site. The determined frequency can be empirically related to sediment thickness by using average local sediment shear-wave velocity or power-law regression analysis calibrated with local sites of known depths to bedrock (Lane and others, 2008).

Heisig (2023) used two regression equations derived from 43 control-point measurements with known bedrock depths from locations across upstate New York to estimate depth to bedrock. The first equation is for high shear-wave velocities in all thicknesses of sand and gravel or till, and mixed predominantly fine-grained stratified sediments greater than or equal to 275 feet thick:

$$DTB = 366.85f - 1.038, R^2 = 0.933; \quad (1)$$

and the second equation is for lower shear-wave velocities in mixed, predominantly fine-grained stratified sediments less than 275 feet thick:

$$DTB = 276.23f - 1.213, R^2 = 0.962; \quad (2)$$

where

DTB is depth to bedrock, in feet,

f is fundamental site resonance frequency, in hertz, and

R^2 is the coefficient of determination.

The HVSR-estimated and known depth-to-bedrock data were compared to the depth-to bedrock coverage in Backhaus (2024), and the coverage was modified where warranted. Estimated sediment thickness and depth-to-bedrock data are available in DeMott and others (2026b).

Groundwater-Level Monitoring

Groundwater level was recorded at two monitoring well sites (TM3860 and TM1144; USGS, 2024b) to document seasonal changes. A Solinst pressure sensor and barometer (internal logging) were installed in well TM1144 in the hamlet of Mclean (fig. 4), from October 3, 2023, through November 8, 2023. From November 8, 2023, through October 28, 2024, an In-Situ Level TROLL 500 (pressure sensor) and In-Situ VuLink (datalogger), with cell modem and antenna, were installed. At groundwater site TM3860 in the Village of Freeville (fig. 4), flowing artesian conditions prevented collection of continuous data, and conventional tape-down measurement methods were ineffective because of heads that often exceeded 25 feet above land surface (fig. 6). Hydraulic head, discharge rate, temperature, and specific conductance of the flowing discharge at TM3680 were measured monthly. For flowing discharge measurements, three volumetric readings using a graduated 5-gallon bucket were taken over 30-second periods and averaged. Water temperature and specific conductance were measured in the same 5-gallon bucket, while water was actively flowing, with an EXO2 water-quality probe. For hydraulic-head measurements, all vents on the well cap were sealed, and a pressure dial connected to the outflow was briefly closed to obtain pound-per-square-inch readings that were converted to head, in feet above land surface (1 pound per square inch is about 2.31 feet of head). The groundwater data collected at the sites are available through Water Data for the Nation (WDFN; USGS, 2024b).

Figure 6. Photograph of the initial attempt to measure hydraulic head at well TM3860 in the Village of Freeville (location shown in fig. 4), Tompkins County, New York. The artesian hydraulic head exceeded the

capacity of the available measuring equipment, resulting in water overflowing from the top of the tubing at 25 feet above land surface. Photograph by Matthew Jennings, U.S. Geological Survey.

Water Sampling and Analyses

Groundwater samples for water-quality analysis were collected from four domestic water wells in the study area (fig. 4; table 1). Water samples were collected from spigots prior to any treatment to ensure that water was representative of natural aquifer conditions. Surface-water samples were collected from three locations along lower Fall Creek (fig. 4; table 1). Samples were collected and processed according to standard USGS protocols (USGS, variously dated).

Table 1. Groundwater and surface-water sites sampled for water-quality analyses, lower Fall Creek valley, Tompkins County, New York.

[From U.S. Geological Survey (USGS) (2024b). NY, New York; —, not applicable]

USGS station identification number	Station name	Date sampled	Source	Well depth, in feet	Well confinement status
423038076204201	TM3860, NY	August 8, 2023	Groundwater	185	Confined
423306076173101	TM1144, NY	August 8, 2023	Groundwater	60	Unconfined
423043076210601	TM1145, NY	August 8, 2023	Groundwater	92	Confined
423036076212101	TM1146, NY	August 8, 2023	Groundwater	200	Confined
423306076173301	Fall Creek at fire station at Mclean, NY	August 7, 2023	Surface water	—	—
423057076210901	Fall Creek at nature preserve at Freeville, NY	August 7, 2023	Surface water	—	—
422819076250801	Fall Creek at Route 13 bridge near Etna, NY	August 7, 2023	Surface water	—	—

Water samples were analyzed for inorganic constituents (calcium, sodium, magnesium, potassium, chloride, sulfate, iron, and manganese) and nutrients (ammonia, nitrate, and orthophosphate) at the USGS Soil and Low-Ionic-Strength Water Quality Laboratory (SLISWQL) in Troy, N.Y., according to methods published in standard operating procedure documentation (U.S. Geological Survey, undated). Acid-neutralizing capacity was determined on unfiltered water samples via titration in the SLISWQL laboratory (Gran, 1952). Arsenic was

analyzed via inductively coupled mass spectrometry at the USGS National Water Quality Laboratory in Denver, Colorado, according to methods in Garbarino and others (2006). In addition, field measurements of pH, specific conductance, water temperature, and dissolved oxygen were collected at all sites. Water-quality data are available from the USGS Water Data for the Nation (USGS, 2024b).

In addition to the water-quality samples collected during this study, groundwater-quality data were compiled from the Water Quality Portal to support this analysis (USGS, 2024c). Water-quality results available via the Water Quality Portal were retrieved for wells ($n=12$) in the study area sampled during 2000–2023 using functions from the dataRetrieval package in RStudio (De Cicco and others, 2022; R Core Team, 2025). USGS site locations included: 423318076151401, 423319076151401, 423318076150902, 423230076144001, 423026076200901, 423322076143801, 423322076143802, 423038076204201, 423036076212101, 423043076210601, 423306076173101, 423327076145706. Results for concentrations of major ions (calcium, sodium, magnesium, potassium, chloride, sulfate, alkalinity), nutrients (ammonia, nitrate, total nitrogen, and orthophosphate), physical parameters (specific conductance, water temperature, dissolved oxygen, pH, and turbidity), and selected trace elements (arsenic, manganese, iron, barium, and cadmium) were retrieved. However, individual samples did not always include results for every analyte. Records were prescreened, units were standardized, and censored data with value-qualifier codes indicating the result value was below the detection limit were excluded from analysis. Concentration results were compared to relevant regulatory standards for drinking-water and public-health advisory levels. A water type classification was assigned to each result with sufficient geochemical data, per methods

described in Piper (1944). Controls on water quality were evaluated relative to potential sources of contamination originating from the land surface and natural processes.

A single sequential replicate sample for groundwater was collected at a well in Freeville, N.Y. (TM1145, table 1). The relative percent difference between sample and replicate was calculated to determine if sample collection may have introduced additional uncertainty to laboratory results. The relative percent difference for each constituent was below 10 percent (minimum of 0 to a maximum of 8 percent difference). Thus, the sample collection process was unlikely to have introduced substantial bias to the groundwater results reported in this report.

Hydrogeology

The geologic setting of central New York results from a long history of tectonic activity and surface processes. Plate tectonics created ocean basins that accumulated marine sediments, which later lithified into sedimentary rocks. These rocks were subsequently uplifted above sea level and modified by erosional forces—primarily water and glacial ice—as well as depositional processes involving fluvial and glacial materials. The bedrock underlying the lower Fall Creek aquifer consists of gently dipping Devonian shale, siltstone, and fine-grained sandstone that have been modified by paleodrainage patterns, multiple glaciations and deglaciations during the Pleistocene, recent sedimentation, and fluvial erosion. Much of the bedrock is covered by unconsolidated sediment, except for small local outcrops on hilltops and along stream banks on valley walls. Tectonics during the Alleghenian orogeny uplifted the region and created the Appalachian Plateau in the late Paleozoic era, approximately 330–250 million years ago (Isachsen and others, 1991). Minor local brittle and ductile deformation resulted, but no significant structural deformation occurred.

Prior to the start of North American glaciations during the Pleistocene epoch, a north-draining river network developed and ultimately discharged into Hudson Bay, Canada (Fairchild, 1926; Spencer, 1890). During the onset of North American glaciation, however, the north-draining rivers were glacially truncated as subsequent glaciations flowed into and modified preexisting drainage networks via erosion (Fairchild, 1925; Foshay, 1890; Grabau, 1908; Holmes, 1937; Lincoln, 1892). The most significant examples are the Finger Lakes, which acted as conduits for fast-flowing ice streams in central New York. Cayuga Lake, the lowest surface elevation of the Finger Lakes and the axial depression of central New York, along with adjacent Seneca Lake, the largest of the Finger Lakes, allowed for dynamic ice streaming by the Laurentide Ice Sheet (Briner, 2007; Kozlowski and others, 2018; Lincoln, 1892). The end result of glacial modifications of drainage in the Finger Lakes region was a valley-plugging end moraine that formed a major drainage divide between north-draining streams (including Fall Creek) that flow into the St. Lawrence River Basin and south-draining streams that flow into the Susquehanna River Basin.

The most recent glaciation by the Laurentide Ice Sheet, known as the Wisconsin glaciation, resulted in most of the sediments deposited in the lower Fall Creek aquifer. Some buried sediments near the bedrock surface may be from earlier glacial periods (Karig and Miller, 2013; Kozlowski, 2020; Miller and Karig, 2010). The history of the ice sheet dynamically advancing and retreating resulted in the complex glacial stratigraphy.

Glaciers, particularly ice sheets, erode and transport substantial quantities of sediment of all grain sizes, ranging from clay and silt (glacial rock flour) to large boulders. Sediment is transported within the ice, on top of the ice, and through subglacial water flow. The subglacial hydrologic system can be under substantial hydraulic pressure, allowing for the mobilization of

large cobbles and boulders underneath the ice in large subglacial channels. Additionally, meltwaters (typically braided streams) transport sands and gravels typically several miles or more from the ice front, to form outwash plains between the valley walls. In north-draining basins, such as the Finger Lakes region of central New York, glacially dammed lakes (proglacial lakes) formed, in which it was common for deposition of thick glaciolacustrine deposits (Fairchild, 1925; Foshay, 1890; Grabau, 1908; Holmes, 1937; Lincoln, 1892).

In central New York, glaciation resulted in a common sequence of sedimentation. In front of the advancing glacier, meltwaters deposited a coarsening upward sequence, from fine silt and sand to coarse gravel outwash, as the ice approached. As the ice flowed and overrode an area, high pressure and shearing (from the weight and movement of the glacier) resulted in compacted fine sediments, deformed and overturned layers, zones of erosion, and then subsequent deposition of basal till. Basal till is a glacially derived deposit composed of a compacted, unstratified mixture of many sediment sizes. The basal till is composed primarily of silt, with some angular pebble to boulder clasts, mostly derived from local bedrock (shale, siltstone, and fine sandstone) in the Finger Lakes region (Fairchild, 1925; Foshay, 1890; Grabau, 1908; Holmes, 1937; Lincoln, 1892).

Major glacial advances typically eroded most previously deposited sediments; however, remnants persist in some locations. In contrast, minor readvances and ice surges resulted in incomplete subglacial erosion within valleys, leaving buried deposits beneath sediments from the most recent readvance. These preserved sequences provide important evidence for reconstructing the timing and extent of cycles of glacial advance and retreat (Karig and Miller, 2013; Kozlowski, 2020).

Starting from above the basal till and upon glacial retreat, the reverse sequence is observed, such that sediment size fines upward, from coarse gravel to sandy outwash and then to fine lacustrine silt and clay where glacial lakes were present for extended periods. In general, the overall thickness of a deposit indicates the duration the ice was at that setting. For example, thick deposits of coarse gravel represent an area where the ice front was stationary and nearby.

Glacial flow can be dynamic and respond variably to changes to climate, ice dynamics, and topography. Glacial flow can respond rapidly or become relatively stagnant if cut off from the main ice-sheet mass. Dynamic, fast-flowing glaciers lubricated at the base with water and soft and conformable fine sediment respond quickly and can form characteristic landforms such as streamlined hills, called drumlins and flutes (Briner, 2007). The fast-flowing glacier front typically has fractures, called crevasses, that allow meltwater and sediment from the surface of the glacier to drain to the bottom of the glacier and deposit small ridges in the crevasses. As meltwater and sediment reaches the bottom of the glacier, subglacial channels form which route water and sediment to the front of the glacier, where it is deposited as outwash and kames. Cobbles and gravels are deposited inside the subglacial tunnels and create sinuous cobble and gravel ridges, called eskers (fig. 7). If part of the glacier becomes cut off from the main ice flow and stagnates, the eskers are more readily preserved, along with ice block melt-out features such as kettle lakes and hummocky topography. Ice-contact, stratified deposits form near stagnant ice, resulting in coarse gravel and sand, with flat or slightly sloping landforms (Ashley and Warren, 1997). Glacial landforms in the study area are shown in figure 7.

Figure 7. Map of major glacial landforms in the lower Fall Creek valley study area in Tompkins and Cortland Counties, New York (DeMott and others, 2026b).

The unconsolidated deposits in the study area range up to 418 feet thick and consist mostly of glacial sediments with some postglacial sediments (figs. 8 and 9). Glacial sediments include unstratified and stratified deposits. Unstratified deposits in the study area are till, which is commonly referred to as “hardpan” by local water-well drillers. Till is present at the surface in the western part of the lower Fall Creek valley and in the uplands bordering the valley. Stratified glacial deposits including glaciolacustrine fine sand, silt, and clay, and glaciofluvial sand and gravel are present in the lower Fall Creek valley. The glaciolacustrine deposits, where present, are commonly more than 100 feet thick and form the confining units in the aquifer system. Glaciofluvial deposits are present at the land surface and (or) buried within or beneath till and glaciolacustrine sediments. Glaciofluvial deposits, which can be up to 100 feet thick in some areas, form the unconsolidated lower Fall Creek valley aquifer units. Postglacial deposits are generally less than 20 feet thick and include alluvium and wetland deposits. Alluvium consists of stratified silt, sand, and gravel deposited in stream channels, alluvial fans, and floodplains. Wetland deposits consist of organic-rich fine-grained sediment in low-lying areas with poor drainage.

Figure 8. Map showing the approximate thickness of the unconsolidated deposits in Tompkins and Cortland Counties, New York (DeMott and others, 2026b).

Figure 9. Surficial geologic map of the lower Fall Creek valley study area (modified from Leone and Backhaus, 2018, and Backhaus and others, 2019) and locations of hydrogeologic sections, Tompkins and Cortland Counties, New York (DeMott and others, 2026b).

Glacial sediments in the lower Fall Creek valley were grouped into four generalized zones that represent distinct hydrogeologic settings based on surficial and subsurface geology (fig. 10A–D). Zone 1, in the southwestern part of the valley, consists of an uppermost till unit as

much as 200 feet thick (figs. 11 and 12), underlain by a coarse sand and gravel layer over bedrock. Zone 2, near Etna and extending northeast, contains up to 100 feet of glaciolacustrine silt and clay beneath the till. In zone 3, from Freeville to McLean, the till pinches out and an unconfined sand and gravel aquifer overlies a clay layer which in turn confines a basal gravel layer. Zone 4 begins near McLean and transitions into the Valley Heads Moraine, discussed in detail below. A nearly continuous basal gravel layer underlies the till and glaciolacustrine deposits throughout the valley and rests on bedrock. Pockets of confined or unconfined sand and gravel are present in the predominantly till-covered uplands. Zones 2–4 are described in detail in the following paragraphs because of their more complex sequences.

Figure 10. Maps showing four sand and gravel aquifer zones and reported well yields. Aquifer and well yields are shown for domestic wells finished in (A) unconsolidated unconfined aquifers, (B) unconsolidated confined aquifers, (C) and bedrock aquifers, and for (D) nondomestic supply wells finished in all aquifer types, Tompkins and Cortland Counties, New York. Well locations and yields are primarily derived from New York State Department of Environmental Conservation domestic well log data base and available in (DeMott and others, 2026b).

Figure 11. Hydrogeologic section A–A' along the axis of lower Fall Creek valley in Tompkins and Cortland Counties, New York. Section line is shown on figures 5 and 9; horizontal scale differs from map scales. Not all thin surficial deposits (such as alluvium) are shown. NYSGS, New York State Geological Survey.

Figure 12. Hydrogeologic section B–B' across the southwestern part of the lower Fall Creek valley in Tompkins New York. Section line is shown on figures 5 and 9; horizontal scale of section differs from map scales. Not all thin surficial deposits (such as alluvium) are shown.

Figure 13. Hydrogeologic section C–C' across the central part of the lower Fall Creek valley in Tompkins County, New York. Section line is shown on figures 5 and 9; horizontal scale differs from map scales. Not all thin and discontinuous surficial deposits (such as alluvium or thin layers of till) may match exactly with figure 9 where mapping at such a fine resolution was beyond the scope of this project.

The central zones (zones 2 and 3), which include the Village of Freeville, contain alternating layers of till (zone 2 only), thick fine silt, and sand and gravel (hydrogeologic sections *A–A'* and *C–C'*; figs. 11 and 13). South along New York Route 38 (locally known as Freeville Road), northwest of Dryden (near what is formerly known as the RMS Gravel mine), a sand and gravel deposit up to 75 feet thick overlies an approximately 100-foot-thick layer of compacted, deformed silt. Beneath this silt is another sand and gravel layer, which overlies a second till layer and additional compacted silt. The lowermost sediment layer above bedrock is a nearly continuous basal gravel deposit.

The northeastern zone (zone 4) contains a thick sand and gravel deposit, as much as 150 feet thick, with a hummocky surface (figs. 11 and 14). Sparse silt lenses are present at land surface and within the sand and gravel in the northern part of the valley (fig. 14). Based on widespread observations of a thin gravel layer over bedrock, this basal gravel is inferred to be present throughout zone 4, except along valley margins where well records indicate till overlies bedrock. Near the northeastern edge of the valley, the USGS Tunison Laboratory of Aquatic Science has a dense network of wells and test borings (hydrogeologic section *A–A'*, fig. 11) with detailed logs that reveal subsurface complexity. Behind the thick gravel outwash head (as much as 140 feet thick) of the Valley Heads Moraine, a complex stack of units includes till, multiple buried sand and gravel lenses interlayered within thick glaciolacustrine silt and clay, and a basal

sand and gravel layer over bedrock. Similar discontinuous sand and gravel lenses are inferred in other parts of zone 3.

Figure 14. Hydrogeologic section *D–D'* across the northwestern part of the lower Fall Creek valley in Tompkins County, New York. Section line is shown on figures 5 and 9; horizontal scale of section differs from map scales. Not all thin surficial deposits (such as alluvium) are shown.

The lower Fall Creek valley is underlain by a complex hydrogeologic framework, with till and glaciolacustrine confining units and unconfined to confined sand and gravel aquifers. Fractured bedrock is generally a low-yielding aquifer but can act as a confining unit where poorly fractured. The major hydrogeologic units in the lower Fall Creek valley are (1) a confined basal gravel deposit that underlies most of the valley (zones 1-4); (2) a sand and gravel layer in the central and eastern part of the valley (zones 2-3), which is confined by a fine-grained silt and clay unit; and (3) an unconfined surficial sand and gravel deposit in the middle and eastern part of the valley (zones 3-4; figs. 10 to 14). In the vicinity of the Village of Freeville, this confined basal aquifer reaches its greatest thickness and confinement, and flowing artesian conditions are common (figs. 6 and 13).

Within the glaciolacustrine confining unit, which typically ranges in thickness from 50 to 125 feet and locally exceeds 200 feet, there are multiple discontinuous, confined sand and gravel aquifers. In the valley, the unconfined sand and gravel aquifer extends from the Village of Freeville to the northeastern boundary of the study area in Cortland County. This unconfined aquifer typically has a saturated thickness ranging from 10 to 60 feet, and in some places, it is greater than 100 feet (figs. 11, 13, and 14).

Groundwater Recharge, Flow, Discharge, and Use

Sources of natural recharge to the unconsolidated aquifer system in the study area include (1) infiltration of precipitation on the valley floor; (2) infiltration of unchanneled runoff from adjacent bedrock and till hillsides along the valley walls; (3) groundwater inflow from the bedrock and till uplands; and (4) infiltration from upland tributary streams, where they flow onto the valley floor and lose water to the subsurface. In valley areas underlain by very permeable surficial sand and gravel, surface runoff is negligible and nearly all precipitation that is not lost to evapotranspiration recharges the aquifer. Where the valley floor is underlain by till, glaciolacustrine deposits, and modern wetlands, most precipitation runs off the land surface and enters streams, and little water infiltrates to recharge underlying aquifers. Adjacent unchanneled till-mantled bedrock hillsides that are not drained by tributary streams provide recharge to the unconsolidated aquifers by infiltration of unchanneled runoff and groundwater inflow at the valley walls. Shallow groundwater inflow through till and fractured bedrock on unchanneled hills adjacent to the aquifer recharge the unconsolidated aquifers at the base of the hills and along the edges of the aquifer, except where Fall Creek is along the valley wall and the shallow groundwater flow enters the stream instead of the aquifer.

Recharge to confined unconsolidated aquifers occurs in some places near the valley walls where surficial sand and gravel deposits are in hydraulic connection with a confined aquifer (fig. 14). A substantial amount of groundwater flows through the unconfined aquifers toward areas of discharge, generally either Fall Creek or wetland areas. Wetlands are typically areas of high evapotranspiration losses. Groundwater in the confined aquifers generally flows toward the center of the valley and discharges in part by upward leakage through the confining unit or by direct (lateral) flow to the unconfined aquifers, where the confining unit is absent.

Groundwater Levels

Groundwater levels primarily fluctuate in response to seasonal variations in aquifer recharge. The hydrograph of median daily water levels in unconfined-aquifer well TM1968 near the hamlet of Slaterville Springs in Tompkins County (11 miles south of McLean, location not shown) shows the trend of typical seasonal water-level fluctuations from October 1, 2023, to October 30, 2024 (fig. 15*A*), of which a similar pattern is observed in the unconfined well near McLean (well TM1144) and the unconfined well (C1373) near the USGS Tunison Laboratory of Aquatic Science (fig. 15*B* and 15*D*).

Figure 15. Hydrographs of daily water levels for October 1, 2023, to October 30, 2024 and period-of-record median daily water levels in (A) unconfined-aquifer well TM1968 near the hamlet of Slaterville Springs, New York, to provide a local reference point; (B) unconfined production well C1373 near the U.S. Geological Survey Tunison Laboratory of Aquatic Science near Cortland, N.Y.; (C) confined artesian well TM3860 near the Village of Freeville, N.Y.; and (D) unconfined well TM1144 near the hamlet of McLean, N.Y (USGS 2024b).

Groundwater levels in the study area are at their lowest in late summer and early fall. In late fall and early winter, water levels rise as recharge increases because of the decrease in evapotranspiration at the end of the growing season. Water levels stabilize or decline slightly during the winter freeze, when the available recharge becomes smaller as precipitation is stored at land surface as snowpack, ice, and frozen ground. Water levels can rise abruptly when recharge increases from infiltration of rain and snowmelt during short-period thaws, which can happen anytime during the winter, and especially during the major spring thaw at the end of winter. In late spring, when the growing season begins and evapotranspiration increases, groundwater levels decline. From late spring to mid-to-late fall, groundwater levels generally

continue to decline, reaching their lowest levels in mid-to-late fall (fig. 15). Despite this general decline, large storms can result in short-term spikes in water levels due to these intermittent periods when rates of recharge exceed rates of discharge.

In the vicinity of the Village of Freeville, New York, both the upper and lower confined aquifers (figs. 11 and 13) exhibit flowing artesian conditions (the water level in both aquifers are under sufficient pressure to rise above the land surface without a pump in uncapped wells; fig. 6). The magnitude of flow (discharge) from such wells varies, depending on the specific location and depth of well completion within the artesian aquifer system. Artesian conditions in lower Fall Creek valley were first documented in the late 19th century (late 1800s), as noted in two undated manuscripts housed in the Cornell University Library's Division of Rare and Manuscript Collections (Cornell University Library, undated). These manuscripts describe wells completed in the Village of Freeville at depths of 150–250 feet and note that “none of the wells visibly affect either the supply or the two stories high of pressure . . . of any of the others,” indicating minimal well interference and artesian heads reaching about 20 feet above land surface.

To evaluate current conditions in the confined aquifer, a flowing artesian well (TM 3860) near the Village of Freeville was monitored during this study. Monthly artesian flow and hydraulic-head measurements made from November 2023 to November 2024 showed that flow rates ranged from about 6.4 to 7.5 gallons per minute (gal/min), and shut-in (flow-prevented) hydraulic heads ranged from about 26 to 29.5 feet above land surface (fig. 15C) (USGS, 2024b). These head and flow values are consistent with the historical descriptions from the late 1800s (Cornell University Library, undated). The confined aquifers beneath the Village of Freeville consist of two units that exhibit unusually high hydraulic heads that have been documented consistently for more than 140 years. These heads are similar in magnitude to those measured in

the middle and lower confined aquifers of the Virgil Creek and Dryden Lake valleys near the Town of Dryden, New York (Miller and Bugliosi, 2013). One hypothesis for the magnitude of the observed heads is that there is a hydraulic connection between the confined aquifers in the lower Fall Creek valley and those in the Virgil Creek and Dryden Lake valleys. Although the Dryden aquifer system contains three confined aquifers to the north, the lower two are the most plausible source of the heads observed in Freeville. However, the roughly 1-mile gap between the two areas lacks well data, preventing direct confirmation of this conceptual linkage. Despite this limitation, no alternative source of groundwater head has been identified that could account for the persistent flowing artesian conditions in Freeville. Therefore, for effective protection and management of the confined aquifers in the lower Fall Creek valley, planners and resource managers may need to consider a possible connection with the upgradient confined aquifer of the Virgil Creek and Dryden Lake valleys.

Groundwater and Surface-Water Interaction

Understanding groundwater and surface-water interaction is important for characterizing aquifer systems because it determines the direction and magnitude of water exchange between streams, lakes, and adjacent aquifers. These interactions influence aquifer recharge, discharge, and overall water availability. Identifying where surficial aquifers contribute water to streams helps define base-flow conditions, while recognizing areas where streams lose water to underlying aquifers is essential for understanding recharge processes. To evaluate groundwater and surface-water interaction in the study area, stream discharge was measured at 24 sites (table 2) along lower Fall Creek and its tributaries (fig. 16), indicating a mix of gaining and losing stream reaches.

Table 2. Surface water discharge measurements from 24 U.S. Geological Survey (USGS) sites along lower Fall Creek and its tributaries, used to identify gaining and losing stream reaches. Sites are organized from upstream to downstream (USGS, 2024b)

WDFN Site ID	Site Name	Map Number (Fig 16)	Flow in (ft ³ /s)
423425076174601	FALL CREEK AT DAVIS ROAD	1	11.996
423363505	BEAVER CREEK AT MOUTH	2	5.520
423236076173201	FALL CREEK NEAR BEAVER	3	20.280
423226076182201	FALL CREEK AT RED MILLS	4	20.689
423225076182201	FALL CREEK TRIB NO 1	5	0.210
423059076194701	FALL CREEK NEAR MUD CREEK	6	23.564
423364505	MUD CREEK AT MOUTH	7	0.325
423027076214901	FALL CREEK NEAR MILL CREEK	8	26.200
423365315	MILL CREEK AT MOUTH	9	2.197
423018076213501	FALL CREEK NEAR VIRGIL CREEK	10	27.528
423370105	VIRGIL CREEK AT MOUTH	11	21.142
423006076213301	FALL CREEK NORTH OF TRIB NO 2	12	49.115
423005076213201	FALL CREEK TRIB NO 2	13	0.419
423003076213701	FALL CREEK SOUTH OF TRIB NO 3	14	49.218
423003076213501	FALL CREEK TRIB NO 3	15	0.288
422943076221701	FALL CREEK AT MAIN STREET	16	50.812
422944076221701	FALL CREEK TRIB NO 4	17	0.114
422858076230601	FALL CREEK NORTH OF TRIB NO 5	18	52.700
422858076230301	FALL CREEK TRIB NO 5	19	0.523
4233740	FALL CREEK NEAR ETNA NY	20	52.200
422836076242301	FALL CREEK TRIB NO 6	21	0.537
422800076260401	FALL CREEK NORTH OF TRIB NO 7	22	54.400
422800076260101	FALL CREEK TRIB NO 7	23	0.015
422725076261801	FALL CREEK AT FREESE ROAD	24	55.000

In general, lower Fall Creek exhibited gaining conditions, with the most substantial increases in discharge (in cubic feet per second) observed between McLean and Freeville. These gains indicate substantial groundwater contributions to streamflow in these segments of the watershed. In contrast, localized losing reaches were identified southwest of both Freeville and

Etna, indicating areas where streamflow may be recharging underlying aquifers. However, some areas showing gains or losses may be within the range of measurement uncertainty ($\pm 5\%$); therefore, the patterns shown in figure 16 should be interpreted with caution.

Figure 16. Map showing gaining and losing sections of lower Fall Creek, in cubic feet per second, which are represented by the numbers above each gaining and losing section; Tompkins County, New York.

Streamflow measurements were collected on November 15, 2023 (DeMott and others, 2026b).

Normalizing streamflow by drainage area allows for meaningful comparisons of runoff and aquifer contributions across subwatersheds. Among the sites, the highest unit discharge—0.94 cubic feet per second per square mile ($[\text{ft}^3/\text{s}]/\text{mi}^2$)—was calculated for an unnamed tributary (Trib #3, fig. 16) entering lower Fall Creek from the south, just downstream from the Village of Freeville. Although this tributary drains a relatively small watershed (0.3 square mile), the presence of a number of beaver dams and associated impoundments likely enhances base flow and causes possible intertributary water transfers, which contribute to the unit discharge observed at this location.

Beaver Creek (fig. 16) also exhibited a high unit discharge ($0.65 [\text{ft}^3/\text{s}]/\text{mi}^2$) relative to other tributaries, which was likely influenced by groundwater contributions from the aquifer in Cortland County (Miller and others, 1998) at the backside of the Valley Heads Moraine, where many springs discharge from the aquifer into Beaver Creek. The USGS Tunison Laboratory of Aquatic Science uses the groundwater-fed springs to supplement its pumped-groundwater sources of water. Virgil Creek had the next highest unit discharge ($0.52 [\text{ft}^3/\text{s}]/\text{mi}^2$). Virgil Creek drains a large watershed encompassing the upper Virgil Creek and Dryden Lake valleys and may receive additional input from the upper confined aquifer identified by Miller and Bugliosi (2013).

Lower Fall Creek had an average unit discharge of $0.44 \text{ (ft}^3\text{/s)/mi}^2$ (range: $0.41\text{--}0.47 \text{ [ft}^3\text{/s)/mi}^2$), influenced by tributary inflows and proximity to measurement points. Unit discharge generally increased downstream but marginally declined in a 1.5-mile-long reach downstream from Etna. Geologic cross section *A–A'* shows that a thick, likely impermeable till (hardpan) layer underlies this reach limiting streambed leakance into the sand and gravel aquifer. Instead, losses may be due to lateral losses through the streambed alluvium, minor losses through the till unit, or an artifact of uncertainty in the discharge measurements.

Other tributaries showed variable unit discharge, which depended on watershed size, presence of beaver dams, and position relative to lower Fall Creek. Northern tributaries generally had lower unitized flows, which ranged from 0.04 to $0.31 \text{ (ft}^3\text{/s)/mi}^2$ and averaged $0.23 \text{ (ft}^3\text{/s)/mi}^2$. Southern tributaries, which commonly were influenced by beaver impoundments, had higher unitized flows than northern tributaries; southern tributaries ranged from 0.24 to $0.42 \text{ (ft}^3\text{/s)/mi}^2$ (excluding Trib #3, which had suspected intertributary water transfer) and averaged $0.35 \text{ (ft}^3\text{/s)/mi}^2$.

At the downstream end of upper Fall Creek at McLean, N.Y., the unit discharge was $0.33 \text{ (ft}^3\text{/s)/mi}^2$. Despite draining a relatively large watershed (approximately 40 square miles), its unit discharge was approximately half that of Beaver Creek, which drains a much smaller area (approximately 8.5 square miles), which may indicate limited groundwater storage in the upper Fall Creek Basin.

Groundwater Use

In the lower Fall Creek valley, groundwater is withdrawn for domestic and nondomestic use from wells and springs. Figure 17 presents the three most common types of well

constructions in the study area: screened, open end, and open hole. Wells tapping fractured bedrock are typically cased to competent rock and completed as open holes. Domestic wells tapping sand and gravel aquifers are typically completed with open-ended casing. Production wells constructed for higher yields from sand and gravel aquifers typically are screened. The locations of domestic and nondomestic wells in the study area are presented in figure 10 (*A–D*).

Figure 17. Types of well completions typical of the study area (modified from Williams and others, 1998).

In the lower Fall Creek valley, domestic water is self-supplied, with no public suppliers operating at the time of the study (2023). In the valley (fig. 8), confined sand and gravel aquifers are the predominant aquifer type that is tapped for domestic water supply (fig. 10*B*). Unconfined sand and gravel aquifers, although generally less utilized than the confined aquifer systems, are still an important water source (fig. 10*A*).

Finally, the bedrock underlying the unconsolidated deposits in the lower Fall Creek valley and in the uplands above the valley floor is also an important source of water in places where the sand and gravel aquifers were not encountered or were not productive during water-well drilling efforts. The bedrock underlying the valley and in the uplands to the north of the valley is generally shale and mudstone, whereas the bedrock south of the valley is generally siltstone and fine sandstone. Bedrock units typically yield a few gallons per minute, but occasionally water-well drillers have reported as much as 100 gal/min. Yields to wells from bedrock units vary, depending on the presence or absence of local bedrock fractures and whether the bedrock fractures are in a confined or unconfined condition (fig. 10*C*). In the lower Fall Creek valley, bedrock wells are not common in zones 2, 3 and 4 (fig. 10*c*), where the most productive sand and gravel aquifers dominate; however, bedrock wells are fairly common in aquifer zone 1 (fig. 10*C*), where the confined sand and gravel aquifers are less productive, too

thin, more silty, or absent. In the uplands, most wells tap bedrock because sand and gravel deposits are mostly absent and till does not typically yield a sufficient amount of water.

The number of domestic wells that tap the aquifers (bedrock and unconsolidated) was estimated using a visual count of homes by adding recent New York State tax parcels over the aquifer boundary and an orthoimagery basemap provided in ArcGIS pro. Tax parcel data that had information that identified a public source was omitted for later water-use calculations. Because there are no U.S. Census data available for the number of people living on the aquifer, the average number of people per household for Tompkins County, 2.06 (U.S. Census Bureau, 2020), was then multiplied by the estimated number of houses (900) to determine the estimated number of people that rely on the aquifer system (including bedrock) as their water source. The estimated number of people, 1,854, was then multiplied by 75, the estimated average water use per person per day, in gallons (Dieter and others, 2018). This led to an estimated groundwater withdrawal from domestic wells that tap the lower Fall Creek valley aquifer system (including bedrock wells) of 139,050 gallons per day or 50,753,250 gallons per year (table 3). Most of the groundwater withdrawal is from the unconsolidated aquifer system because most wells in the lower Fall Creek valley tap the sand and gravel aquifer system.

Table 3. Estimated domestic groundwater use in lower Fall Creek valley (sand and gravel aquifers and bedrock), Tompkins and Cortland Counties, New York.

[Data from Dieter and others (2018) and U.S. Census Bureau (2020)]

Estimated number of households that tap the aquifers in lower Fall Creek valley	Average number of persons per household	Estimated population	Average water use per person, in gallons per day	Estimated withdrawal, in gallons per day	Estimated annual withdrawal from aquifer, in gallons per year
900	2.06	1,854	75	139,050	50,753,250

Well Yield

Reported yields of more than 300 domestic wells and 26 nondomestic wells were analyzed to evaluate the water-yielding capabilities of the aquifers in lower Fall Creek valley (figs. 10 and 18; tables 4 and 5). Following completion of a well drilled for domestic supply, drillers estimate the yield of the well by bailing the well (if the well was drilled by the cable-tool method) or by blowing air through the drill stem and forcing water out of the well (if the well was drilled by the air-rotary or percussion method). Reported yields of domestic wells from drillers' acceptance tests generally underestimate the potential yield of productive aquifers because (1) drilling commonly is stopped after an adequate yield is obtained (5 to 10 gal/min for domestic supply), (2) domestic wells are not constructed for high yields (well screens are not typically used), (3) yield estimates from bailing are limited by how fast the driller can remove the well water, and (4) a substantial amount of water blown by the airlift methods may be forced back into the aquifer rather than pushed to the surface. Conversely, reported yields determined by drillers commonly overestimate the potential yield of low-yield aquifers because tests typically are less than 1 hour in length and may be affected by well-bore storage, and drillers rarely report yields of less than 3 gal/min (minimal yield required for a domestic supply). However, besides these limitations, an analysis of reported yields of domestic wells can be used to determine the relative water-yielding capabilities of the aquifers.

Figure 18. Boxplots of reported well yields for (A) domestic wells and (B) nondomestic wells, in the lower Fall Creek valley study area, Tompkins and Cortland Counties, New York. Data are from DeMott (2026b).

Table 4. Summary of reported yields for domestic wells and nondomestic wells by aquifer type (fig. 18), Tompkins and Cortland Counties, New York.

[Reported yields are available in DeMott and others (2026b). The unconsolidated wells are in the lower Fall Creek valley only, whereas the bedrock wells are within the boundary of the entire study area]

Aquifer type	Number of wells	Well depth—median, in feet below land surface	Well yield—median, in gallons per minute
Domestic wells			
Bedrock	157	196	6
Unconsolidated—confined	90	109	12
Unconsolidated—unconfined	54	50	12
Nondomestic wells			
Bedrock	11	220	15
Unconsolidated—confined	8	123	90
Unconsolidated—unconfined	7	60	150

Table 5. Well properties, specific capacity, and estimated aquifer transmissivity and hydraulic conductivity of selected production and test wells at the U.S. Geological Survey Tunison Laboratory of Aquatic Science near Cortland, New York. Data available in DeMott and others (2026b)

[—, no data or not applicable]

Well name	Well depth, in feet below land surface	Top of opening, in feet below land surface	Bottom of opening, in feet below land surface	Yield, in gallons per minute	Drawdown, in feet	Specific capacity, in gallons per minute per foot of drawdown	Transmissivity, in feet squared per day	Hydraulic conductivity, in feet per day	Aquifer type
C 138	52	40	50	150	17	8.9	3,000	330	Confined sand and gravel
C 139	60	—	—	100	—	—	—	—	Unconfined sand and gravel
C 140	69	64	69	100	18	5.5	2,900	160	Confined sand and gravel
C 143	185	—	—	42	3.5	12	—	—	Confined sand and gravel
C 148	81	—	—	570	60	9.5	—	—	Confined sand and gravel

C 151	135	136	139	70	109	0.64	—	60a	Confined sand and gravel
C 152	79	—	—	45	—	—	—	880	Unconfined sand and gravel
C 155	60	—	—	37	—	—	—	—	Unconfined sand and gravel
C 291	137	115	125	80	80	1.0	340	34	Confined sand and gravel
C432	90	68	90	1,430	—	—	—	—	Unconfined sand and gravel
C1461	127	96	125	1,000	10	100	23,000	660	Unconfined sand and gravel

Reported yields of domestic wells are summarized by aquifer type in table 4 and figures 10A–C and 18A. Note that the unconsolidated wells are in the lower Fall Creek valley only, and the bedrock wells are within the boundary of the entire study area. Unconsolidated aquifers generally have higher domestic well yields than those for bedrock aquifers. The median reported yield for wells completed in unconfined and confined unconsolidated aquifers is 12 gal/min, whereas that for bedrock aquifers is 6 gal/min. The interquartile range of reported yields for domestic wells completed in the confined aquifers was from 6 to 19 gal/min for confined aquifers, from 10 to 15 gal/min for unconfined aquifers, and from 3 to 12 gal/min for bedrock (fig. 18A).

Reported yields from production and test wells drilled for nondomestic uses, including fishery, industrial, livestock, irrigation, and mining, in the lower Fall Creek valley provide a more accurate measure of water-yielding capabilities than yields from domestic wells. Nondomestic wells are constructed to maximize well yield (they are drilled deep enough to penetrate a substantial thickness of the aquifer and, for those tapping unconsolidated aquifers, typically are screened and have larger diameter casings than domestic wells). High-yield wells typically are tested for yield by use of a submersible or turbine pump. Pumping a well at a

constant rate for an extended period provides a good yield estimate without the multiple limitations associated with short-term driller tests of domestic wells.

Reported yields of nondomestic wells are summarized by aquifer type in table 4 and figures 18*B* and 10*D*. For nondomestic wells, the difference in yields between unconsolidated aquifers (confined and unconfined) and bedrock is pronounced. Median reported yields for nondomestic wells completed in confined and unconfined unconsolidated aquifers are 90 and 150 gal/min, respectively, whereas that for bedrock aquifers is 15 gal/min (fig. 18*B*). The interquartile range of reported yields for nondomestic wells ranged from 68 to 178 gal/min for wells finished in confined aquifers, 59–425 gal/min for unconfined aquifers, and 9–40 gal/min for bedrock (fig. 18*B*). The largest nondomestic well yields were in the northeastern section of the study area (Beaver Creek tributary valley) and were installed for the USGS Tunison Laboratory of Aquatic Science (fig. 10*D*).

Specific Capacity, Aquifer Transmissivity, and Hydraulic Conductivity

Understanding key hydraulic properties—such as specific capacity, transmissivity, and hydraulic conductivity—is essential for evaluating aquifer productivity and managing groundwater resources. These parameters help characterize how water moves through aquifer materials and how wells respond to pumping, which is critical for water-supply planning and groundwater modeling.

Specific capacity is a measure of a well's production potential, expressed as the ratio of pumping rate to drawdown. Higher specific capacity values indicate a more productive aquifer with less water-level decline during pumping. Specific capacity is commonly used to estimate transmissivity, which represents the rate at which water moves through the full saturated

thickness of an aquifer. Aquifers with high transmissivity values typically experience less drawdown in wells, whereas low transmissivity aquifers are less productive and more susceptible to drawdown. Hydraulic conductivity is a fundamental property of aquifer materials that describes how easily water can move through pore spaces or fractures; it is used, along with aquifer thickness, to calculate transmissivity. Seven specific-capacity values were computed from pumping tests conducted in test and production wells at the USGS Tunison Laboratory of Aquatic Science near Cortland, N.Y., during 1962–2005 (table 5). The seven tested wells were pumped for 24 to 72 hours at rates that ranged from 42 to 1,000 gal/min. Drawdown, which is pumping water level at the end of the test minus static water level, was measured, allowing calculation of specific capacity, which is the pumping rate divided by the drawdown. The median specific capacity for six wells that tap the confined sand and gravel aquifer was 7.2 gallons per minute per foot of drawdown. The specific capacity of production well C1461, which is finished in the unconfined aquifer, was 100 gallons per minute per foot of drawdown.

Aquifer transmissivity and hydraulic conductivity were estimated from the specific-capacity test data through the analytical method described by Bradbury and Rothschild (1985). Hydraulic conductivity, expressed in feet per day (ft/d), is the rate at which water flows through a unit cross-sectional area of an aquifer under a unit hydraulic gradient. Transmissivity, expressed in feet squared per day (ft²/d), is the rate at which water flows under a unit hydraulic gradient through a unit width of an aquifer and is the product of the aquifer saturated thickness and hydraulic conductivity. Table 5 presents the estimated transmissivity and hydraulic conductivity for the aquifers at the USGS Tunison Laboratory of Aquatic Science. Estimated transmissivity values for well sites tapping 9- to 18-foot-thick confined aquifers ranged from 340 to 3,000 ft²/d, and estimated hydraulic conductivity values ranged from 34 to 330 ft/d, which is

consistent with values for silty to clean sand and gravel. The estimated transmissivity for production well C1461, tapping a 40-foot-thick unconfined aquifer, was 23,000 ft²/d, and the estimated hydraulic conductivity was 660 ft/d, which is consistent with values for coarse sand and gravel. Even with this high transmissivity and hydraulic conductivity, during drought conditions of fall 2020, the pumping rate from this well had to be reduced from 650 gal/min to 200 gal/min to raise the pumping water level and avoid cavitation at the pump (Paul Wells, USGS, oral communication, 2020). This situation emphasizes the susceptibility of unconfined aquifers to drought conditions.

Water Quality

The following subsections discuss water quality analysis of both groundwater and surface water in the Lower Fall Creek study area.

Groundwater Quality in the Lower Fall Creek Study Area

Groundwater in the lower Fall Creek valley was characterized as calcium-bicarbonate type waters, and groundwater in selected wells completed in bedrock units from the study area was typically characterized as mixed type (fig. 19). The locations of wells with water-quality data are shown in figure 4. Hard water was prevalent in both unconsolidated and bedrock aquifers across the groundwater-quality dataset for the study area. Durfor and Becker (1964) established calcium and magnesium hardness of greater than 180 milligrams per liter (mg/L) as CaCO₃ as “very hard” and calcium and magnesium hardness of 121 to 180 mg/L as CaCO₃ as “hard.” Almost all samples in this study area exceeded the threshold for designation as “very hard” ($n=12$ of 13). Groundwater wells in unconfined unconsolidated aquifers were likely more susceptible than other wells to detections of constituents that may be introduced through the land

surface (for example, nitrate from agricultural practices and septic leachate, and chloride from anthropogenic practices such as winter deicing), but concentrations of nitrate, sodium, and chloride also occurred in deep wells finished in bedrock. Groundwater wells completed in confined unconsolidated settings tended to have elevated concentrations of redox-sensitive geogenic constituents, such as arsenic, iron, and manganese, relative to wells in other settings, but the small sample size of our dataset precluded quantitative confirmation of these patterns. Statistical results for groundwater quality in the four wells sampled in the unconsolidated aquifers in lower Fall Creek valley in 2023 are provided in table 6, and statistical results for all 12 wells sampled in the unconsolidated aquifers and in bedrock in the study area from 2000 through 2023 are provided in table 7.

Figure 19. Piper trilinear diagram displaying relative proportion of major ions (in percent milliequivalents per liter) for surface-water and groundwater samples in the lower Fall Creek valley study area, Tompkins and Cortland Counties, New York. Sample concentration data are available in the U.S. Geological Survey (USGS) Water Data for the Nation (WDFN; USGS, 2024b).

Table 6. Descriptive statistics for groundwater-quality results from U.S. Geological Survey (USGS) wells TM3860, TM1144, TM1145, and TM1146 collected for this study in 2023 in Tompkins County, New York. Sample concentration data are available in the USGS Water Data for the Nation (WDFN; USGS, 2023).

[U.S. Environmental Protection Agency (EPA) maximum contaminant levels (MCLs) and secondary maximum contaminant levels (SMCLs) are listed in EPA (2025, 2026). Concentration results correspond to the dissolved fraction for major ions, nutrients, arsenic, manganese, and iron. Concentration results for alkalinity were reported as the total fraction. Samples below the detection limit were excluded from statistics. mg/L, milligram per liter; CaCO₃, calcium carbonate; Ca, calcium; Mg, magnesium; °C, degree Celsius; µS/cm, microsiemens per centimeter; N, nitrogen; P, phosphorus; µg/L, microgram per liter; —, not applicable]

Constituent	Number of samples	Minimum	Maximum	Median	EPA MCL or SMCL
Alkalinity (mg/L CaCO ₃)	4	190	280	200	—
Ca, Mg hardness (mg/L CaCO ₃)	4	152	323	207	—
pH	4	8.08	8.19	8.11	SMCL: 6.5–8.5

Temperature (°C)	4	11	18.8	14.4	—
Total dissolved solids (mg/L)	4	220	609	247.5	SMCL: 500
Specific conductance (µS/cm at 25 °C)	4	350	1,080	387	—
Chloride (mg/L)	4	1.25	175	4.46	SMCL: 250
Sulfate (mg/L)	4	16.8	27.8	24.85	SMCL: 250
Nitrate (mg/L as N)	1	0.27	0.27	0.27	MCL: 10
Orthophosphate (mg/L as P)	2	0.01	0.01	0.01	—
Calcium (mg/L)	4	40.6	99.4	53.3	—
Magnesium (mg/L)	4	12.2	18.3	17.85	—
Potassium (mg/L)	4	0.95	3.2	1.06	—
Sodium (mg/L)	4	9.27	110	16.76	—
Arsenic (µg/L)	4	0.39	2	0.42	MCL: 10
Iron (µg/L)	4	130	891	236.5	SMCL: 300
Manganese (µg/L)	4	130	270	185	SMCL: 50

Table 7. Descriptive statistics for groundwater-quality results from samples collected from 12 U.S.

Geological Survey (USGS) wells in the study area from 2000 through 2023, Tompkins County, New York.

Individual samples did not always include results for every analyte. Sample concentration data are available in the USGS Water Data for the Nation (WDFN; USGS, 2024b).

[U.S. Environmental Protection Agency (EPA) maximum contaminant levels (MCLs) and secondary maximum contaminant levels (SMCLs) are listed in EPA (2025, 2026). Concentration results correspond to the dissolved fraction for major ions, nutrients, arsenic, manganese, and iron in all but one sample. Concentration results for alkalinity were reported as the dissolved fraction for samples collected before 2023. Samples below the detection limit were excluded from statistics. mg/L, milligram per liter; CaCO₃, calcium carbonate; Ca, calcium; Mg, magnesium; °C, degree Celsius; µS/cm, microsiemens per centimeter; N, nitrogen; P, phosphorus; µg/L, microgram per liter; —, not applicable]

Constituent	Number of samples	Minimum	Maximum	Median	EPA MCL or SMCL
Alkalinity (mg/L CaCO ₃)	12	131	367	172	—
Ca, Mg hardness (mg/L CaCO ₃)	12	152	442	224	—
pH	12	7.4	8.19	7.8	SMCL: 6.5–8.5
Temperature (°C)	12	8.3	18.8	9.45	—
Dissolved oxygen (mg/L)	8	0.1	9.1	1.05	—
Total dissolved solids (mg/L)	12	220	609	269	SMCL: 500
Specific conductance (µS/cm at 25 °C)	8	450	787	488.5	—
Chloride (mg/L)	12	1.25	175	29.2	SMCL: 250
Sulfate (mg/L)	12	14	47.9	25	SMCL: 250
Nitrate (mg/L as N)	6	0.27	6.56	4.22	MCL: 10
Ammonia and ammonium (mg/L as N)	3	0.108	0.175	0.108	—
Orthophosphate (mg/L as P)	3	0.004	0.007	0.006	—
Calcium (mg/L)	12	40.6	122	62.8	—
Magnesium (mg/L)	12	12.2	33.4	17.9	—

Potassium (mg/L)	12	0.7	3.2	0.92	—
Sodium (mg/L)	12	4.68	110	13.3	—
Arsenic (µg/L)	5	0.33	2.00	0.4	MCL: 10
Iron (µg/L)	10	8.3	940	161	SMCL: 300
Manganese (µg/L)	9	1.11	270	180	SMCL: 50

Groundwater quality in the lower Fall Creek valley study area generally met drinking-water standards, with concentrations below maximum contaminant levels (MCLs) and secondary maximum contaminant levels (SMCLs) established for the protection of health by the EPA and adapted by the New York State Department of Health (NYSDOH) (tables 6 and 7).

Concentrations of several chemical constituents were above the EPA SMCLs for drinking water. Iron exceeded the SMCL of 300 µg/L in two of 10 wells finished in the unconsolidated aquifers in this study area (20 percent), with concentrations ranging from 8.3 to 940 µg/L. Manganese exceeded the SMCL of 50 µg/L in seven of nine samples (78 percent) in each aquifer setting, with a maximum concentration of 270 µg/L. There is currently no Federal or State drinking-water standard for sodium, but NYSDOH recommends that drinking water for individuals following severely restricted sodium diets not exceed 20 mg/L (New York State Department of Health, 2019). Sodium exceeded 20 mg/L in two of 12 samples (17 percent) in wells finished in the confined unconsolidated aquifer and bedrock aquifers in the study area and had a maximum concentration of 110 mg/L.

Arsenic in Groundwater in the Lower Fall Creek Valley

Arsenic in groundwater in Tompkins County has received considerable public attention. Eight percent of over 800 groundwater samples in Tompkins County exceeded the NYSDOH MCL for arsenic in a study conducted by the Water Resources Council of Tompkins County (WRCTC) between 2000 and 2012 (Aquifer Committee of the Tompkins County Water Resources Council, 2014). Several arsenic concentrations above the EPA maximum contaminant

level were observed in aquifers in the lower Fall Creek valley (particularly near Etna) and in the contiguous aquifers in neighboring Virgil Creek valley (Aquifer Committee of the Tompkins County Water Resources Council, 2014). The highest concentrations of arsenic in the WRCTC study were found in wells completed in confined unconsolidated aquifers. Arsenic concentrations in this study were notably lower (0.33 to 2.0 µg/L) than previous observations (Aquifer Committee of the Tompkins County Water Resources Council, 2014), but the small sample size ($n=4$) likely fails to capture the inherent variability of the aquifer system for this constituent. Therefore, caution should be taken in assuming the results fully characterize the expected concentration range in all wells. Although arsenic concentrations in sample results for this study were below the EPA MCL of 10 µg/L, arsenic was detected above laboratory reporting levels in all four samples collected, with the maximum concentration of 2.0 µg/L in well TM3860, completed in a confined unconsolidated aquifer. Although arsenic is a naturally occurring constituent, its presence in drinking water can be dependent on site-specific conditions and temporal variability.

Surface-Water Quality in the Lower Fall Creek Valley

Surface-water quality of Fall Creek generally mirrored that of shallow groundwater (fig. 19), with major-ion geochemistry classified as calcium-bicarbonate type waters. Because samples were collected during seasonal low flows in August (recorded at the downstream instantaneous USGS streamgage: Fall Creek near Ithaca, N.Y., station 04234000; USGS, 2024b), flow was likely composed mostly of contributions from groundwater that discharged into the stream channel. Sodium exceeded 20 mg/L in a single sample, which had a result of 23.3 mg/L. The remainder of the chemical constituents were below relevant standards meant to protect public health and sensitive aquatic organisms (table 8).

Table 8. Descriptive statistics for surface-water-quality results for three samples collected from Fall Creek for this study (refer to table 1 and fig. 4 for locations), Tompkins County, New York. Sample data are available from the U.S. Geological Survey (USGS) Water Data for the Nation (WDFN; USGS, 2024b).

[U.S. Environmental Protection Agency (EPA) maximum contaminant levels (MCLs) and secondary maximum contaminant levels (SMCLs) are listed in EPA (2025, 2026). mg/L, milligram per liter; CaCO₃, calcium carbonate; Ca, calcium; Mg, magnesium; °C, degree Celsius; µS/cm, microsiemens per centimeter; N, nitrogen; P, phosphorus; —, not applicable]

Constituent	Number of samples	Minimum	Maximum	Median	EPA MCL or SMCL ²
Alkalinity (mg/L CaCO ₃)	3	140	170	150	—
Ca, Mg hardness (mg/L CaCO ₃)	3	160	196	165	—
pH	3	8.25	8.37	8.29	SMCL: 6.5–8.5
Temperature (°C)	3	23.1	26.9	24.2	—
Total dissolved solids (mg/L)	3	199	243	228	SMCL: 500
Specific conductance (µS/cm at 25 °C)	3	346	423	403	—
Chloride (mg/L)	3	22.9	40.9	30.8	SMCL: 250
Sulfate (mg/L)	3	8.03	12.2	11.1	SMCL: 250
Nitrate (mg/L as N)	3	0.33	0.91	0.80	MCL: 10
Orthophosphate (mg/L as P)	3	0.005	0.011	0.006	—
Calcium (mg/L)	3	47	58	50	—
Magnesium (mg/L)	3	8.5	12.6	11.5	—
Potassium (mg/L)	3	1.23	1.62	1.34	—
Sodium (mg/L)	3	13.9	23.3	17.7	—

Summary

This report presents the results of a hydrogeologic investigation of the lower Fall Creek valley aquifer system, mostly in Tompkins County and a small part of Cortland County, New York, by the U.S. Geological Survey, in cooperation with Tompkins County and the Town of Dryden. The report describes the geologic setting, aquifer framework, groundwater and surface-water quality, groundwater and surface-water interaction, and groundwater use associated with the unconsolidated aquifer system in the lower Fall Creek valley. The region’s unconsolidated deposits and aquifers have been significantly shaped by multiple glacial advances and retreats,

which have influenced the aquifer framework and groundwater-flow characteristics of the aquifer units.

For the approximately 2,300 people that live over the aquifers, groundwater is the sole source of drinking water. Most withdrawals are from a confined basal sand and gravel aquifer that overlies bedrock throughout much of the valley. In some areas, such as near the Village of Freeville, this aquifer is artesian, with potentiometric heads exceeding 25 feet above land surface. Additional water supply is derived from the unconfined sand and gravel aquifer and from bedrock aquifers. The unconfined aquifer is less extensive than the confined aquifers but is locally important. Unconsolidated aquifer areas in the study area are potentially susceptible to contamination from farm runoff, pesticides, and other chemicals that are applied on land surface.

Groundwater in the study area is generally characterized as hard, having elevated concentrations of redox-sensitive constituents such as iron and manganese. Groundwater generally meets available Federal and State drinking-water standards. Arsenic was not detected above the maximum contaminant level in the four groundwater samples analyzed as a part of this study but remains a regional concern and has been reported above the MCL in other local studies.

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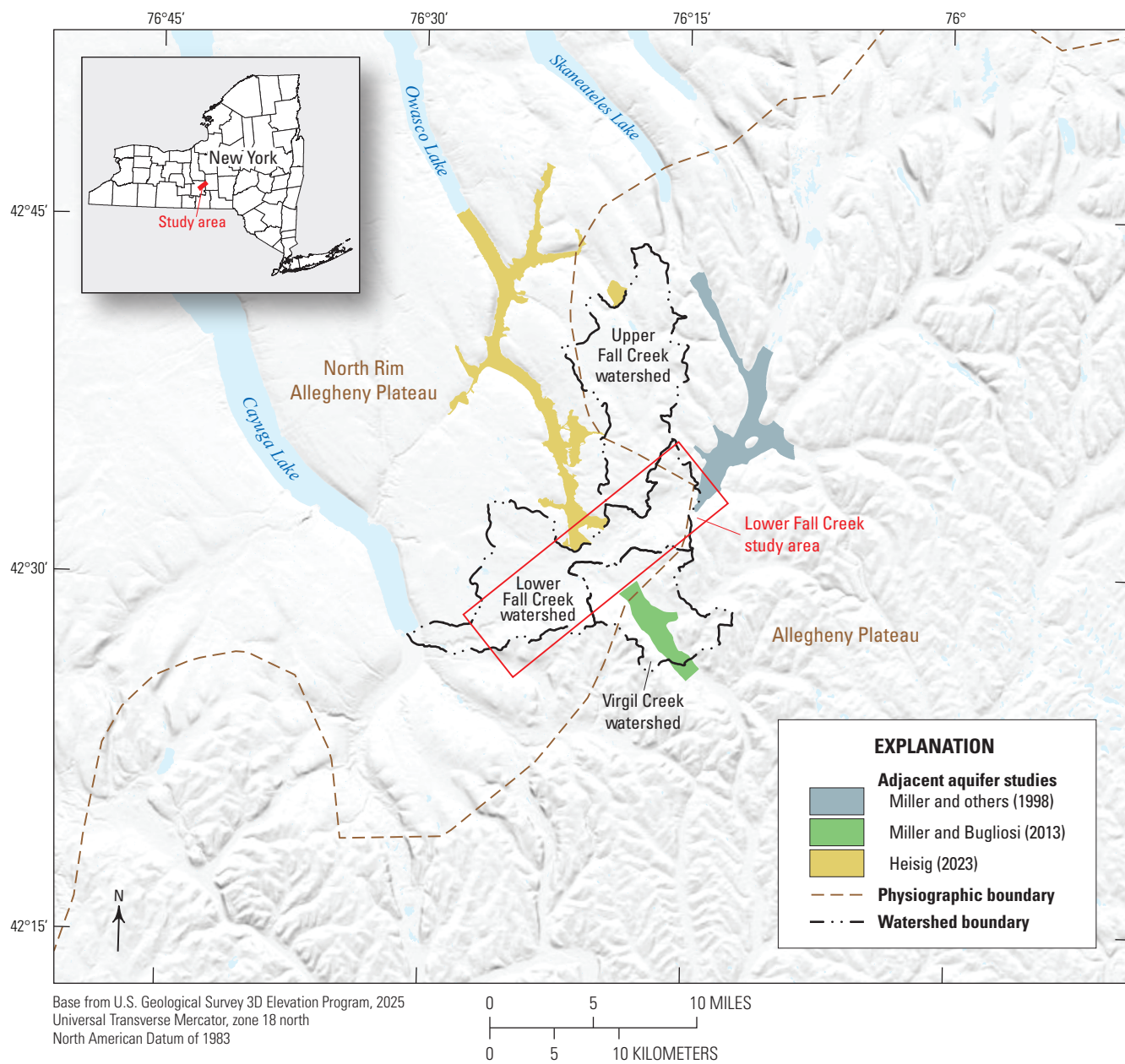
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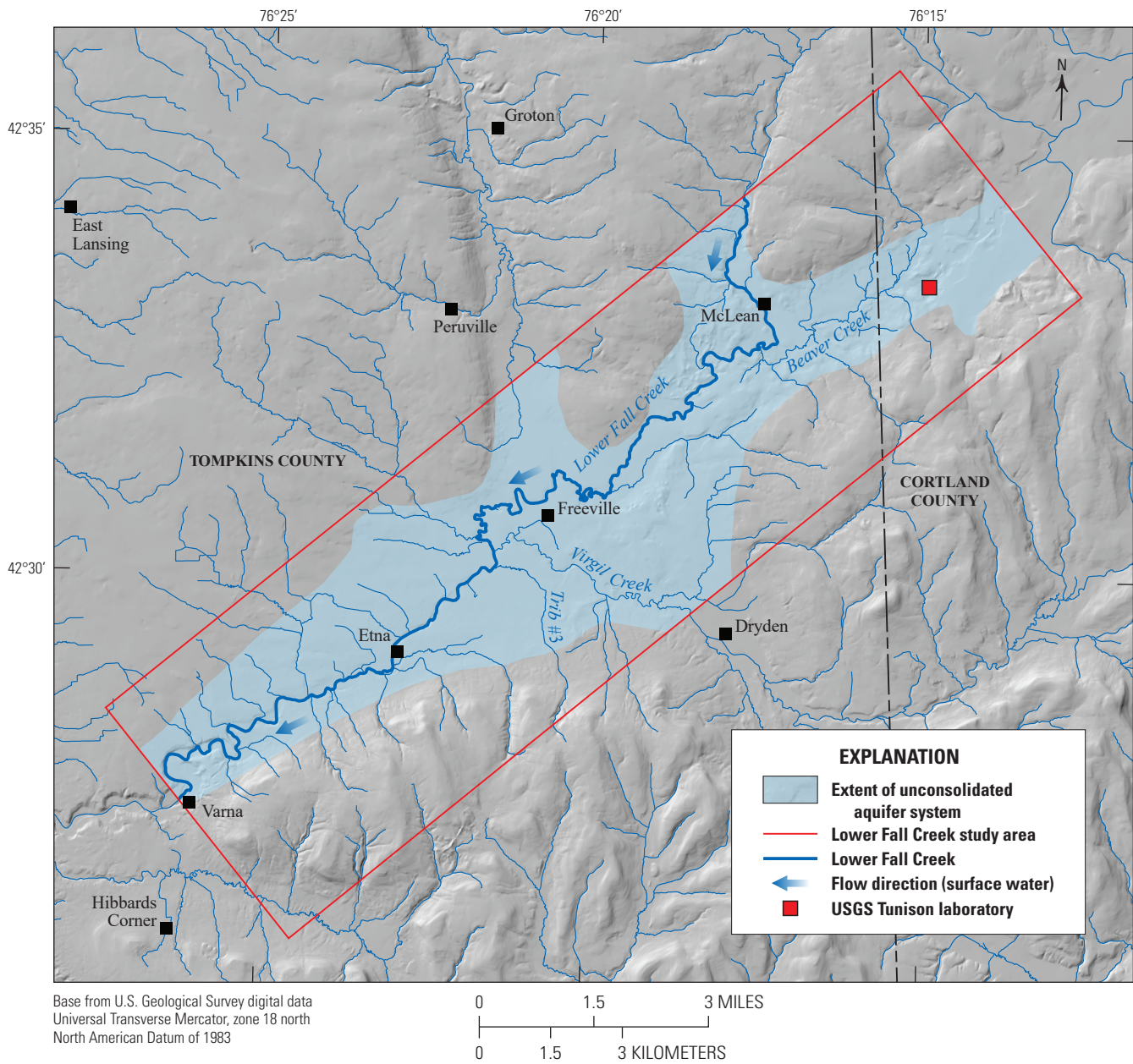
U.S. Geological Survey, 2024c, Water Quality Portal: U.S. Geological Survey database, accessed January 31, 2025, at <https://www.usgs.gov/tools/water-quality-portal>.

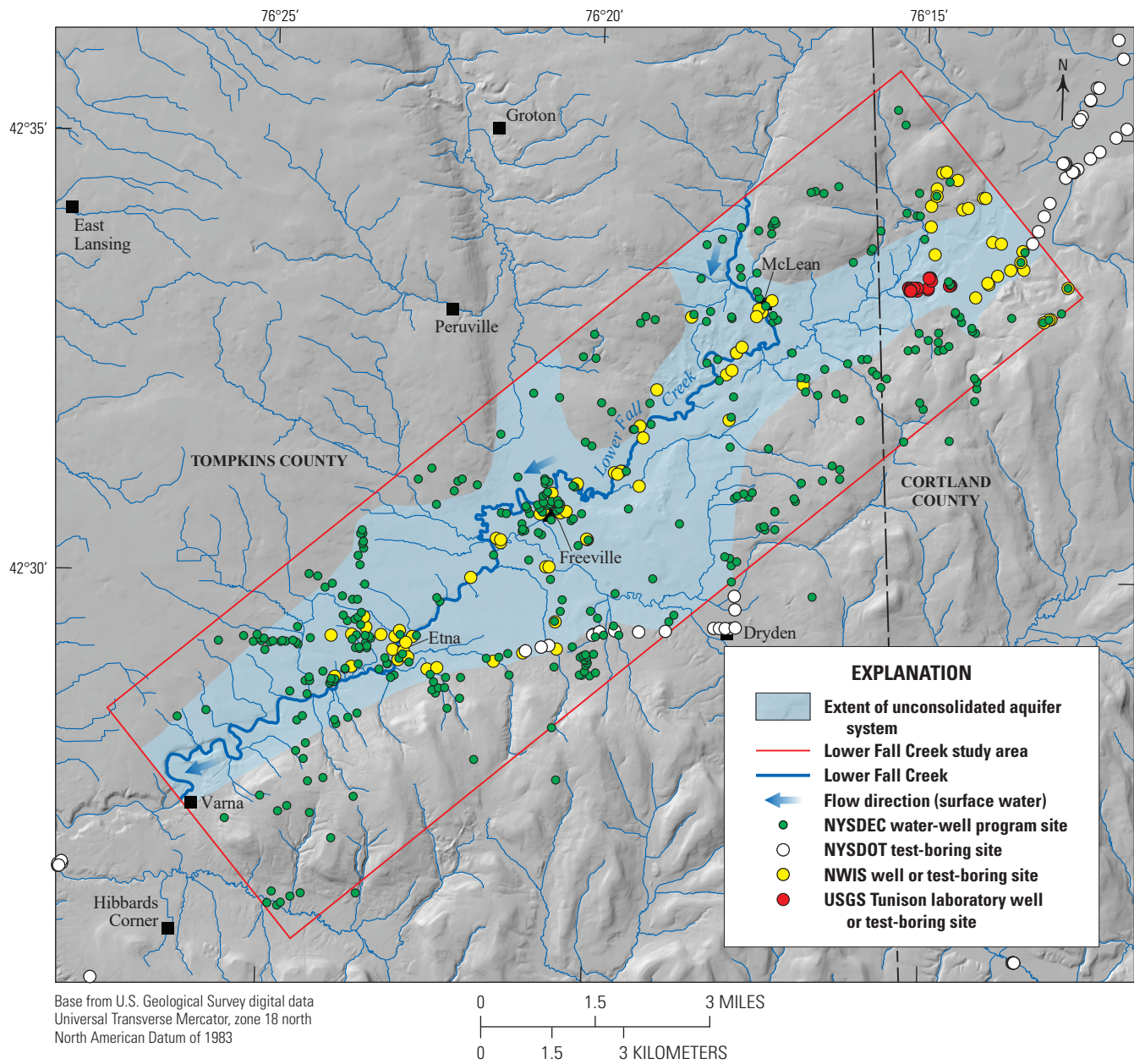
U.S. Geological Survey, [variously dated], National field manual for the collection of water-quality data, sec. A of Handbooks for water-resources investigations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1–A8, accessed January 31, 2024, at <https://www.usgs.gov/mission-areas/water-resources/science/national-field-manual-collection-water-quality-data-nfm>.

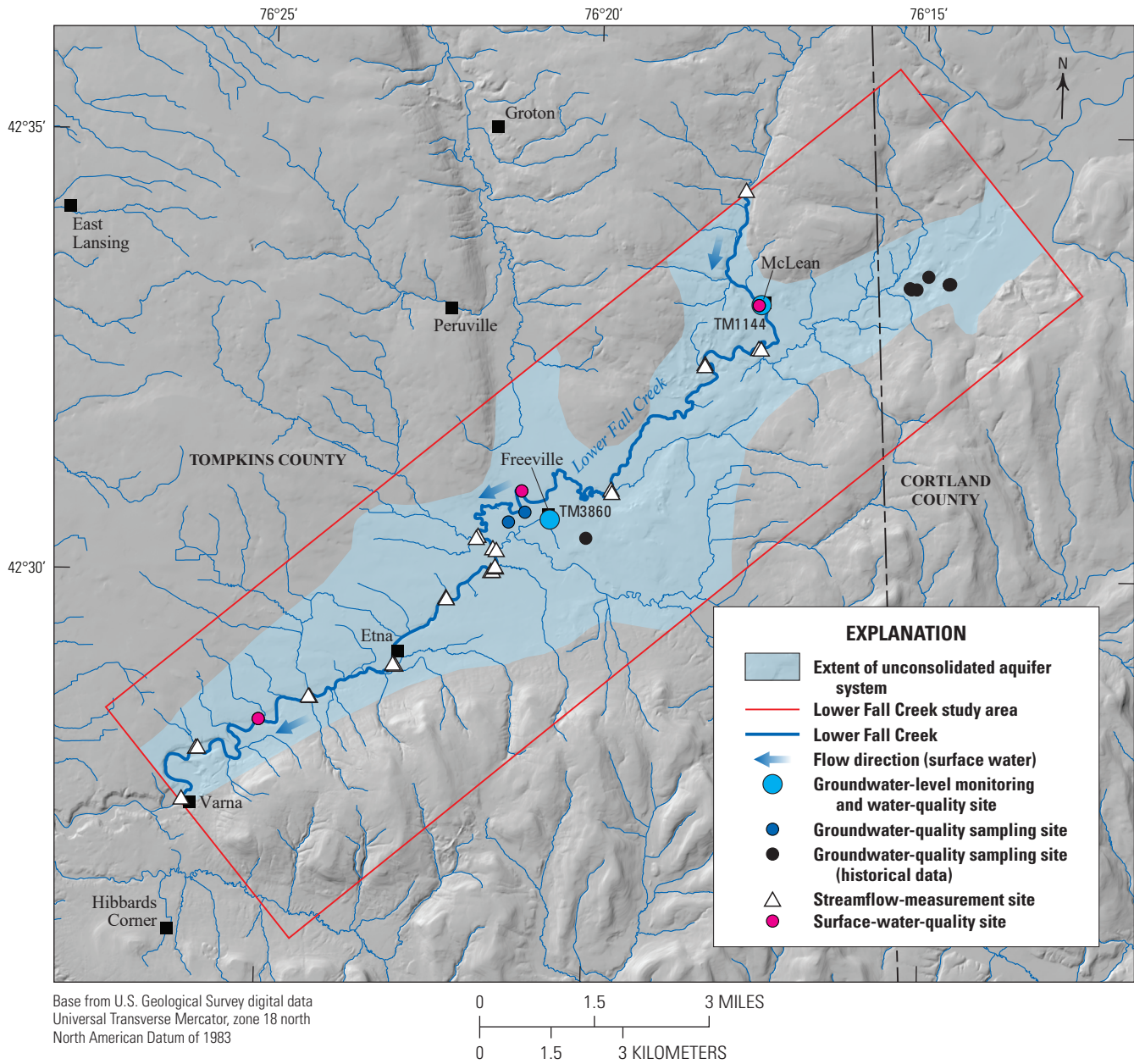
U.S. Geological Survey, [undated], Soil and Low-Ionic-Strength Water Quality Laboratory: U.S. Geological Survey web page, accessed January 2024 at <https://www.usgs.gov/centers/new-york-water-science-center/soil-and-low-ionic-strength-water-quality-laboratory>.

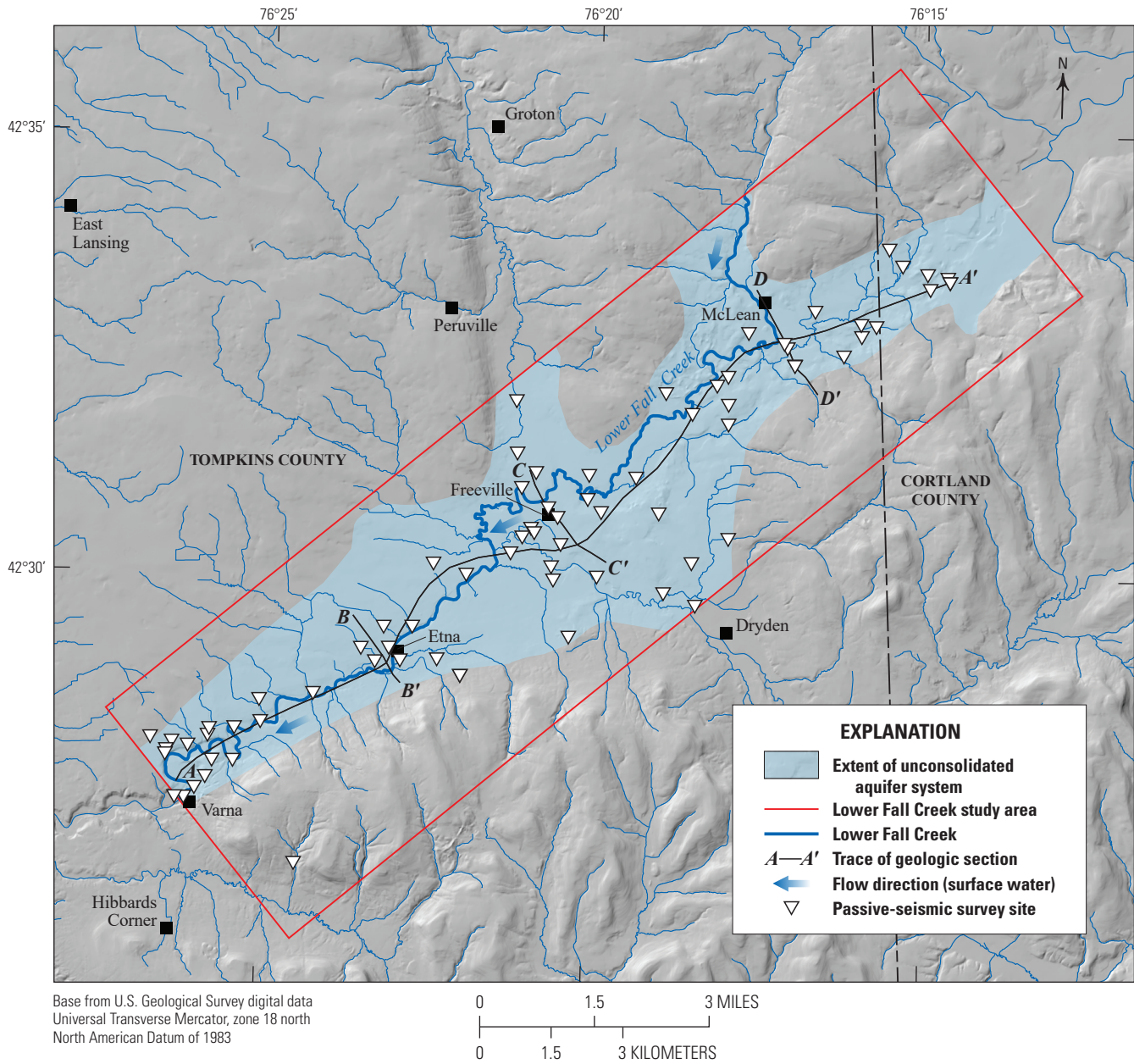
Williams, J., Taylor, L., and Low, D., 1998, Hydrogeology and groundwater quality of the glaciated valleys of Bradford, Tioga, and Potter Counties, Pennsylvania: U.S. Geological Survey Water Resource Report 68, 89 p.



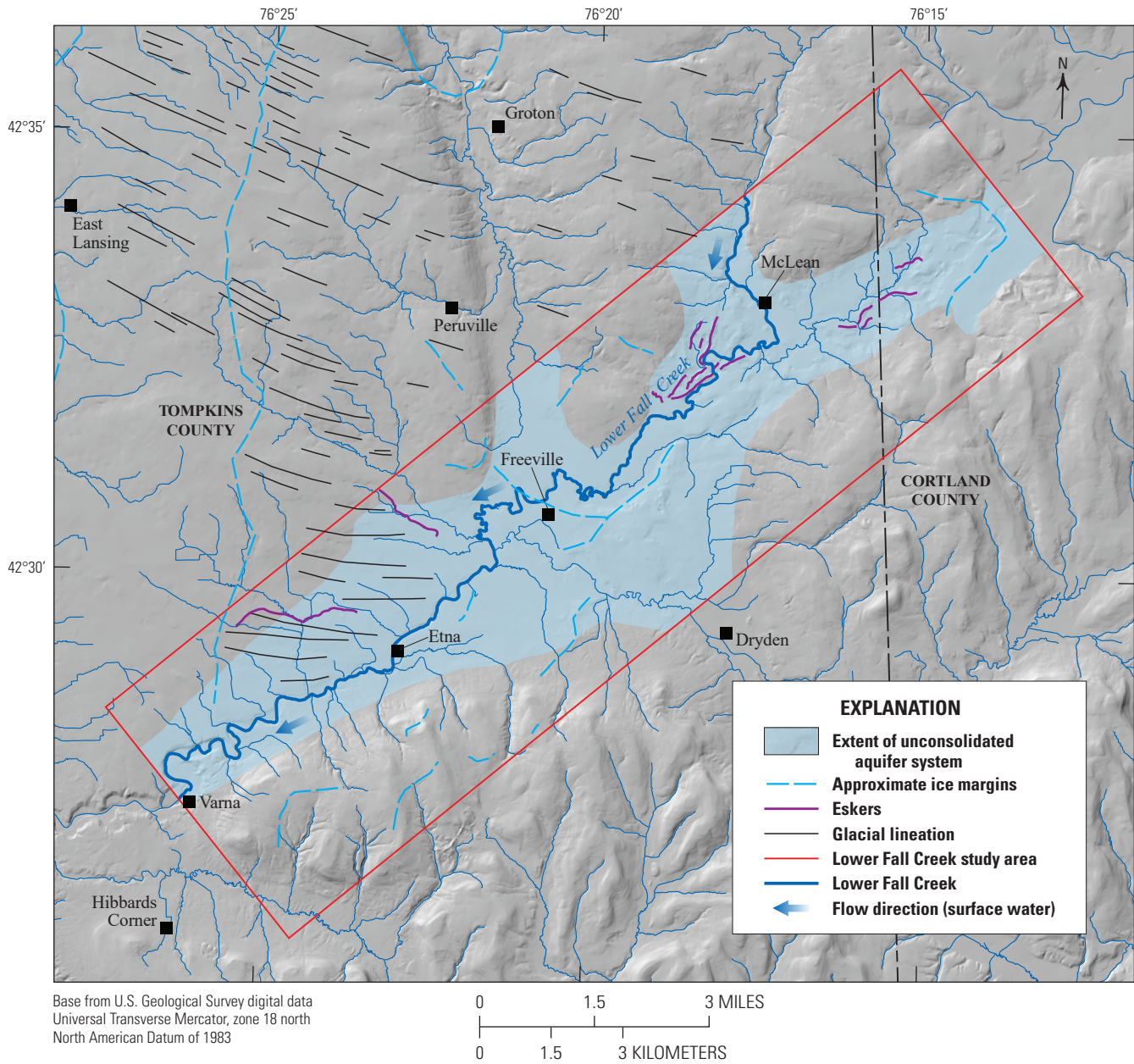


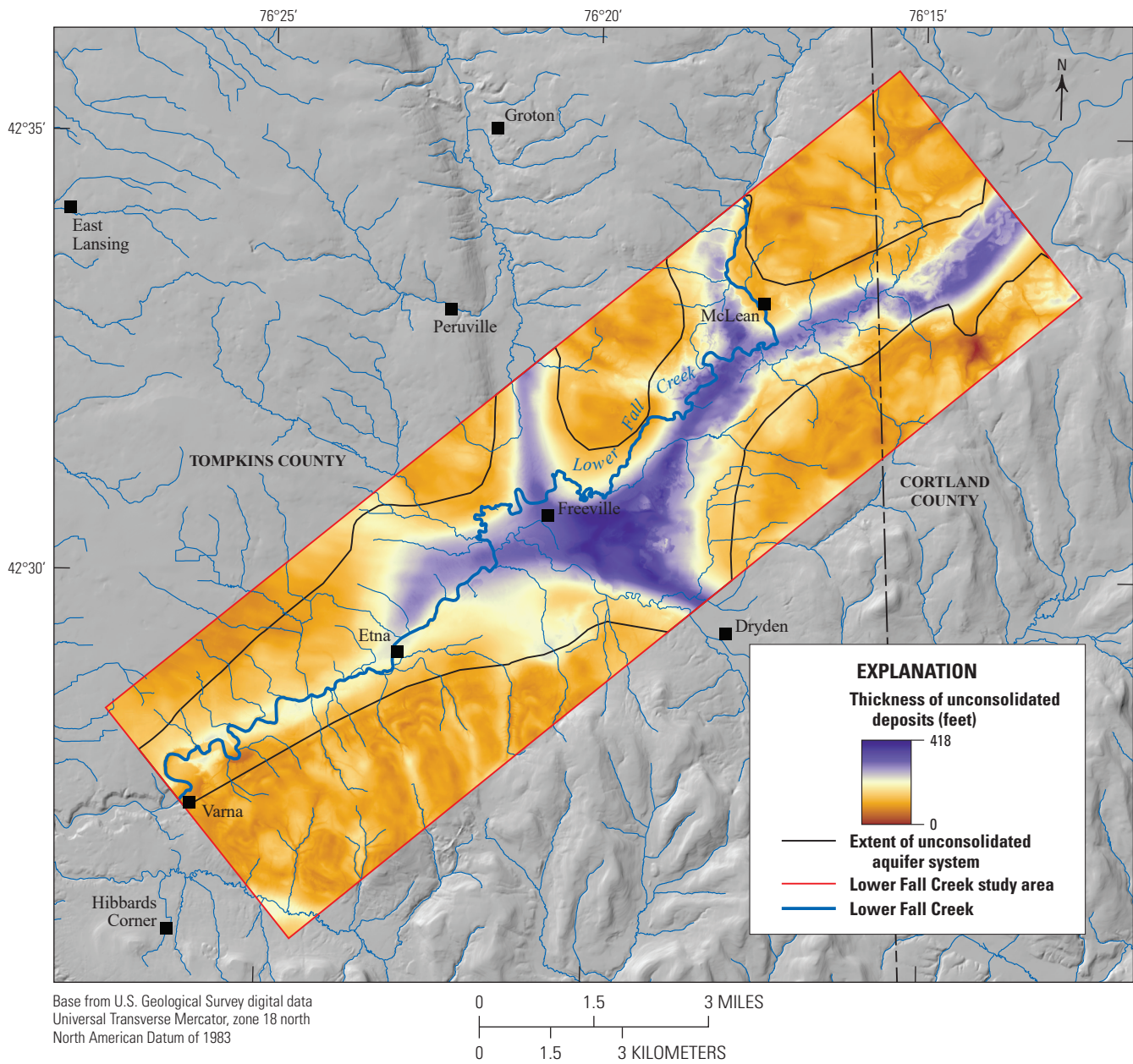


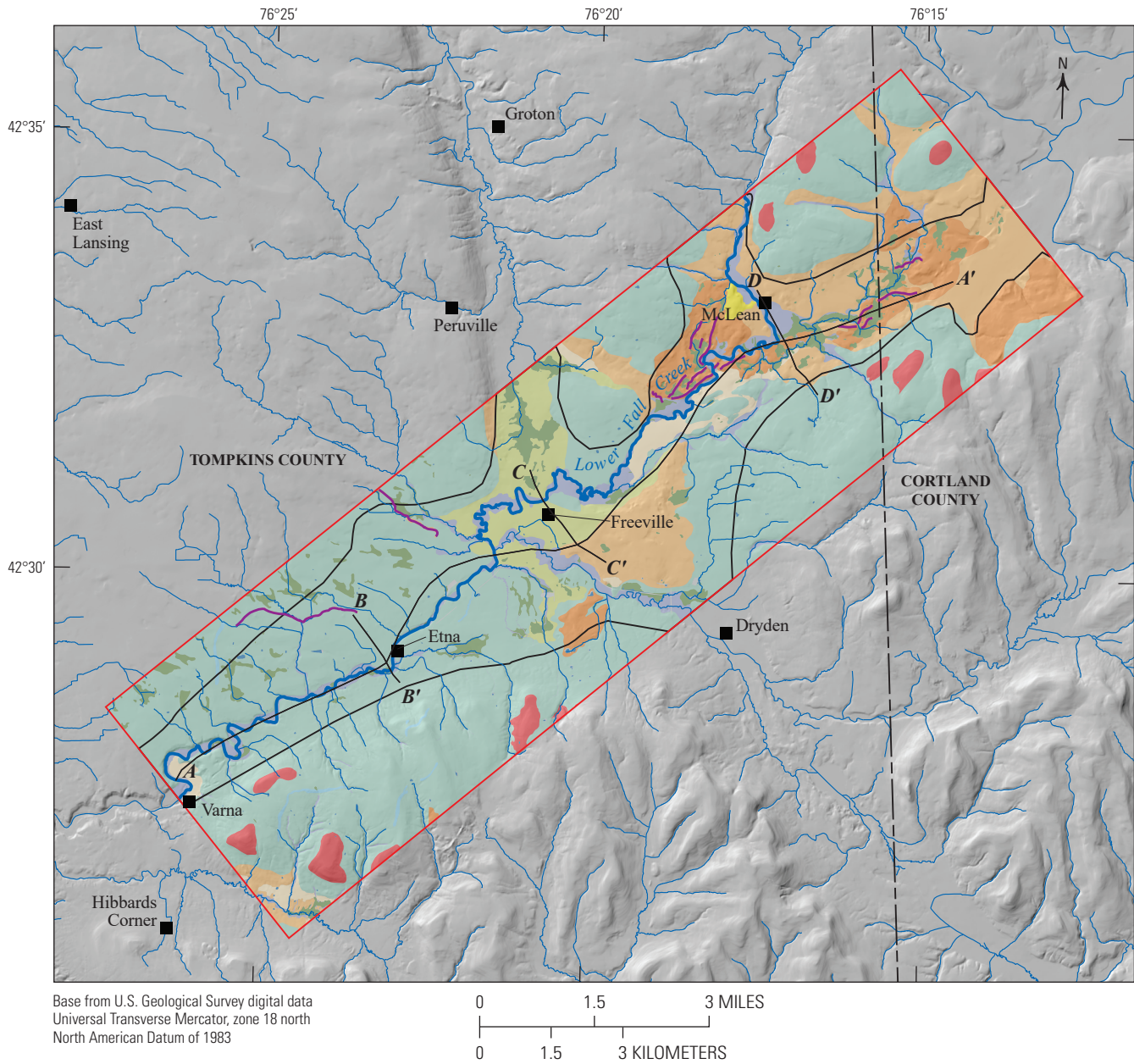






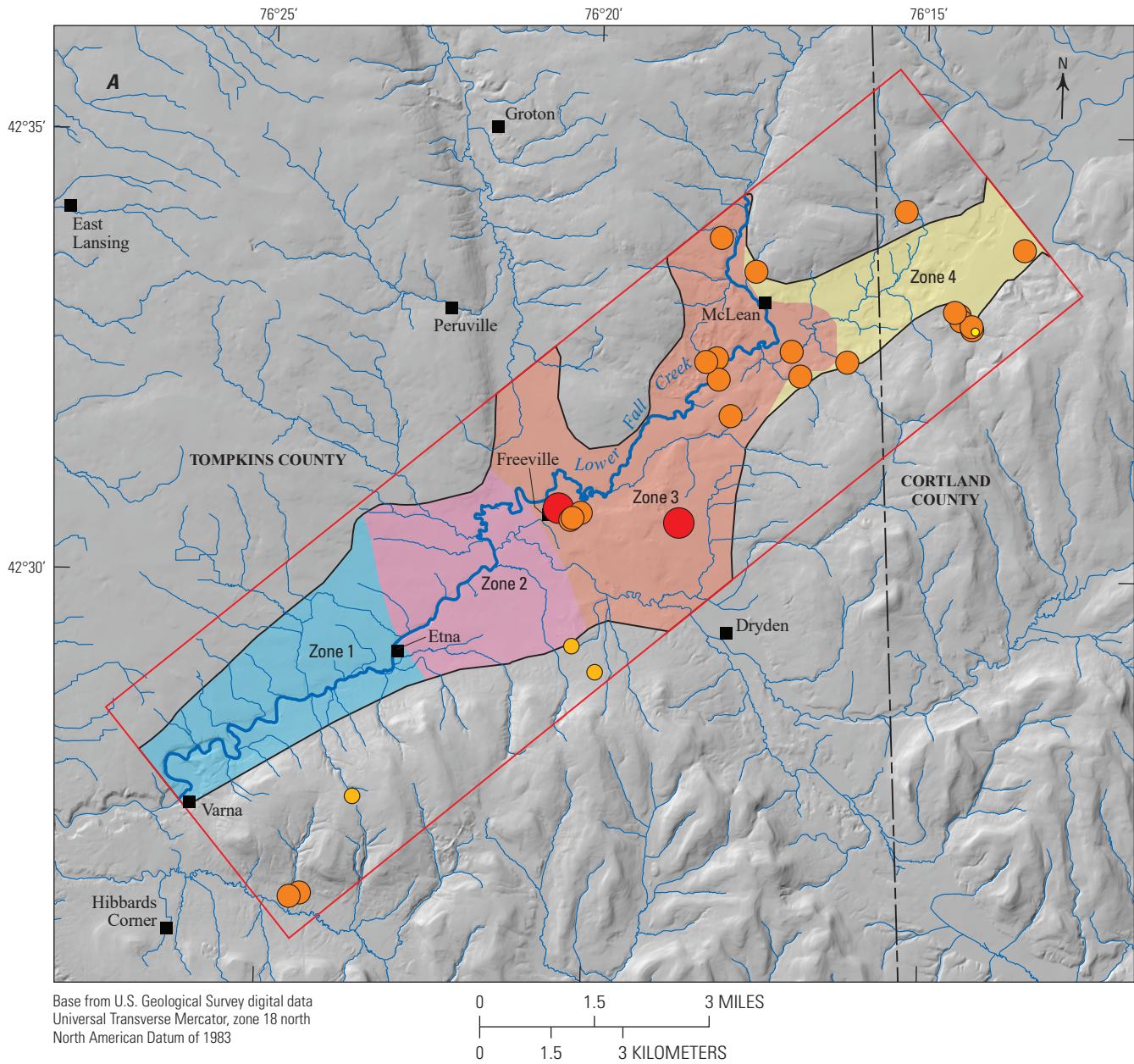




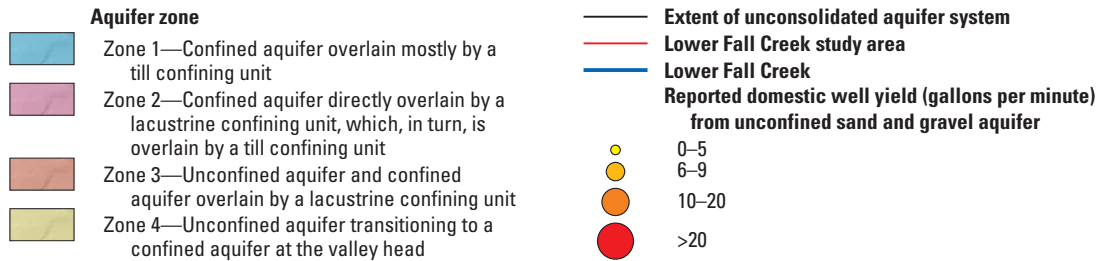


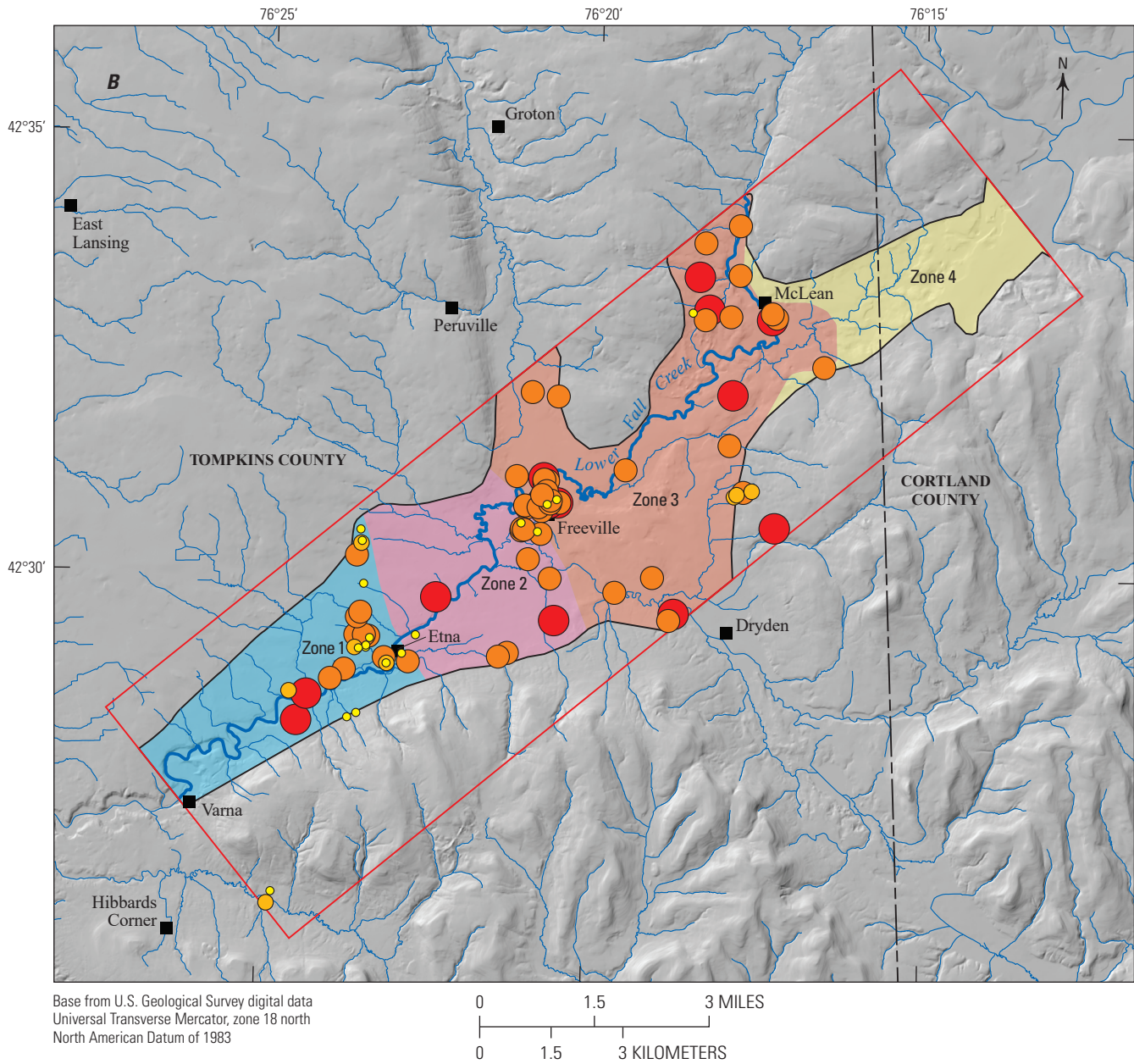
EXPLANATION

Surficial geologic unit		
	Artificial fill	Stratified sand
	Bedrock	Stratified sand and gravel
	Cobbles to sand	Stratified silt, sand and gravel (alluvium)
	Till (diamicton)	Water
	Ice-contact silt and clay	Wetland deposit
	Silt and clay	
		Eskers
		Extent of unconsolidated aquifer system
		Lower Fall Creek study area
		Lower Fall Creek
		A—A' Trace of geologic section

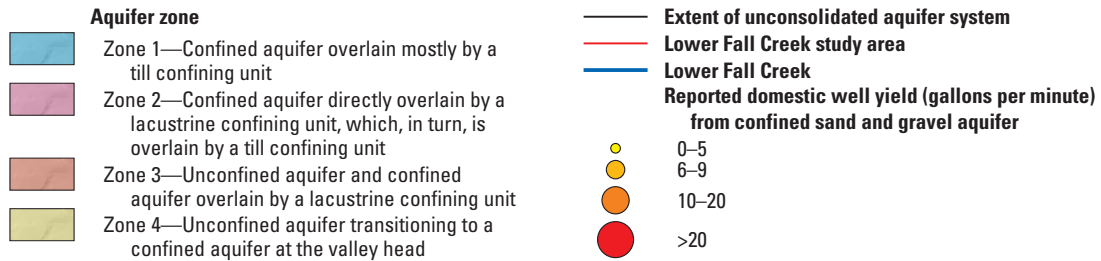


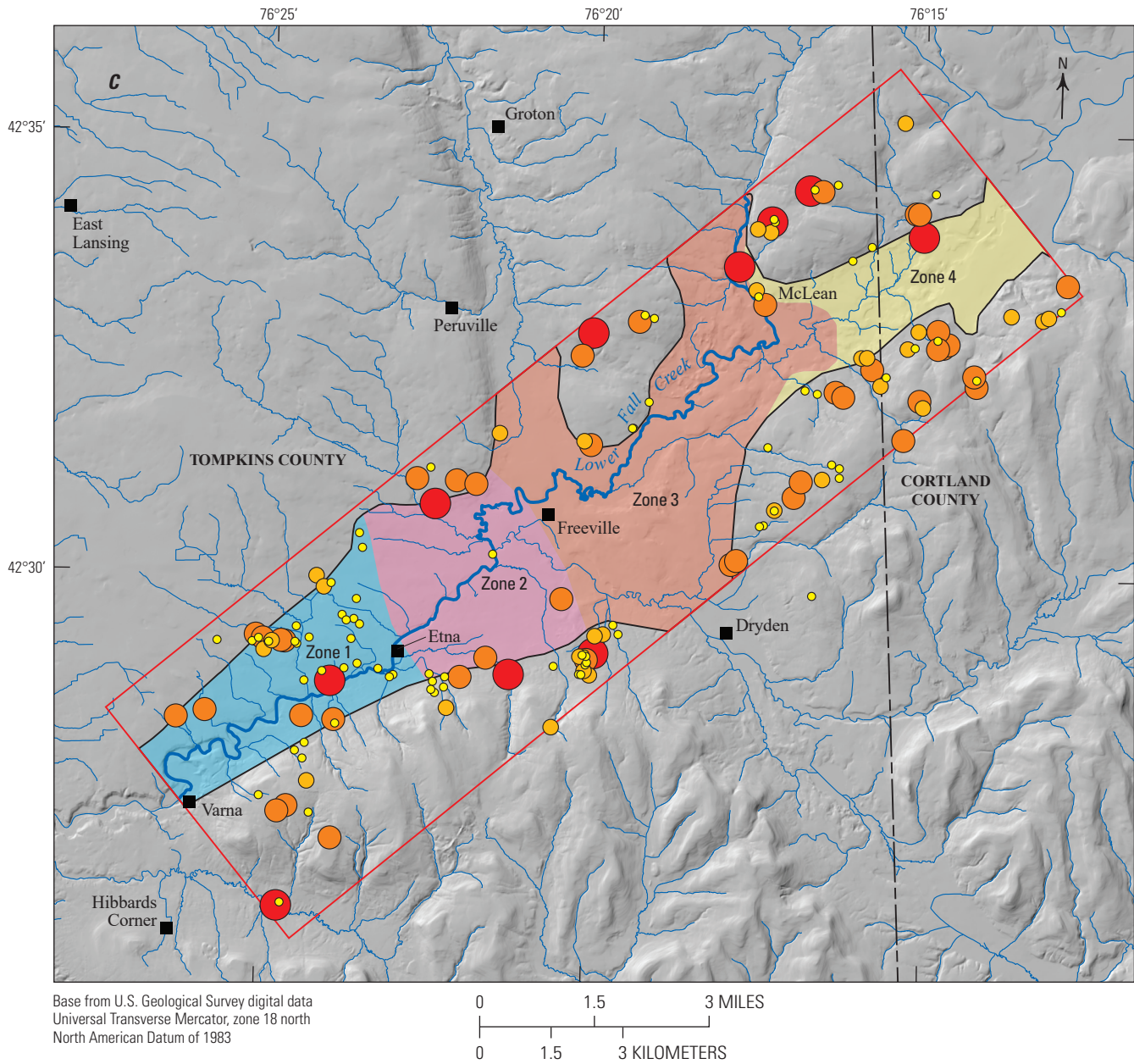
EXPLANATION





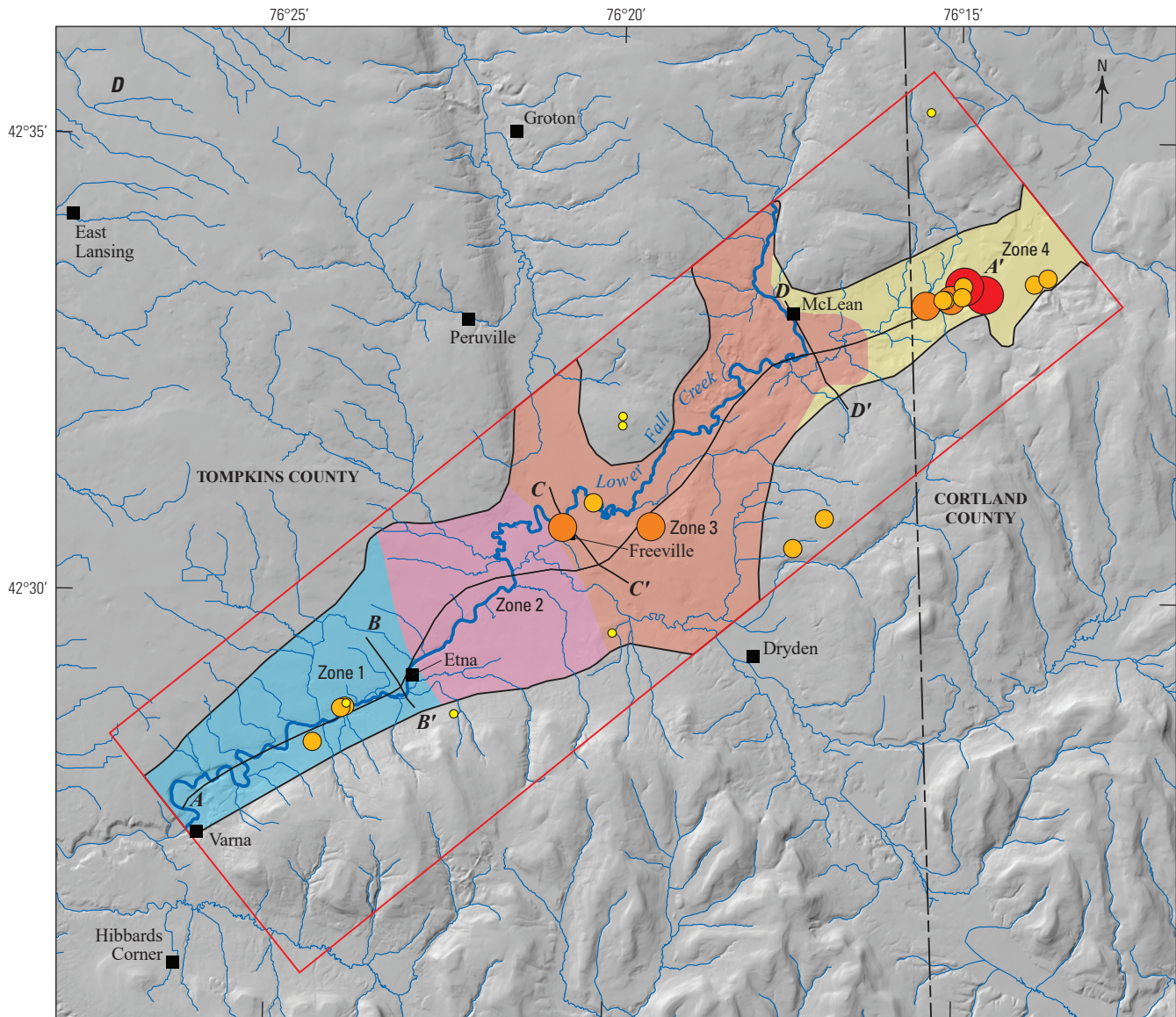
EXPLANATION



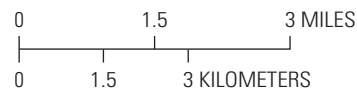


EXPLANATION

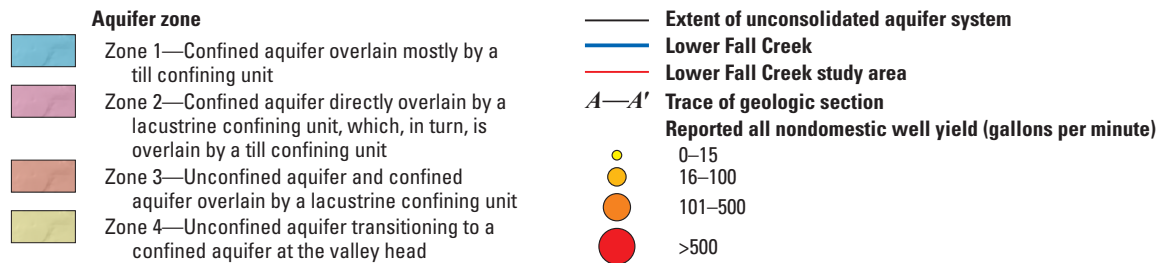
Aquifer zone		Extent of unconsolidated aquifer system
	Zone 1—Confined aquifer overlain mostly by a till confining unit	
	Zone 2—Confined aquifer directly overlain by a lacustrine confining unit, which, in turn, is overlain by a till confining unit	
	Zone 3—Unconfined aquifer and confined aquifer overlain by a lacustrine confining unit	
	Zone 4—Unconfined aquifer transitioning to a confined aquifer at the valley head	
		Reported domestic well yield (gallons per minute) from bedrock
		 0–5
		 6–9
		 10–20
		 >20

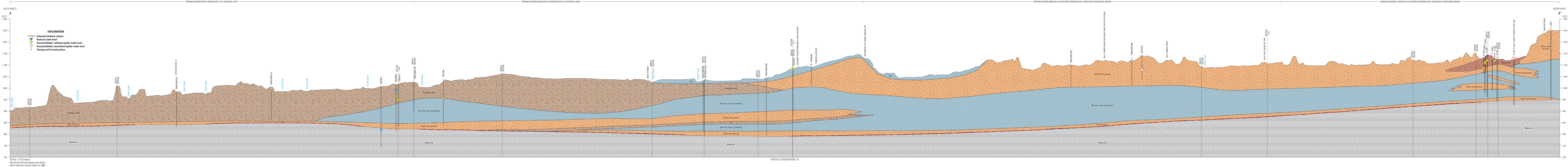


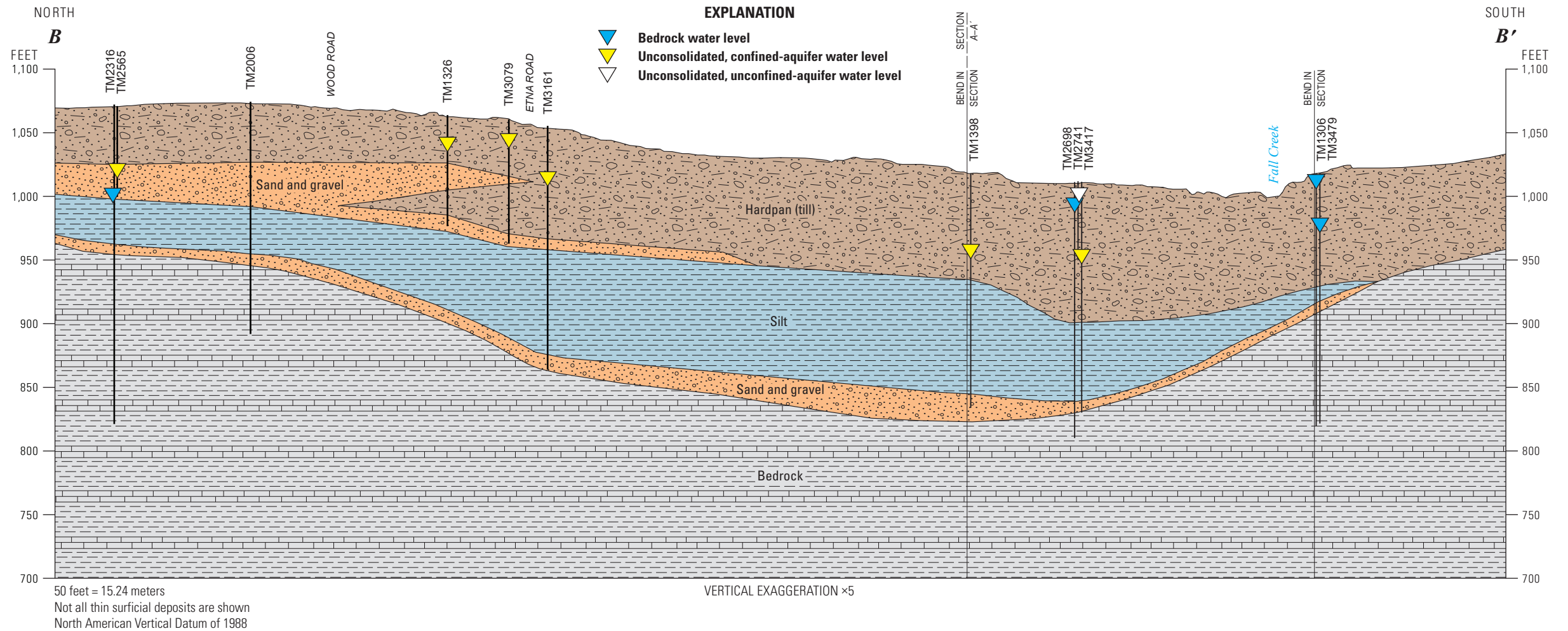
Base from U.S. Geological Survey digital data
Universal Transverse Mercator, zone 18 north
North American Datum of 1983

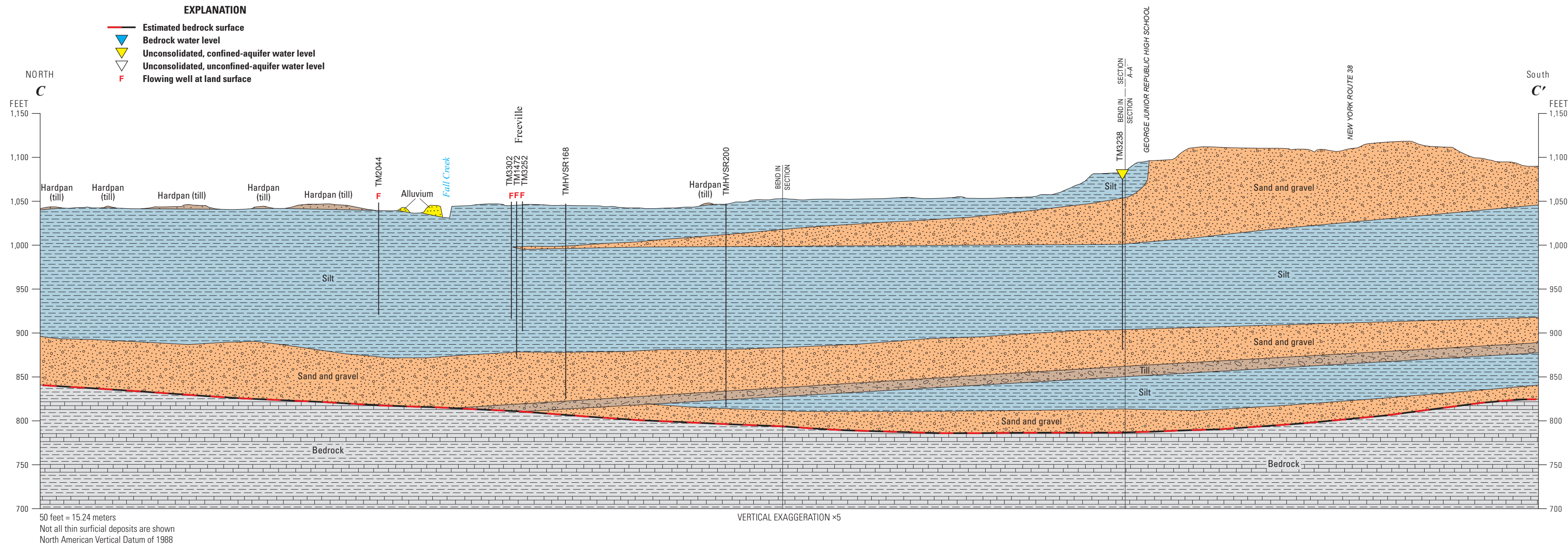


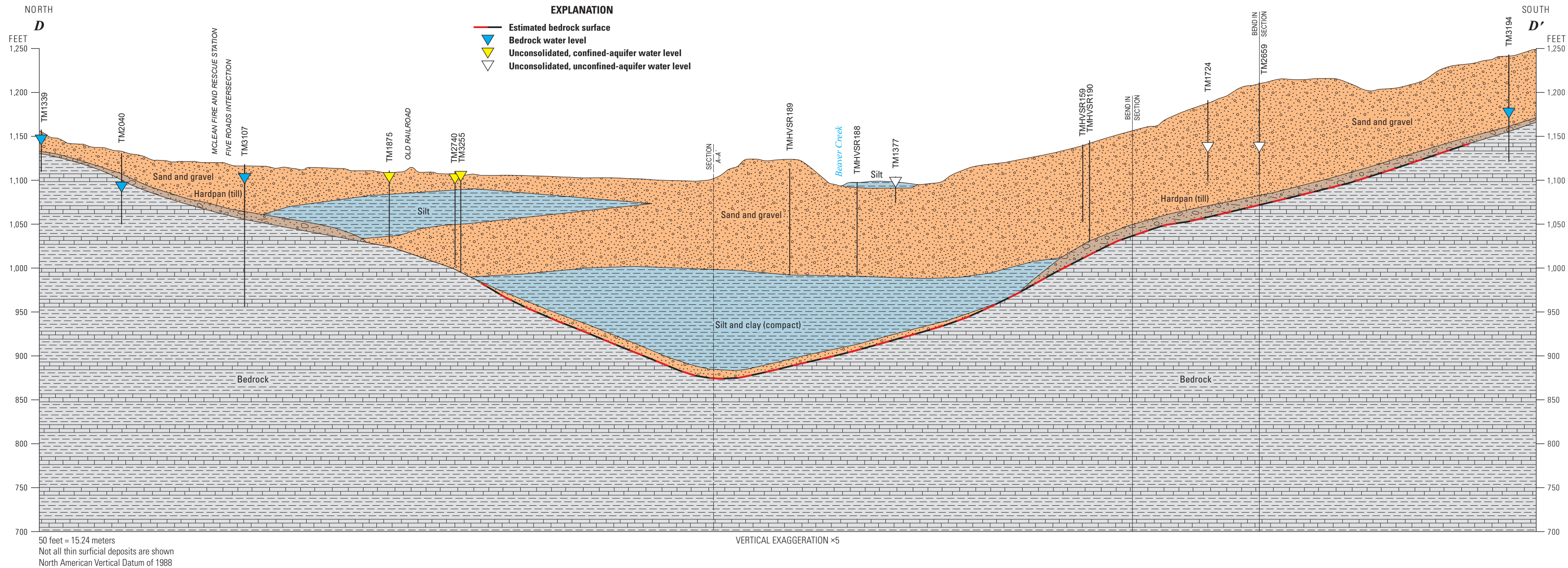
EXPLANATION



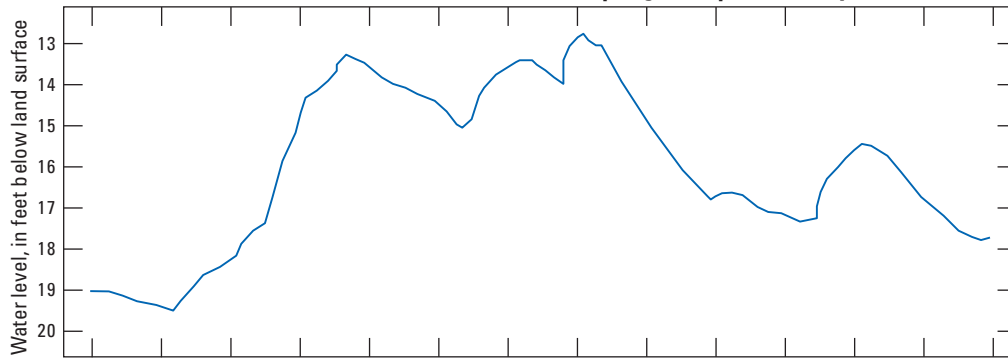




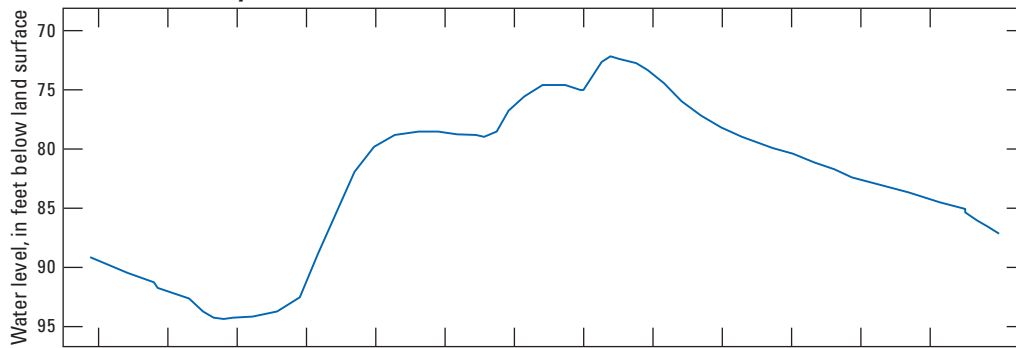




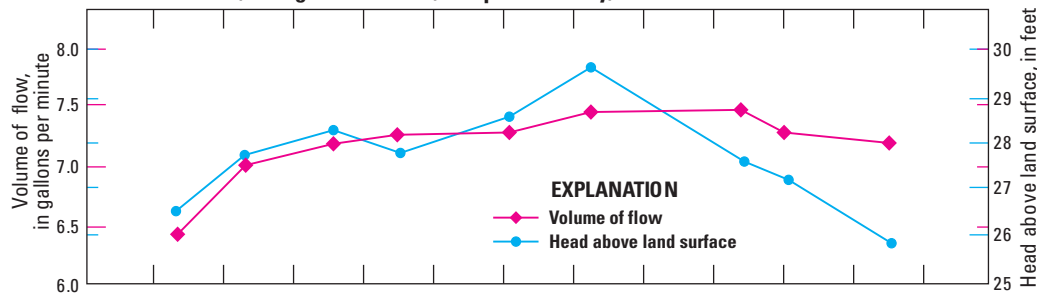
A. Groundwater level in well TM1968 near Slaterville Springs, Tompkins County, New York



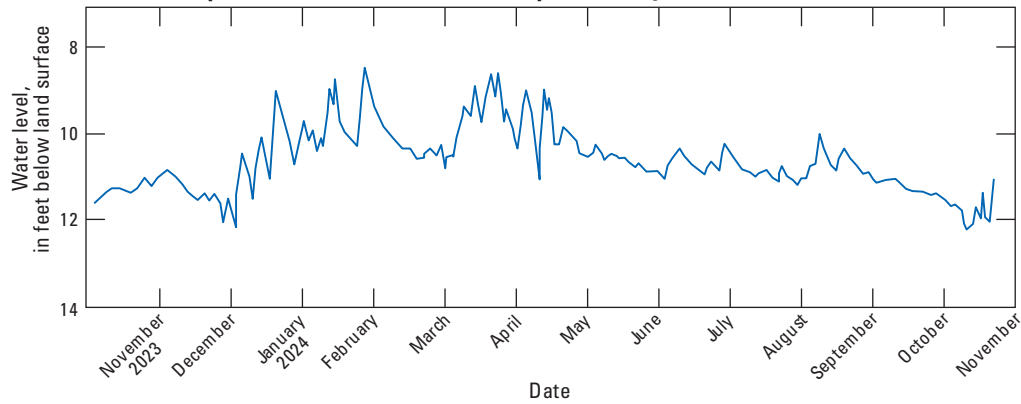
B. Groundwater level in well C1373 at the Tunison fish laboratory near City of Cortland, Cortland County, New York

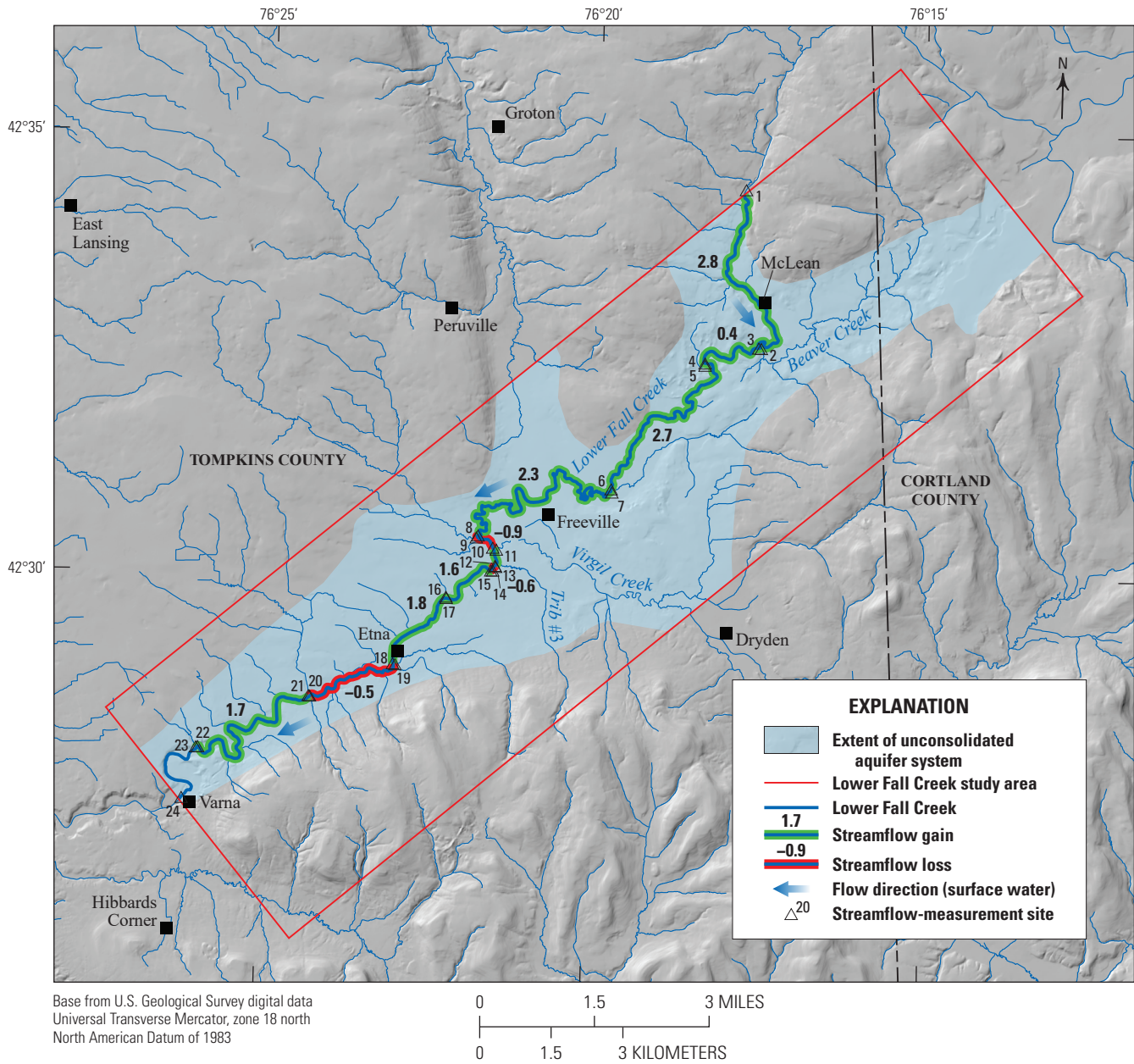


C. Artesian head (water level above land surface) and volume of artesian flow (discharge) at well TM3860, Village of Freeville, Tompkins County, New York

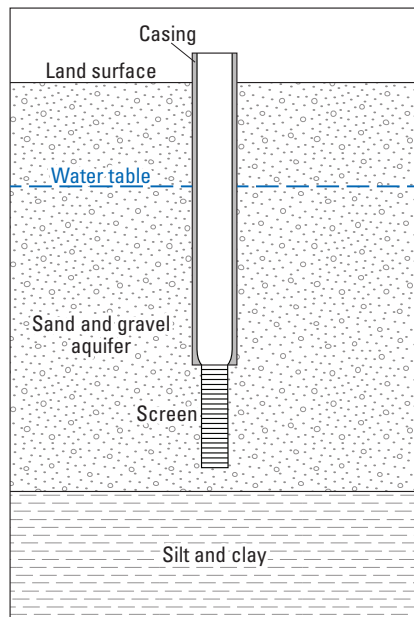


D. Groundwater level in well TM1144 (under the influence of Fall Creek and water use by the fire department), hamlet of McLean, Tompkins County, New York





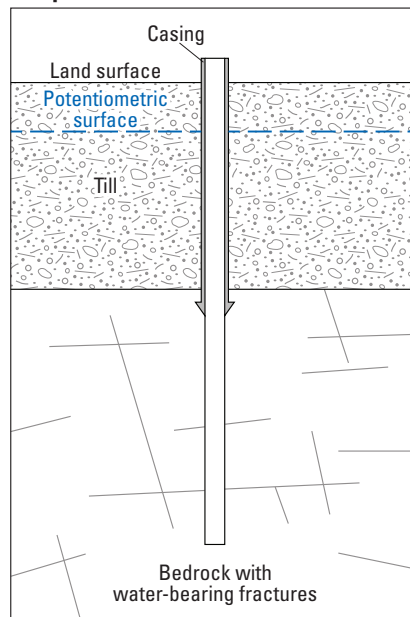
A. Screened well



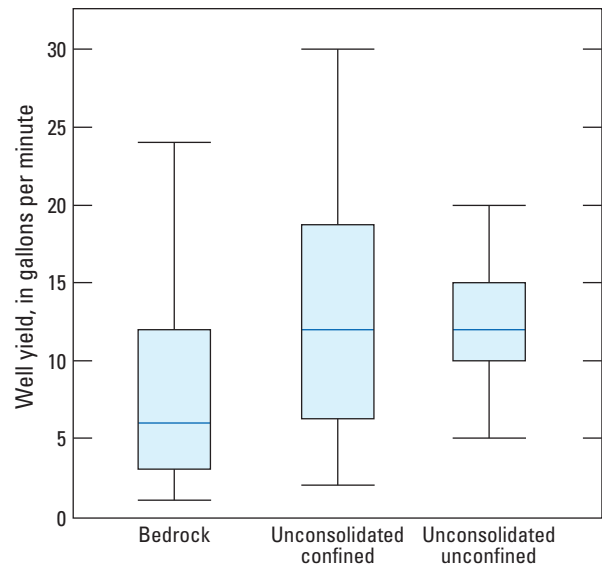
B. Open-end well



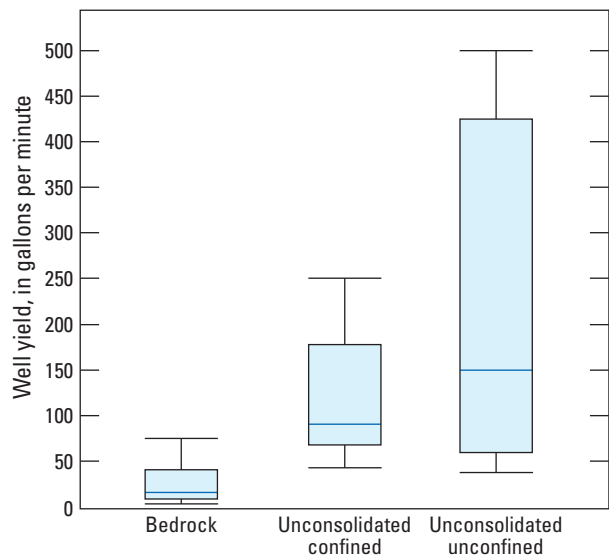
C. Open-hole well



A. Domestic wells



B. Nondomestic wells



EXPLANATION

