Prepared in cooperation with the New York State Department of Environmental Conservation

Hydrogeology of the Susquehanna River Valley-Fill Aquifer System in the Towns of Conklin and Kirkwood, Broome County, New York

Scientific Investigations Report 2021–5026

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

Cover. View of Susquehanna River valley, looking north from near Corbettsville, New York. Photograph by P.M. Heisig, U.S. Geological Survey.

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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)
	Slope	
feet per mile (ft/mi)	0.189394	meters per kilometer (m/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)
million gallons (Mgal)	3,785	cubic meter (m^3)

Multiply	By	To obtain
	Flow rate	
gallon per minte (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
gallon per day per square mile ([gal/d]/mi^2)	0.001461	cubic meter per day per square kilometer ([m^3/d)]/km^2)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

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

$$°F = (1.8 \times °C) + 32.$$

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

$$°C = (°F - 32) / 1.8.$$

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).

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

Abbreviations

GLGB	Glacial Lake Great Bend
lidar	light detection and ranging
NYSDEC	New York State Department of Environmental Conservation
USGS	U.S. Geological Survey

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Abstract

The hydrogeology of the Susquehanna River valley-fill aquifer system and adjacent areas in south-central Broome County, New York, was investigated in cooperation with the New York State Department of Environmental Conservation. The study area encompasses roughly 55.5 square miles and includes the towns of Conklin and Kirkwood. Multiple small, perhaps discontinuous, valley-fill aquifers of unknown extent and hydraulic interconnection underlie the Susquehanna River valley from easternmost Binghamton south to Riverside, New York, near the Pennsylvania border. The hydrogeologic framework of these aquifers is described in this report on the basis of existing descriptions of surficial materials, especially those related to deglaciation, and subsurface data extracted from well and boring logs. A compilation of surficial geology, the descriptions of the spatial distribution of confined and unconfined aquifers, hydrogeologic sections, and well locations is provided as an oversized map plate and in a U.S. Geological Survey data release.

Residential households are one of the principal consumers of groundwater in the study area. Approximately half of these households are served by public water-supply systems that obtain water from wells, chiefly from highly productive but small and likely discontinuous surficial deposits of sand and gravel, while others obtain water from sand-and-gravel aquifers beneath till and (or) fine-grained lacustrine deposits, and a few from bedrock. Residents outside the public-supply service areas rely on private wells. In till-mantled upland areas, nearly all private wells tap bedrock. Water-resource potential is likely greatest north of Kirkwood Center, New York, where the valley is narrowest, and local aquifers are in thick stratified glacial deposits. Well yields are highest in this part of the valley, and the local aquifer system is likely replenished through induced infiltration from the Susquehanna River and numerous small tributaries. The area between Langdon and Kirkwood is filled with a mixture of stratified and unstratified glacial sediments and contains one high-yield well. This area likely has moderate water-resource potential, but limited well data make this difficult to verify. Well yields from suitable stratified glacial sediments generally decrease southward toward Riverside, New York.

Characterizing potential groundwater resources is also helpful for prioritizing source-water-protection efforts. Water resources throughout New York are at risk of contamination from commercial and industrial surface activities. As in many valley areas throughout the Susquehanna River watershed in south-central New York, valley wells with depths greater than roughly 100 to 150 feet are susceptible to contamination by naturally occurring saltwater and methane. New York currently has a moratorium on hydraulic fracturing, but the study area is underlain by rocks suitable for unconventional methods of gas production that would likely be initiated if the moratorium were to be lifted.

Introduction

The U.S. Geological Survey (USGS), in cooperation with the New York State Department of Environmental Conservation (NYSDEC), began characterizing the valley-fill aquifers of southeastern Broome County in 2014. The area of the present study is the same as the area of the Binghamton East topographic quadrangle map, which encompasses 55.5 mi^2 and includes an approximately 9-mile (mi) stretch of the Susquehanna River valley between Pine Manor and Riverside, New York.

This study supports a collaborative effort with NYSDEC to characterize the hydrogeology of New York through the Aquifer Mapping Program, which has been active since 1980. These studies inform policy and decision making for wellhead-protection programs, groundwater remediation, and water-resource management and planning in upstate New York. Aquifers throughout New York State are at risk of contamination from human activities—for example, commercial, industrial, agricultural, and residential land uses.

For example, the dramatic rise of high-volume hydraulic fracturing throughout the United States in the mid-2000s led to increased interest in expanding unconventional natural-gas production in the Marcellus and Utica Shales throughout the Appalachian Basin. New York State currently (2020) has a moratorium on hydraulic fracturing. There are many potential environmental impacts related to hydraulic fracturing, but aquifer contamination and high rates of surface-water and groundwater withdrawal are most relevant to this study. Fracturing fluids and a variety of petroleum byproducts can contaminate potable-water sources through runoff or spills (NYSDEC, 2015). Mapping potentially at-risk aquifer systems and water sources would be invaluable if the moratorium is lifted and unconventional natural-gas production develops across the southern-tier counties of New York, including Broome County.

Purpose and Scope

This report summarizes the hydrogeology of the valley-fill aquifer system of a 9-mi stretch along the Susquehanna River in Broome County, New York (fig. 1). It includes detailed descriptions of (1) the study area, (2) water-well characteristics, (3) groundwater use, (4) surficial geologic units, (4) the spatial distribution of thin and thick till, (5) the valley-fill aquifer system, and (6) groundwater-resource potential. A rationale for resource potential and a generalized summary of groundwater characteristics within the aquifer system is also provided.

The following information is provided in plate 1:

- Well locations
- Surficial geology
- Extent of thin and thick till deposits
- Locations of hydrogeologic sections
- Subsurface extent of the valley-aquifer system
- Extent of clay-rich lacustrine and till confining layers
- Light detection and ranging (lidar)-derived hillshade representing topography

Study-Area Description

The Binghamton East 1:24,000 quadrangle encompasses 55.5 mi^2 in south-central Broome County, New York, and the southern edge borders Pennsylvania. The quadrangle includes most of the Towns of Conklin and Kirkwood and parts of the Towns of Binghamton and Windsor (fig. 1). The population in the quadrangle is approximately 13,000, the average population density is 396 people per mi^2, and average population change from 2010 to 2018 was −4.9 percent (U.S. Census Bureau, 2018). Land cover is variable with approximately 62-percent forested, 18-percent agriculture, 14-percent developed, and the remainder is water or wetlands (U.S. Geological Survey, 2016a). The region experiences a moist, warm summer and a continental mid-latitude climate (Dfb as defined by the Köppen-Geiger classification system Beck and others, 2018). The average-annual air temperature varies with altitude from 38 to 55 degrees Fahrenheit, and the average-annual precipitation is 40 inches (U.S. Geological Survey, 2016b; National Oceanic and Atmospheric Administration, 2020). Historical settlement patterns are concentrated in the broad Susquehanna River valley and narrow stream valleys, where urbanization and steep slopes covered with impermeable soils make this region vulnerable to seasonal and storm-related flooding (Morisawa and Montz, 1981; Knuepfer and Montz, 2008; Secord and Lowell, 2019).

The study area is in the glaciated region of the northern Appalachian Plateau physiographic province. The landscape is bisected by the Susqehanna River valley, which is steep-walled and bordered by rounded hills that are separated by numerous hollows and ravines. The bedrock is a mixture of Late Devonian clastic and carbonate marine sedimentary rocks that dip gently to the south (Rickard and Fisher, 1970). Elevations range from 800 to 1,850 ft. The highest summits are in the eastern and southwestern parts of the quadrangle. The elevations of low terraces that occupy most of the valley floor decrease from 850 ft in the south near Riverside to 830 ft in the north near Pine Manor. The valley floor is about 0.5 mi wide near Riverside, widens downstream to about 1 mi near the town of Conklin, then narrows to about 0.2 mi where the valley turns west and leaves the quadrangle.

The Susquehanna River enters the study area from Great Bend, Pennsylvania (about 1.5 mi south of the New York-Pennsylvania border; not shown on any figure), and flows north to northwest about 7.5 mi, then turns northwest at Five Mile Point for the last 2.5 mi before exiting the study area. The drainage area of the river is 2,270 mi^2 at the northwestern edge of the study area (U.S Geological Survey, 2016b). This area was calculated from a user-defined “pour point” approximately 0.7 mi west of Pine Manor (fig. 1). This pour point represents the lowest elevation along the river and is used by StreamStats to calculate the upstream contributing area. The largest tributaries to the Susquehanna in this area include Snake Creek and Little Snake Creek, which enter from the west approximately 2 mi from the Pennsylvania border, and Park Creek and Stanley Hollow Creek, which enter from the northeast about 2.5 mi east of Binghamton.

The entire study area was covered and affected by multiple glacial advances during the Pleistocene. The modern southeast-to-northwest-trending Susquehanna River valley was likely a preexisting drainage channel oriented roughly parallel to ice flow (Denny and Lyford, 1963; Gillespie, 1980; Kirkland, 1983). This orientation allowed advancing ice to more effectively carve a steep-walled glacial trough that was further modified by meltwater streams (King and Coates, 1973; Randall and Coates, 1973). Glacial erosion also trimmed ridges descending from the uplands. This erosion created numerous truncated spurs that now define the large-scale topographic features of the valley (King and Coates, 1973).

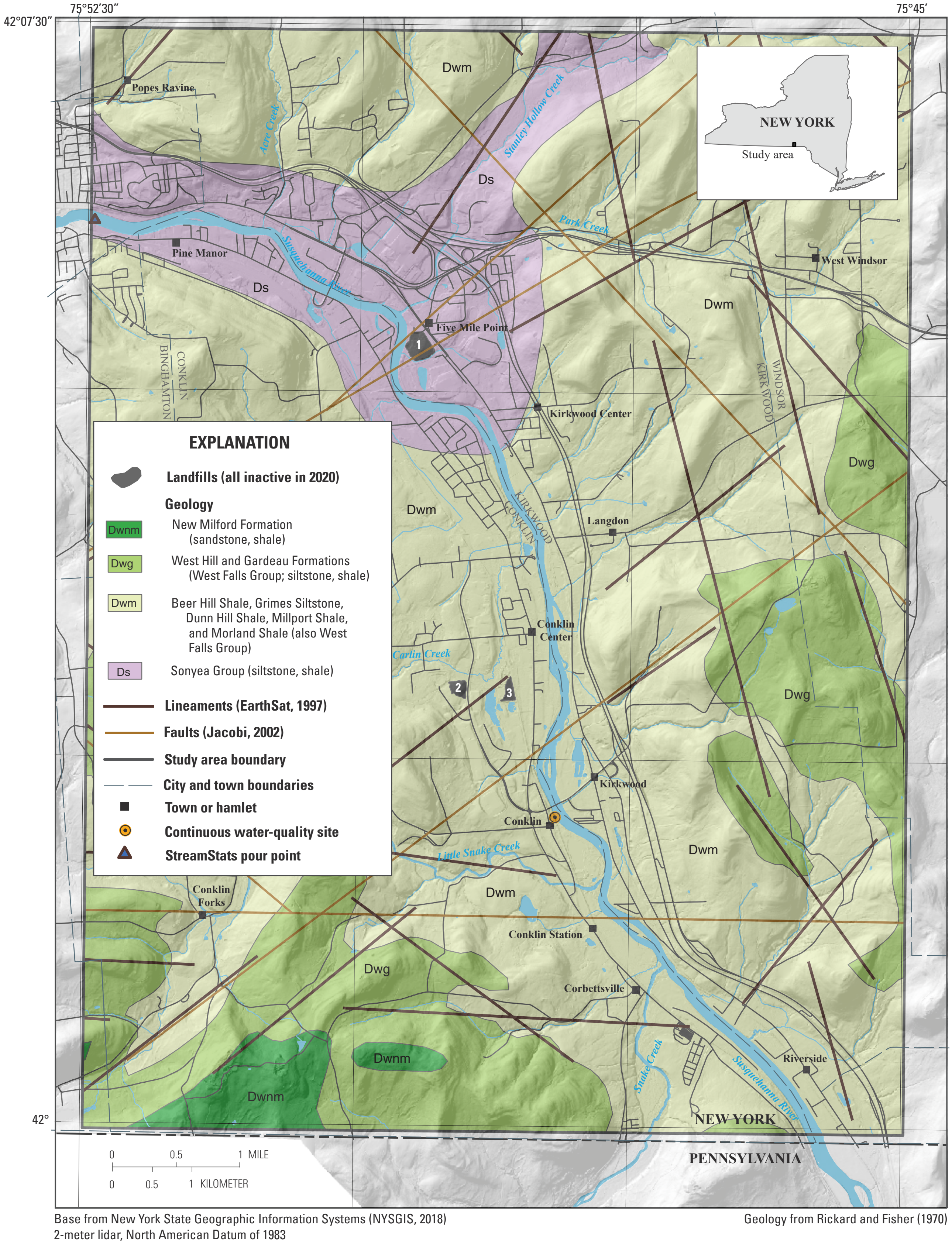


Figure 1. Topography, political boundaries, roads, hydrography, bedrock geology, lineaments, inferred faults, and landfills (1, Gorick C&D landfill; 2, upper Conklin landfill; and 3, lower Conklin landfill) of the Binghamton East quadrangle in central Broome County, New York. The Susquehanna River flows from Riverside north past Pine Manor.

Deglaciation of the region began in the highlands, primarily through stagnation and downwasting rather than through frontal retreat or backwasting (Harrison and Coates, 1966; Harrison, 1966; Fleisher, 1986a, b, 1993, 2003). Continued melting created ephemeral supraglacial and subglacial streams that filled depressions in the ice with ice-contact deposits (Fleisher, 1986a, b, 1993; Randall, 1986). As stagnant ice languished in the valleys, subglacial and proglacial meltwater streams deposited discontinuous outwash sand and gravel (Randall, 1977, 1978a, 1986; Fleisher, 1993). When valley ice tongues began retreating up the Susquehanna River valley, abundant meltwater filled a series of proglacial lakes impounded by sediment down valley (Harrison, 1966; Randall, 1986; Fleisher, 1993; Braun, 1999, 2006a). The largest of these lakes, Glacial Lake Great Bend (GLGB), likely drained when the ice margin retreated north of Five Mile Point, which created an outlet to the west (Harrison, 1966; Randall and Coates, 1973; Coates, 1981; Braun, 1999).

Bedrock Geology

Near-surface bedrock exposures in the study area consist of Late Devonian age shales, siltstones, and sandstones of the West Falls and Sonyea Groups (Rickard and Fisher, 1970; Sutton and others, 1970; Ehrets, 1981; McGhee and Sutton, 1985). The regional bedrock is warped by low-amplitude folds trending from east to west and north to northwest (Wedel, 1932; Finn, 1949). This deformation produced regional bedding that dips southward approximately 10 to 40 feet per mile (ft/mi) (Wedel, 1932; Coates, 1981). These structural relations resulted in the exposure of older rocks in the north and younger rocks in the south (fig. 1).

The Middlesex Shale Member of the Sonyea Group and the Rhinestreet and Nunda Formations of the West Falls Group are natural gas-bearing shales (Schieber, 1999; Zagorski and others, 2012; Milici and Swezey, 2014); however, it is difficult to differentiate between gas-bearing black shales and non-gas-bearing gray shales, so there is uncertainty regarding whether both occur in the study area (Craft and Bridge, 1987). The Marcellus and Utica Shales are organic-rich units that underlie the region. In the study area, the depth to the Marcellus Shale ranges between 4,000 to 4,500 ft, and the depth to the Utica Shale ranges between 9,000 and 9,500 ft (Milici and Swezey, 2014; New York State Museum, 2020).

Regional deformation also facilitated the formation of fractures and faults, which are exposed as linear topographic features (lineaments) with an east-to-west and southeast-to-northwest orientation (fig. 1). These linear features represent fractures or faults that formed in response to orogenic deformation and hydrocarbon formation within weaker rock units like black shale (Isachsen and McKendree, 1977; EARTHSAT, 1997; Jacobi, 2002; Lash and others, 2004; Kreuzer, 2017). The counties along the southern boundary of New York State exhibit a well-developed joint pattern characterized by two fracture sets (one trending roughly east-northeast and another northwest) that intersect at nearly right angles (fig. 1; Parker, 1942; Bahat and Engelder, 1984; Jacobi, 2002; Lash and Engelder, 2009). The drainage pattern of this section of the Susqeuhanna River valley likely developed by preferential exploitation of these preexisting linear weaknesses. For example, the Susquehanna River valley in this area may have developed along a major thrust fault (Kreuzer, 2017). The intersections of lineaments are suitable locations for targeting high-yield wells and offer potential pathways for the recharge of bedrock groundwater resources, especially in areas covered by permeable, unconsolidated sediments with relatively high infiltration capacity.

The presence of natural gas and saline water has been observed in valley wells throughout the counties in southern New York (Williams, 2010; Osborn and others, 2011; Heisig and Scott, 2013; Kreuzer, 2017; Kreuzer and others, 2018; McMahon and others, 2019) and in adjacent northern tier Tioga and Susquehanna Counties, Pennsylvania (Breen and others, 2007; Molofsky and others, 2013).

Data Sources and Methods

This section describes data sources, data processing, and methods used to produce a surficial geologic map and related hydrogeologic-data layers. Derivative products depict the extent of thin and thick till deposits, the distribution of clay-rich lacustrine and till confining layers, hydrogeologic sections, and the subsurface extent of the valley-aquifer system.

A surficial geologic map was compiled through the use of a variety of sources. These sources include earlier surficial maps and soil surveys (Randall and Coates, 1973; Randall, 1978a; Holecek and others, 1982; Muller and Cadwell, 1986; Yager, 1993), lidar 2-meter resolution data (Terrapoint USA, 2008), and well- and test-boring logs from prior investigations and State and national agencies (Brown and Ferris, 1946; Randall, 1972; O'Brien and Gere, 1984; URS Consultants, 1992; U.S. Department of Agriculture, 2011; U.S. Geological Survey, 2012; NYSDEC data from New York State water well permit database, available in Fisher and others, 2021; New York State Department of Transportation data from New York State Geotechnical Engineering Bureau database, available in Fisher and others, 2021; New York State Museum, 2020). Well and boring logs were also used to identify derivative layers that define the valley-fill aquifer boundary, evaluate till thickness, and depict subsurface facies based on the distribution of stratified deposits that underlie surficial units. Seven hydrogeologic cross sections were constructed perpendicular to the Susquehanna River along transects near interesting topographic features, high-yielding wells, and in areas with higher densities of wells.

The geographic locations of all well and boring sites used in this study were verified and, when appropriate, relevant information from original paper logs was added to records in the National Water Information System database (U.S. Geological Survey, 2012). A list of wells and borings that informed the study is provided in a USGS data release (Fisher and others, 2021).

Overview of Groundwater Use and Sources

Groundwater is the primary source for commercial, industrial, and domestic water use in the study area. Differentiating among these three water-use sectors presents challenges. Parcel data collected by New York State tax assessors, however, indicate subtle variations between public and private water supplies, but both sources serve mostly residential-property owners. An approximate public-supply service-area boundary was created by using parcel data (fig. 2) from New York State Geographic Information Systems (2018) and combining these with block-level population data from the U.S. Census Bureau (2018). Of the estimated 13,000 residents in the study area, approximately 6,200 receive public-supply water, and an additional 6,800 rely on private wells. More than half the population resides outside the public-service-area boundary, which highlights the importance of private wells in meeting domestic groundwater-usage needs.

Four public-supply wells provide most of the water to residents within the service-area boundary (table 1). Data collected over 8 years indicate that the Conklin public-supply wells had an average yield of 1,375 gallons per minute (gal/min), and that the average annual withdrawal was 0.22 million gallons per day (Mgal/d). The Kirkwood wells had an average yield of 1,563 gal/min, and the average annual withdrawal was 0.84 Mgal/d. Approximately 1,300 residents are served by Binghamton public-supply sources outside the study area. Of the 127 verified wells within the study area but outside the service-area boundary, roughly 82 percent are completed in bedrock and have a median yield of 10 gal/min (fig. 2).

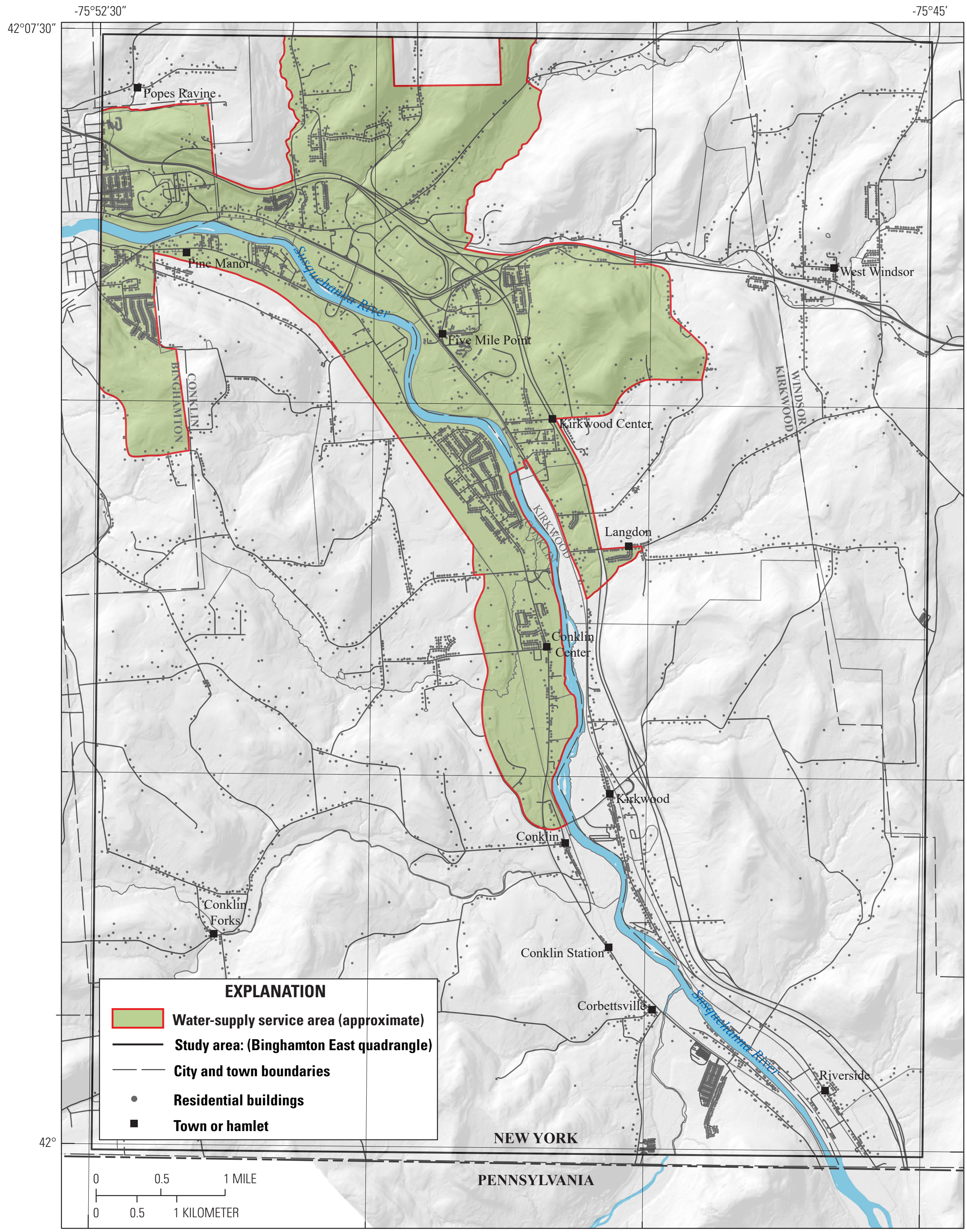
Previous Investigations

Glacial Geology

The earliest studies of surficial deposits in New York were regional and focused on deciphering the glacial history of central and western New York. These studies attempted to provide relative constraints on the timing and frequency of glacial advances and the local and regional glacial lakes that formed during deglaciation. Fairchild (1925) proposed a “Glacial Lake Binghamton” that drowned the Susquehanna River valley from Towanda, Pennsylvania (not shown on any figure), upstream through Binghamton, Kirkwood, and Conklin, New York, and back into Pennsylvania at Great Bend. While mapping the distribution of moraines in western New York, Fairchild (1932) named the Valley Heads moraine and identified kame deposits in the Susquehanna River valley. MacClintock and Apfel (1944) identified multiple glacial advances and described three distinct till deposits, which they used to define the boundaries of each advance. They differentiated between a drab-colored till derived from local bedrock and a bright-colored till containing exotic carbonate-rich clasts carried in from the north.

Coates and King (1973) mapped glacial-ice margins across the study area, including a bisected moraine in the narrowest part of the valley east of Binghamton at Pine Manor (fig. 3). Cadwell (1981) described a sequence of valley deposits that formed proximal to a decaying ice tongue within the Chenango River valley between Binghamton and Norwich, New York. This mosaic of deposits included a valley plug of till, like the “valley choker” moraines described by MacClintock and Apfel (1944), and interbedded glaciofluvial and glaciolacustrine sediments deposited in small proglacial lakes (Cadwell, 1981; Harrison, 1966). Randall and Coates (1973) identified evidence for ice-margin oscillations but, unlike MacClintock and Apfel (1944), attributed them to a single glacial advance. These oscillations produced a series of short-lived proglacial lakes as downwasting ice tongues retreated northward (Harrison, 1966; Fleisher, 1993; Braun, 1999). One lake, which Braun (1999) named Glacial Lake Great Bend (GLGB), persisted for approximately 360 years as it followed a retreating mass of ice moving northward between Great Bend, Pennsylvania, and Binghamton. The lake initially drained to the south through the New Milford Sluiceway, but as the ice retreated, it offered access to the northwest-trending Susquehanna River valley (Braun, 1999). Eventually, GLGB drained across and may have incised a low moraine that partially blocked the Susquehanna River valley near Pine Manor. The lake eventually filled with sediment, capped by a valley-filling layer of sand and gravel deposited by abundant meltwater flow as the ice margin retreated northward (fig. 3).

Coates (1966) and King and Coates (1973) described the asymmetry of hillslopes in the glaciated Appalachian Plateau and attributed this variability to differential glacial erosion and deposition. North-facing slopes in the uplands are commonly twice as steep as south-facing slopes because they experienced greater glacial erosion. South-facing slopes experienced less abrasion and, more importantly, downwasting ice margins deposited thicker layers of till (Ozsvath, 1985). Coates (1966) referred to these leeward accumulations of till as till shadows (fig. 3). Braun (1999) suggested that till-shadow stratigraphy is not homogeneous but, instead, includes a basal layer of lodgment and deformation till overlain by ablation till. The Binghamton East quadrangle includes asymmetrical slopes (fig. 3); however, they are generally less common than in surrounding regions. King and Coates (1973) and Coates (1981) described the presence of concavo-convex landforms and interpreted them as rotational slump blocks of till that moved downslope under periglacial conditions. Coates (1981) also described differences in the textures of the glaciofluvial and



Base from New York State Geographic Information Systems (NYSGIS, 2018)
2-meter lidar, North American Datum of 1983

Figure 2. Approximate public water-supply service area and residential population density derived from New York State address-point data (New York State Geographic Information Systems, 2018). The number of residents located outside the approximate public water-supply service area illustrates the importance of private wells in meeting residential water demand.

Table 1. Summary of average well yields and annual withdrawals from public-supply wells from 2010 to 2018 in Conklin and Kirkwood, New York (New York State Department of Environmental Conservation, 2020). The Kirkwood wells have both a higher average yield and higher withdrawal rates.

[gal/min, gallon per minute; Mgal/d, million gallons per day]

Conklin public-supply wells (*n*=2)			Kirkwood public-supply wells (*n*=2)		
Average yield (gal/min), 2010–18	Year	Average annual withdrawals (Mgal/d)	Average yield (gal/min), 2010–18	Year	Average annual withdrawals (Mgal/d)
1,375	2010	0.22	1,563	2010	0.88
	2011	0.24		2011	0.78
	2012	0.23		2012	0.74
	2013	0.074		2013	0.76
	2014	0.26		2014	0.83
	2015	0.21		2015	0.9
	2016	0.22		2016	0.96
	2017	0.26		2017	0.85
	2018	0.23		2018	0.89

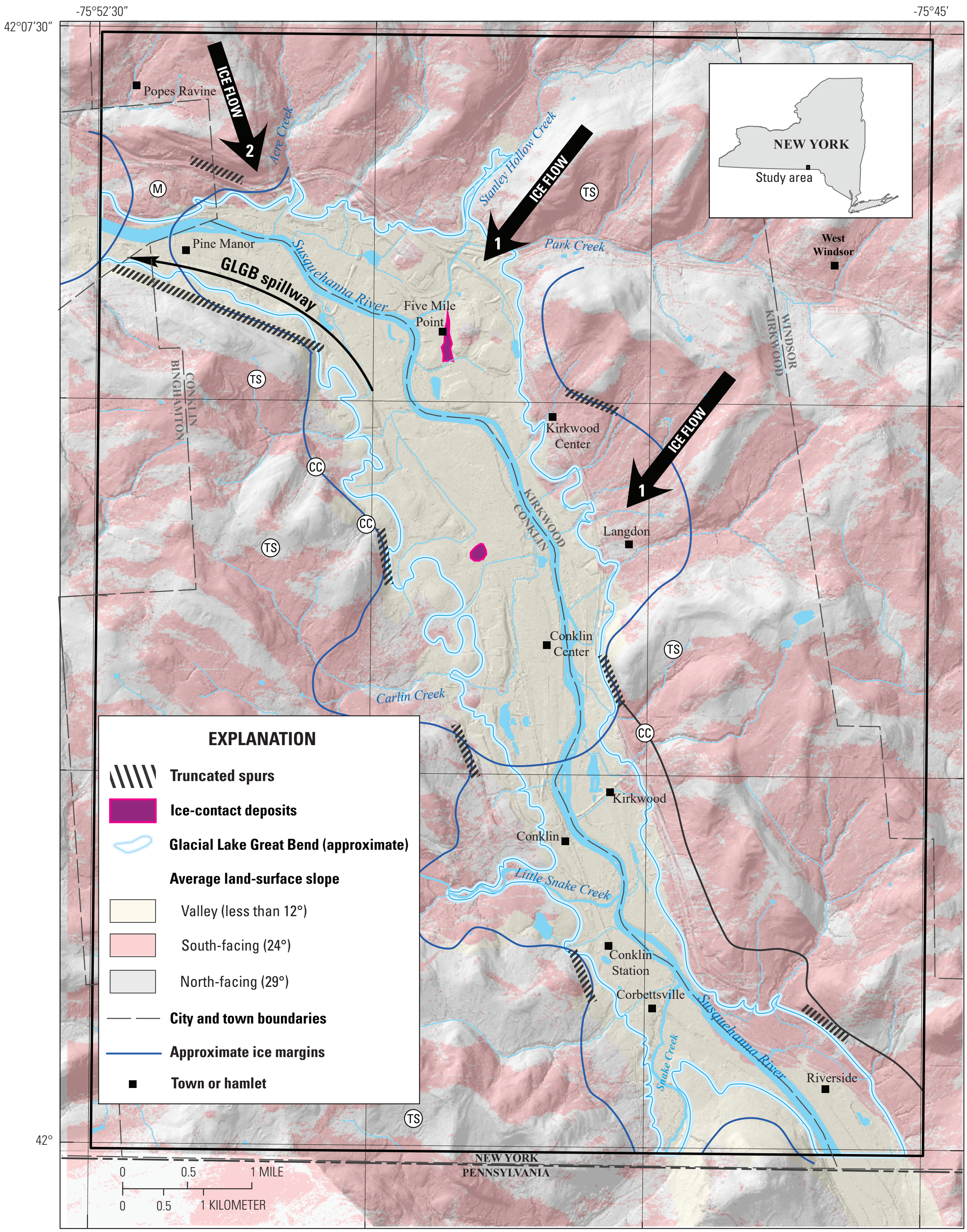
glaciolacustrine deposits in valleys with different orientations. Coarse-grained sediments are typically more common in south-draining valleys because finer grained particles were removed by meltwater. North-draining valleys were blocked by receding ice and experienced impoundment, allowing more clay and silt to accumulate.

Randall (1978a) and Randall and Coates (1973) provided a detailed stratigraphy of Pleistocene and Holocene deposits in the Binghamton area on the basis of well-log interpretations. They identified both drab and bright stony glacial till, stratified deposits of sand to gravel interbedded with lake deposits, and fine-grained deposits associated with younger proglacial lakes. They also described coarse-outwash gravels, river-terrace alluvium, alluvial-fan deposits, and modern alluvium. Moss and Ritter (1962), Denny and Lyford (1963), and Muller and Cadwell (1986) provided additional descriptions of surficial deposits and offered refinements to descriptions of regional ice margins and till genesis. Lounsbury and others (1932) and Giddings and others (1971) conducted soil surveys in Broome County and described the characteristics of surficial sediments and the types of soils that developed in each sediment. Harrison (1966) completed surficial mapping in the Great Bend area and identified two distinct tills, morainic loops, glacial outwash, fluvial sand and gravel, ice-contact deposits (for example, kames, kame terraces, and eskers), fine-grained lake sediments, modern alluvium, and peat and muck deposits. Braun (1999, 2006a, b) mapped surficial geology and ice-margin boundaries south of the study area in the Great Bend quadrangle. Surficial units included alluvium, alluvial fans, outwash, glacial-lake clay, ice-contact deposits, and till of variable thickness.

Hydrogeology of Valley-Fill Aquifers

Numerous hydrogeologic studies conducted within and adjacent to the area have provided information about sediments in the subsurface and their relation to the aquifer system. The earliest study that describes subsurface-aquifer characteristics and potential groundwater resources on the basis of well logs was completed by Brown and Ferris (1946). They concluded that the most productive valley aquifers were found in lenses of sand and gravel within the valley-fill sediments. Brown and Ferris (1946) also cautioned, even in this early phase of exploration, against the overdevelopment of existing resources. Randall (1972) produced an inventory of more than 2,700 wells and borings in the Susquehanna River Basin; subsequent studies used this inventory for subsurface hydrological and geological interpretations.

Randall (1978b) and Randall (1981) described the surficial deposits of the region and their hydrologic connectivity to coarse sand-and-gravel aquifers within the valley-fill sediments. Holecek and others (1982) conducted a comprehensive study of the aquifer system in southwestern Broome County that resulted in maps depicting surficial geology, aquifer extent and thickness, well yields, and an estimated potentiometric surface. MacNish and Randall (1982) expanded this effort to define the depth and thickness of sand-and-gravel valley aquifers within the entire Susquehanna River Basin of New York. Randall (2001) developed a simplified conceptual model for interpreting the hydrogeologic framework of stratified glacial deposits across the glaciated northeastern United States. Kontis and others (2004) reported hydraulic properties for these valley-fill aquifers and used them to characterize recharge from upland areas and to develop regional groundwater-flow models.



Base from New York State Geographic Information Systems (NYSGIS, 2018)
2-meter lidar, North American Datum of 1983

Figure 3. Approximate location of ice margins, approximate extent of Glacial Lake Great Bend (GLGB) (Braun, 1999), truncated spurs, surface exposures of ice-contact deposits, till shadows (TS) (Coates, 1966; Braun, 2006a), concavo-convex landforms (CC) (King and Coates, 1973; Coates, 1981), dissected moraine (M), and likely outlet for GLGB near Pine Manor. Ice-flow direction is indicated for both an earlier glaciation (indicated by number 1) and later glaciation (indicated by number 2). Approximate ice margins within the valley are older than the approximate boundary of GLGB and were defined by identifying truncated spurs, lidar-derived trimlines, and patterns in the subsurface facies.

Site-specific studies have described and evaluated infiltration, recharge, withdrawal rates, aquifer hydraulic conductivity, and groundwater flow within aquifers that underlie parts of the towns of Conklin and Kirkwood (Waller and Finch, 1982; Yager, 1986, 1993). Comprehensive studies have characterized the hydrogeology beneath the (now-closed) Gorick C & D landfill in Kirkwood and the similarly closed upper and lower Conklin landfills in Conklin (O'Brien and Gere, 1984, 1985; URS Consultants, 1992; Delaware Engineering, 2007). Additional USGS studies have characterized sand-and-gravel aquifers in the Susquehanna River valley to the east and west of the study area (Randall, 1977, 1986; Coon and others, 1998; Heisig, 2012; Randall and Kappel, 2015).

Spatial Distribution of Glacial and Postglacial Deposits

The spatial distribution, areal extent, and descriptions of surficial sediments are presented on plate 1. A generalized depiction of subsurface facies mantling the valley floor is shown in figure 4, and the relations between surficial geology and subsurface glacial and postglacial deposits in the study are illustrated by seven hydrogeologic sections that cross the Susquehanna River valley (figs. 5–12).

Glacial Deposits—Subsurface Facies

The distribution of subsurface sediments depicted in figure 6 is consistent with the type of regional deglaciation described by Harrison (1966), MacNish and Randall (1982), and Fleisher (1986b, 1993). As the glacier receded north of Great Bend into the study area, ice initially thinned and deposited sediment in the highlands and along the valley walls. These deposits are almost exclusively ablation till, but a few isolated deposits of till overlying sand and gravel (about 10–60 ft thick) are on south-facing slopes to the north of Conklin Forks (figs. 1 and 2). The ice tongue in the valley backwasted, and the narrowest part of the valley near Riverside was dammed by ablation till and outwash. Coarse deltaic-lake sediments and isolated ice-contact deposits were deposited in the stagnant water that ponded between this dam and the receding ice margin (figs. 4 and 6).

Continued melting and recession upvalley either created a new proglacial lake or expanded the preexisting lake. Lacustrine sediments of various compositions were deposited that also contained small, discontinuous lenses of sand and gravel. Lacustrine sediments generally thicken from south to north in the valley between the hamlets of Corbettsville, Conklin Station, Conklin, and Kirkwood (figs. 7 and 8). An oscillating ice margin persisted near a valley constriction just north of Kirkwood. The waxing and waning ice front fed a subglacial stream that filled the valley bottom with a thick (approximately 100 ft) sequence of lacustrine fine sand and clay interbedded with till and ice-contact sand and gravel (fig. 9). This sedimentary package extends from Kirkwood to just north of Langdon. As the ice continued retreating, the proglacial lake margin fed by meltwater followed north. A layer of ice-contact deposits accumulated when the ice paused between Kirkwood Center and Langdon (fig. 10). Extensive ice-contact deposits accumulated in the proglacial lake as the ice retreated past Five Mile Point (fig. 11) and paused near the valley-choker moraine west of Pine Manor. Meltwater from downwasting ice in the highlands and the remaining valley-ice tongue continued to produce outwash and feed the lake that formed behind the valley-choker moraine. Eventually, this tongue became detached from the active ice front, leaving stagnant ice to melt in place.

The exact mechanism by which western drainage was established is uncertain. An outlet stream from a small proglacial lake in the study area may have initially incised the Pine Manor moraine prior to the invasion of GLGB; however, it is more likely that GLGB followed the melting ice margin up the Susquehanna River valley, and that western drainage was not established until the ice retreated to the north of Pine Manor. Evidence that this late stage of GLGB was likely short lived in the study area is based on the lack of high-stand (highest lake level) and valley-bottom clay-rich lacustrine deposits. The collapse of GLGB was catastrophic, and outburst waters were concentrated along a prominent truncated spur that defines the southern valley wall (fig. 3). Previously deposited stratified sediment was preferentially scoured from the valley near the southeastern terminus of the truncated spur (fig. 12). The release of GLGB was followed by meltwater from ice occupying the Susquehanna River valley and watershed north of Great Bend. This influx of sediment-rich water blanketed the valley bottom with thick layers of outwash and remobilized preexisting ice-contact and lacustrine sediments (plate 1).

Glacial Deposits—Surficial Exposures

The entire study area was covered by the Laurentide ice sheet during the Wisconsinan glaciation. The ice was at least 3,000 feet thick, and the highest summits were likely covered by 1,000 feet of ice (King and Coates, 1973). Deglaciation occurred between 20,000 and 18,000 years ago, leaving behind a landscape sculpted by glacial erosion and deposition (Fleisher, 1986a, b; Ridge, 2003; Braun, 2006a). Downwasting and retreat first occurred in the highlands, exposing nunatuks (bedrock exposures that protrude through the surrounding ice) and eventually lower elevation hilltops to periglacial processes (Harrison, 1966; King and Coates, 1973). Southern to southwestern ice flow became concentrated in the remaining valley ice tongue. As ice retreated down the valley, it left deposits adjacent to stagnant ice, fine-grained sediment in an ice-dammed lake, and a surficial train (outwash) of sand and gravel beyond the ice margin.

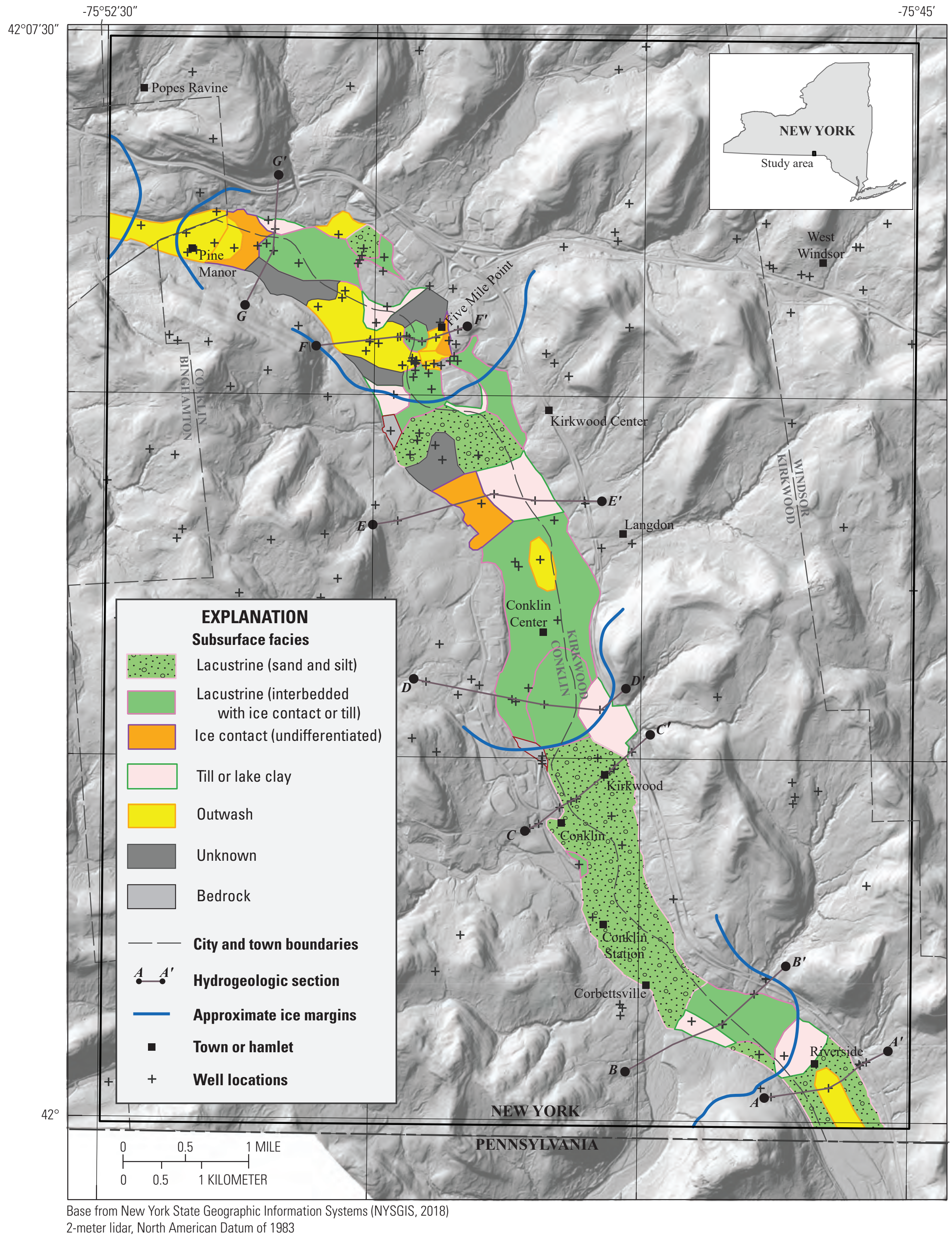


Figure 4. Generalized depiction of subsurface facies that occur beneath surficial deposits of alluvium, alluvial fan, and outwash within the Susquehanna River valley. Hydrogeologic section lines and approximate ice margins are included for reference.

DESCRIPTIONS OF STRATIFIED AND UNSTRATIFIED SEDIMENTS
for cross sections within this report (figures 6 through 12)

w — **Open water**—Areas of open water such as rivers, lakes, large ponds, and reservoirs

lf — **Landfill**—Inactive sites; three localities limited to the Susquehanna River valley

f — **Artificial fill**—Earth materials and manmade materials that have been artificially emplaced

al — **Alluvium**—Postglacial river and stream floodplain deposits consisting predominantly of stratified silt and clean to silty sand, commonly with some gravel at the base of the deposit. Thickness as much as 10 to 40 feet (ft) in the Sushehanna River valley and 1 to 10 ft in the smaller tributaries. Typically underlain by stratified glacial and lacustrine deposits in main valleys and by till in upland valleys

alf — **Alluvial fan**—Fan-shaped accumulation of stratified silt, sand, and gravel, deposited by tributary streams where they enter the Sushehanna River valley. Fans are typically underlain by outwash or coarse sand and gravel derived, in part, from the drainage area of the alluvial fan

osg — **Outwash sand and gravel**—Proglacial river and stream floodplain deposits consisting predominantly of stratified silt and clean to silty sand, commonly with some gravel at the base of the deposit. Thickness as much as 15 to 25 ft in the Susquehanna River valley and most tributary valleys. Typically underlain by stratified glacial and lacustrine deposits in main valleys and by till or bedrock in upland valleys

ic — **Ice-contact deposits**—Stratified sand, gravel, and silt deposited by meltwater in both subaerial and subaqueous environments adjacent to glacial ice. May include isolated kames in valley areas of ice stagnation or occur as subaqueous fans in the subsurface overlying bedrock in areas of active ice retreat. May be interbedded with diamict

l — **Lacustrine deposits**—Stratified sand, silt, or clay deposited by meltwater in proglacial lakes. Typically sand to silt, but grain size is variable. May be interbedded with till

t — **Till**—Unsorted, unstratified mixture of clay, silt, sand, gravel, and boulders deposited beneath the ice as lodgement till during glacial advance, or at the edge of an ice sheet by melting ice as ablation till during a pause, or retreat, of the ice front. Found mostly in uplands. Thickness ranges from greater than 30 to 220 ft

tv — **Valley till**—Unsorted, unstratified mixture of clay, silt, sand, gravel, and boulders deposited beneath the ice as lodgement till during glacial advance. Occurs along the confining walls of the Susquehanna River valley, may overlie sand and gravel. Thickness ranges from 40 to 90 ft

ts — **Slumped till**—Unsorted, unstratified mixture of clay, silt, sand, gravel, and boulders. Originally deposited beneath the ice as lodgement till during glacial advance/readvance or via melting ice as ablation till. Occurs as convex landforms overlying valley till at the base of concave slopes as described by King and Coates (1973). Thickness ranges from 55 to 100 ft

tt/r — **Thin till over bedrock**—Thin, discontinuous veneer of till, typically 0 to 30 feet thick, over fractured bedrock

r — **Bedrock**—Miscellaneous sandstones, siltstones, claystones

BM 1 — **Well location**—Label corresponds to site name assigned by the U.S. Geological Survey (BM = Broome County). Small horizontal blue line indicates approximate depth to groundwater measured by driller and recorded on well-log form submitted to the New York State Department of Environmental Conservation

Figure 5. Descriptions of stratified and unstratified sediments depicted in hydrogeologic cross sections (figs. 6–12).

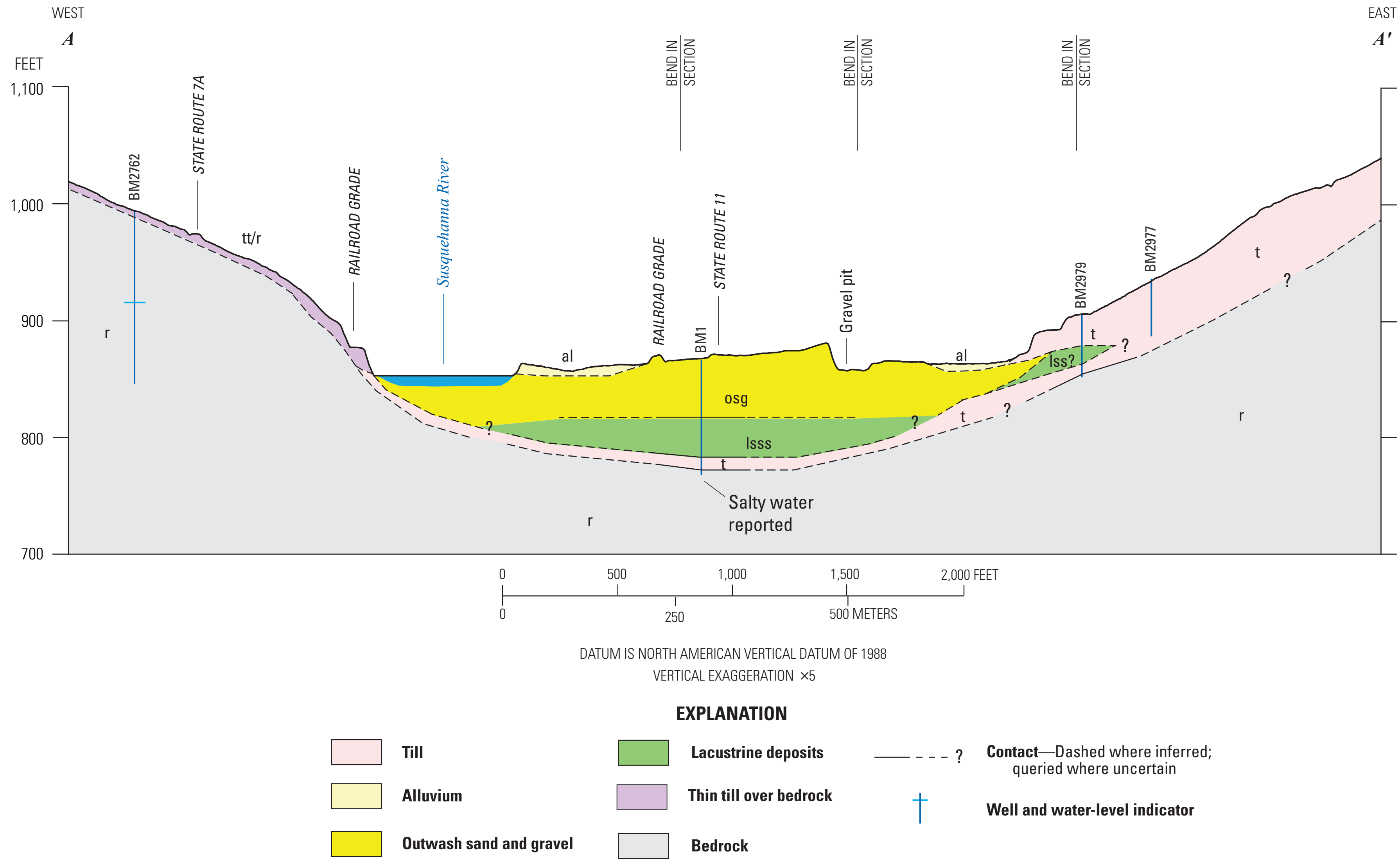


Figure 6. Hydrogeologic cross section *A–A′*, Susquehanna River valley south of Riverside, New York. Section line is shown on figure 4 and plate 1; horizontal scale of section differs from map scales. Sediments are described in figure 5. Iss?, lacustrine silt, uncertain; Isss, lacustrine silt, sand.

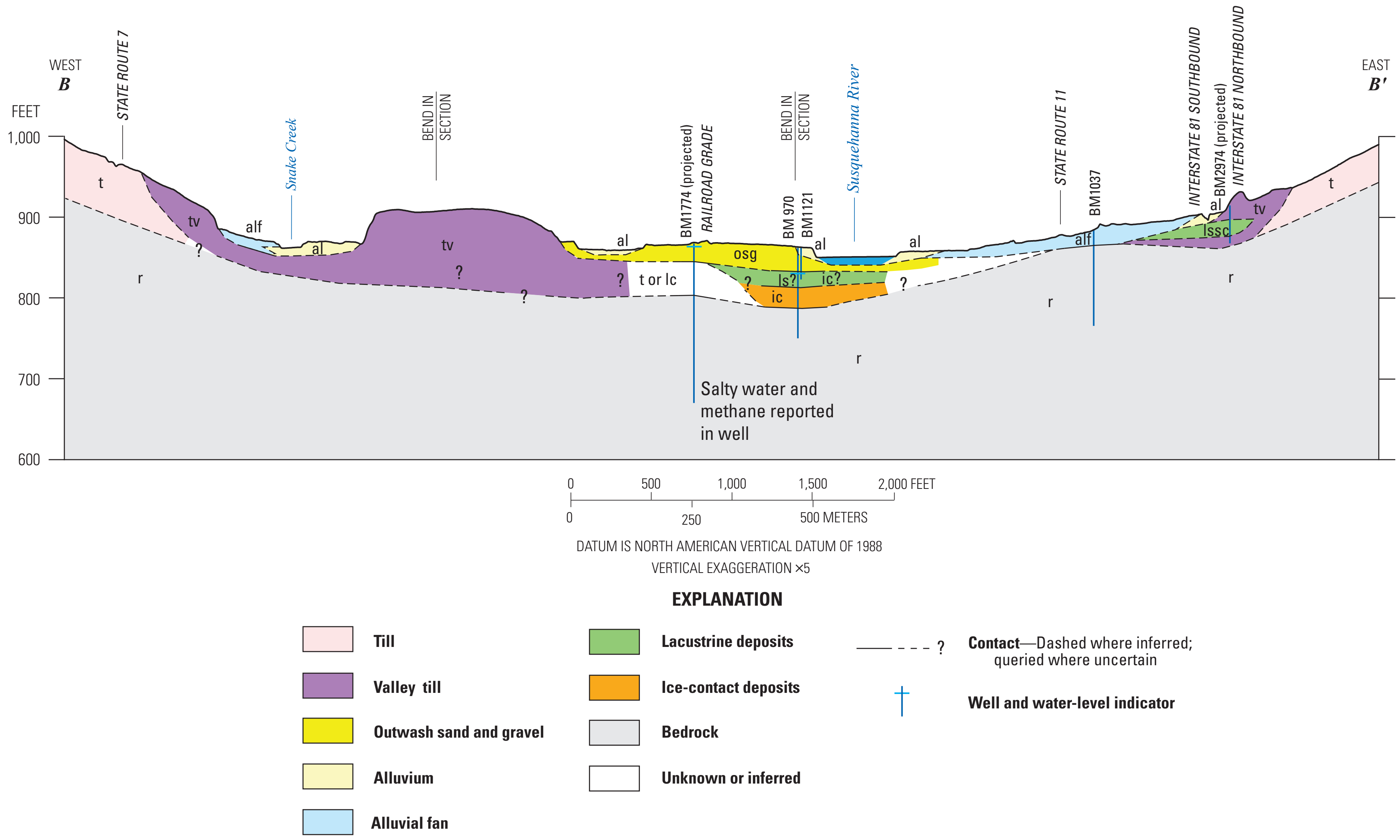


Figure 7. Hydrogeologic cross section *B–B′*, Susquehanna River valley south of Corbettsville, New York. Section line is shown on figure 4 and plate 1; horizontal scale of section differs from map scales. Sediments are described in figure 5. ic?, ice-contact deposit, uncertain; lc, lacustrine clay; ls?, lacustrine sand, uncertain; lssc, lacustrine silt, clay.

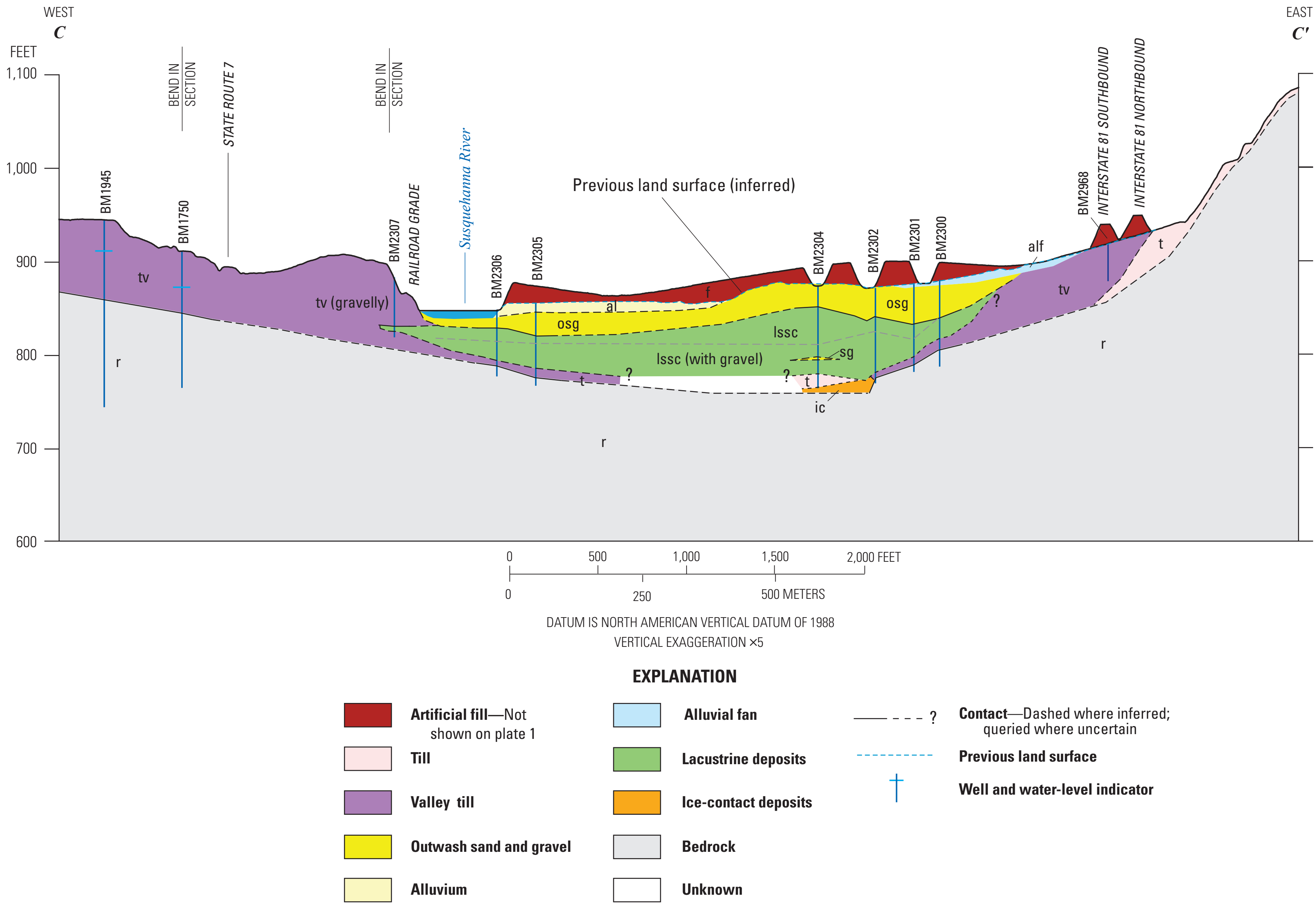


Figure 8. Hydrogeologic cross section *C–C′*, Susquehanna River valley at Conklin and Kirkwood, New York. Section line is shown on figure 4 and plate 1; horizontal scale of section differs from map scales. Sediments are described in figure 5. lssc, lacustrine silt, clay; sg, sand, gravel.

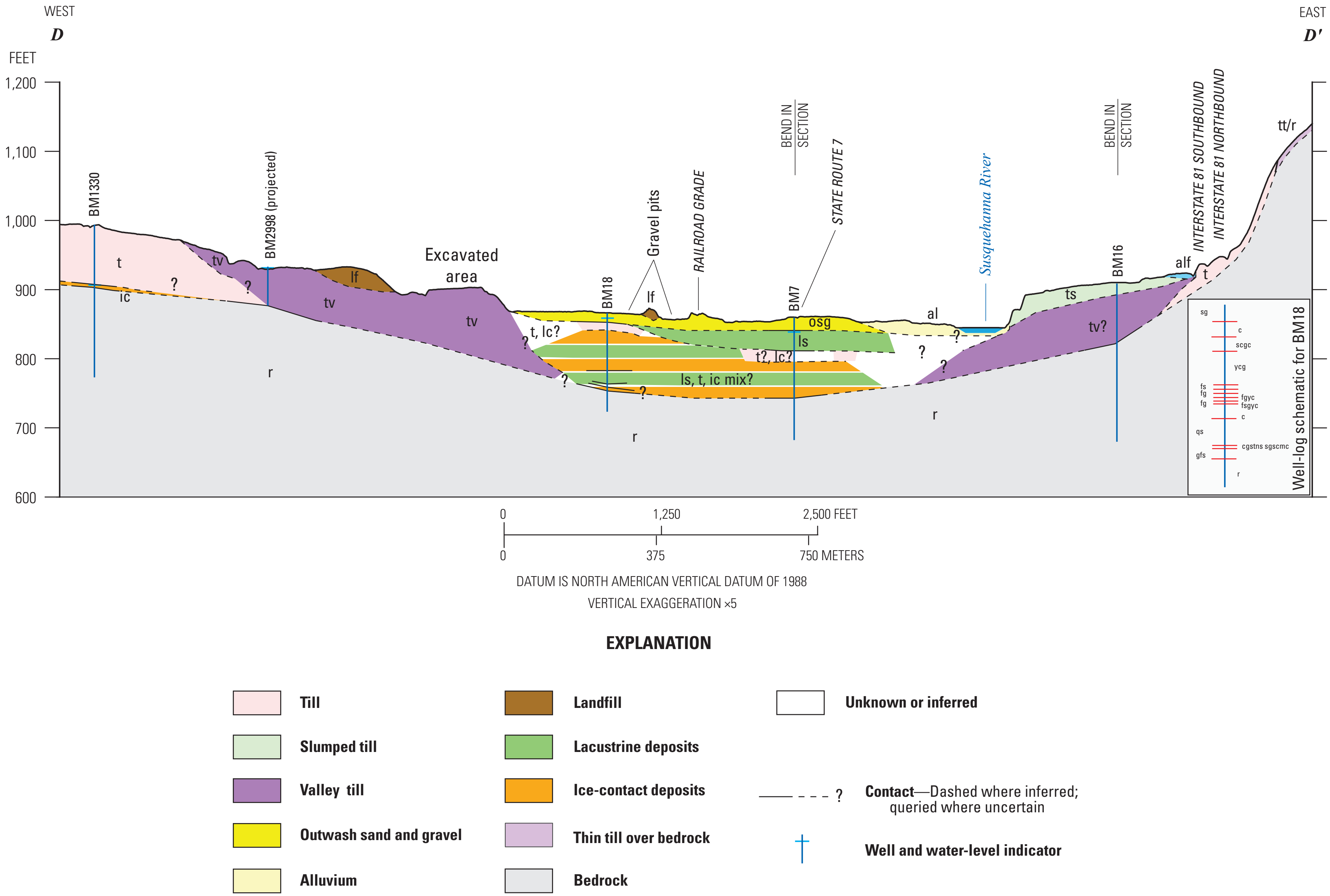


Figure 9. Hydrogeologic cross section *D–D′*, Susquehanna River valley north of Kirkwood, New York. Section line is shown on figure 4 and plate 1; horizontal scale of section differs from map scales. Sediments are described in figure 5. The inset log (BM 18) illustrates the complexity of stratified sediments filling the valley. c, clay; cgstns sgsmc, coarse gravel with stones, sand, gravel, and some clay; fg, fine gravel; fgyc, fine gravel, yellow clay; fs, fine sand; fsgcy, fine sand, gravel, yellow clay; gfs, gravel, fine sand; lc?, lacustrine clay, uncertain; ls, lacustrine sand; qs, quicksand; scgc, sand, coarse gravel, clay; sg, outwash sand and gravel; ycg, yellow clay, gravel.

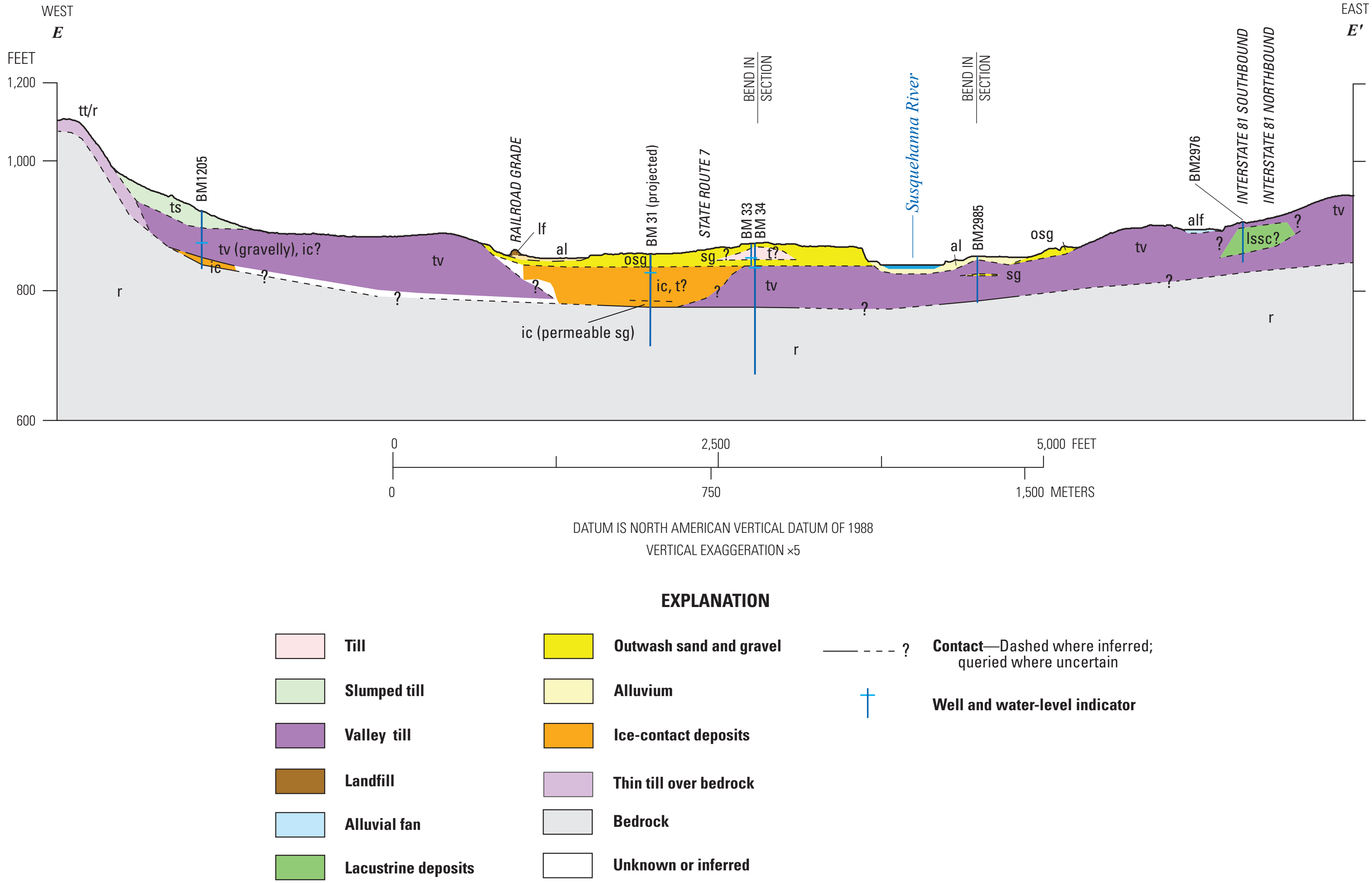


Figure 10. Hydrogeologic cross section *E–E′*, Susquehanna River valley northwest of Langdon, New York. Section line is shown on figure 4 and plate 1; horizontal scale of section differs from map scales. Sediments are described in figure 5. lssc?, lacustrine silt, clay, uncertain; sg, sand, gravel.

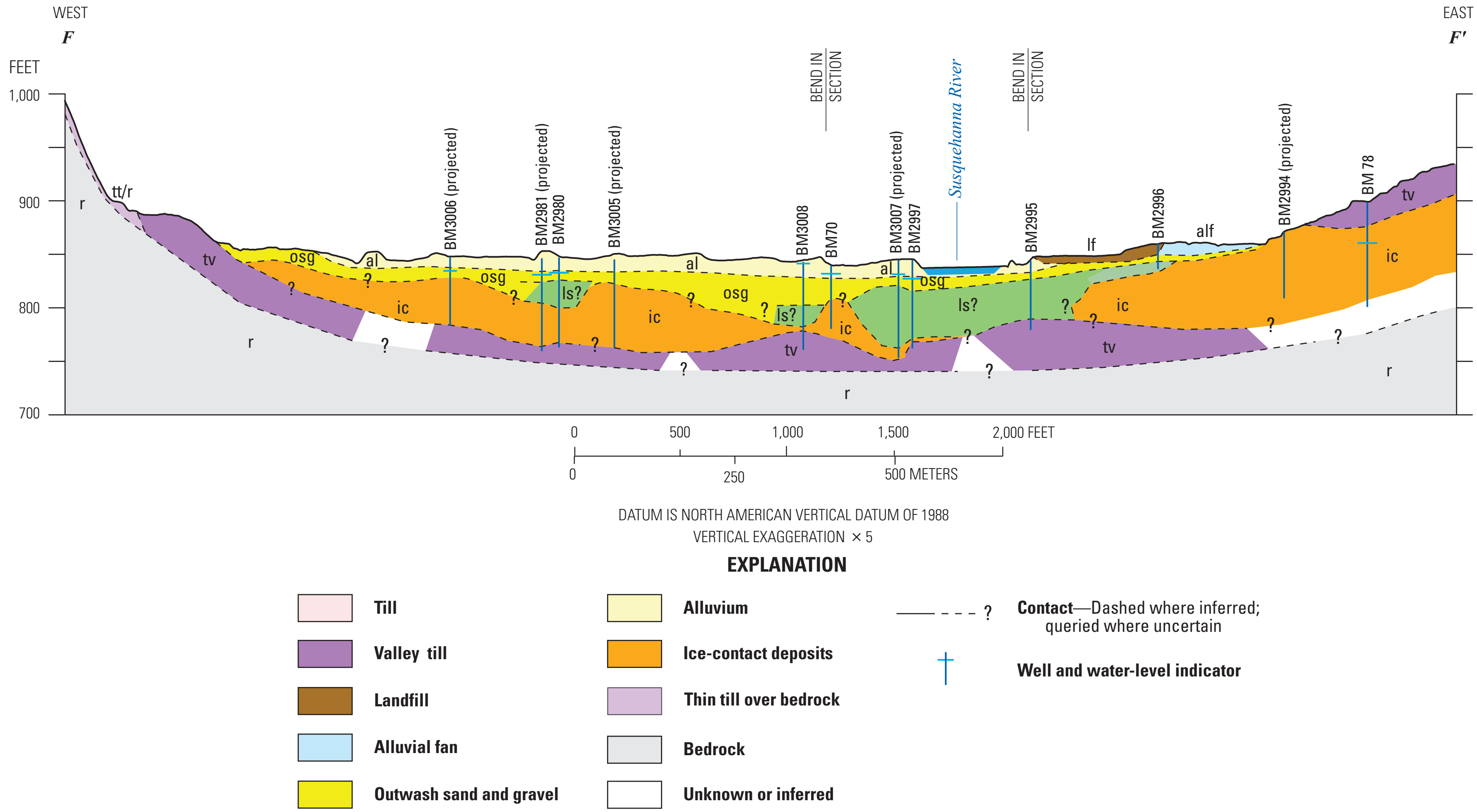


Figure 11. Hydrogeologic cross section *F–F′*, Susquehanna River valley south of Five Mile Point, New York. Section line is shown on figure 4 and plate 1; horizontal scale of section differs from map scales. Sediments are described in figure 5. ls?, lacustrine sand, uncertain.

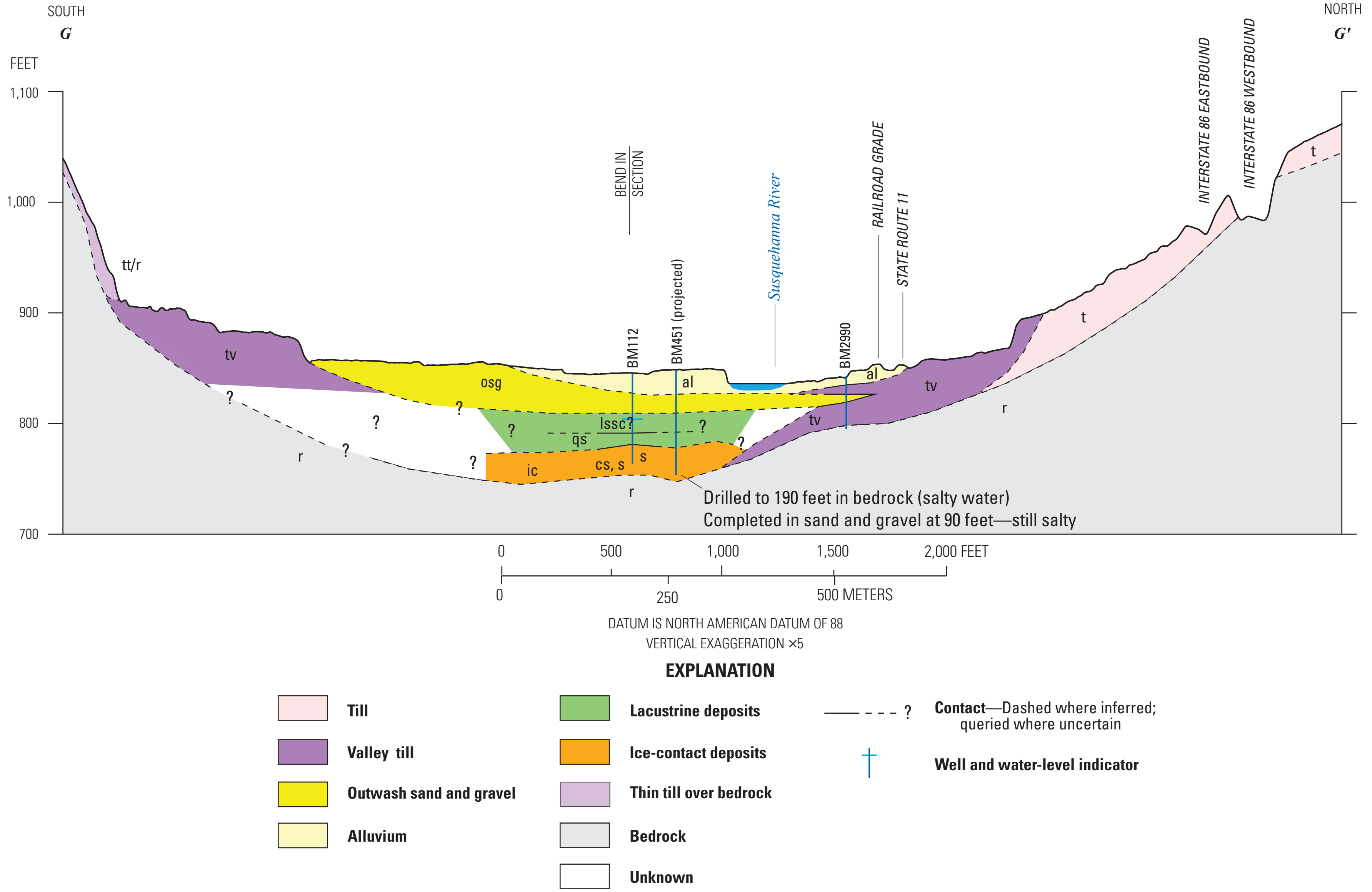


Figure 12. Hydrogeologic cross section *G–G′*, Susquehanna River valley east of Pine Manor, New York. Section line is shown on figure 4 and plate 1; horizontal scale of section differs from map scales. Sediments are described in figure 5. cs, coarse sand; lssc?, lacustrine silt, clay, uncertain; qs, quicksand; s, sand.

Till is the most common unconsolidated deposit in the region and predominantly present in the highlands. Upland till is poorly sorted with variable grain sizes and typically includes dense lodgment till but less dense ablation till. It occurs as a thin (0–30 feet), discontinuous veneer covering summits and northeast-facing slopes. It also occurs as thicker till shadows on southwest-facing slopes (fig. 3). Upland till also occurs as thicker (about 40–200 feet) deposits on lower elevation slopes that lead down to the valley floor. Upland till transitions into a valley till near the bottom of both sides of the valley for almost its entire length. Valley till is thicker along the valley walls but becomes thinner near the center of the valley. A few small, lobate deposits of slumped till—similar to the concavo-convex features described by King and Coates (1973)—are draped over valley till at the base of concave slopes (fig. 3).

Stratified glacial sediments in the study area are confined to the Susquehanna River valley and have limited surface exposure. The ice tongue retreated to the north through back-wasting beginning at the constriction near Riverside, New York. The ice front also underwent episodic stagnation and downwasting at the ice margin (MacNish and Randall, 1982; Fleisher, 1986a, b, 1993). Each pause produced a pulse of coarse-grained outwash that was deposited in front of the ice margin. The longer the pause, the more extensive the resulting outwash plain. Each successive retreat spawned another small proglacial lake in which fine-grained lacustrine sediments and ice-contact deposits could accumulate. This repeating sequence of (1) coarse meltwater and ice-marginal deposits that (2) prograde into fine-grained lacustrine deposits, which (3) commonly overlie coarse-grained deposits of the previous ice margin, is present throughout the Susquehanna River Basin (Harrison, 1966; Cadwell, 1981; Fleisher, 1986a, b; Fleisher, 1993).

Braun (1999) estimated that the lake persisted for approximately 360 years as the ice margin retreated north from New Milford, Pennsylvania (not shown on any figure). Eventually the ice margin retreated north of Great Bend, which allowed GLGB to invade the Susquehanna River valley; however, its subsequent presence in the study area was short-lived. Fine-grained lacustrine deposits (fig. 4) collected in the valley until the ice margin moved north of Five Mile Point. The persistence of morainal material northwest of Pine Manor indicates that stagnant ice remained in the valley long enough to concentrate meltwater along the southern wall of the valley. Subsequent meltwater flow across the moraine dissected it and created a western outlet through Binghamton for both the lake and meltwater from the eastern Susquehanna River valley upstream from Great Bend (fig. 3, plate 1). Erosion caused by catastrophic lake drainage once the ice margin retreated north of Great Bend or by the prolonged subsequent input of meltwater might explain the limited surface exposures of lacustrine and ice-contact deposits (fig. 3). After the lake drained an influx of sediment-choked meltwater from retreating ice in the surrounding uplands, the upper Susquehanna drainage deposited an extensive outwash plain (valley train) from Riverside north to Pine Manor (fig. 4). Residual meltwater and the modern Susquehanna River have since eroded and incised the valley floor, leaving discontinuous islands of outwash (see the abbreviation "osg," plate 1).

Postglacial Deposits

After deglaciation, postglacial processes modified the distribution of surficial sediments in the study area. High-gradient streams developed in small valleys between ridgelines and further incised the sediments down to the valley floor. Variable discharge rates in these tributaries made possible the transporting of a mixture of fine-to-coarse sediment. Where streams entered the low-gradient valley, sediments of variable grain sizes were deposited as alluvial fans. These fans are near the mouths of almost all of the tributaries to the modern Susquehanna River (see the abbreviation "alf," plate 1), and their thicknesses range from 15 to 30 ft. Most of the fine-grained fractions in the tributaries were transported into the valley and deposited as alluvium. The Susquehanna River meandered between the valley walls and deposited extensive floodplain alluvium. Alluvium in the Susquehanna River valley is thickest (about 15–20 ft) from Five Mile Point northwest to Pine Manor and from Corbettsville south past Riverside. Alluvium is generally thinner between Conklin and Kirkwood Center (plate 1).

Groundwater-Resource Potential of Valley-Fill Aquifers and Uplands

As ice retreated north through the Susquehanna River valley from Riverside, the oscillating ice margin fed proglacial lakes impounded by sediments that were deposited at previously stable ice margins. This type of deglaciation was typical for the region and produced a mixture of fine-grained lacustrine sediment interbedded with coarser ice-contact deposits and till that blanketed the valley bottom from Riverside to Langdon. As the ice retreated north from Kirkwood Center over the highlands, it left a tongue of ice in the northwest-to-southeast-trending valley. This downwasting ice likely remained in contact with the last phase of GLGB until it also drained to the west. This dynamic style of deglaciation filled the valley bottom with a mosaic of till and coarse-to-fine-grained sediments and thus explains why the groundwater-resource potential in much of the valley is variable, and high yields are generally limited to small localized aquifers. The valley-fill aquifer system in the study area includes both confined and unconfined aquifers. Approximate minimal boundaries for these aquifers were delineated (fig. 13) by using well and borehole logs, surficial geology, and hydrogeologic sections produced by previous studies (Randall, 1972, 1986; Yager, 1986, 1993). Confined aquifers are characterized by either lacustrine silt and clay or till overlying sand

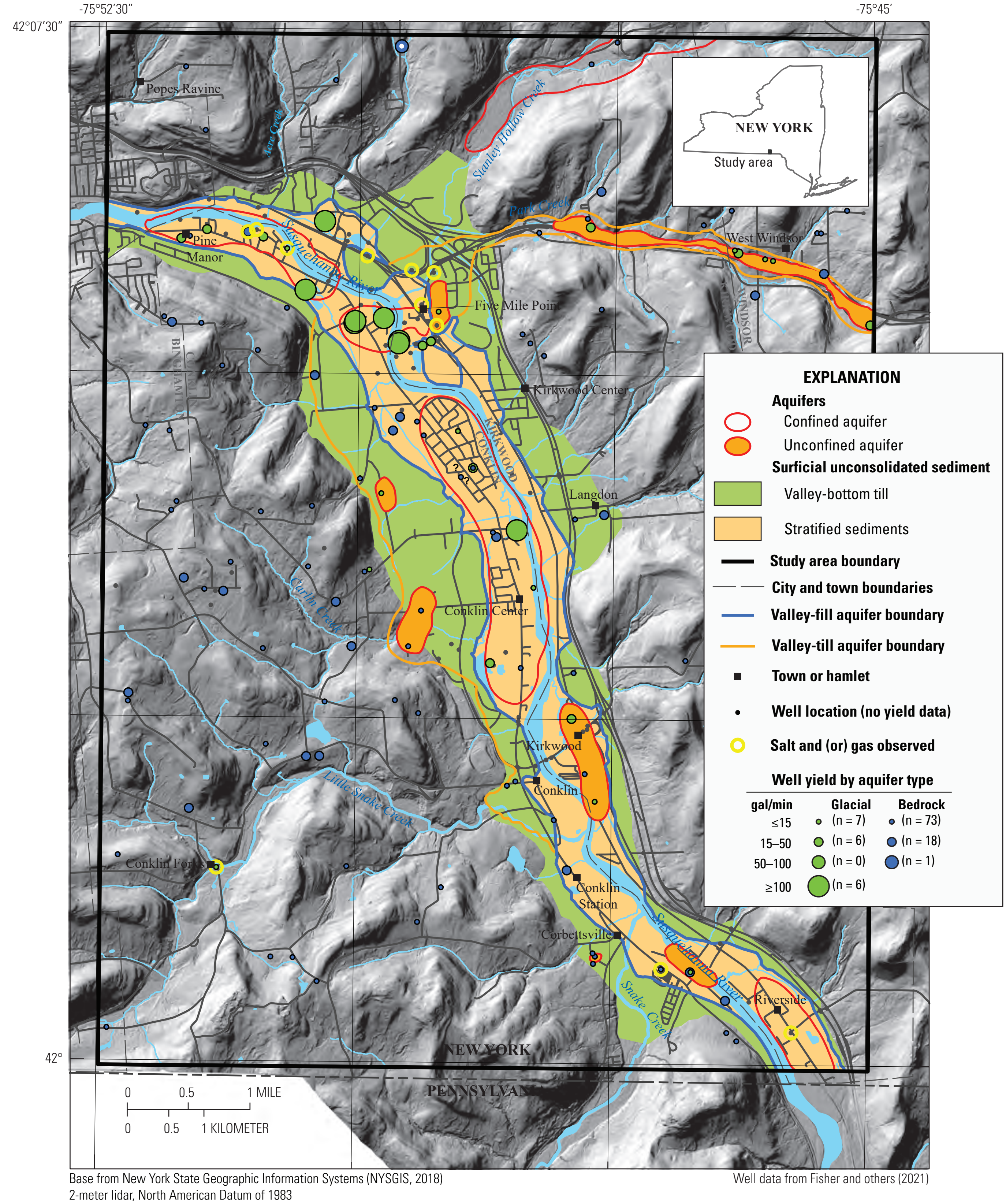


Figure 13. Approximate locations of the valley-fill aquifer and local confined and unconfined aquifers and the approximate valley-till aquifer boundary in relation to stratified sediments. Confined aquifers are typically sand and gravel overlain by till or lacustrine sediments. Unconfined aquifers are typically thick surficial deposits of sand and gravel. Question marks indicate uncertainty about the boundary of a confined aquifer. The map also depicts the distribution of well yields in gallons per minute (gal/min) on the basis of aquifer type. Wells that terminate in stratified glacial aquifers (n=82) are predominant in the northern end of the valley; a few low-yield wells are found near tributaries. Bedrock wells (n=137) have been finished throughout the study area, but most are in the uplands and typically have low yields.

and gravel. Sand and gravel aquifers (both confined and unconfined) are present mostly in the main valley; however, other glacial aquifers of limited extent and saturated thickness are likely present in the lower reaches of any large tributary valley. Two tributary valleys with documented aquifer material, both northeast of Five Mile Point, include Park Creek, in which sand and gravel are confined by till, and Stanley Hollow Creek, which contains unconfined sand and gravel (fig. 13, plate 1). Stratified sediments confined by till but with limited saturated thickness also occur in the uplands (see well numbers BM 915, BM1033, BM1048, BM1186, BM1305, and BM1335).

Wells and boreholes from which data were compiled for this study (*n*=221) are roughly evenly divided between those in the valley aquifer-boundary (fig. 13, plate 1) and those in the surrounding uplands: there are approximately 10 percent more wells in the valley than in the uplands. More than 60 percent of valley wells terminate in glacial (unconsolidated) sediments, and 100 percent of true upland wells (that is, wells at a higher elevation) terminate in bedrock (table 2); however, a small percentage of wells in upland valleys and hollows are completed in sand and gravel. The range of well yields reported for bedrock and glacial wells is summarized in table 3 and on figure 13. Bedrock wells are more abundant and deeper than glacial wells, but the median yield from glacial wells is twice as high.

All of the highest yielding production wells are completed in the thickest unconfined aquifer areas adjacent to the Susquehanna River between Pine Manor and Conklin Center (fig. 13, plate 1). Two production wells for the town of Conklin have reported yields of 750 and 2,000 gal/min, and two production wells that serve the town of Kirkwood have reported yields of 1,000 and 2,000 gal/min. These high, sustainable yields are the result of both permeable aquifer material and induced infiltration of water from the Susquehanna River (Randall, 1978b; Yager, 1986, 1993). Additional recharge of valley aquifers likely occurs through lateral migration from the valley walls; however, since there is no sizeable groundwater withdrawal from confined aquifers that would initiate recharge from bedrock aquifers, recharge through upward leakage from the underlying bedrock is likely very slow and limited to diffusion. The presence of very poor water quality in a shallow bedrock well (BM1774) is consistent with observations throughout the Susquehanna River drainage area (Heisig and Scott, 2013). If bedrock beneath the valleys had a dynamic flow system, there would be evidence of more frequent flushing.

Table 2. Summary depth characteristics for domestic and commercial wells (excludes public-supply wells) that terminate in bedrock and glacial sediments.

[Undifferentiated means the well log did not differentiate between bedrock or glacial sediments. gal/min, gallon per minute; ft, foot, —, no data]

Aquifer type	Number	Median yield (gal/min)	Median well depth (ft)	Well-depth range (ft)
Bedrock	137	10	180	19–520
Glacial	82	20	60	1–424
Undifferentiated	2	—	—	—

Table 3. Summary of yield ranges for domestic and commercial wells (excludes public-supply wells) that terminate in bedrock and in glacial sediments.

[gal/min, gallon per minute; ≥, greater than or equal to]

Wells terminating in bedrock		Wells terminating in glacial sediments	
Yield range (gal/min)	Well count	Yield range (gal/min)	Well count
1–15	82	1–15	13
16–50	22	16–50	10
≥50	1	50–100	0
No data	32	≥100	4
		No data	53

Most reported yields for domestic or commercial wells represent short-term withdrawals measured by the driller from open-ended wells rather than sustained pumping tests of screened wells, which represent maximum desirable yield at that site. This difference implies that most reported well yields likely underestimate the groundwater potential of the underlying aquifers. Estimations of the potential yields of individual aquifers are also complicated by the variability and extent of subsurface sediments, hydraulic conductivity, and saturated thickness.

Aquifers in stratified valley sediments extending north from Conklin Center have the highest known groundwater potential in the study area (fig. 13). The highest reported yields are from wells that tap thick (approximately 60–80 ft) unconfined sand and gravel deposits adjacent to the Susquehanna River (figs. 13 and 14, table 3). The proximity of pumping wells to the Susquehanna River induces recharge to the aquifer from the river, which supports sustainable high yields. Yager (1993) estimated that induced river infiltration accounted for 58 percent of the recharge during October 1984. Numerous tributaries enter this reach of the valley, but the thicker till in the valley bottom likely limits infiltration until the streams cross onto alluvium closer to the center of the valley (fig. 14). There is likely slow, limited recharge from rainfall and snowmelt to bedrock beneath till-covered lower hillsides and to bedrock or confined sand and gravel beneath valley-bottom till.

Aquifers within stratified valley sediments between Conklin Center and Corbettsville are tapped by a limited number of wells. This part of the aquifer system occupies a narrow reach of the valley filled with stratified glacial sediment interbedded with till. Stratified deposits are thickest beneath

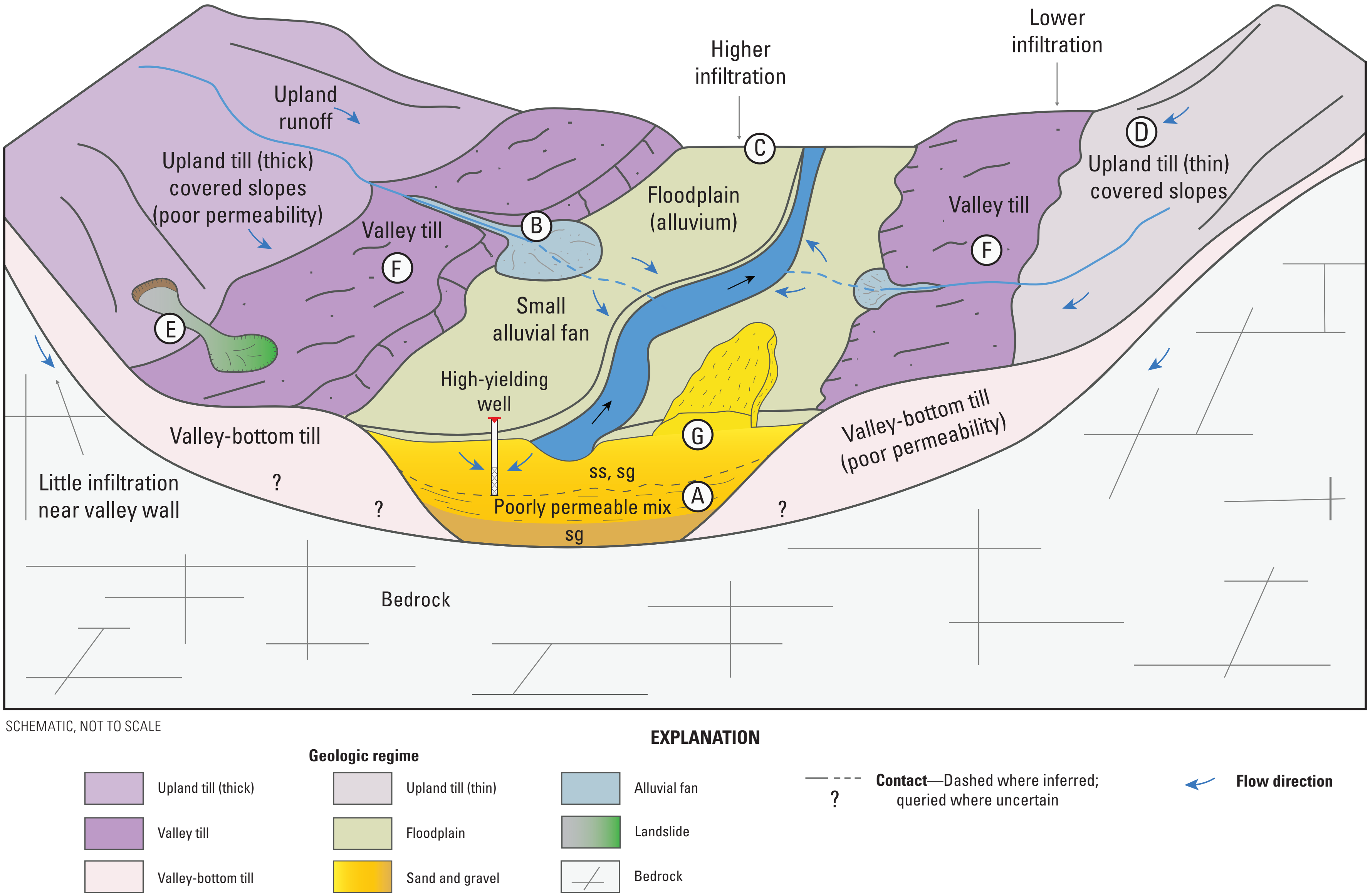


Figure 14. A simplified conceptual block diagram of groundwater flow in the Conklin-Kirkwood valley-fill aquifer system. Subsurface units include till, sand and gravel (sg), silty sand and gravel (ss, sg), and interbedded low-permeability sediments (for example, mixed fine-grained lacustrine and till) located at (A). Upland runoff creates infiltration, tributary streams, and alluvial fans that overlie floodplain alluvium. Little infiltration occurs where alluvial fans cover valley-bottom till (B). Precipitation infiltrates floodplain alluvium (C) and (or) alluvial fans that overlie alluvium. Valley-bottom and thick upland till have low infiltration capacity (D), and slumped till overlies valley-bottom till in some locations (E), further decreasing infiltration. Valley till (either lodgment or ablation) typically grades into upland till near the valley inflection point (F), and the valley contains discontinuous thick deposits of outwash sand and gravel, both of which have high values of infiltration and permeability (G). Arrows indicate direction of groundwater flow.

the towns of Conklin and Kirkwood; however, the proportion of fine-grained lacustrine to sand-and-gravel deposits is highly variable. In general, sand and gravel units thicken from north to south in this part of the valley. Carlin, Snake, and Little Snake Creeks enter the Susquehanna River from the west, and several smaller tributaries drain uplands to the east. Well-log data is limited, and only a few wells report saturated thickness and yield. The maximum estimated saturated thickness is approximately 45 feet, and yields range from 2 to 16 gal/min; these ranges indicate low groundwater potential relative to other aquifers in the study area (fig. 13).

The valley aquifer south of Corbettsville occupies a constricted reach of the valley. It includes a confined aquifer with a single reported well yield of 10 gal/min and an unconfined aquifer in approximately 50 ft of sand and gravel that overlies lacustrine sediment. A few small tributaries enter the valley upstream of the unconfined aquifer. This unconfined aquifer is untested but might represent a significant water resource that could provide induced recharge if its silt content is not excessive (given its proximity to the Susquehanna River).

Unconfined and confined valley aquifers have different water-quality vulnerabilities. Unconfined valley aquifers typically have the highest yields, largely due to hydraulic connection with the Susquehanna River, but they are the most vulnerable to contamination caused by human activities on the land surface and changes in the quality of the river water. Confined aquifers in the area produce limited yield, but the confining units offer protection from human activities at the land surface. Water samples from both confined sand-and-gravel and bedrock wells in valley settings in this area, however, are likely to contain high concentrations of dissolved solids and methane (Heisig and Scott, 2013). The increased likelihood of these conditions in samples from deep valley wells has been reported widely in the region (Kappel and Nystrom, 2012; Molofsky and others, 2013; Lautz and others, 2014). Figure 13 depicts study-area locations of wells in which saline water was collected in water samples that also typically contained methane. Salty water and (or) methane were identified in deep valley wells north of Kirkwood Center, south of Corbettsville, and in one well along Little Snake Creek near Conklin Forks. Saline waters include a wide, elevated concentration range of dissolved solids, and the water is typically unpotable. Saline water in shallow bedrock or deep confined aquifers indicates that limited flushing by more recent dilute recharge has restricted groundwater flow. The widespread presence of till in valley-bottom deposits and on lower hillsides inhibits recharge to confined aquifers, and till's generally low permeability in valley fill beneath alluvium and outwash slows groundwater flow (fig. 14).

Outside of the Susquehanna River valley and major tributary valleys, almost all residents in upland areas obtain water from wells completed in the bedrock aquifer. The reported yields from upland wells range between 2 and 30 gal/min, and the median yield is 10 gal/min. These yields are typically lower than yields from wells in valley settings but generally adequate for domestic supply. Most of these wells are drilled through 1 to 200 ft of till to reach the fractured-bedrock aquifer. Groundwater from upland bedrock wells is generally of good quality; this relatively young groundwater has had limited time within hilltop/hillside fractured-bedrock-flow systems (Heisig and Scott, 2013; McMahon and others, 2019).

Upland areas of thin till are unconfined or semiconfined with exposed bedding and fractures, which can lead to higher rates of infiltration and recharge to the bedrock aquifer. Areas covered by thin till, however, also have the greatest risk for contamination by upslope activities. In till shadows and other areas covered by thick till, bedrock is locally confined, and the aquifer is characterized by low rates of infiltration. These areas offer greater groundwater protection and should therefore be preferentially considered for siting activities that could potentially contaminate groundwater.

Summary

The hydrogeology of the Susquehanna River valley-fill aquifer system and associated water resources in southeastern Broome County, New York, were investigated in cooperation with the New York State Department of Environmental Conservation. The hydrogeologic framework of the study area was deduced by interpreting maps and other types of geological information about surficial deposits, subsurface information extracted from well-log and boring data, and previous studies in the area. A summary of well and boring data is provided in the accompanying data release. The study area is in the glaciated region of the northern Appalachian Plateau physiographic province. Deglaciation and resulting glacial deposits strongly influence well yields and have influenced the distribution of confined and unconfined aquifers throughout the valley. These well locations, width and thickness measurements of aquifers, surficial geology, distribution of thin versus thick till deposits, and locations of hydrogeologic sections are presented on a lidar-derived base map.

Groundwater extraction in the region is primarily used to meet the needs of residential property owners. Four public-supply wells, two each in Conklin and Kirkwood, supply water to approximately half the population in the study area. The Conklin public-supply wells have an average yield of 1,375 gallons per minute (gal/min), and the Kirkwood wells have an average yield of 1,563 gal/min. Residents outside the public-supply-service areas rely on private domestic wells. Most of these wells are in the highlands, and the majority terminate in bedrock and produce a median yield of 10 gal/min. A few private wells terminate in small confined and unconfined glacial aquifers in the valley fill south of Kirkwood.

Groundwater-resource potential is likely highest in valley-bottom sediments north of Conklin Center. There are more confined and unconfined aquifers in this part of the valley, and their areas are more extensive than aquifers to the south. Wells completed in unconfined aquifers terminate in thick deposits of sand and gravel. Wells completed in

confined aquifers terminate in sand and gravel overlain by lake clay or till. Saturated thickness is greater in unconfined aquifers. Domestic- and commercial-well yields north of Conklin Center range between 3 and 305 gal/min, but yields are highest north of Kirkwood Center, where aquifers may be replenished through induced infiltration from the Susquehanna River and numerous smaller tributaries. Future aquifer testing is needed, however, to characterize the hydraulic connectivity of the valley aquifer system with the Susquehanna River and its tributaries.

The confined aquifer in Park Creek valley is narrow, but well logs report penetrating roughly 5 to 55 feet of saturated sand and gravel and yields ranging between 8 and 35 gal/min. In the Susqhehanna River valley, south of Conklin Center, unconfined and confined aquifers of sand or gravel are generally small, and their approximate saturated thicknesses range between 20 and 25 feet. Driller's records for this part of the valley report well yields of 10 to 45 gal/min. A few small unconsolidated gravel aquifers in valley-bottom till and upland till west of Conklin Center produce yields ranging between 2 and 13 gal/min. Although most private wells outside the public-supply-area boundary produce low yields, they are typically enough to meet residential water demand.

Roughly half the population in the Binghamton East quadrangle relied on four high-capacity public-supply wells for the entire year of 2020. The remaining population relied on wells in small, discontinuous valley aquifers and bedrock wells in the uplands. Many aquifers are unconfined and potentially susceptible to contamination from industrial and commercial activities on the land surface. Given the potential for infiltration and recharge of valley aquifers through surface runoff and tributary streams, source-water and wellhead-protection efforts should also focus on upland slopes. Protection efforts should be prioritized in thin-till and exposed-bedrock areas, which are most at risk and most likely to supply surface-water runoff that will recharge to valley aquifers. Till shadows and other areas covered by thick till have lower rates of infiltration and should be preferentially considered for siting any activities that could potentially contaminate groundwater. The possible contamination of surface runoff at these sites could be detected more easily, and more promptly treated or halted, than contamination of groundwater.

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