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

Geohydrology, Water Quality, and Simulation of Groundwater Flow in the Stratified-Drift Aquifer System in Virgil Creek and Dryden Lake Valleys, Town of Dryden, Tompkins County, New York

Scientific Investigations Report 2013–5070

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

Front cover: Test drilling and aquifer test near Dryden Lake, Town of Dryden, New York. Drilling completed in 2004. Aquifer test, January 5, 2005. All photos courtesy Todd Millller, USGS.

Back cover. Three-dimensional-grid representation of groundwater-flow model of the stratified-drift aquifer system in the Virgil Creek and Dryden Lake valleys, Town of Dryden, Tompkins County, New York.

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SALLY JEWELL, Secretary

U.S. Geological Survey
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Conversion Factors and Datum

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.09290	square meter (m^2)
square inch (in^2)	6.452	square centimeter (cm^2)
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)
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
million gallons per day per square mile [(Mgal/d)/mi^2]	1,461	cubic meter per day per square kilometer [(m^3/d)/km^2]
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
Radioactivity		
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)
Specific capacity		
gallon per minute per foot [(gal/min)/ft)]	0.2070	liter per second per meter [(L/s)/m]
Hydraulic conductivity		
foot per day (ft/d)	0.3048	meter per day (m/d)
Hydraulic gradient		
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
Transmissivity*		
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88) where light detection and ranging (lidar) and Digital Elevation Model (DEM) data were used, and to the National Geodetic Vertical Datum of 1929 (NGVD 29) elsewhere.

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

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

Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [$(ft^3/d)/ft^2$]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Abbreviations

BP	before present
CFC	chlorofluorocarbons
GMS	Groundwater Modeling System
HA	health advisory
H/V	horizontal-to-vertical
LiDAR	light detection and ranging
MCL	maximum contaminant level
NWIS	National Water Information System
NWQL	National Water Quality Laboratory
NYSDEC	New York State Department of Environmental Conservation
SMCL	secondary maximum contaminant level
^3H	tritium
TU	tritium unit
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

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Geohydrology, Water Quality, and Simulation of Groundwater Flow in the Stratified-Drift Aquifer System in Virgil Creek and Dryden Lake Valleys, Town of Dryden, Tompkins County, New York

By Todd S. Miller and Edward F. Bugliosi

Abstract

In 2002, the U.S. Geological Survey, in cooperation with the Tompkins County Planning Department and the Town of Dryden, New York, began a study of the stratified-drift aquifer system in the Virgil Creek and Dryden Lake Valleys in the Town of Dryden, Tompkins County. The study provided geohydrologic data needed by the town and county to develop a strategy to manage and protect their water resources. In this study area, three extensive confined sand and gravel aquifers (the upper, middle, and lower confined aquifers) compose the stratified-drift aquifer system. The Dryden Lake Valley is a glaciated valley oriented parallel to the direction of ice movement. Erosion by ice extensively widened and deepened the valley, truncated bedrock hillsides, and formed a nearly straight, U-shaped bedrock trough. The maximum thickness of the valley fill in the central part of the valley is about 400 feet (ft). The Virgil Creek Valley in the east part of the study area underwent less severe erosion by ice than the Dryden Lake Valley, and hence, it has a bedrock floor that is several hundred feet higher in altitude than that in the Dryden Lake Valley.

The sources and amounts of recharge were difficult to identify in most areas because the confined aquifers are overlain by confining units. However, in the vicinity of the Virgil Creek Dam, the upper confined aquifer crops out at land surface in the floodplain of a gorge eroded by Virgil Creek, and this is where the aquifer receives large amounts of recharge from precipitation that directly falls over the aquifer and from seepage losses from Virgil Creek. The results of streamflow measurements made in Virgil Creek where it flows through the gorge indicated that the stream lost 1.2 cubic feet per second (ft^3/s) or 0.78 million gallons per day (Mgal/d) of water in the reach extending from 220 ft downstream from the dam to 1,200 ft upstream from the dam. In the southern part of the study area, large amounts of recharge also replenish the stratified-drift aquifers at the Valley Heads Moraine, which consists of heterogeneous sediments including coarse-grained outwash and kame sediments, as well as zones containing till with a fine-grained matrix. In the southern part of the study area, the confining units are thin and likely to be discontinuous in some places, resulting in windows of permeable sediment, which can more readily transmit recharge from precipitation and from tributaries that lose water as they flow over the valley floor. In contrast, in the northern part of the study area, the confining units are thick, continuous, and comprise homogeneous fine-grained sediments that more effectively confine the aquifers than in the southern part of the study area.

Most groundwater in the northern part of the study area discharges to the Village of Dryden municipal production wells, to the outlet to Dryden Lake, to Virgil Creek, and as groundwater underflow that exits the northern boundary of the study area. Most northward-flowing groundwater in the southern part of the study area discharges to Dryden Lake, to the inlet to Dryden Lake, and to homeowner, nonmunicipal community (a mobile home community and several apartments), and commercial wells. Most of this pumped water is returned to the groundwater system via septic systems. Most southward-flowing groundwater in the southern part of the study area discharges to the headwaters of Owego Creek and to agricultural wells; some flow also exits the southern boundary of the study area as groundwater underflow.

The largest user of groundwater in the study area is the Village of Dryden. Water use in the village has approximately tripled between the early 1970s when withdrawals ranged between 18 and 30 million gallons per year (Mgal/yr) and from 2000 through 2008 when withdrawals ranged between 75 and 85 Mgal/yr. The estimated groundwater use by homeowners, nonmunicipal communities, and small commercial facilities outside the area supplied by the Village of Dryden municipal wells is estimated to be about 18.4 Mgal/yr. Most of this pumped water is returned to the groundwater system via septic systems.

For this investigation, an aquifer test was conducted at the Village of Dryden production well TM 981 (finished in the middle confined aquifer at a well depth of 72 ft) at the

Jay Street pumping station during June 19–21, 2007. The aquifer test consisted of pumping production well TM 981 at 104 gallons per minute over a 24-hour period. The drawdown in well TM 981 at the end of 24 hours of pumping was 19.2 ft. Results of the aquifer-test analysis for a partially penetrating well in a confined aquifer indicated that the transmissivity was 1,560 feet squared per day, and the horizontal hydraulic conductivity was 87 feet per day, based on a saturated thickness of 18 ft.

During 2003–5, 14 surface-water samples were collected at 8 sites, including Virgil Creek, Dryden Lake outlet, and several tributaries. During 2003 through 2009, eight groundwater samples were collected from eight wells, including three municipal production wells, two test wells, and three domestic wells. Calcium dominates the cation composition, and bicarbonate dominates the anion composition in most groundwater and surface-water samples. None of the common inorganic constituents collected exceeded any Federal or State water-quality standards.

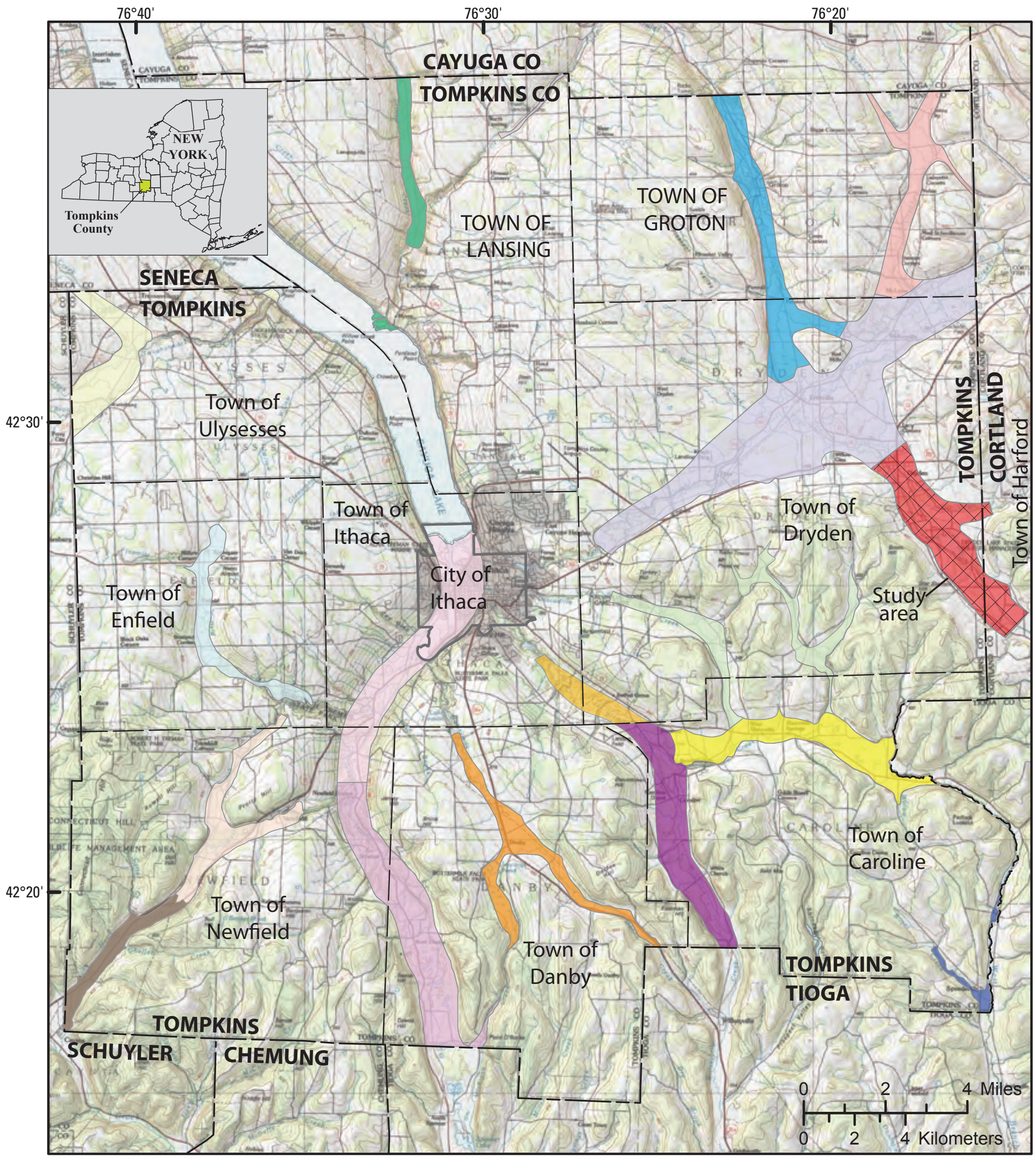
Results from a three-dimensional, finite-difference groundwater-flow model were used to compute a water budget and to estimate the areal extent of the zone of groundwater contribution to the Village of Dryden municipal production wells. The model-computed water budget indicated that the sources of recharge to the confined aquifer system are precipitation that falls directly on the valley-fill sediments (40 percent of total recharge), stream leakage (35.5 percent), seepage from wetlands and ponds (12 percent), unchanneled runoff and groundwater inflow from the uplands (8.5 percent), and groundwater underflow into the eastern end of the model area (4 percent). Most groundwater discharges to surface-water bodies, including Dryden Lake (33 percent), streams (33 percent), and wetlands and ponds (10 percent of the total). In addition, some groundwater discharges as underflow out of the southern and northern ends of the model area (15 percent), to simulated pumping wells (4.5 percent), and to drains that represent seepage from the bluffs exposed in the gorge in the vicinity of the Virgil Creek Dam (4.5 percent).

The areal extents of the zones of groundwater contribution for Village of Dryden municipal production wells TM 202 (Lake Road pump station, finished in the upper confined aquifer) and TM 981 (Jay Street pump station, finished in the middle confined aquifer) are 0.5 square mile (mi^2) and 0.9 mi^2, respectively. The areal extent of the zone of contribution to production well TM 202 extends 2.2 miles (mi) southeast into the Virgil Creek Valley, whereas production well TM 981 extends 3.8 mi south in the Dryden Lake Valley. The areal extent of the zone of contribution to production well TM1046 (South Street pump station) is 1.4 mi^2 and extends 2.4 mi into Dryden Lake Valley and 0.5 mi into Virgil Creek Valley.

Introduction

In 2000, the U.S. Geological Survey (USGS) published a reconnaissance-level map depicting the extent of unconsolidated aquifers in Tompkins County, New York (Miller, 2000b). During 2000 through 2002, the USGS and the Tompkins County Planning Department used the map to develop a plan to study the unconsolidated aquifers in more detail. The objectives of the more detailed aquifer studies were to provide geohydrologic data for planners to develop a strategy to manage and protect their water resources. An area with 17 valleys that contain unconsolidated aquifers was outlined, and a program was developed to study these aquifers over a 20-year period. The extents of these unconsolidated aquifers were defined mostly on natural hydrologic boundaries, but in some cases political boundaries were used as well. In order to have study areas of manageable size, the aquifer reaches were limited in length to about 3 to 10 miles (mi) each. Virgil Creek Valley (fig. 1) was one of the locations identified on the list of major aquifers to be studied. Where there are multiple aquifers in a valley, such as in the Virgil Creek Valley, the aquifers are referred to as a stratified-drift aquifer system.

In 2002, the USGS, in cooperation with the Tompkins County Planning Department and the Town of Dryden, began a study of the stratified-drift aquifer system in the Virgil Creek and Dryden Lake Valleys in the Town of Dryden, Tompkins County, and in part of the Owego Creek Valley in the Town of Harford, Cortland County, N.Y. (fig. 1). The Virgil Creek, Dryden Lake, and Owego Creek Valleys were selected to be studied because this area is undergoing increasing development and the aquifers underlying the valleys are the most used in the counties. The purpose of this study was to characterize the geohydrology of the stratified-drift aquifer system in Virgil Creek and Dryden Lake Valleys and provide the geohydrologic data needed by the Town of Dryden and Tompkins County to develop a strategy to manage and protect their water resources. Evaluation, development, and protection of these aquifers require information on aquifer framework (the three-dimensional extent and distribution of aquifers and confining units), sources of recharge, discharge areas, hydraulic properties, direction of groundwater flow, and water quality. As a result, a numerical groundwater-flow model was developed as a tool to help hydrologists and water-resource managers understand the relatively complicated flow system of the aquifer system. In addition, this study fulfills the mission of the USGS to publish and disseminate the Earth-science information needed to understand, to plan the use of, and to manage the Nation's water resources. This study also adds to the volume of knowledge the USGS is collecting to further understand, plann, and manage the Nation's water resources with a view to conservation and energy uses.



Base from TOPO! 2003 ©National Geographic, scale 1:100,000

Aquifers mapped by T.S. Miller (2000)

EXPLANATION

Aquifer reaches

- Cascadilla Creek valley and upland Sixmile Creek valley
- Enfield Creek valley
- Lower Cayuga Inlet valley
- Lower Fall Creek valley
- Lower Sixmile Creek valley (towns of Dryden and Ithaca)
- Owasco Inlet valley
- Lower Sixmile Creek and Willseyville Creek valleys (town of Caroline)

Aquifer reaches, continued

- Pony Hollow valley
- Salmon Creek/Myers Point/Locke Creek
- Taughannock Creek valley and delta
- Upper Buttermilk Creek and Danby Creek valleys
- Upper Cayuga Inlet valley
- Upper Fall Creek valley
- Upper Sixmile Creek and West Branch Owego Creek valleys
- Virgil Creek, Dryden Lake, and Owego Creek valleys (this study area)
- West Branch Cayuga Inlet and Fish Kill valleys
- West Branch Owego Creek valley and tributaries

Figure 1. Locations of 17 unconsolidated aquifer reaches in Tompkins County, New York.

Purpose and Scope

This report describes the geohydrology, water quality, and simulated groundwater flow in the stratified-drift aquifer system in Virgil Creek and Dryden Lake Valleys in Tompkins County and a small part of the headwaters in Owego Creek Valley in Cortland County. The report describes (1) the geology of the study area, including the geologic framework of the stratified-drift aquifer system; (2) the groundwater-flow system, including water levels, groundwater and surface-water interaction, direction of groundwater flow, and recharge and discharge conditions; (3) the water quality of the study area, including concentrations of common inorganic ions and nutrients; (4) the age of the groundwater in the study area; and (5) the construction, calibration, and interpretation of results from a numerical groundwater-flow model. The groundwater-flow model was used as a tool to understand the relatively complicated flow system of the aquifer system and to estimate the areal extent of the zones of groundwater contribution to the existing Village of Dryden municipal supply wells and to a hypothetical pumping well at a potential supply-well site. Also included are (1) geohydrologic sections; (2) maps and diagrams depicting well locations, geology, groundwater levels, and direction of groundwater flow; and (3) tables of well records and water-quality data.

Data Collection

The USGS collected the following types of information for inclusion in this report: geologic data, seismic-refraction surveys, well stratigraphic records collected through well inventory and test drilling, water-level and streamflow measurements, and water-quality data on surface water and groundwater. In addition, leveling was done to obtain the altitude of measuring points of wells (top of casings) and selected sites along streams and standing bodies of water (lakes, ponds, and wetlands).

Geologic Data

This report includes geologic mapping that builds on and modifies the mapping done by Miller (1993). Geologic data were collected by seismic-refraction surveys, field reconnaissance, interpretation from topographic maps and orthophoto interpretation, and review of available geologic reports, soils maps, and well-drilling records.

Well Inventory, Test Drilling, Water-Level Measurements, and Leveling

Records from approximately 100 wells (appendix 1) were used to determine the geohydrologic characteristics of the aquifer system. Sources of well and test-boring data include published USGS groundwater studies, the USGS National Water Information System (NWIS), files of the New York State Department of Environmental Conservation (NYSDEC) Water Well Drillers Registration Program, test boring data from the New York State Department of Transportation (appendix 1), and records from test wells that were drilled during this study.

Altitudes of 50 water-level-measuring points, which are typically the tops of the well casings, were determined to 0.01 foot (ft) using standard surveying techniques. Depths to water below the measuring points were then converted to altitudes, which were subsequently used in the calibration of the numerical groundwater-flow model. The altitudes at selected locations of the channel bottoms and water surfaces of the streams were also determined to 0.01 ft using standard surveying techniques. Elsewhere, altitudes of the land surface at wells and channel bottoms and water surfaces of the streams were estimated using light detection and ranging (lidar) or 1:24,000-scale topographic contour maps.

Streamflow Measurements

Streamflow was measured by using a current meter in Virgil Creek and tributary streams during collection of stream water-quality samples during 2003 and 2004. Streamflow measuring techniques are described by Rantz and others (1982).

A streamgage (USGS station number 0423368620) was installed on Virgil Creek at State Highway Route 13 in Dryden on October 18, 2002, and was maintained by the USGS New York Water Science Center, Ithaca Program Office. The drainage area of the streamgage is 29.7 square miles (mi^2). Stage and discharge data were collected from October 18, 2002, through September 30, 2004. In addition to these data, eight water-quality samples were collected during base-flow conditions and analyzed for selected chemical constituents (see Water Quality section). The water-quality and streamflow data collected for streamgage station 0423368620 from October 18, 2002, through September 30, 2004, are presented by Hornlein and others (2004, p. 182–183; 2005, p. 177–180).

Seismic-Refraction Surveys

Seismic-refraction surveys were conducted at three sites to supplement data from test drilling and well records. These surveys obtained data on depth to the water table and the bedrock surface. Seismic-refraction techniques used in this study are described by Haeni (1988). A series of 12 geophones spaced either 50 or 100 ft apart were inserted into the ground, and arrival times of compressional waves generated by explosives were recorded and plotted as a function of source-to-geophone distances. Either a two-layer (saturated unconsolidated sediments and bedrock surface) or a three-layer (unsaturated unconsolidated sediments, saturated unconsolidated sediments, and bedrock surface) boundary-formula computer analysis (Scott and others, 1972) was used to calculate depths to the water table and to the bedrock surface.

One of the limitations to using seismic-refraction techniques, which was encountered in this study area, is the presence of slow-seismic velocity units (saturated sand and gravel) underlying high-seismic velocity units (compact till). In this setting, the low-velocity unit will not be detected, and the calculated depth to the deep refractor (top of bedrock) will likely be in error (the computed seismic depth to bedrock will be greater than the actual depth; Haeni, 1988). Where the depths to bedrock were available at drill holes along the seismic line, those depths were used to depict the top of bedrock in the geologic section. In the parts of the seismic lines where depths to bedrock were unavailable from drill-hole data, it is likely that the depth to bedrock computed from seismic-refraction data is deeper than actual depths.

Water Sampling and Analysis

Stream samples were analyzed for inorganic constituents and nutrients at the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado. Field properties including pH, specific conductance, and water temperature were measured before sample collection. The samples were collected and processed by methods described in the USGS manual for the collection of water-quality data (U.S. Geological Survey, 2004a).

Groundwater samples were collected from public-supply wells at raw-water spigots after the well had been pumped for more than an hour. Domestic wells were sampled after 20 minutes of pumping or until at least five casing volumes of well water had passed the sampling point; then a raw-water spigot between the well and the pressure tank was opened, and the water was allowed to run for several more minutes to flush the spigot. Samples were collected from the raw-water spigot to avoid all water-treatment systems and to ensure that the water collected was representative of the water in the aquifer. In unused test wells, a stainless-steel submersible pump was used to purge the well of 5 to 10 casing volumes of water before collecting the water samples from the pump.

Tritium samples, collected to estimate groundwater age, were analyzed at the USGS Isotope Geochemistry Laboratory in Menlo Park, California. Chlorofluorocarbon (CFC) samples were collected according to specific sampling methods to minimize atmospheric exposure (U.S. Geological Survey, 2004b) and were analyzed at the USGS Chlorofluorocarbon Laboratory in Reston, Virginia. Age-dating of groundwater using these methods gives an approximate date since the water recharged the aquifer (from precipitation) and entered the saturated zone. The ages are based on matching the concentrations of the tracers in groundwater to the historical atmospheric concentrations of these tracers, which are well documented. Details of CFC dating are explained in Plummer and others (1993) and Reilly and others (1994).

Dissolved gases were also analyzed from the five wells where CFC samples were collected. Dissolved-gas data are used to define recharge temperatures for CFC dating, to reconstruct initial nitrate concentrations based on the amount of denitrification that has occurred, and to trace sources of groundwater recharge. Temperature and excess air in recharge water are important components in determining the age of the water based on concentrations of CFCs, and these factors can be calculated from the ratios of dissolved nitrogen and argon gas concentrations in the water along with the altitude at which recharge occurs (Heaton, 1981; Heaton and Vogel, 1981; Stute and Schlosser, 1999).

Description of Study Area

The study area is in the Appalachian Plateau physiographic province (fig. 2). The plateau is characterized by hills and valleys that resulted from millions of years of dissection by initially south-flowing streams that have been pirated (captured) by advancing northward-flowing streams draining into Lake Ontario (fig. 2). The hills and valleys have been subsequently modified by several glaciations.

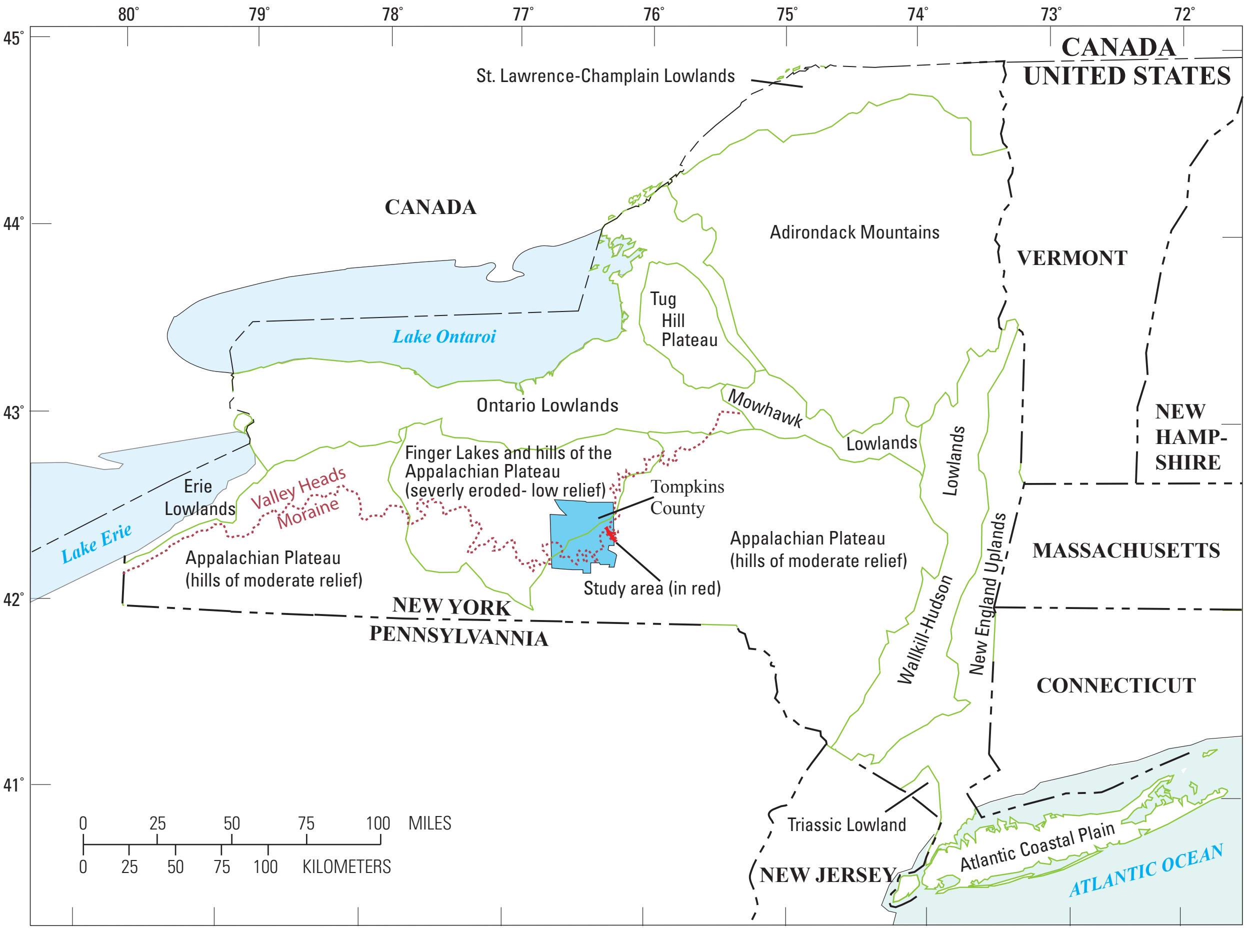
The study area is 5.3 mi long and 1.0 mi wide and encompasses 5.4 mi^2 in the Dryden Lake Valley and parts of the Virgil Creek and Owego Creek Valleys (fig. 3). The Dryden Lake Valley and the Virgil Creek Valley have northerly flowing drainage that joins Fall Creek 2.7 mi northwest of the Village of Dryden. The Owego Creek Valley drains to the south and is part of the Susquehanna River Basin (fig. 3).

The study area is of moderate relief, with altitudes ranging from as low as 1,060 ft in the channel where Virgil Creek leaves the north part of the study area to a little more than 2,000 ft on the highest hilltops (fig. 4). The Virgil Creek Valley is an intrusive valley that incised through a 600- to 800-ft high escarpment (referred to as the Portage escarpment by von Engeln (1961)) in the northern part of the study area (fig. 4).

Geology

Geologic materials present in the study area include bedrock, unstratified and stratified glacial drift, and recent alluvium and swamp deposits. Bedrock consists of Devonian shale, siltstone, and fine-grained sandstone. In most places, bedrock is covered by unconsolidated sediments; however, in some places, bedrock crops out at land surface, such as on hilltops and on upper parts of oversteepened valley walls.

The sedimentary rocks that form the bedrock in the study area were deposited in ancient seas during the Devonian period, 416 to 359.2 million years ago (Isachsen and others, 1991). The rocks were uplifted during the Alleghanian orogeny in the late Paleozoic, about 330 to 250 million years ago (Isachsen and others, 1991). The uplifted rocks formed



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000
Albers equal-area conic projection
Standard parallels 20°30' and 45°30', central meridian -96°00'

Figure 2. Physiographic features of New York State and location of Virgil Creek Valley and Dryden Lake Valley study area in Tompkins County, New York.

a plateau (Appalachian Plateau) which has subsequently undergone dissection by streams that resulted in a region dominated by hills and valleys. The bedrock landforms in the study area were modified by several glaciations during the Quaternary period, which extended from 2.6 million years ago to when the last glacier left the study area about 14,400 years before present (BP).

Glacial till is a poorly sorted and unstratified mixture of stones embedded in a fine-grained matrix consisting of clay, silt, and very fine sand. The stones in till can range in size from pebbles to boulders. Till is deposited directly by glacial ice, rather than by meltwater. In this study area, there are at least two till units that are interbedded within the stratified drift in the valley. Till has very low permeability (hydraulic conductivity is very low) because it is poorly sorted and has a fine-grained matrix that was compacted by the weight of the glacier.

Stratified drift consists of layered and sorted sediments that were deposited chiefly in valleys as glaciofluvial sediments by glacial meltwater streams and as glaciolacustrine sediments deposited in proglacial lakes. Coarse-grained (sand and gravel) glaciofluvial sediments deposited as outwash and kames form either extensive confined aquifers where they are overlain by a confining unit or smaller unconfined aquifers where they are found on top of the uppermost confining unit. Fine-grained glaciolacustrine sediments of very fine sand, silt, and clay deposited in a proglacial lake form confining units, along with till.

Glacial History

The study area underwent several major glaciations during the Pleistocene epoch (fig. 5), commonly referred to as the ice age, which began 2.6 million years ago and ended

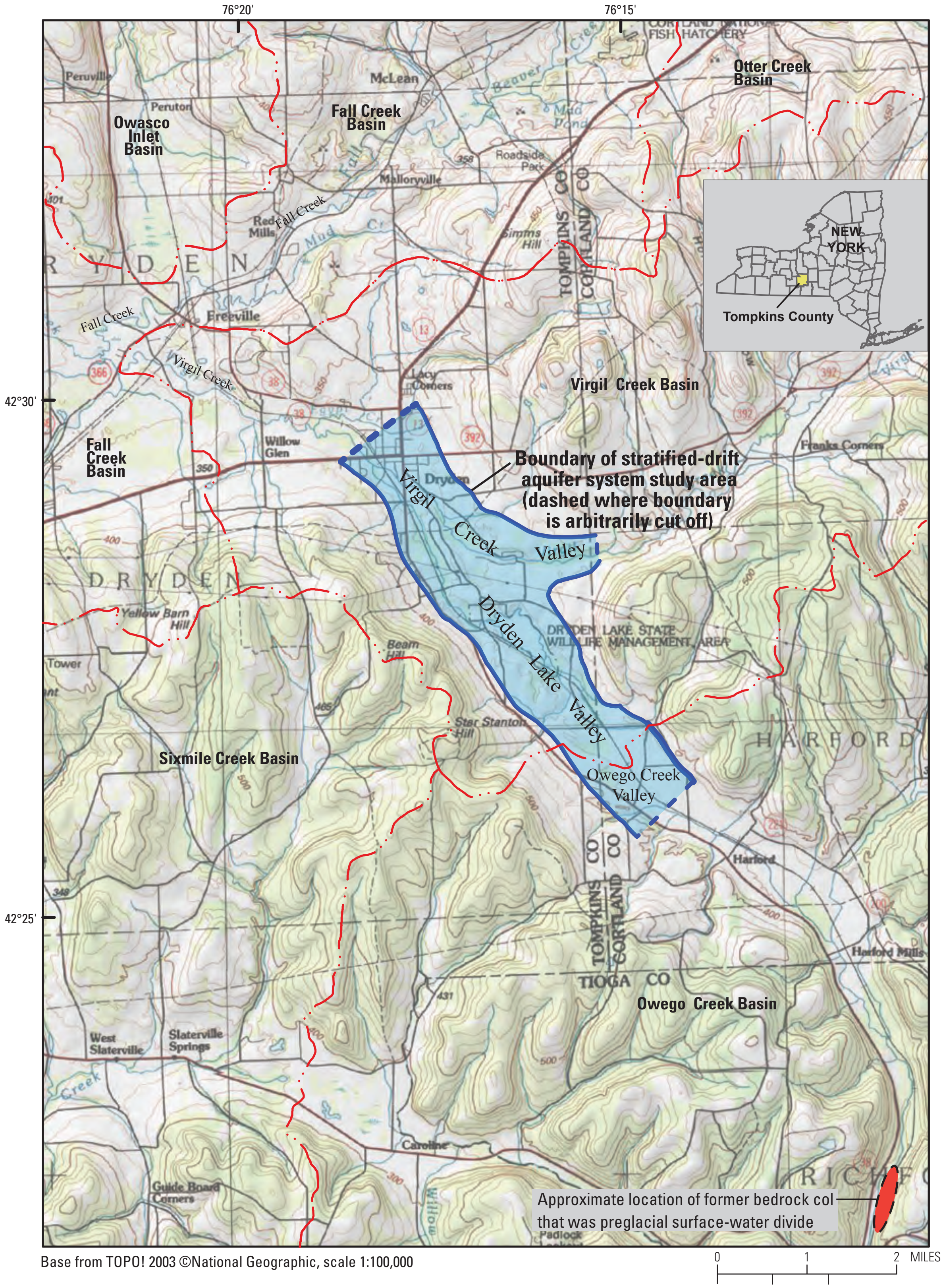


Figure 3. The boundary of the stratified-drift aquifer system extending across the Virgil Creek and Owego Creek Basins, Tompkins and Cortland Counties, New York. Basin boundaries indicated by red lines.

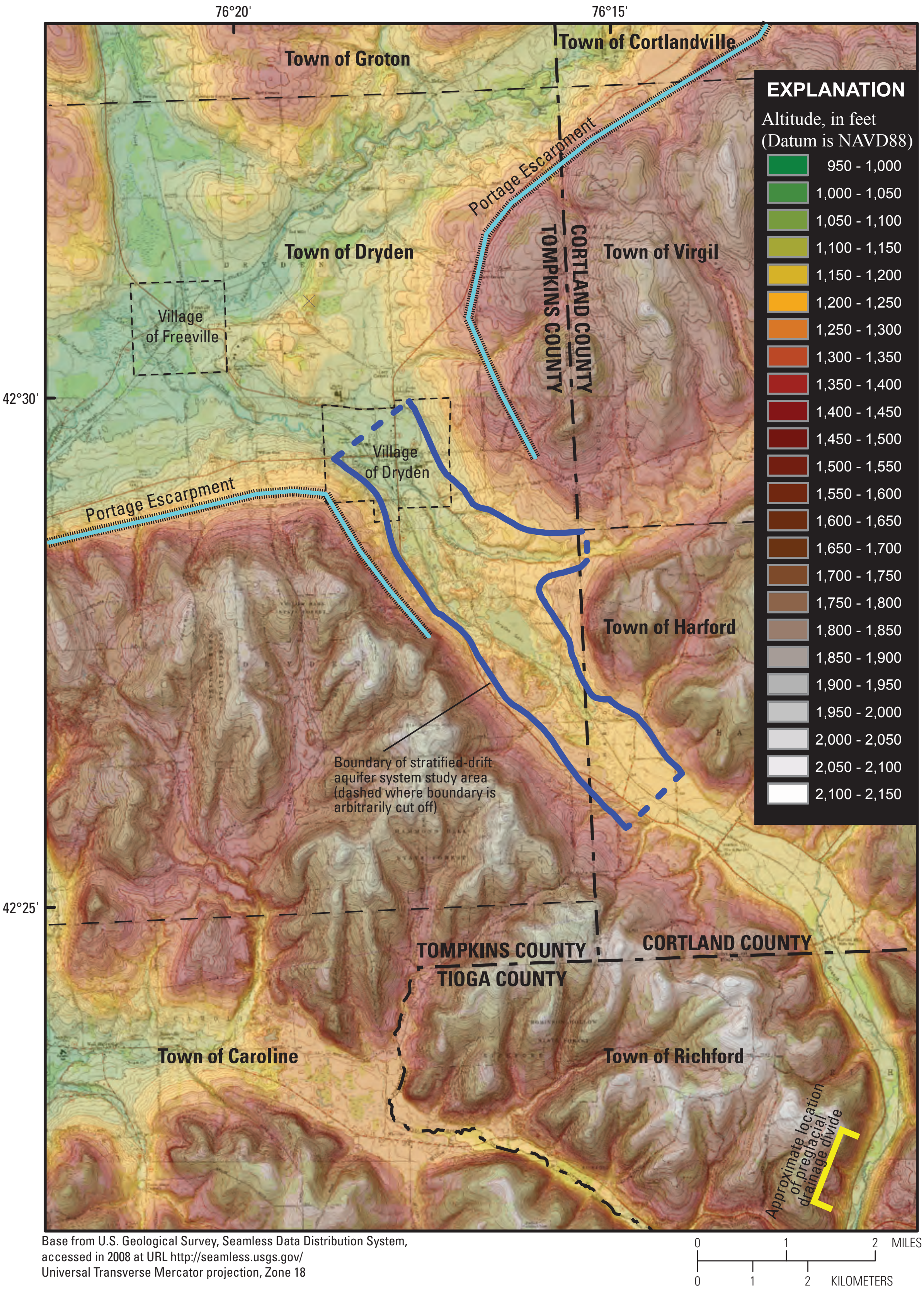


Figure 4. Topographic altitudes, shaded relief, and boundary of stratified-drift aquifer system study area in the Virgil Creek, Dryden Lake, and Owego Creek Valleys, Tompkins County, New York. NAVD88, North American Vertical Datum of 1988.

System/Period	System/Epoch	Stage	Substage	Stades and interstades	^{14}C age YBP	Events that affected the study area
Quaternary	Holocene	Holocene	Late Wisconsinan		11,850	Postglacial erosion and depostion by recent streams
	Pleistocene	Wisconsinan		Two Creeks interstade	12,500	
				Port Huron stade	13,000	
				Mackinaw interstade	13,500	Ice retreats north of Ithaca
				Port Bruce stade	15,500	Valley Heads readvance-forms massive moraines
				Erie interstade	16,500	Ice retreats north of Ithaca
				Nissouri stade	23,000	Wisconsinan ice sheet spreads across New York
			Middle Wisconsinan	Plum Point interstade	32,000	New York is ice free
				Cherrytree stade	36,000	
				Port Talbot interstade	53,000	
			Early Wisconsinan	Guildwood stade	63,000	
				St. Pierre interstade	68,000	
				Nicolet stade	75,000	

Figure 5. Chronostratigraphic classification of Pleistocene stades and interstades in northeastern North America and their effect on the study area. Modified from Dreimanis and Karrow (1972) and Fulton and others (1984). ^{14}C, carbon 14; YBP, years before present.

11,850 years BP (uncalibrated radiocarbon years; 13,700 calibrated calendar years; Fullerton, 1980). A raw BP date cannot be used directly as a calendar date because the level of atmospheric ^{14}C has not been strictly constant during the span of time that can be radiocarbon dated. The raw radiocarbon dates, in BP years, are calibrated to give calendar dates.

Each successive glaciation removed or reworked most of the previously deposited sediments; therefore, most of the unconsolidated deposits consist of sediments deposited during and after the last glacial episode (Wisconsinan glaciation). During the Wisconsinan glaciation, the Laurentide Ice Sheet expanded southward from northeastern Canada and advanced and retreated several times into New York State.

During the last major glacial episode in Late Wisconsinan time, the maximum extent of the glacier occurred during the Nissouri stade (a period of time represented by a glacial advance) about 24,000 to 23,000 years BP (Muller and Calkin, 1993), when the ice extended as far south as northern Pennsylvania. During the Erie interstade (about 16,500 to 15,500 years BP; fig. 5), the ice retreated northward from Pennsylvania and is believed to have melted back to north of the study area. The location of the ice margin during the retreat is uncertain because there are no radiocarbon data in New York for this period (Muller and Calkin, 1993) and evidence for the Erie interstade is based on circumstantial data (Dyke and others, 2002).

Following the Erie interstade, ice readvanced into central New York during the Port Bruce stade (about 15,500 years BP; fig. 5). In the study area, the advancing ice deposited a massive kame moraine, called the Valley Heads Moraine (fig. 6, surficial geologic unit km), in the southern part of the Dryden Lake Valley and in the eastern part of the Virgil Creek Valley. During this period, the ice had likely surged back and forth as evidenced by multiple sequences of glacial deposits that include interlayers of till, lacustrine sediments, and fluvial sand and gravel. The final retreat of ice from the study area commenced around 14,400 years BP (Muller and Calkin, 1993); the ice retreated rapidly northward and probably took several hundred years to retreat north of the study area. The retreat of Valley Heads ice north of the study area marked the end of the influence of ice in the study area. The multiple advances and retreats of the ice during stadial and interstadial periods, in addition to the minor surges of ice, resulted in a complex array of multiple sequences of glacial deposits in the study area that, in some places, makes it difficult to map and correlate geologic units.

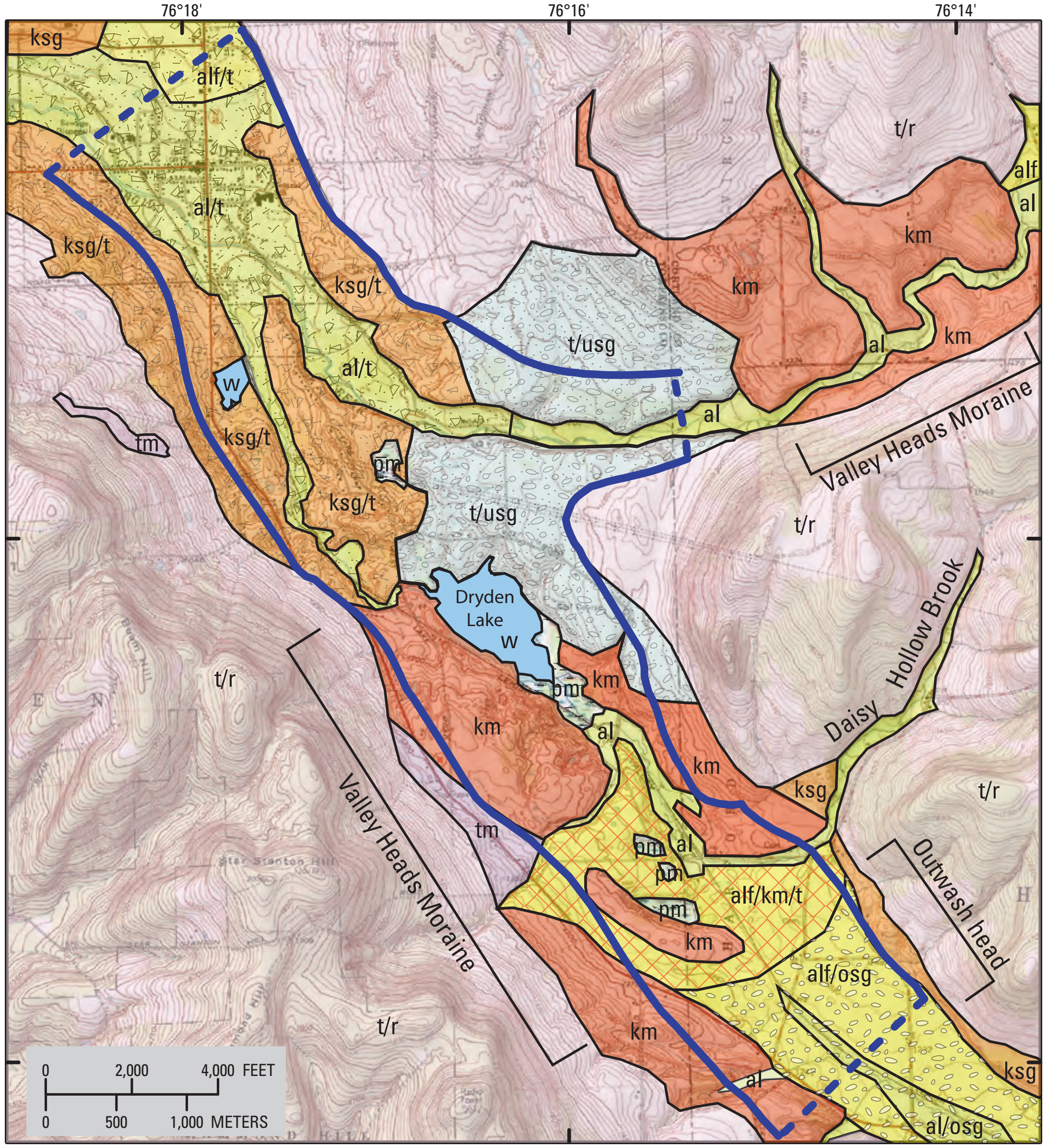
Scouring by Ice

In the area south of the Finger Lakes region, including the study area, scouring by flowing ice and subglacial meltwaters played a major role in modifying the preglacial landscape. Most scouring was concentrated in the valleys (hill tops were little modified), which resulted in smoothed and truncated hillsides along valley walls, U-shaped transverse valley profiles, and displacement of a bedrock col (a high, narrow pass or saddle through a divide or between two adjacent hilltops) that was a preglacial surface-water drainage divide (fig. 3). The configuration of the altitude of the bedrock valley as a result of glacial scouring is shown on figure 7.

The Dryden Lake Valley and many other valleys along the northern part of the Appalachian Plateau (fig. 2) are referred to by Clayton (1965) as intrusive troughs. Intrusive troughs were north-draining, preglacial valleys that were oriented in the direction of glacier flow. As the ice flowed south from the Ontario lowlands (fig. 2) and uphill against the regional slope of a higher landmass (Appalachian Plateau), ice flow was funneled and concentrated into preglacial, north-draining tributary valleys. The concentration of ice flow extensively scoured (widened and deepened) these valleys forming deep troughs. Results of test drilling at the Village of Dryden well field (TM1695; location shown in fig. 8, well log shown in fig. 9) in the northern part of the study area, and a seismic-refraction survey along Purvis Road in the southern part of the study area (figs. 10A, B), indicate that the valley is filled with about 400 ft of unconsolidated sediments and the bedrock floor in the Dryden Lake Valley rises from an altitude of 728 ft at the Village of Dryden in the northern part to an altitude of about 800 ft at Purvis Road in the southern part of the study area (fig. 7).

The northwest-southeast-oriented Dryden Lake Valley, which was aligned parallel to the direction of ice flow, underwent more extensive erosion (greater amount of deepening and widening) than the eastern branch of Virgil Creek Valley, which diverges eastward from Dryden Lake Valley (fig. 7). The eastern branch of Virgil Creek Valley, which was orientated nearly perpendicular to the direction of ice flow (southwest-northeast), underwent less intensive erosion (less deepening and widening) than that in the Dryden Lake Valley. In the eastern branch of the Virgil Creek Valley, a log of test well TM 997 (fig. 11) at the Virgil Creek Dam and results of a seismic-refraction survey in the floodplain of the Virgil Creek channel (figs. 12A, B) indicate that the altitude of the bedrock floor ranges from 1,085 to 1,100 ft, while the bedrock floor in the Virgil Creek Valley at the Lake Road pumping station in the Village of Dryden is at altitude 728 ft (fig. 9). Consequently, the eastern branch of the Virgil Creek Valley is a hanging valley (fig. 7) with a bedrock floor that is several hundred feet higher than that in the Dryden Lake Valley.

In the Dryden Lake Valley, the deepest part of the valley is not in the center, but rather along the southwestern side of the valley (figs. 7 and 10A, B), which indicates that either the ice dynamics were such that ice flow was concentrated against the southwestern valley wall or the preglacial valley may have been located there or both. The more extensive scouring along the southwestern side of the valley resulted in an asymmetrical transverse profile of the bedrock surface in that part of the study area (fig. 10B).



Base from U.S. Geological Survey, Seamless Data Distribution System, accessed in 2007 at http://seamless.usgs.gov / Universal Transverse Mercator projection, Zone 18

Geology modified from Miller, 1993

EXPLANATION

Surficial geologic units

- w — Water
- pm — Wetland
- alf — Alluvial fan
- alf/km/t — Alluvial fan over kame moraine and till
- alf/osg — Alluvial fan over outwash sand and gravel
- alf/t — Alluvial fan over till
- al — Alluvium
- al/osg — Alluvium over outwash sand and gravel
- al/t — Alluvium over till
- ksg — Kame sand and gravel
- ksg/t — Kame sand and gravel over till
- km — Kame moraine (Valley Heads Moraine)
- tm — Till moraine
- t/usg — Valley till over unclassified sand and gravel
- t/r — Upland till over bedrock
- Stratified-drift aquifer system study area—dashed where boundary is arbitrarily cut off

Figure 6. Surficial geology map of Virgil Creek, Dryden Lake, and Owego Creek Valleys, Tompkins and Cortland Counties, New York. Modified from Miller (1993).

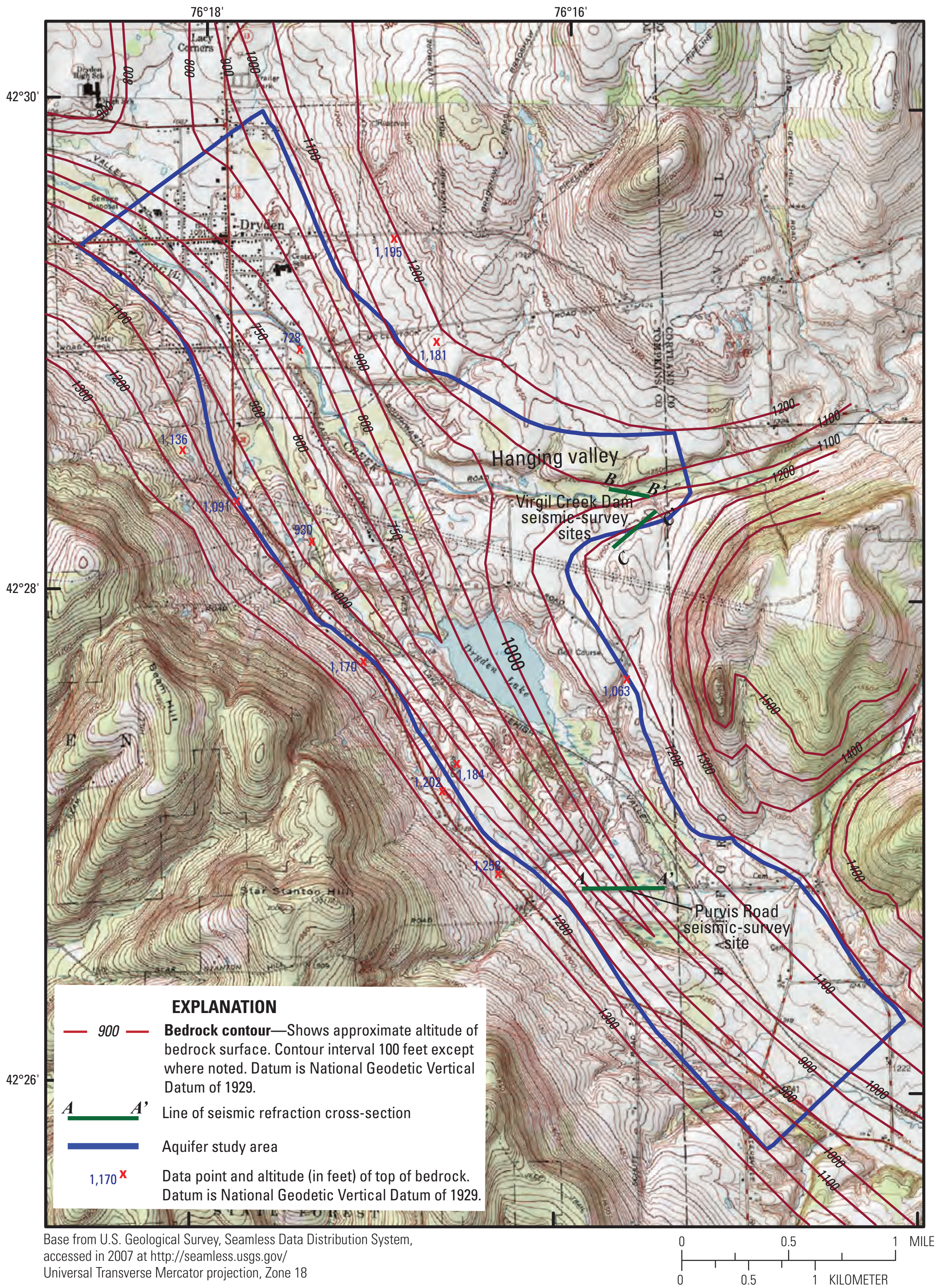


Figure 7. Altitude of bedrock surface and location of lines of seismic refraction cross-sections in the study area in the Virgil Creek, Dryden Lake, and Owego Creek Valleys, Tompkins and Cortland Counties, New York.

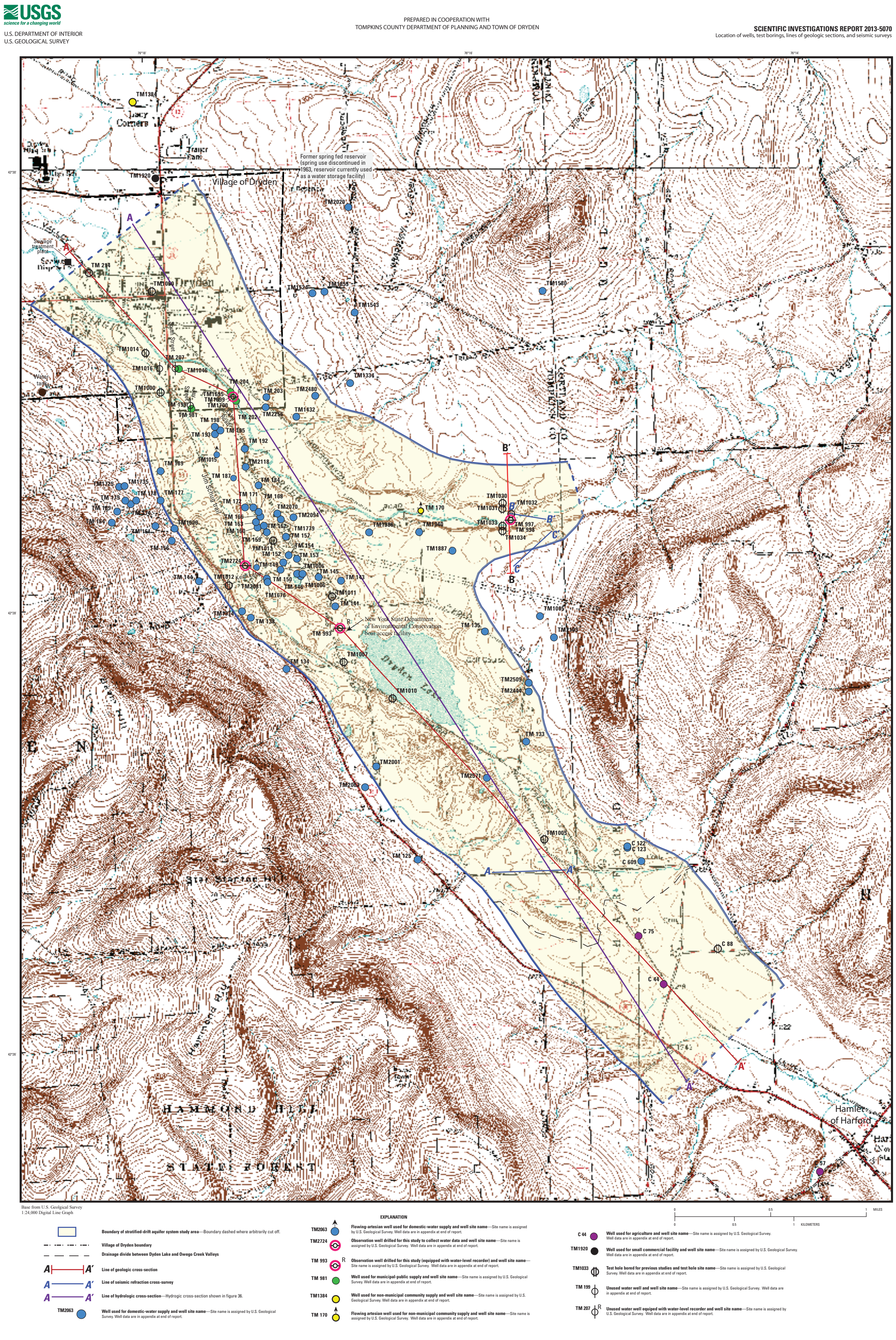


Figure 8. Locations of wells and lines of geologic cross-sections, seismic refraction cross-sections, and a hydrologic cross-section in the study area in the Virgil Creek, Dryden Lake, and Owego Creek Valleys, Tompkins and Cortland Counties, New York. (Available separately at http://pubs.usgs.gov/sir/2013/5070/pdf/sir2013-5070_miller_fig08_sheet.pdf)

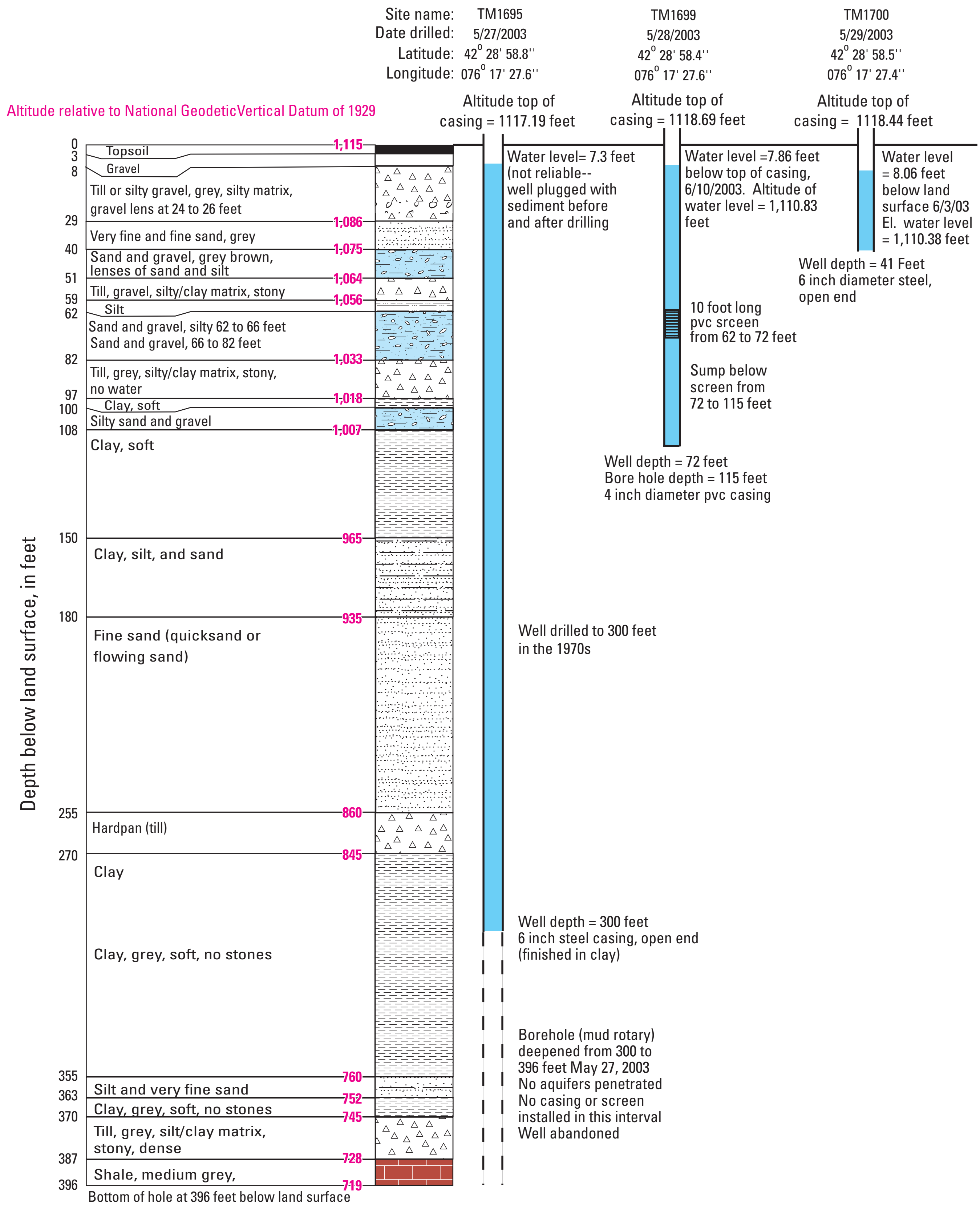


Figure 9. Construction details of U.S. Geological Survey test wells TM1695, TM1699, and TM1700 and well log of test well TM1695 at Lake Road near Dryden, New York. Locations shown on figure 8.

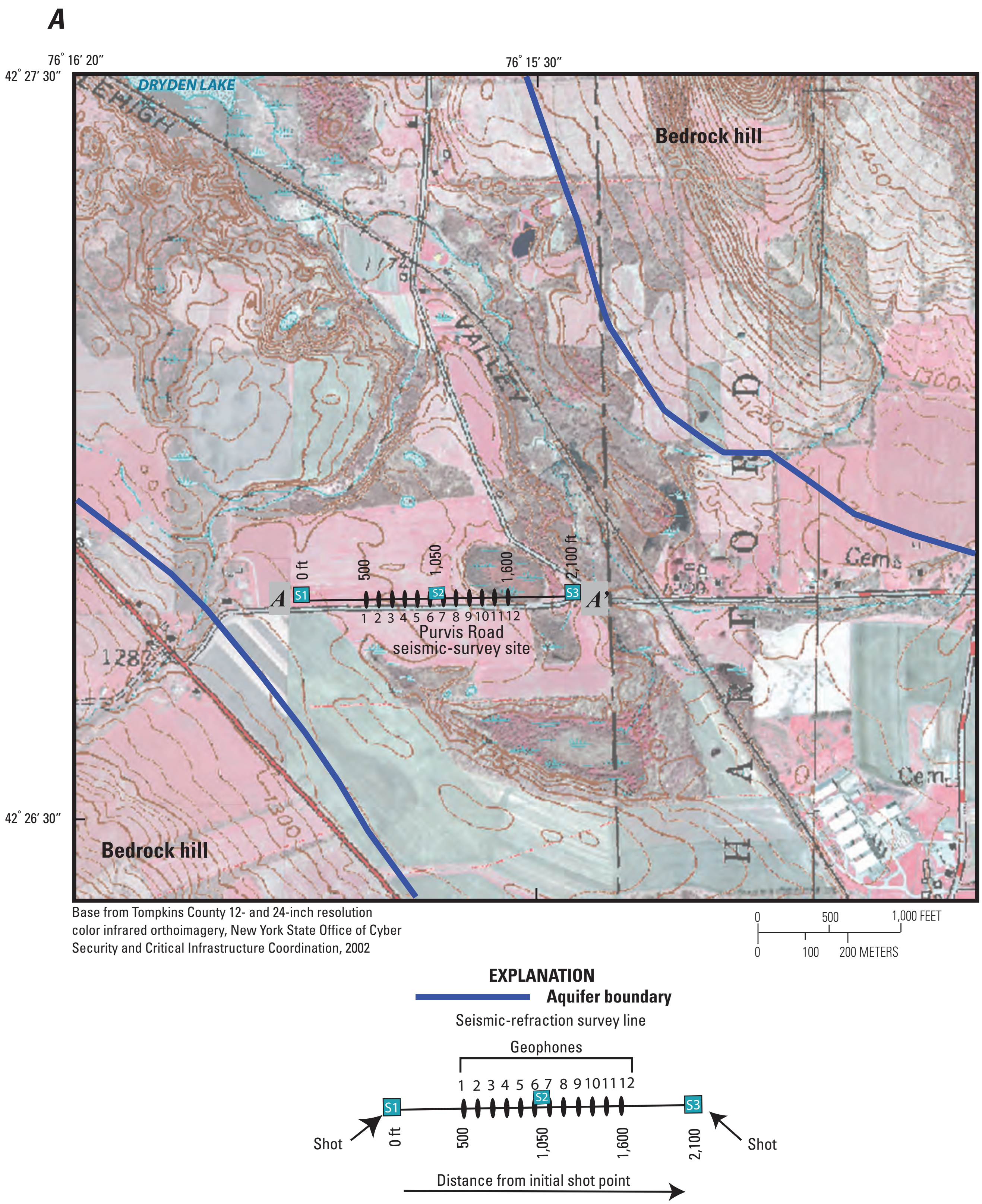


Figure 10. *A*, location of line of seismic refraction cross-section and *B*, seismic refraction cross-section *A*–*A*′ along Purvis Road, Town of Dryden, New York, in the southern part of Dryden Lake Valley. Location of line of seismic refraction cross-section shown on figure 8.

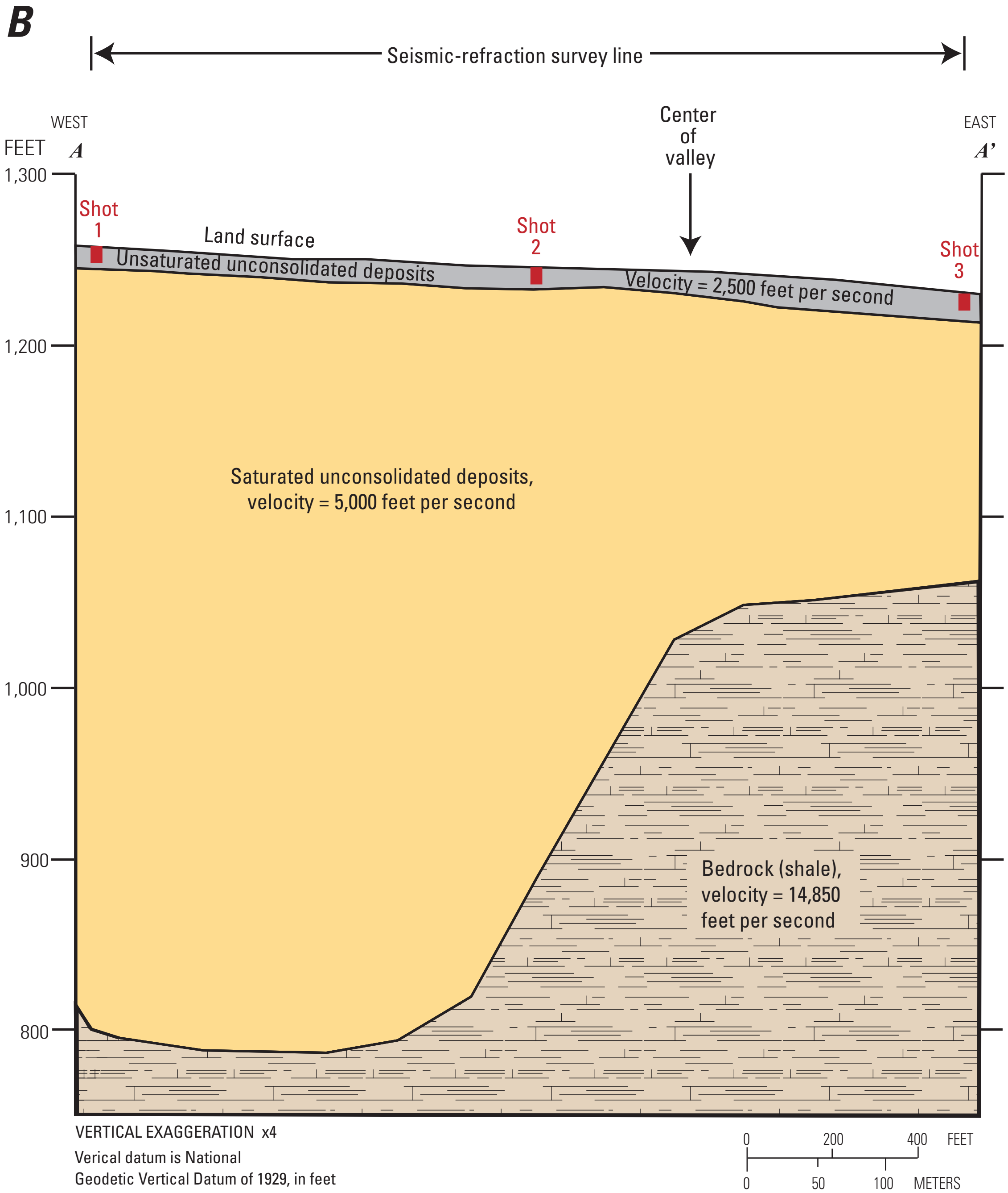


Figure 10. *A*, location of line of seismic refraction cross-section and *B*, seismic refraction cross-section *A*–*A′* along Purvis Road, Town of Dryden, New York, in the southern part of Dryden Lake Valley. Location of line of seismic refraction cross-section shown on figure 8.—Continued

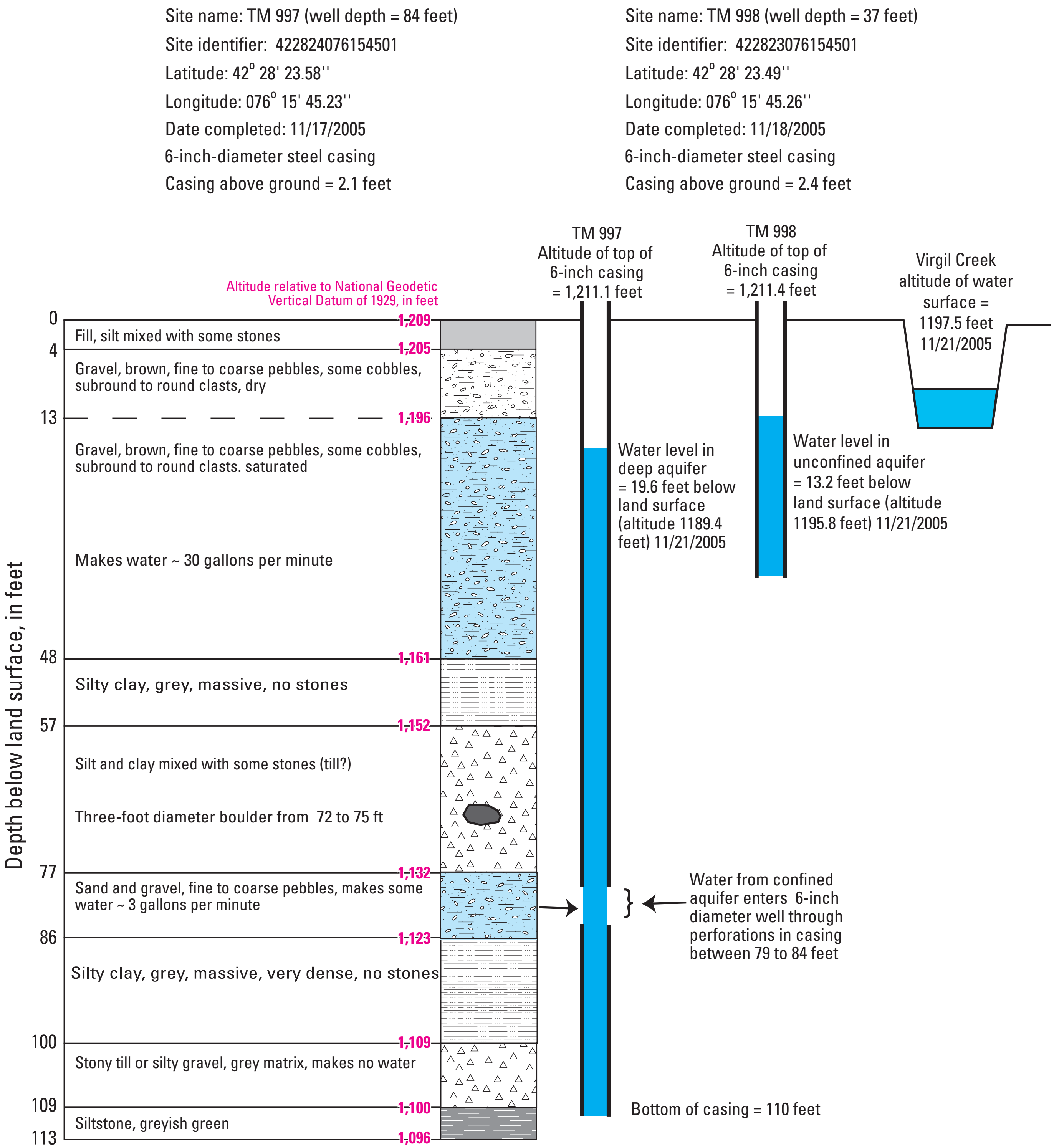


Figure 11. Construction details of U.S. Geological Survey test wells TM 997 and TM 998 at Virgil Creek Dam in the Town of Dryden, New York. Locations shown on figure 8.

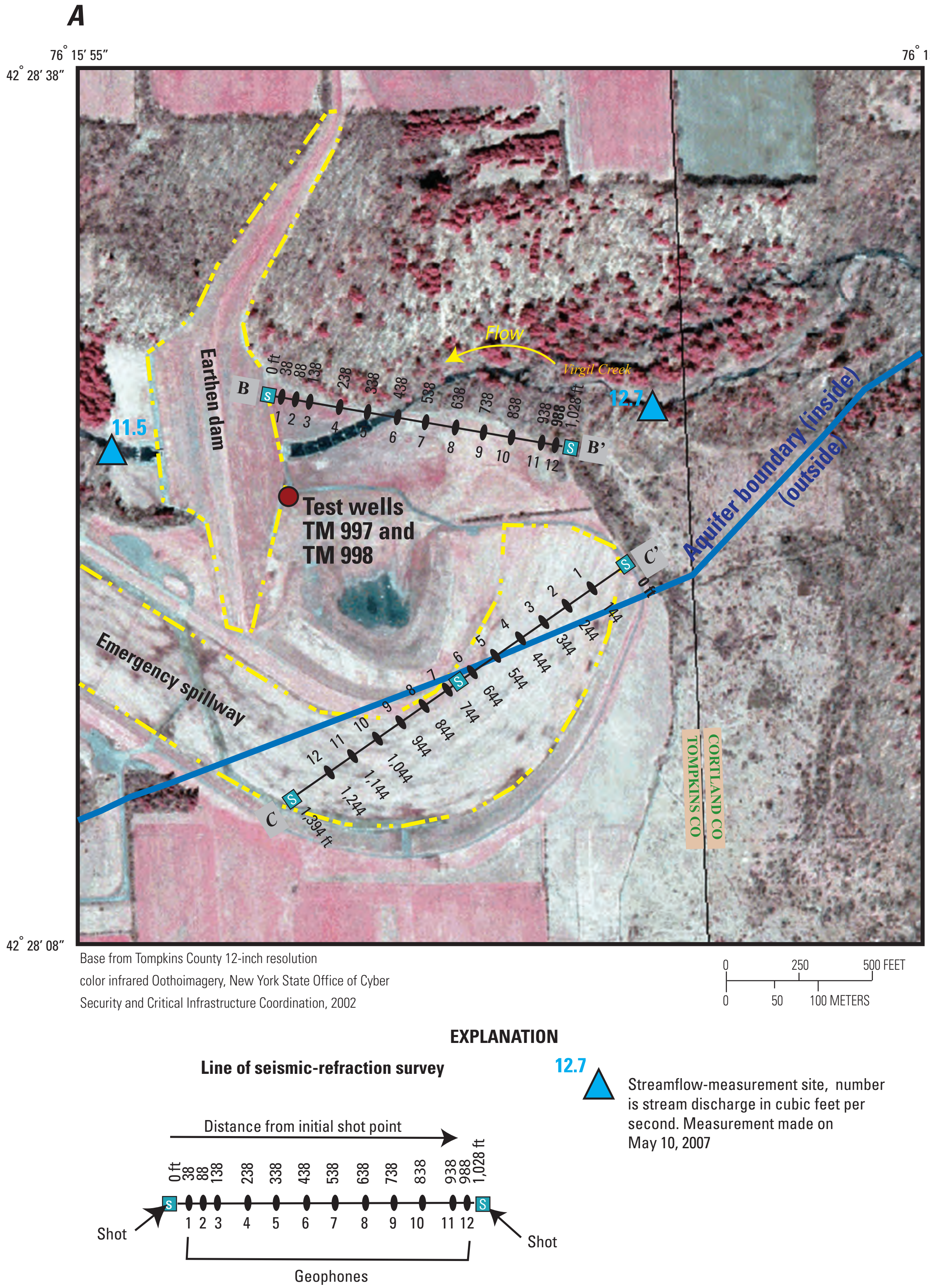


Figure 12. *A,* locations of lines of seismic refraction cross-sections, test wells TM 997 and TM 998, and streamflow-measurement sites near the Virgil Creek Dam, Town of Dryden, New York, *B,* seismic refraction cross-section *B–B′* along the Virgil Creek floodplain, and *C,* seismic refraction cross-section *C–C′* in the spillway of the Virgil Creek Dam. Locations of wells and lines of seismic refraction cross-sections are shown on figure 8.

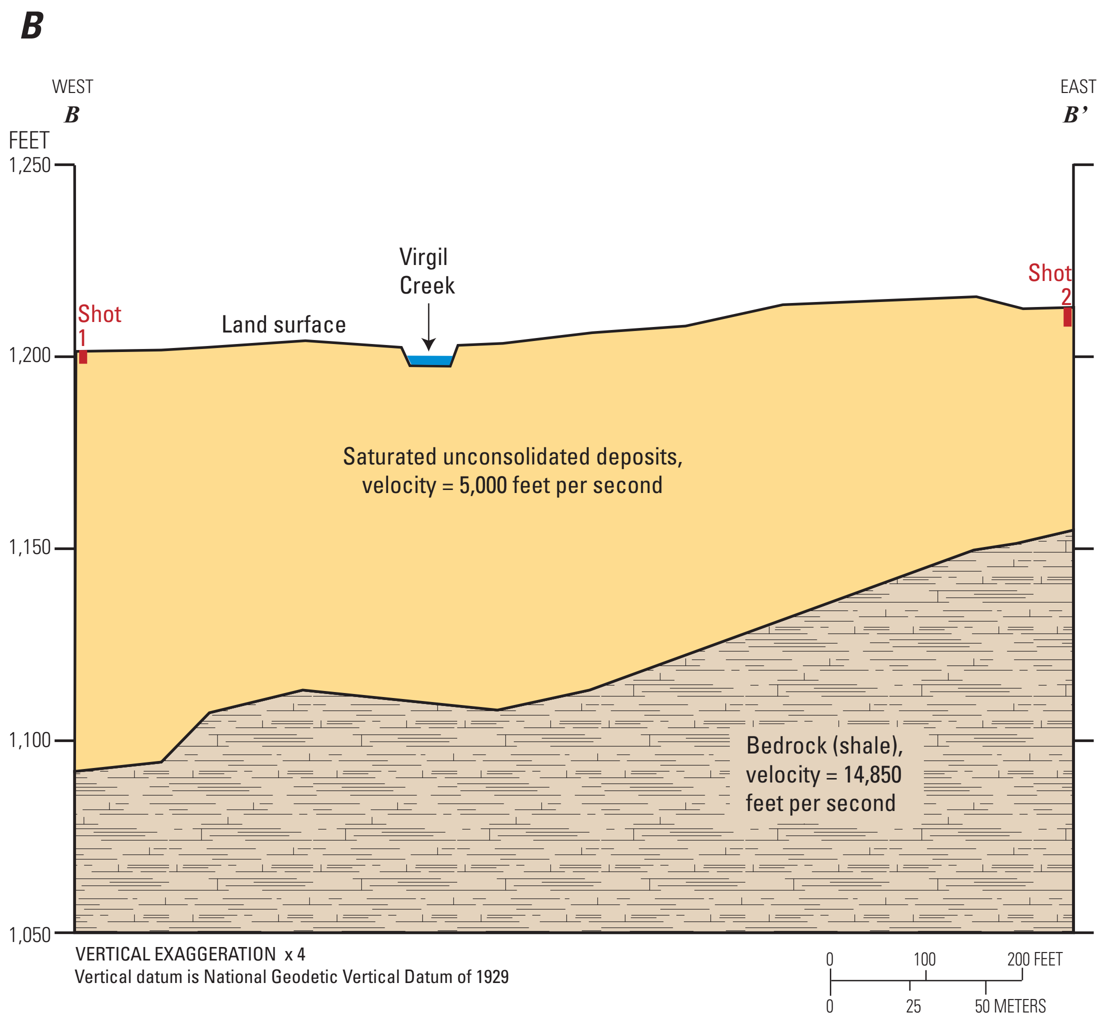


Figure 12. *A,* locations of lines of seismic refraction cross-sections, test wells TM 997 and TM 998, and streamflow-measurement sites near the Virgil Creek Dam, Town of Dryden, New York, *B,* seismic refraction cross-section *B–B′* along the Virgil Creek floodplain, and *C,* seismic refraction cross-section *C–C′* in the spillway of the Virgil Creek Dam. Locations of wells and lines of seismic refraction cross-sections are shown on figure 8.—Continued

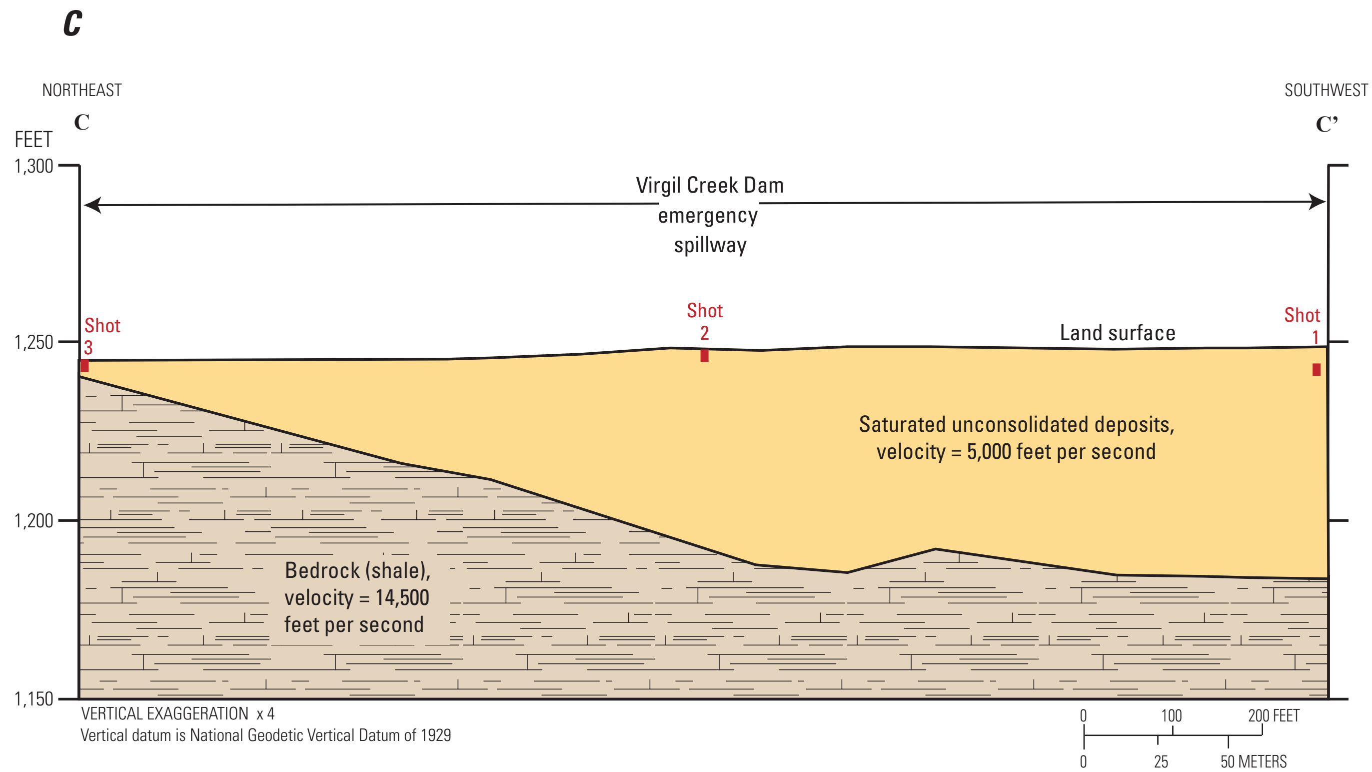


Figure 12. Map and diagrams showing *A,* locations of lines of seismic refraction cross-sections, test wells TM 997 and TM 998, and streamflow-measurement sites near the Virgil Creek Dam, Town of Dryden, New York, *B,* seismic refraction cross-section *B–B′* along the Virgil Creek floodplain, and *C,* seismic refraction cross-section *C–C′* in the spillway of the Virgil Creek Dam. Locations of wells and lines of seismic refraction cross-sections are shown on figure 8.—Continued

Wisconsinan Deposits in the Study Area

The valley fill in the study area contains glacial drift that consists of unstratified (till) and stratified (glaciolacustrine and glaciofluvial) glacial sediments deposited during Wisconsinan glaciation and recent (postglacial) alluvium and swamp deposits (fig. 6). The unstratified drift consists of till. In most places in the uplands, till is the sole unconsolidated deposit that overlies bedrock. However, in the valley, there are typically multiple till units that are interlayered with other units of stratified drift. In the study area, till makes up a large portion of the drift, and in some places, it crops out at land surface.

The stratified glacial drift (glaciolacustrine and glaciofluvial deposits) consists of layered and sorted sediments. Glaciolacustrine deposits (lake-bottom and deltaic sediments) were deposited where meltwater that had flowed on top, within, or at the sole of the ice debouched into a lake in front of the ice. The deposits consist of (1) coarse-grained sediments (sand and gravel) deposited at nearshore subaerial environments and at the mouths of subglacial tunnels, (2) medium-grained sediments (mostly sand and pebbly sand) deposited in shallow water, such as at the front of the delta shore (foresets), and (3) fine-grained sediments (fine sand, silt, and clay) deposited in deep water at distal parts of a delta.

Glaciofluvial deposits consist of layered and sorted coarse-grained sediments (sand and gravel) that were transported and deposited by meltwaters that flowed on top, beneath, or within a glacier. Glaciofluvial deposits include outwash, kame, and kame end moraine sediments. Outwash was deposited by meltwaters that flowed away (southward) from the ice front. In the study area, outwash was deposited in front of the Valley Heads Moraine in the Dryden Lake Valley and extends southward as an outwash plain in the Owego Creek Valley (fig. 6).

Kame deposits consist of glaciofluvial (sand and gravel that was transported by meltwater) and inwash (silt, sand, and gravel transported by streams that drain uplands) that accumulated between the ice and the adjacent valley wall and on top of the ice. Those sediments that were supported by the ice were laid down (often chaotically) as the ice melted. Kame deposits are commonly present in most places along the sides (kame terraces) and in some places in the central parts of the Dryden Lake Valley (fig. 6).

Kame end-moraine deposits consist of ice-contact deposits (poorly sorted and consist of silt, sand, and gravel) and, in some places, till. These end moraines form one or more of the following landforms (1) linear or arcuate ridges; (2) complex accumulations of mounds, knobs, hummocks; or (3) belts of both types of landforms. The sediments were deposited at or near a stagnating glacial ice margin. In the study area, kame end-moraine deposits are found at the terminus of the Valley Heads Moraine in the southern part of the Dryden Lake Valley and in the eastern part of the Virgil Creek Valley (fig. 6). The deposits that formed kame-end moraines were initially laid down as well-stratified sediments on top or adjacent to ice but, as the ice that supported the sediments melted, the sediments collapsed chaotically and the sediments became poorly stratified and often ended up dipping steeply at various angles of repose. Thus, the kame-end-moraine deposits commonly have highly variable stratification and contain lenses of sediments with little continuity.

Recent (postglacial) deposits consist of alluvium deposited by recent streams, lake sediments that were deposited in Dryden Lake, and peat and muck that were deposited in some wetlands and kettles (depressions formed where blocks of ice that became partially or entirely buried by sediment). Alluvium includes coarse sand and gravel deposited in channels and fans, and silt and fine to medium sand deposited as overbank sediments in floodplains.

Southern Part of Study Area

The prominent surficial geologic features in the southern part of the study area (from the southern boundary of the study area to the north end of Dryden Lake) include (1) alluvium overlying outwash interbedded with till units in the Owego Creek Valley, (2) a kame moraine (Valley Heads Moraine) that forms the drainage divide between the Susquehanna River and Great Lakes basins, and (3) a large kettle lake (Dryden Lake) that is underlain by several till and sand-and-gravel units (figs. 6 and 13).

The Valley Heads Moraine was formed during a readvance of ice during the Port Bruce stade about 15,500 years BP (Muller and Calkin, 1993). At that time, the main ice sheet abutted against the northern rim of the Portage escarpment (fig. 4) and a tongue of ice intruded several miles southward into the north-draining Virgil Creek and Dryden Lake Valleys. The moraine is part of the most extensive moraine system in New York State, which forms a roughly 240-mi-long ridge across central and western New York (fig. 2). The landforms at the moraine include terminal moraine ridges and ice-disintegration features such as kame terraces, hummocky knobs and kettles (kames), and channels carved by postglacial streams.

Meltwaters that flowed south from the Valley Heads Moraine deposited an outwash plain in the Owego Creek Valley that has subsequently been covered by a veneer of recent alluvial sediments (fig. 6). Near the Valley Heads Moraine, the outwash consists of coarse sand and gravel that is interlayered with two till units (fig. 13), which suggests that the ice had surged twice past the main crest of the moraine and into the outwash plain. However, the southernmost extent of the till layers is unknown because they extend beyond the southern limit of the study area.

Dryden Lake occupies a large kettle in the central part of the Dryden Lake Valley (figs. 6 and 13). Sand and gravel deposited by meltwaters between the valley wall and the block of ice were subsequently laid down as the supporting ice melted. These collapsed sediments formed kame moraine deposits (fig. 6) that drape downward toward the central part of the valley and extend beneath Dryden Lake.

The preglacial surface-water divide between the St. Lawrence River Basin and the Susquehanna River Basin was a former preglacial bedrock col in the Owego Creek Valley about 4 mi south of the study area. The area of the former bedrock col coincides with an upland region with hilltops of slightly higher altitude than the surrounding area (figs. 3 and 4). The bedrock col was removed by glacial erosion and became covered by glacial drift. The present surface-water divide is formed by the Valley Heads Moraine (a subtle ridge that loops across the valley) and an alluvial fan deposited by Daisy Hollow Brook (geologic unit alf/km/t; fig. 6).

The result of a seismic-refraction survey along Purvis Road, which crosses the Valley Heads Moraine, indicated that the unconsolidated deposits are greater than 400-ft thick in the south-central part of the Dryden Lake Valley (figs. 10A, B). Well records indicate that the upper part of the moraine (upper 100 to 150 ft) comprises layers of kame sand and gravel; till; and glaciolacustrine fine sand, silt, and clay.

In the southern part of the Dryden Lake Valley, the stratigraphy is mostly unknown because there are no wells that extend to the deep zones of the valley fill. However, basal confined sand and gravel aquifers are typically present on top of bedrock at the Valley Heads Moraine in other major valleys across central New York (Wellner and others, 1996; Miller and others, 1998; Yager and others, 2001; Kappel and Miller, 2003, 2005), and it is reasonable to assume that there is a basal confined aquifer underlying the southern part of this study area also. Well C57 (fig. 8) and several other wells (not shown in map) near the hamlet of Harford (0.9 mi south of the study area, fig. 8) were reported to have been drilled to depths about 200 ft each and were finished in sand or sand and gravel, which suggests that the deep confined aquifer extends south beyond the study area.

Northern Part of Study Area

The prominent surface geologic features in the northern part of the study area (from Dryden Lake to the northern boundary of the study area, fig. 13) include alluvium, ground moraine (till), and kames (figs. 6 and 13). All these surficial deposits overlie buried units of sand and gravel, till, and glaciolacustrine deposits (fig. 13). In the floodplains of the outlet to Dryden Lake and of Virgil Creek (west of the Virgil Creek Dam), there is 5 to 20 ft of alluvium that overlies till

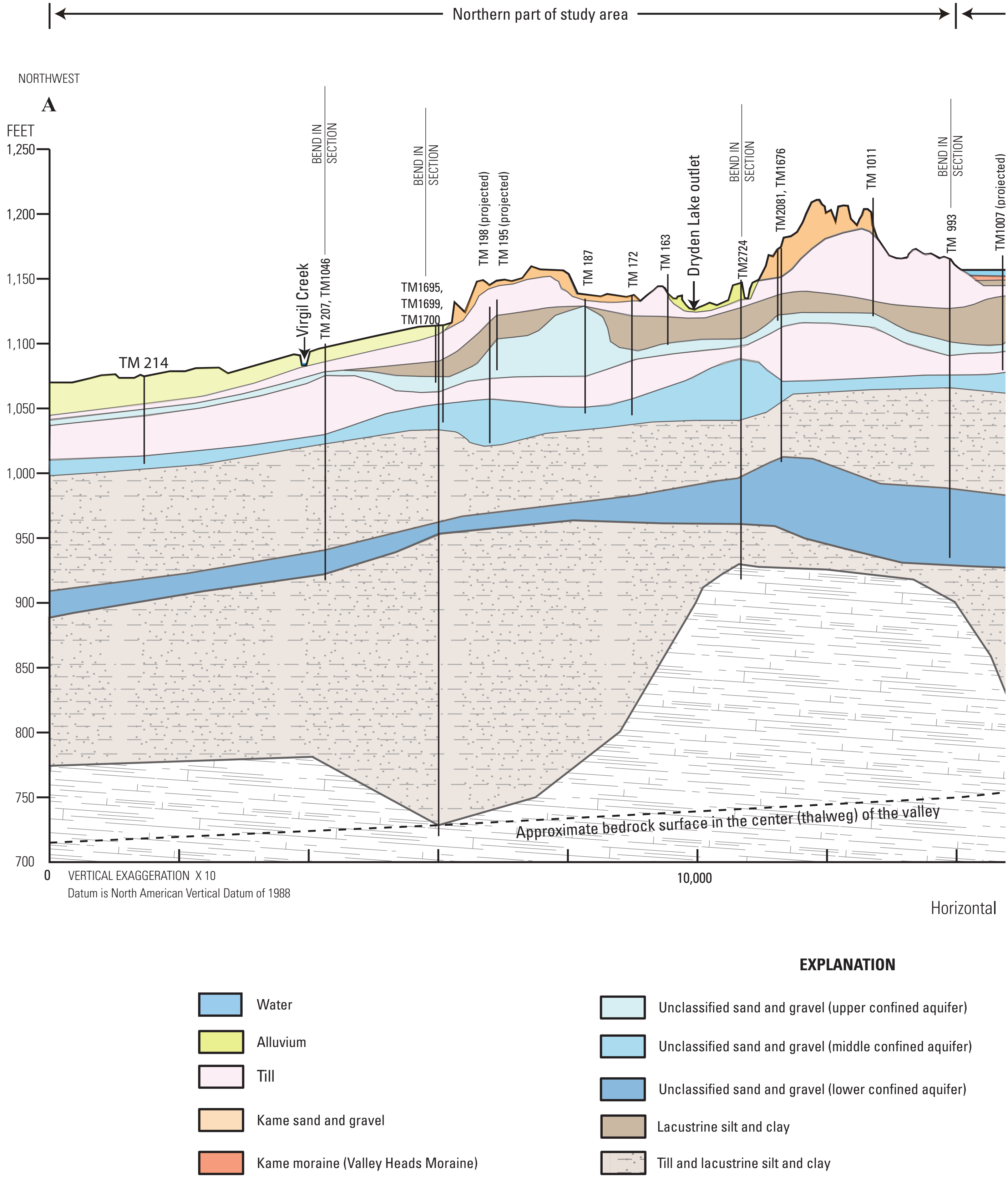
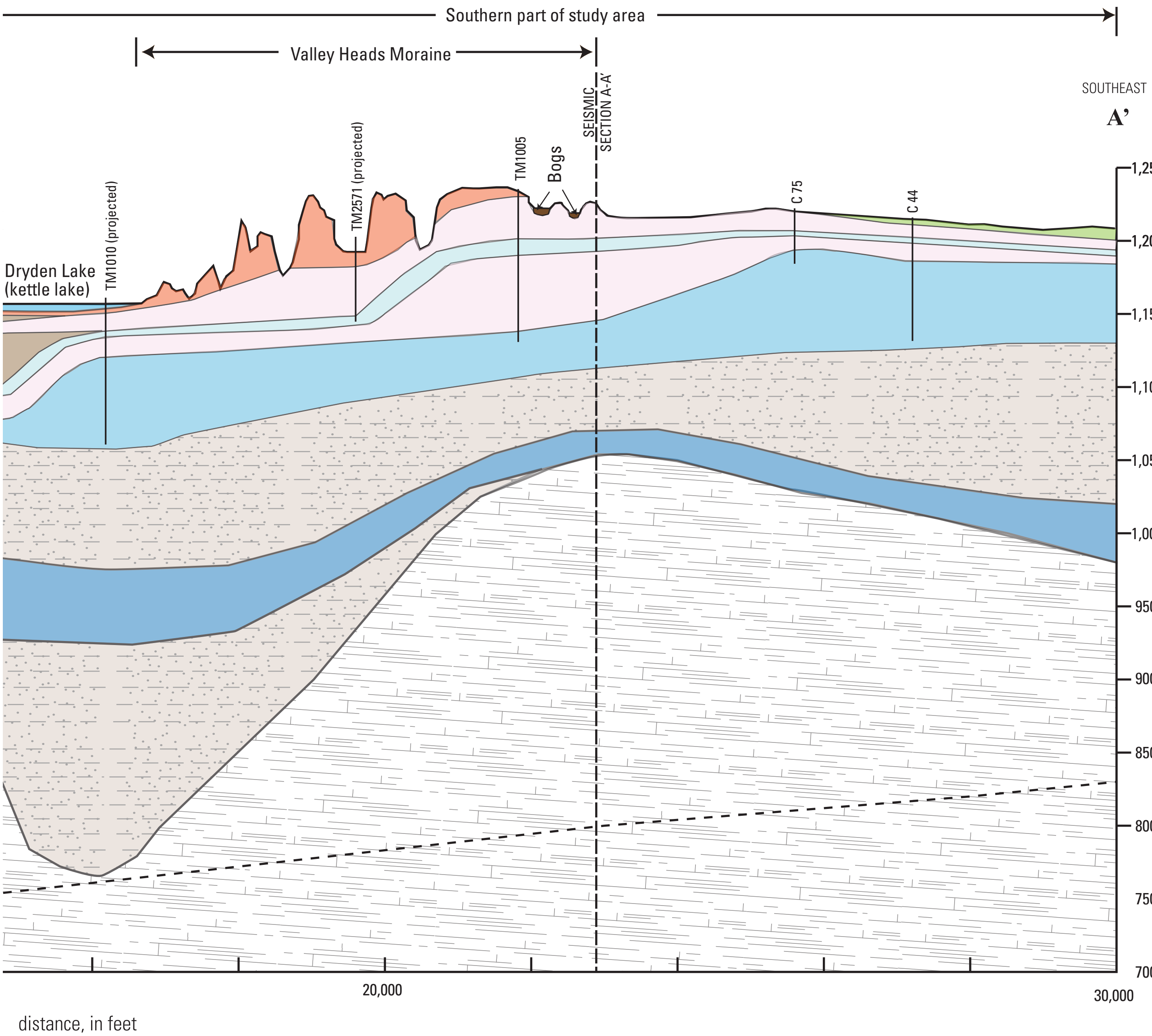


Figure 13. Longitudinal geologic cross-section *A–A′* in the Virgil Creek and Dryden Lake Valleys, Town of Dryden, New York. Location of line of section shown on figure 8. (Available separately at http://pubs.usgs.gov/sir/2013/5070/pdf/sir2013-5070_miller_fig13_11x17.pdf)




Bedrock (shale and siltstone)

Well and well number— Number is assigned by U.S. Geological Survey. Well data are in appendix at end of report

Figure 13. Longitudinal geologic cross-section *A–A′* in the Virgil Creek and Dryden Lake Valleys, Town of Dryden, New York. Location of line of section shown on figure 8.—Continued

(fig. 13). However, in the floodplain of Virgil Creek east of the Virgil Creek Dam, the creek has removed the surficial till layer and deposited a thin layer of recent alluvium overlying kame sand and gravel (fig. 14). Records of test wells and borings at the dam indicate that the stratified-drift deposits are 100- to 150-ft thick in this area and consist of three sand and gravel units that are interlayered with relatively impermeable units (having low hydraulic conductivity) such as till and glaciolacustrine fine-grained sediments (very fine sand, silt, and clay).

In the areas above the Virgil Creek floodplain and on the backside (northwest) of the Valley Heads Moraine, ground moraine (till) and kame deposits are present at or near land surface (fig. 6). The uppermost till is underlain by at least three extensive sand and gravel units that form confined aquifers bounded between relatively impermeable till and glaciolaustrine units (fig. 13). The multiple till units suggest that the ice front of the glacier had oscillated back and forth in this area.

The well log of TM 993 (fig. 15; location shown in figs. 8 and 13), a 234-ft-deep test well in the NYSDEC parking lot at the north end of Dryden Lake, indicates that the upper 105 ft of deposits consists of a surficial till that overlies a lacustrine unit, which in turn overlies at least two thin sand and gravel units. Below a depth of 110 ft, there is a 67-ft-thick confining unit consisting of lacustrine silt, clay, and till that overlies a more than 68-ft-thick coarse sand and gravel unit (177 to 245 ft below land surface).

The well log of TM2724 (fig. 16; location shown in figs. 8 and 13), a 229-ft-deep test well, located 300 ft north of Keith Lane and along the Jim Schug trail, penetrated three major sand and gravel units (40–52 ft, 69–106 ft, and 152–187 ft below land surface), several minor sand and gravel units interlayered with confining units consisting of till and glaciolacustrine sediments, and bedrock at 218 ft below land surface. The three major sand and gravel units probably correlate with the three sand and gravel units encountered in test well TM 993 near Dryden Lake (fig. 13). The minor sand and gravel units encountered in test well TM2724 above the bottom major sand and gravel unit are probably discontinuous lenses that do not form extensive aquifers.

Logs for test wells TM1695, TM1699, and TM1700 at the Village of Dryden Lake Road pumping station indicate that the wells were drilled to depths of 396 ft, 72 ft, and 41 ft, respectively (fig. 9; locations shown on figs. 8 and 13). Well TM1695 penetrated interbedded till and sand and gravel units in the upper 108 ft, mostly glaciolacustrine fine sand, silt, and clay from 108 to 387 ft, and bedrock at 387 ft below land surface. At the Village of Dryden South Street pumping station, a now-abandoned well (TM 207) and a production well operating since 1986 (TM1046) (fig. 17; locations shown on figs. 8 and 13) penetrated a confined sand and gravel aquifer between depths 155 ft and 185 ft and possibly one or two minor shallow confined sand and gravel units, but they were deemed unsuitable for finishing as production wells for municipal purposes. There are few subsurface data northwest of the Village of Dryden (northwest of the boundary of the study area). Therefore subsurface geologic conditions there are unknown.

Geohydrology of the Stratified-Drift Aquifer System

Characterization of the stratified-drift aquifer system in the Virgil Creek and Dryden Lake Valleys in the Town of Dryden, Tompkins County, and in part of the Owego Creek Valley, Town of Harford, included describing the (1) aquifer type (confined or unconfined), (2) aquifer framework, and (3) groundwater-flow system, including water levels and recharge and discharge conditions. Because drilling more than a few wells was beyond the scope of this study, most data used to characterize the geologic framework of the aquifers were obtained from existing well records. Many of the wells used in this study are within the central part of the study area, where the density of self-supply wells is higher; however, attempts were made to characterize the southern and northern parts of the aquifer system using available well logs, water-level data, and correlations made from seismic data. The locations of wells used to characterize the stratified-drift aquifer system are shown on figure 8, and well records are presented in appendix 1.

The major aquifers in the study area are confined. However, there are several thin, discontinuous unconfined aquifers as well. Because unconfined aquifers are thin, discontinuous, and are tapped by few wells, this report concentrates on the three more extensive confined aquifers in which most wells are finished. A confined aquifer (also known as an artesian aquifer) is bounded between confining layers and is composed of sediments of sufficient permeability that it is able to store and yield usable amounts of water to wells. In a confined aquifer, the potentiometric surface is, by definition, always above the top of the permeable sediments in which the water is stored and transmitted. When a confined aquifer is tapped by a well, water in the casing is forced up to its potentiometric altitude. If the hydraulic pressure in the confined aquifer is great enough, it may cause the water in the well to flow above land surface, in which case the well is referred to as a flowing artesian well.

Confining layers are made up of sediments with low permeability (low hydraulic conductivity) that prevent groundwater from rapidly moving through them. In the study area, the confining layers consist of fine-grained glaciolacustrine sediments (clay, silt, and very fine sand) and till.

An unconfined aquifer comprises sediment of sufficient permeability that can store and yield usable amounts of water to wells. In an unconfined aquifer, the water table is at or near atmospheric pressure and is the upper boundary of the aquifer.

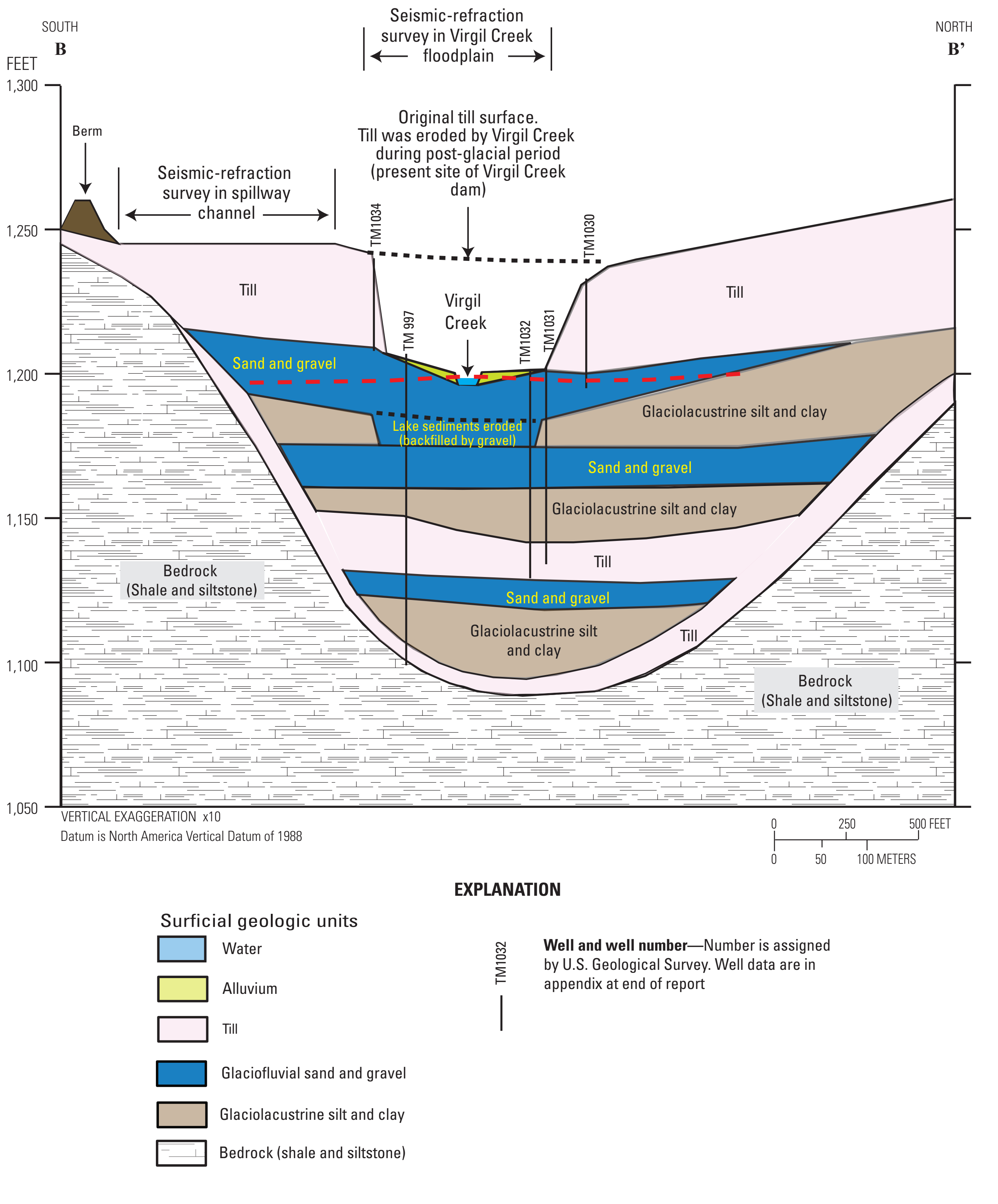
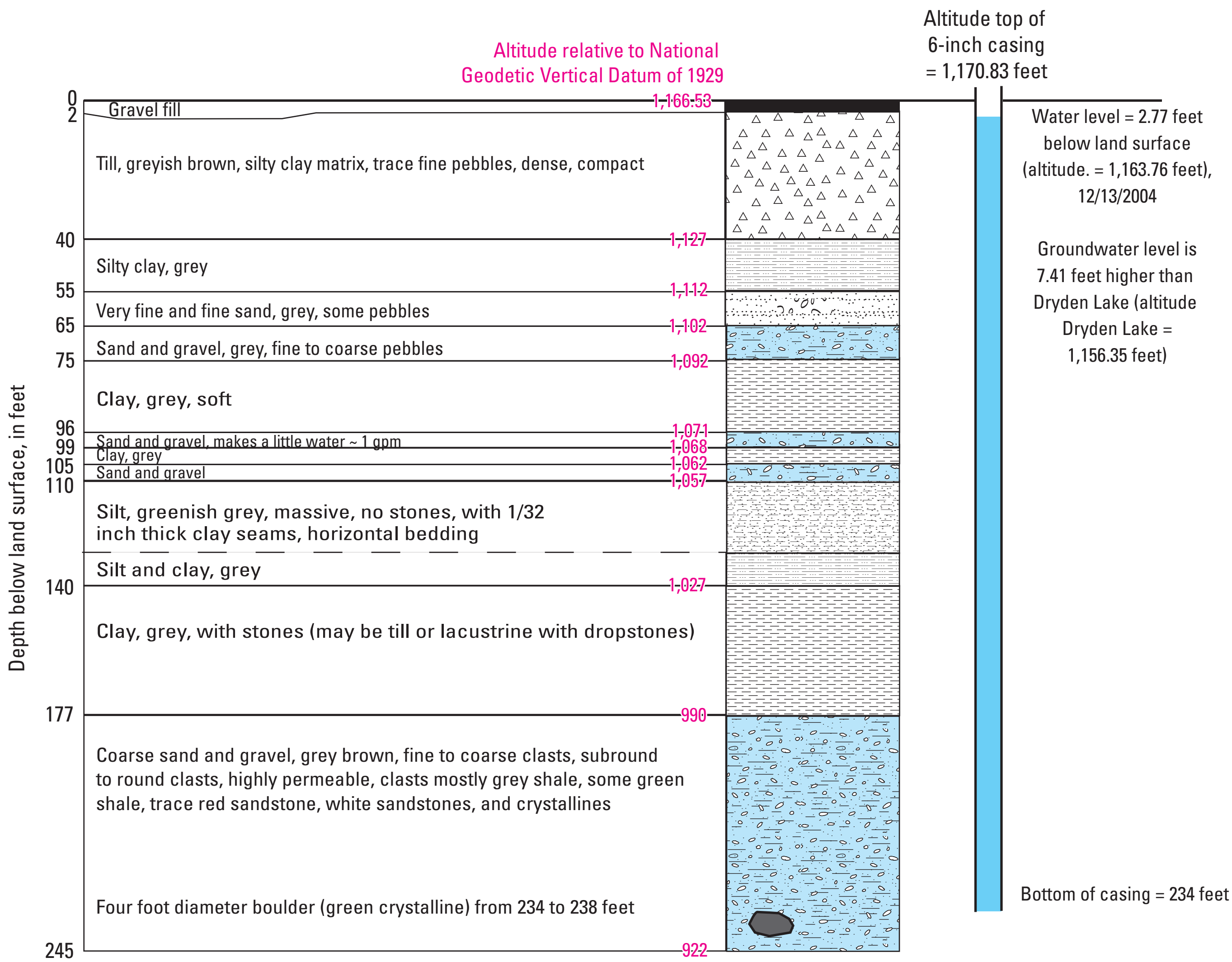


Figure 14. Geologic section *B–B'* at the Virgil Creek Dam, Town of Dryden, New York. Location of line of section shown on figure 8.

Site name: TM 993 (well depth = 234 ft)
Site ID: 422755076164801
Latitude: 42° 27' 55.23''
Longitude: 076° 16' 47.92''

Drilling contractor: Barber & Deline, Tully, NY
Date completed: 12/9/04
6-inch- diameter steel casing
Casing above ground = 4.3 feet



Refusal at 234 feet where a 4-foot diameter boulder was encountered. Casing ends at 234 feet, uncased borehole was drilled through boulder to depth 245 feet. A thick sequence of coarse sand and gravel extends from 177 to 245 feet.

Developed well 2 hours at a pumping rate of 200 gallons per minute (12/9/04)
Pumped well at a rate of 45 gallons per minute for 1 hour, drawdown = 0.8 feet (12/13/04).

Figure 15. Well log and well construction details of U.S. Geological Survey test well TM 993 at the New York State Department of Environmental Conservation boat access facility at Dryden Lake, in the Town of Dryden, New York. Location shown on figure 8.

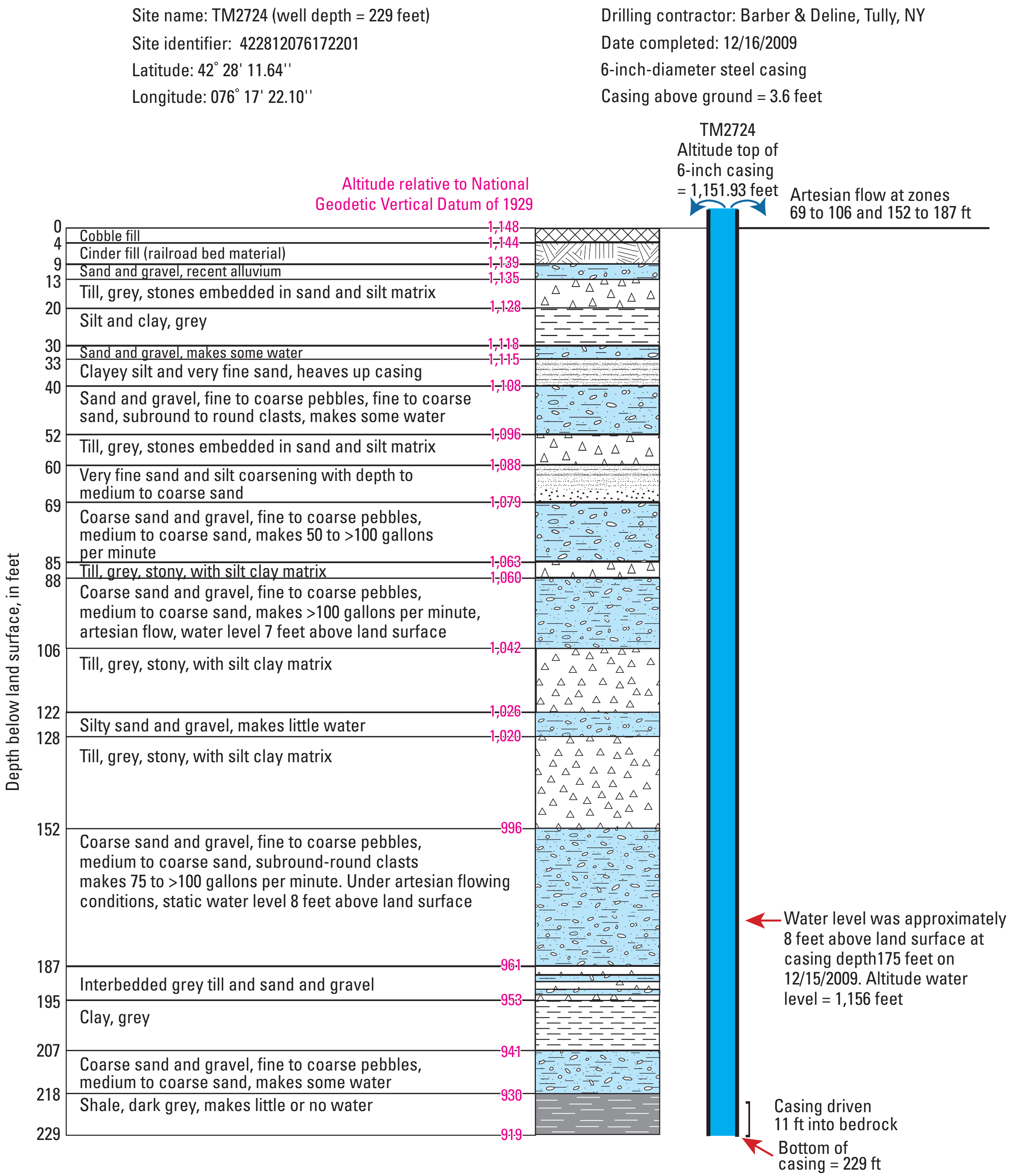


Figure 16. Well log and well construction details of U.S. Geological Survey test well TM2724, on the Jim Schug trail near Keith Lane Road, Town of Dryden, New York. Location shown on figure 8.

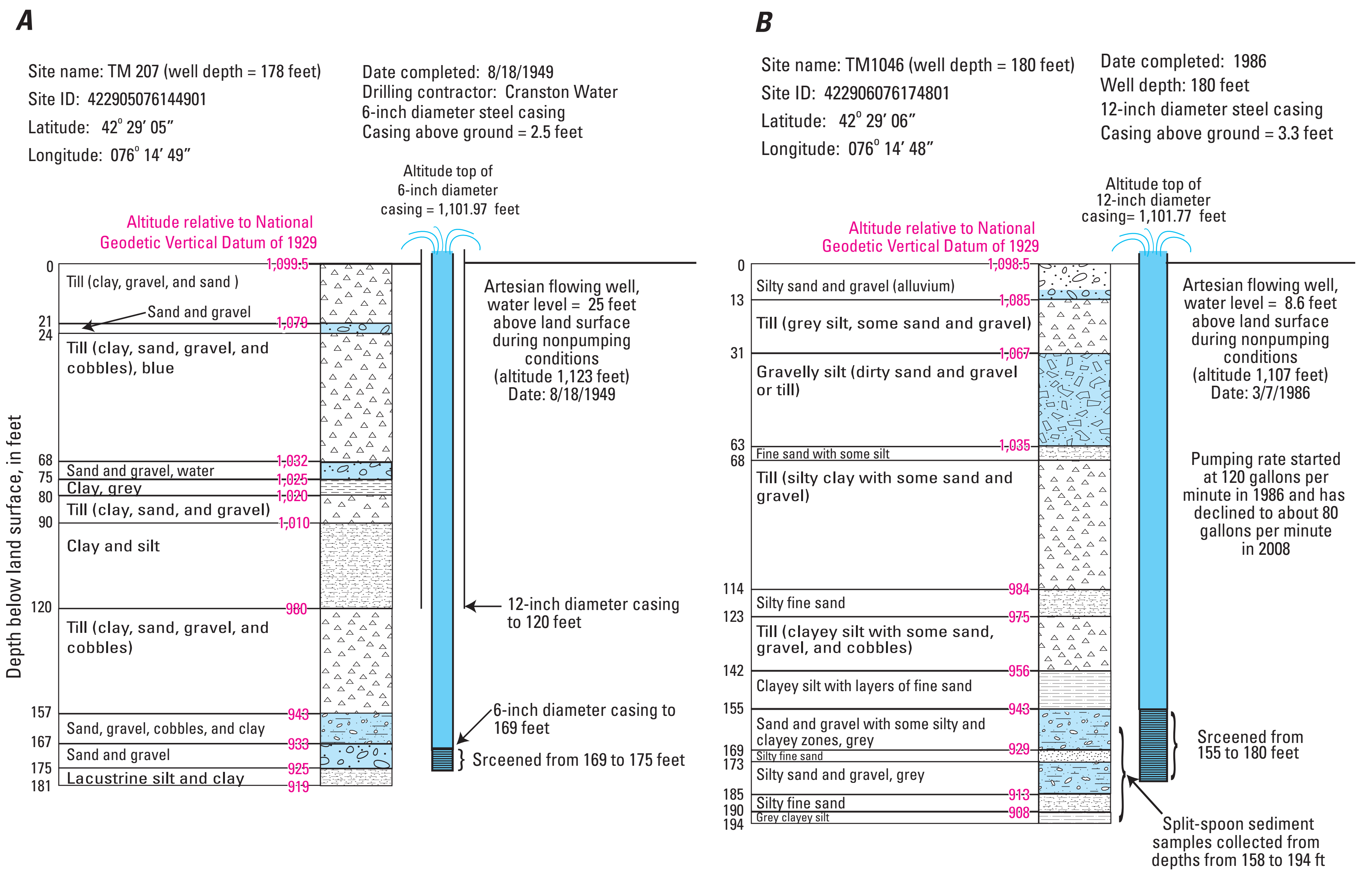


Figure 17. Well logs and well construction details of *A*, abandoned well TM 207 and *B*, production well TM1046 at the South Street pumping station, Village of Dryden. Abandoned well TM 207 is used as an observation well and is equipped with a water level recorder. Locations shown on figure 8.

Aquifer Geometry

The stratified-drift aquifer system in the study area contains three extensive and continuous confined sand and gravel aquifers and several small and discontinuous unconfined and confined aquifer units (figs. 18 and 19). Most wells in the study area tap the three confined aquifers. The discontinuous unconfined and confined aquifer units are of local extent and are tapped by only a few wells.

Unconfined Aquifers

Except for locally thick unconfined alluvial deposits in the Virgil Creek floodplain west of the Virgil Creek Dam (fig. 19), there are only small discontinuous patches of kame sand and gravel or surficial alluvial deposits (fig. 18) that form unconfined aquifers. However, most of these deposits are thinly saturated or only seasonally saturated. Therefore, these minor aquifers generally are not tapped by wells in the study area. These unconfined aquifers include the alluvial Virgil Creek floodplain east of the Virgil Creek Dam, kame terraces along the valley walls, kame and kame moraine deposits, and the alluvial fan complex in the Owego Creek Valley south of the Valley Heads Moraine (fig. 6). The dam, completed in 1998, is used for flood control purposes and does not contain water except during high storm-runoff events.

Confined Aquifers and Confining Units

There are three extensive and continuous confined sand and gravel aquifers in the study area. These aquifers are designated in this report as the upper, middle, and lower confined aquifers and are confined by units that have low hydraulic conductivity, such as till and lacustrine clay, silt, and very fine sand. Most wells in the study area, including the production wells for the Village of Dryden, are finished in these aquifers.

The upper confined aquifer typically lies 20 to 45 ft below land surface and ranges in thickness from 5 to 10 ft, but locally it can be as much as 65 ft thick (fig. 18). The upper confined aquifer is typically the thinnest of the three confined aquifers. The upper confined aquifer underlies a thin till confining unit (5 to 20 ft thick) in the northern and southern parts of the study area and underlies a thicker till and lacustrine silt and clay confining unit (combined thickness of 20 to 50 ft) in the central part of the study area (fig. 13). Many domestic wells tap the upper aquifer in the central part of the study area, as do two Village of Dryden municipal wells (TM 202 and TM 204) at the Lake Road well field in the northern part of the aquifer (fig. 8).

The middle confined aquifer typically lies from 70 to 100 ft below land surface and ranges in thickness from 10 to 15 ft. Locally the aquifer can be as much as 60 ft thick (fig. 18). The middle confined aquifer is confined above and below by 10 to 40 ft of till throughout the study area (fig. 13). Most homeowner wells are finished in the middle confined aquifer, as is the Village of Dryden municipal well TM 981 at the Jay Street pumping station, in the northern part of the aquifer (fig. 8).

The lower confined aquifer typically lies from 150 to 250 ft below land surface. The aquifer ranges in thickness from 15 to 25 ft in the northern part of the study area but can be more than 50 ft thick in the central part of the study area (fig. 18). The extent and thickness of the lower confined aquifer are mostly unknown in the southern part of the study area because of the lack of deep subsurface data there (fig. 13). The lower confined aquifer is confined above by 50 to 80 ft of till and lacustrine sediments and is confined below by mostly fine-grained lacustrine deposits or low-permeability bedrock (fig. 13). The lower confined aquifer is tapped by several domestic wells and one Village of Dryden municipal well (TM1046 at South Street; figs. 8, 13, and 17).

Bedrock

Generally, water-well drillers do not drill wells more than 300 ft deep into bedrock because well yields typically decline, and the water typically becomes increasingly more mineralized and less potable with increasing depth. Well yields generally decline with increasing depth because the density, width of openings, and connectivity of water-bearing fractures decrease with depth as a result of the diminishing effects of weathering and the increasing weight of overlying rock which results in fewer, less-open, and less-connected fractures. In the southern part of Tompkins County, records from water-well drillers indicate that 2 to 5 gallons per minute (gal/min) typically can be obtained from wells that tap Devonian-age sedimentary rocks at most locations, and locally, yields as large as 10 to 30 gal/min or as small as less than 1 gal/min are obtained (Miller, 2009).

Groundwater Recharge

Recharge is replenishment of water to an aquifer. The amount of recharge to an aquifer is important in the determination of the long-term availability of groundwater. Recharge to confined aquifers is limited because the unconfined aquifers are surrounded in large part by confining units and typically have only a small portion of the aquifer open to the atmosphere that can readily accept recharge directly from precipitation. Conversely, recharge is readily available to unconfined aquifers because all of the aquifer is open to the atmosphere and thus recharge from precipitation and losing streams is easier to estimate than in confined aquifer settings. The distribution and amount of recharge in the study area varies from place to place; the amount of estimated recharge used for the input into the numerical groundwater-flow model is discussed in the Boundary Conditions section of this report.

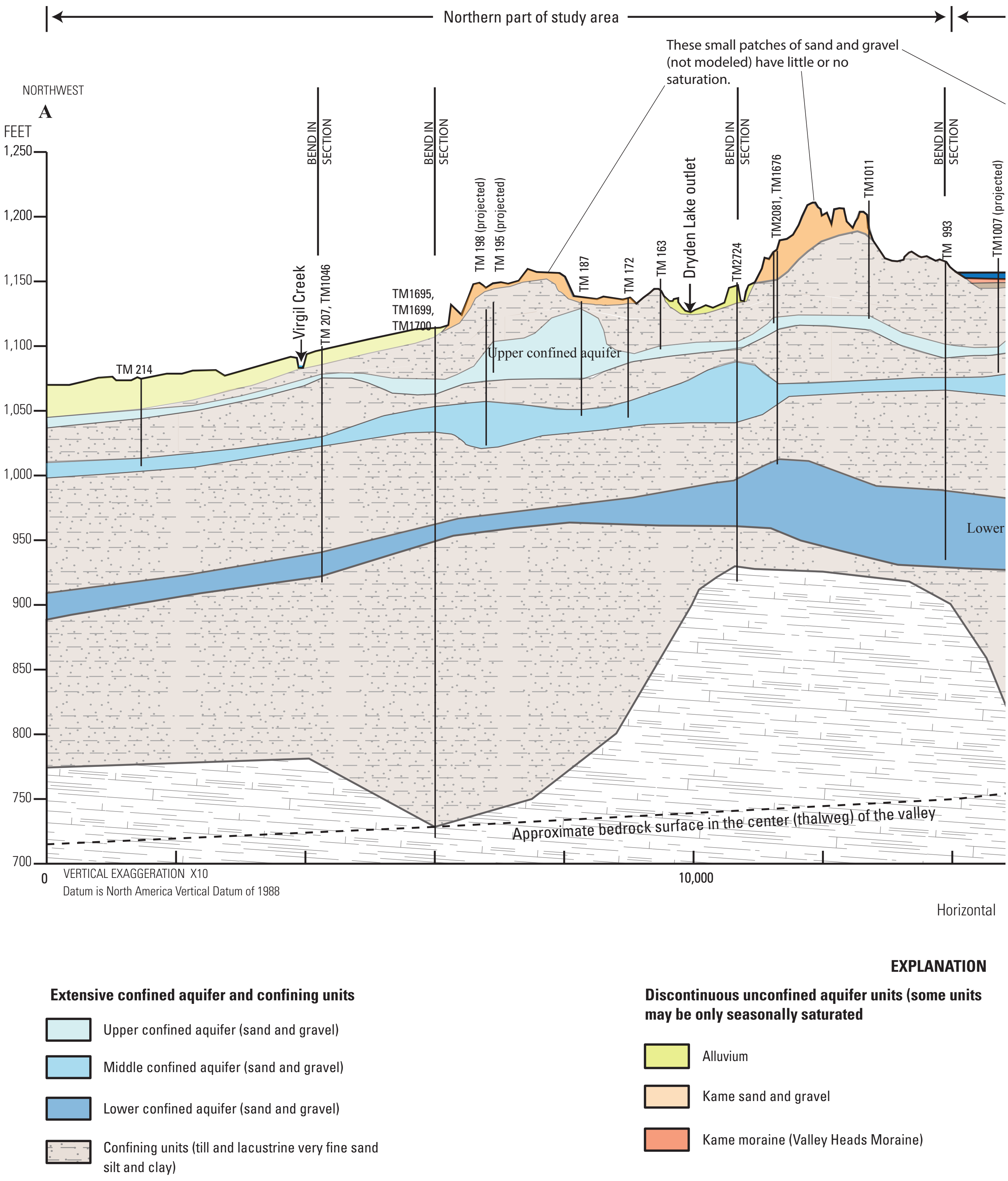


Figure 18. Geohydrology across longitudinal geologic cross-section *A–A′* in the Virgil Creek and Dryden Lake Valleys, Town of Dryden, Tompkins County, and in headwaters of Owego Creek, Town of Harford, Cortland County, New York. Location of line of section shown on figure 8. (Available separately at http://pubs.usgs.gov/sir/2013/5070/pdf/sir2013-5070_miller_fig18_11x17.pdf)

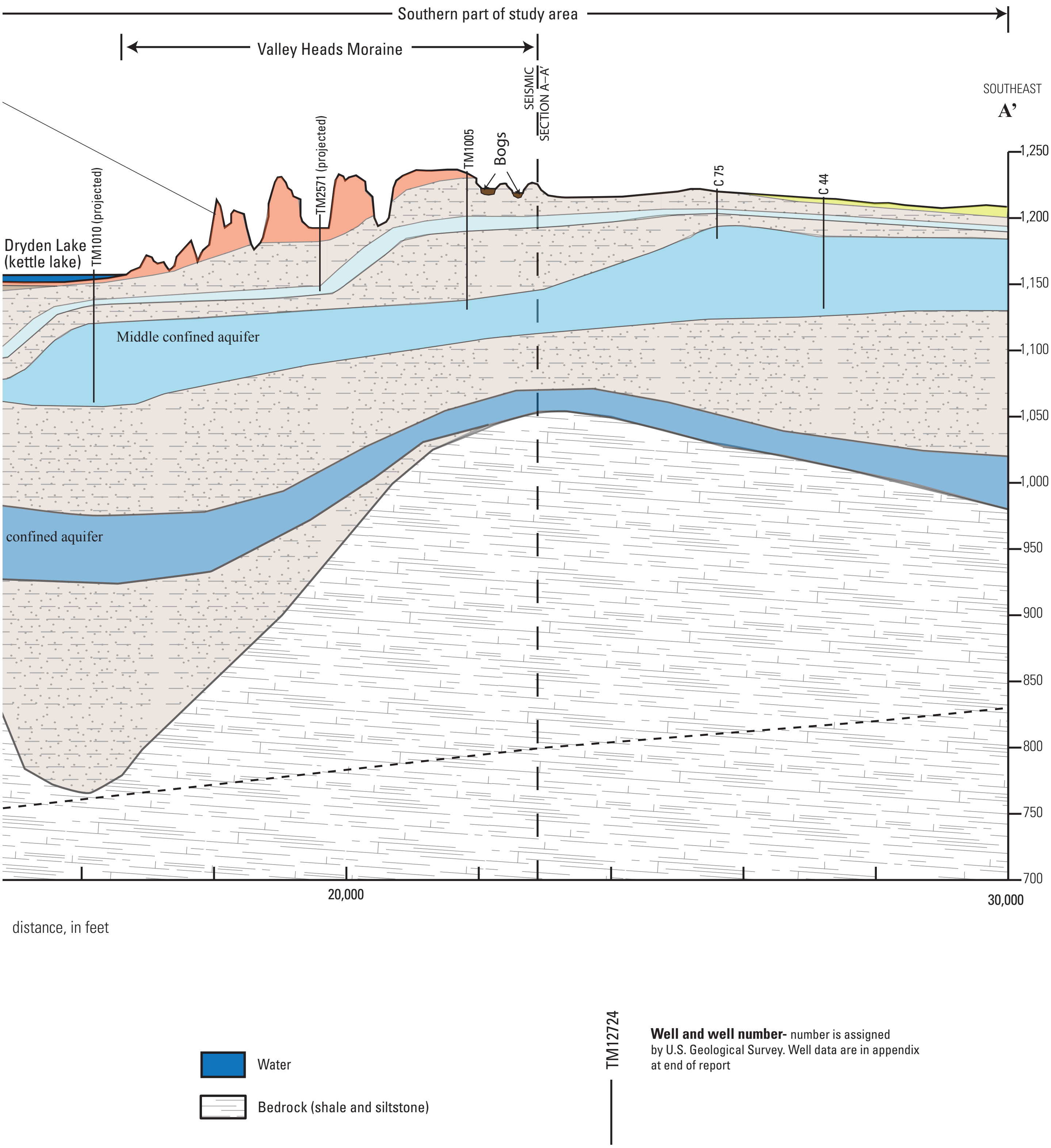


Figure 18. Geohydrology across longitudinal geologic cross-section *A–A'* in the Virgil Creek and Dryden Lake Valleys, Town of Dryden, Tompkins County, and in headwaters of Owego Creek, Town of Harford, Cortland County, New York. Location of line of section shown on figure 8.—Continued

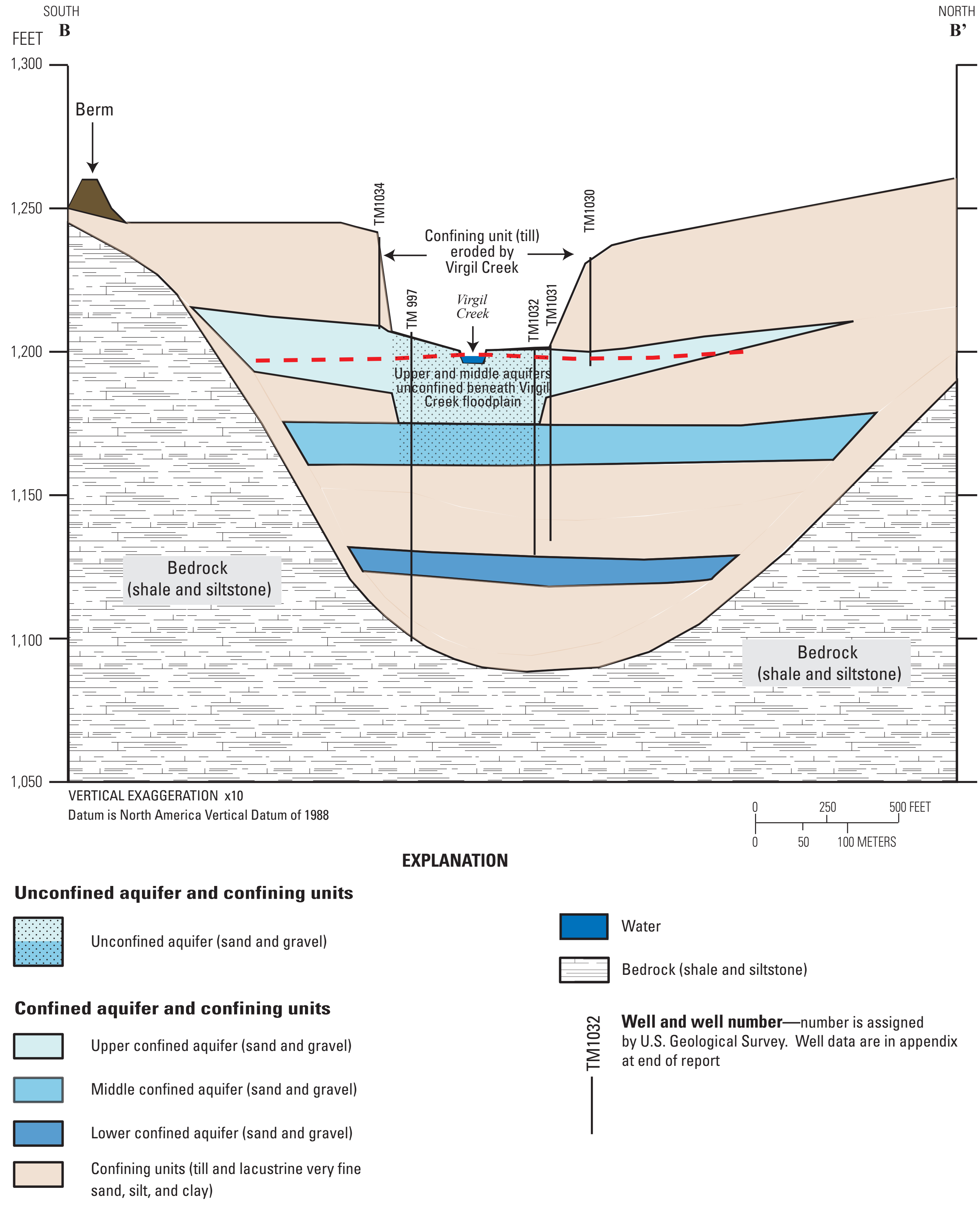


Figure 19. Geohydrology across geologic cross-section *B–B′* at the Virgil Creek Dam, Town of Dryden, New York. Location of line of section shown on figure 8.

Unconfined Aquifer

In general, the principal sources of recharge to unconfined aquifers in the study area are (1) direct infiltration of precipitation (rain and snow melt) at land surface, (2) unchanneled surface and subsurface runoff and groundwater inflow from till and bedrock of adjacent upland areas, (3) leakage from tributary streams and from Virgil Creek in the vicinity of the Virgil Creek Dam (fig. 19), and (4) upward leakage from the underlying fine-grained confining units (fig. 20). Over areas of sand and gravel, surface runoff is generally negligible; therefore, precipitation that is not lost to evapotranspiration recharges the unconfined aquifer. Unchanneled upland runoff and groundwater inflow from till and bedrock typically contribute about 20 percent of the total recharge to unconfined stratified-drift aquifers in central New York (Miller and others, 1998, 2008; Kontis and others, 2004). Recharge from seepage losses in tributary streams is a minor source of recharge to the aquifers in this study area because most of the major aquifers are confined.

In the Virgil Creek Dam area (the dam normally allows creek water to pass without restriction and only holds back water during high storm-runoff events), erosion by Virgil Creek has cut a 40-ft-deep gorge into the Valley Heads Moraine (fig. 19). Test wells TM 997 and TM 998 (fig. 11) were drilled at the dam during this study to determine (1) whether the upper confining unit had been removed by this erosion (thus creating a window where part of the upper confined aquifer has become exposed at land surface, forming a local unconfined aquifer) and (2) the hydraulic-head relation between the stream and aquifer. In unconfined aquifer settings, streams are hydraulically connected to the aquifer and the hydraulic-head relation between the water level in the aquifer and in the stream determines whether the stream gains (receives groundwater discharge) or loses (recharges the aquifer) water to the aquifer.

Results of the test drilling indicate that the upper confining unit (till) was missing at the dam (figs. 11, 14, and 19) and that there was an unconfined sand and gravel aquifer at depths from 0 to 48 ft in the floodplain of Virgil Creek (figs. 11, 14, and 19). On November 11, 2005, the water level in Virgil Creek was measured and found to be 2.3 ft higher than the groundwater level in well TM 998 (well depth of 37 ft and finished in the unconfined aquifer, fig. 11), which indicates that the stream probably loses water and therefore recharges the aquifer. The higher head in the stream than in the aquifer may be a result of a series of unlined stream-drop structures that were constructed behind the dam for erosion-control purposes, and the stream may lose water only close to the dam. There were no streamflow measurements made in Virgil Creek before the dam was constructed to determine whether the stream lost water before it was constructed. To determine the amount of stream loss, a set of seepage measurements was made in Virgil Creek on May 10, 2007, at a time of average annual base flow. The results of the stream measurements indicated that the stream lost 1.2 cubic feet per second (ft^3/s) (0.78 million gallons per day (Mgal/d)) of water in the reach from 1,200 ft upstream from the dam to 220 ft downstream from the dam (fig. 12*A*).

Confined Aquifers

The confined aquifers in the study area are surrounded by fine-grained sediments of low hydraulic conductivity that impede or slow infiltration of water (recharge) from surface sources to the aquifer. In most of the study area, the sources of recharge were difficult to identify and amounts of recharge were difficult to quantify because the aquifers are overlain by confining units and the hydraulic properties, such as hydraulic conductivity, are not known. Therefore, the recharge conditions in most of the study area are approximated (fig. 20). However, one area was an exception: the Virgil Creek Dam area described above.

In the northern part of the Dryden Lake Valley, well records indicate that the confining units are continuous and extensive. Therefore, the confined aquifers receive recharge mostly by slow seepage of water through the fine-grained drift (till and glaciolacustrine very fine sand, silt, and clay) that surround them. Locally along the sides of the valley, the confined aquifers either may extend up along the flank of the bedrock valley wall, becoming unconfined where they crop out at land surface, or are overlain and in contact with surficial coarse-grained kame sand and gravel deposits that constitute an avenue through which direct precipitation and seepage losses from tributary streams (fig. 20*A*) can enter the aquifer. Seepage from adjacent fine-grained sediment may be substantial in the vicinity of the large pumping wells for the Village of Dryden. Large pumping withdrawals lower the water levels and increase the vertical hydraulic gradients in the confining units resulting in substantial amounts of water flowing through confining layers and into the aquifers (fig. 20*A*). In areas distal from the municipal pumping wells and where the confined aquifers are mostly isolated and completely surrounded by low-permeability material, the rates of flow through the confining units are lower than in proximity to pumping wells. Although the rates of flow through confining units that are distal from pumping wells are small, substantial total amounts of water flow through these units and into aquifers because the confining units extend over large areas. In this study area, the most isolated confined aquifer is the lower confined aquifer.

Most recharge to the confined aquifers occurs at the Valley Heads Moraine and outwash plain in the southern part of the study area (fig. 6) where there are many ice-disintegration features and deposits (kame and kettle topography). In this area, the stratigraphy is chaotic because the ice surged back and forth and sediments that were on top or adjacent to ice collapsed as ice melted. The confining units (till) are likely to consist of heterogeneous material (reworked sand and gravel mixed with till) and locally to contain windows of permeable sediment that can readily transmit recharge from precipitation and tributaries that lose water as

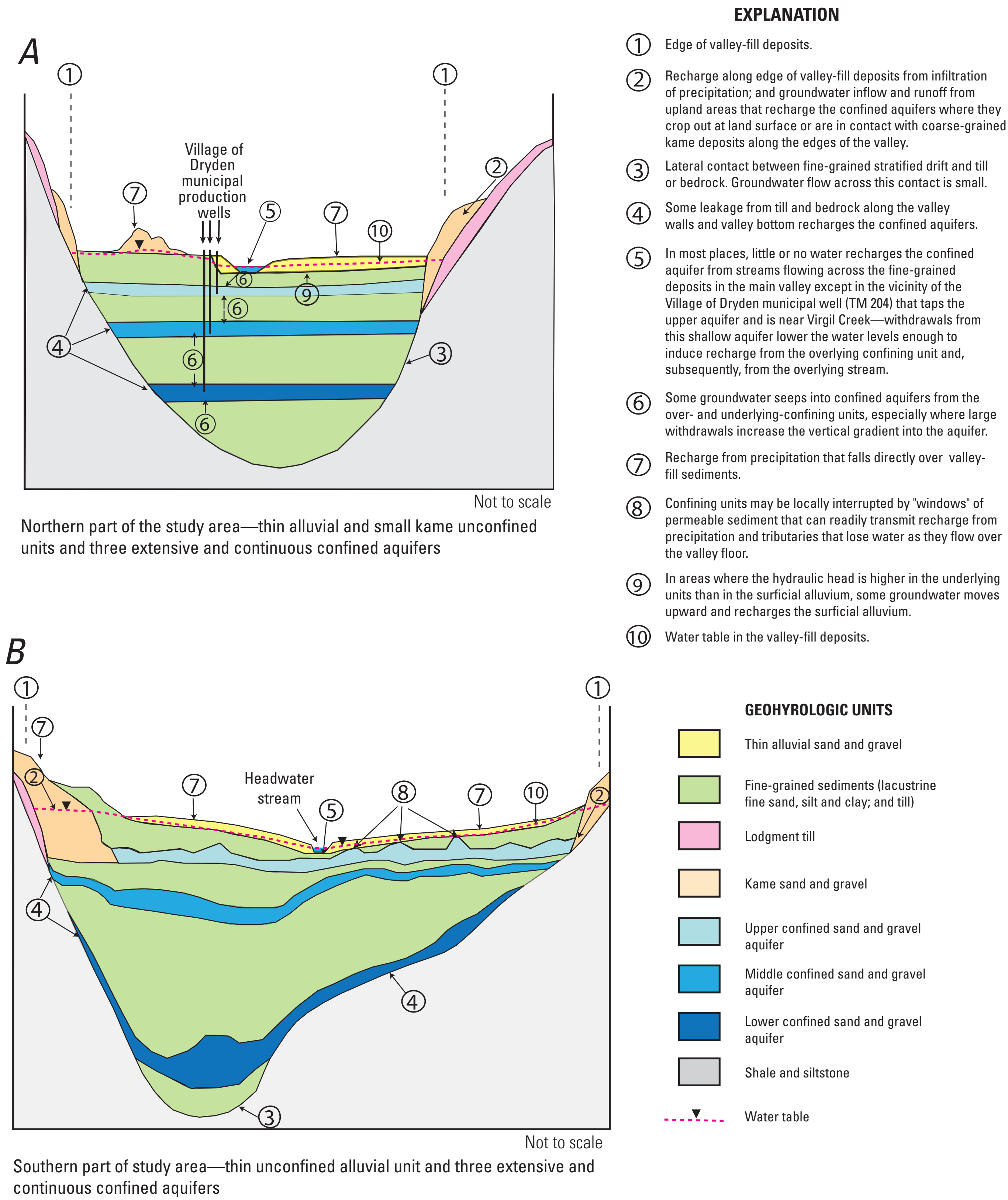


Figure 20. Sources of recharge to aquifers in *A*, the northern part of the study area and *B*, the southern part of the study area, Tompkins and Cortland Counties, New York.

they flow over the valley floor (fig. 20*B*). Two wells (TM2001 and TM2063) on the crest of the Valley Heads Moraine on the west side of the valley (fig. 8) penetrated coarse-grained material (bouldery gravel that extends from land surface to bedrock), indicating that at least the upper confined aquifer (and possibly the middle aquifer) is connected to an unconfined part of the kame moraine and, therefore, receives recharge from direct precipitation and runoff from the valley walls over that zone (fig. 20*B*).

Groundwater Discharge

In the northern part of the study area, groundwater discharges to (1) the Village of Dryden municipal wells; (2) domestic, nonmunicipal community (mobile home parks and apartments), and several commercial wells; and (3) a Dryden Lake outlet and Virgil Creek. In addition, some groundwater exits as underflow through the three confined aquifers at the arbitrary aquifer boundary at the northern end of the study area near the northern boundary of the Village of Dryden.

In the southern part of the study area, groundwater discharges to (1) Dryden Lake, (2) the inlet to Dryden Lake, and (3) domestic, commercial, and agricultural wells. Throughout the study area, evapotranspiration during the growing season reduces the percentage of infiltrated water that reaches the water table. Evapotranspiration is estimated to range between 19 and 20 inches per year or roughly half of the annual precipitation in this area (Kontis and others, 2004, plate 1).

Municipal Withdrawals

The largest user of groundwater in the study area is the Village of Dryden. The village uses four production wells (TM1046, TM 981, TM 202, and TM 204; fig. 8) at three pumping stations (South Street, Jay Street, and Lake Road). Well TM1046 at the South Street pump station is pumped continuously, well TM 981 at the Jay Street pumping station is pumped daily but for only several hours per day, and wells TM 202 and TM 204 at the Lake Road pumping station are pumped irregularly—typically for a few hours a couple days a month or during high water-demand periods such as during hot summer intervals (Ron Moore, superintendent of public works, Village of Dryden, written commun., 2008). After water pumped from the municipal wells is used by homeowners, organizations, and businesses, most of the water is then routed to the sewage treatment plant (200 ft north of the northern boundary of the study area; fig. 8) where it is treated and discharged into Virgil Creek.

Before 1963, a spring-fed reservoir 1 mi northeast of the Village of Dryden (fig. 8) was used to supplement water pumped from well TM 207 at the South Street pumping station. Well TM 207 is 176 ft deep and screened in the lower confined aquifer. In 1964, the spring-fed reservoir was discontinued for use because the Tompkins County Health Department determined that the springs were susceptible to contamination. In 1964, municipal production wells TM 202 and TM 204 (45 and 51 ft deep, respectively) were installed at the Lake Road pumping station to replace the reservoir and to meet increasing water demand in the village. Both wells were screened in the upper confined aquifer. In 1964, wells TM 202 and TM 204 were reported to yield 125 gal/min and 115 gal/min, respectively. However, yields from the Lake Road wells have declined over time. In 1998, the combined sustained flow from the two wells was about 140 gal/min (Rice and Foster, 1998).

In 1977, municipal production well TM 199 (well depth 212 ft) was installed at the Jay Street pumping station (fig. 8) and yielded 65 gal/min. However, the yield had declined from 65 gal/min in 1977 to 20 gal/min by 1986 when it was abandoned. The well was used as a production well from 1980 to 1986 (fig. 21).

In 1986, well TM1046 (fig. 8) was constructed and replaced well TM 207 at the South Street pumping station and well TM 199 at the Jay Street pumping station, the yields from both of which were declining to the point where the wells were not producing enough water to meet demand from the village. Well TM1046 (180 ft deep) is screened in the lower confined aquifer and initially began pumping at a rate of about 120 gal/min in1986, but the pumping rate had steadily declined to about 77 gal/min by 2008 (fig. 21). The decreased pumping rate is believed to be due to encrustation of the screen openings, siltation of the aquifer in the vicinity of the screen, or both.

To offset the decline of production from well TM1046, pumping from well TM 981 (Jay Street pumping station) has increased from 1998 through 2008 (fig. 21). In 2008, wells TM1046 (South Street pumping station), TM 981 (Jay Street pumping station), and TM 204 (Lake Road pumping station) supplied 57 percent, 41 percent, and 2 percent of the village's water consumption, respectively. It is estimated that the Village of Dryden municipal wells supply water to 1,832 village residents (U.S. Census, 2000), 3,800 college students (residents in dormitories and transients), 1,900 high school students, and several small businesses.

The water use for 1963 was reported (Morrell Vrooman Engineers, 1964) to be 26.3 million gallons per year (Mgal/yr). Since 1970, the Village of Dryden has compiled pumping records. The total pumpage from all wells is summarized on figure 22. Water use has approximately tripled between the early 1970s, when withdrawals ranged between 18 and 30 Mgal/yr, and from 2000 through 2008, when withdrawals ranged between 75 and 85 Mgal/yr (fig. 22). The rate of increase of groundwater withdrawal during the 39-year period from 1970 to 2008 was about 1.3 Mgal/yr. Water use increased substantially in the mid to late 1970s, when Tompkins Cortland Community College opened about 1 mi north of the village, and during subsequent periods of expansion at the college. From 2006 through 2008, the college used 16 to 17 percent of the water withdrawn by the municipal

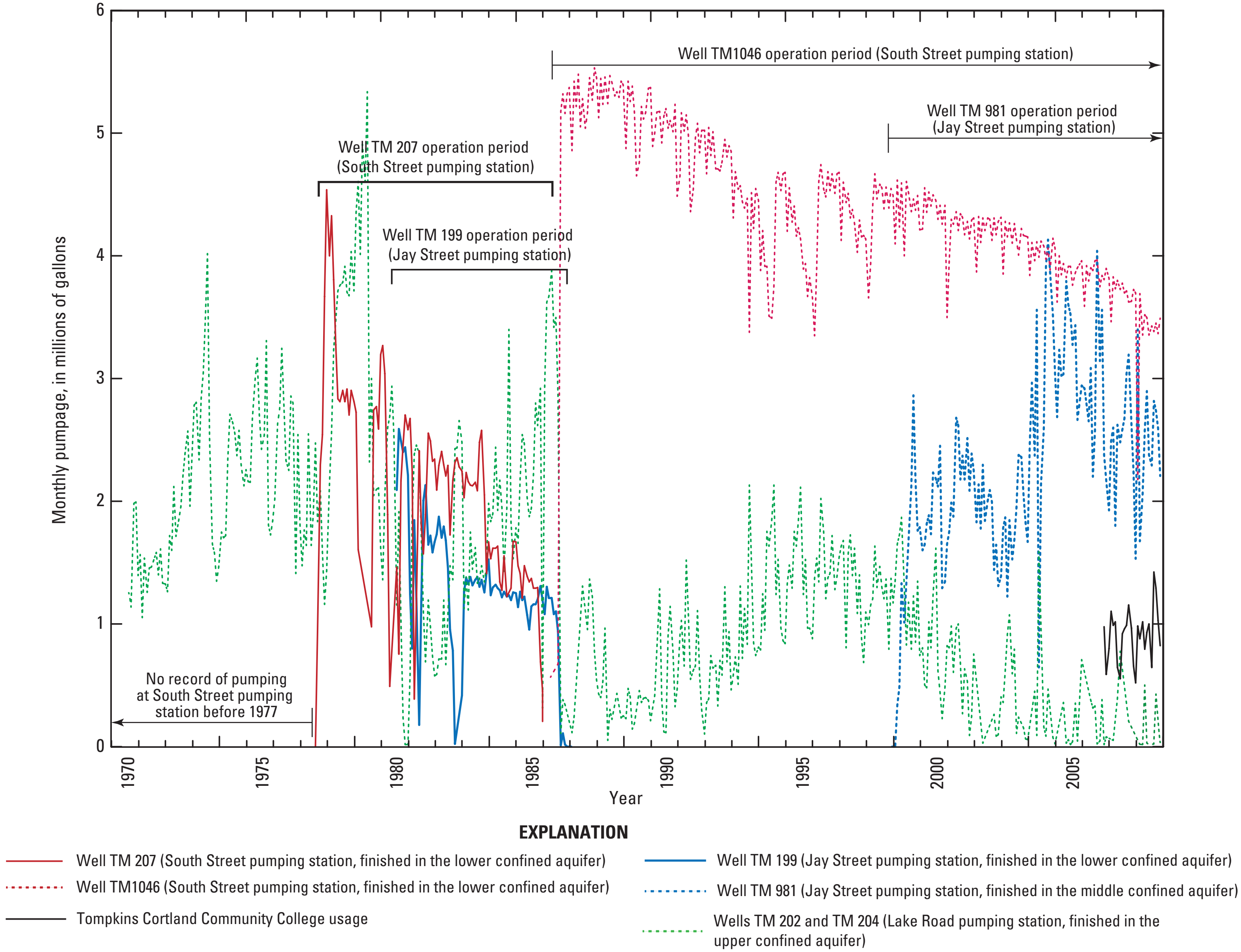


Figure 21. Monthly withdrawals from Village of Dryden, New York, municipal production wells, September 1970 through December 2008, and water usage by Tompkins Cortland Community College, 2006 through 2008. Pumping data obtained from the Village of Dryden in 2008.

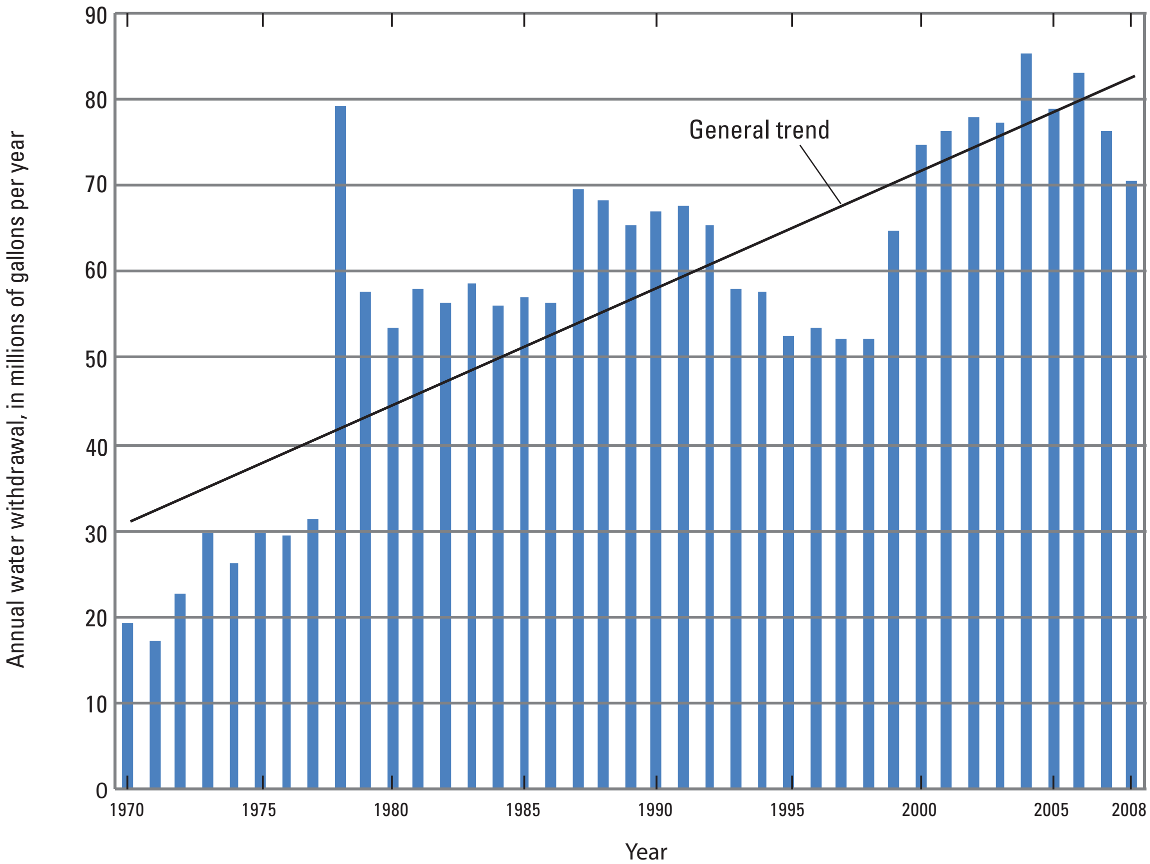


Figure 22. Annual withdrawals from the Village of Dryden, New York, municipal production wells from 1970 through 2008. Pumping data obtained from the Village of Dryden in 2008.

production wells. Water use has been greatest during the mid-2000s, when it exceeded 80 Mgal/yr in 2004 and 2006. Water use decreased slightly in 2007 and 2008 as a result of repair of leaks in the water infrastructure and implementation of water-saving fixtures, especially at the college.

Other Withdrawals

Other groundwater withdrawals from the aquifer system that are outside the Village of Dryden supply system include domestic wells, community supply wells for a mobile home community and several apartment complexes, and wells that supply water to several small farms (table 1).

About 670 people outside the water distribution system of the Village of Dryden depend on water from the Virgil Creek and Dryden Lake stratified-drift aquifer system (table 1). The estimated total groundwater use for human consumption outside the water distribution system of the Village of Dryden is about 50,300 gallons per day (gal/d) or 18.4 Mgal/yr based on an estimated average water use of 75 gal/d per person for self-supplied water systems in New York (Hutson and others, 2000) multiplied by the estimated 670 people that pump from the stratified-drift aquifers. Additional but unknown quantities of water are also withdrawn from wells in the stratified-drift aquifers from several small farms and small commercial facilities. The total withdrawal from the aquifer system in 2008 was about 89.0 Mgal/yr (70.6 Mgal/yr from the Village of Dryden production wells plus 18.4 Mgal/yr from withdrawals outside the village's distribution system).

Groundwater Levels

Natural changes in aquifer storage, which are exhibited by fluctuations in groundwater levels, generally follow seasonal patterns. These changes include short periods of increased storage during late fall and late winter through early spring, when recharge to the aquifer exceeds discharge from the aquifer, and long periods of decreased storage from late spring through early fall, when discharge generally exceeds recharge.

For unconfined aquifers, gravity drainage and filling or emptying of void spaces is the dominant mechanism for storage change, and generally the storage coefficient (specific yield) ranges from about 0.02 where the aquifer includes

Table 1. Estimated groundwater withdrawals from users outside the Village of Dryden municipal supply system and within the Virgil Creek and Dryden Lake valley-fill aquifer system study area, 2008.

Users	Number of homes or appartment units	Average persons per household[1]	Number of persons using water	Average use per person, in gallons per day[2]	Total use, in gallons per day
Private homes over the aquifer	218	2.32	506	75	37,932
Pleasant Valley Mobil Home Park	49	2.32	114	75	8,526
Keith Lane Appartments	8	2.32	19	75	1,392
Lake Road Apartments	8	2.32	19	75	1,392
Colongeli Apartments	6	2.32	14	75	1,044
Total	289		670		50,286

[1]Source: http://www.publicrecordfinder.com/county-public-records/Tompkins-NY.html, accessed July 27, 2010.

[2]Estimated from Hutson and others (2000).

fine-grained sediments to 0.35 where the aquifer includes very coarse-grained sediments (Freeze and Cherry, 1979). Storage changes for confined aquifers are dominated by water and sediment compression and expansion, and storage coefficient values are much lower than those for unconfined aquifers—storage coefficients reported for confined stratified-drift aquifers in the glaciated Northeast range from 0.01 to 0.0001 (Crain, 1974; Randall, 2001; Kontis and others, 2004).

Water-level data loggers were installed in four observation wells (TM1699 and TM1700 at the Lake Road pumping station, fig. 23; TM 207 at the South Street pumping station, fig. 24*A*; and test well TM 993 at Dryden Lake, fig. 24*B*). The water levels were recorded in these wells for 1.5 to 3 years.

At the Lake Road pumping station, the municipal production wells (TM 202 and TM 204; fig. 8) pump irregularly and for short periods of time (several hours a day approximately once a month), and drawdown is represented in the hydrograph as downward-pointing spikes on figure 23. When pumping is conducted at the Lake Road pumping station, well TM 204 is typically used. Observation wells TM1699 and TM1700 are roughly midway between the municipal production wells TM 202 and TM 204 (120 ft from the pumping wells; fig. 8). Because the production wells are rarely used, the water-level record represents mostly static water levels (nonpumping conditions).

During nonpumping conditions at the Lake Road pump station, the water levels in wells TM1699 and TM1700 fluctuated approximately 6 ft per year for the period of record (fig. 23). During pumping conditions, the water levels declined an additional 3 to 8 ft below the static water level in well TM1700 and an additional 2.5 to 6.5 ft below the static level in well TM1699. The water levels in observation wells TM1699 (depth 71 ft and finished in the middle confined aquifer) and TM1700 (depth 41 ft and finished in the upper confined aquifer) at the Lake Road pumping station paralleled each other, especially during nonpumping conditions when the water level in well TM1699 was typically 0.3 ft higher than in well TM1700, indicating that there may be hydraulic connection between these aquifers in this area with an upward hydraulic gradient. Well TM1699 penetrated a thin confining unit (an 11-ft-thick till and silt unit; fig. 9) that separates the upper confined aquifer from the middle confined aquifer. During pumping conditions, the water level in well TM1700 is typically 1 to 1.5 ft lower than that in well TM1699 (fig. 23), indicating that pumping has more effect on the upper confined aquifer than on the middle confined aquifer, which is expected because the municipal production wells and observation well TM1700 are finished in the upper confined aquifer. These minimal hydraulic head differences between the upper and middle aquifers may be due to (1) hydraulic connections established between the upper and middle confined aquifers as a result of poor or improper well construction in one or more of the six wells in the well field (for example, grout had not been used or was used improperly resulting in the two units having been connected through an outer skin of permeable drill cuttings adjacent to the casings), (2) the unit between the upper and middle aquifers being a leaky confining unit (consisting of semipermeable sediments such as fine to medium sand), or (3) the confining unit in this area having variable thickness and possibly being locally absent, which would result in windows where the two aquifer units are connected.

At the South Street pumping station, municipal production well TM1046 (finished in the lower confined aquifer; fig. 8) is pumped continuously except when mechanical problems caused the pump to turn off from 1 to 4 hours periodically (as often as several times a month). When the pump is turned off, water levels rise sharply 20 to 25 ft in observation well TM 207 (15 ft west of well TM1046), and these rises are seen as sharp upward spikes on the hydrograph in figure 24*A*. Except for these short-term water-level spikes due to mechanical problems, the water level at TM 207 represents water levels in the lower confined aquifer under

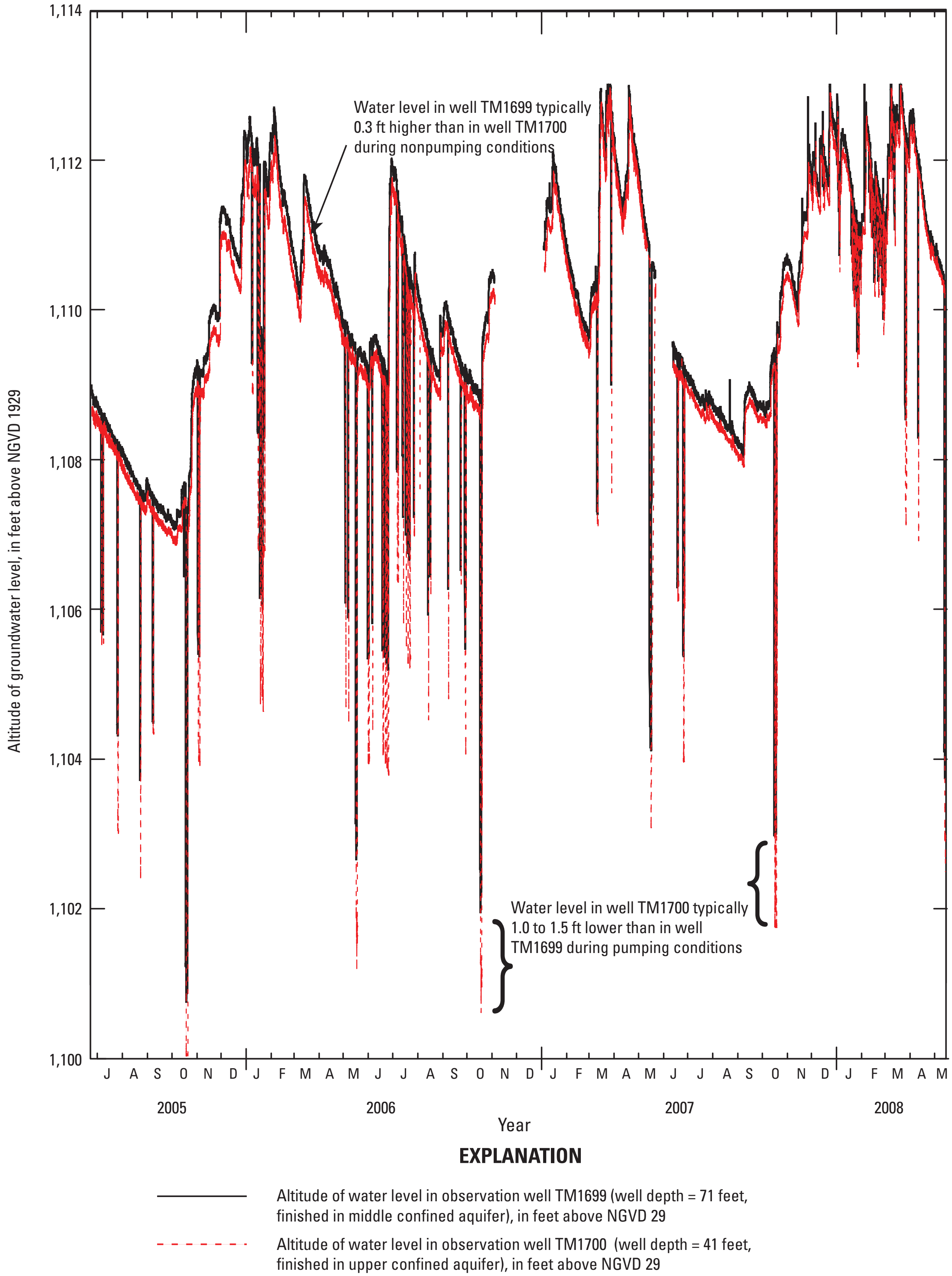


Figure 23. Hydrograph of the altitude of the groundwater levels from June 24, 2005, through May 14, 2008, in observation wells TM1699 and TM1700 at the Lake Road pumping station, Village of Dryden, New York. Locations of wells shown on figure 8.

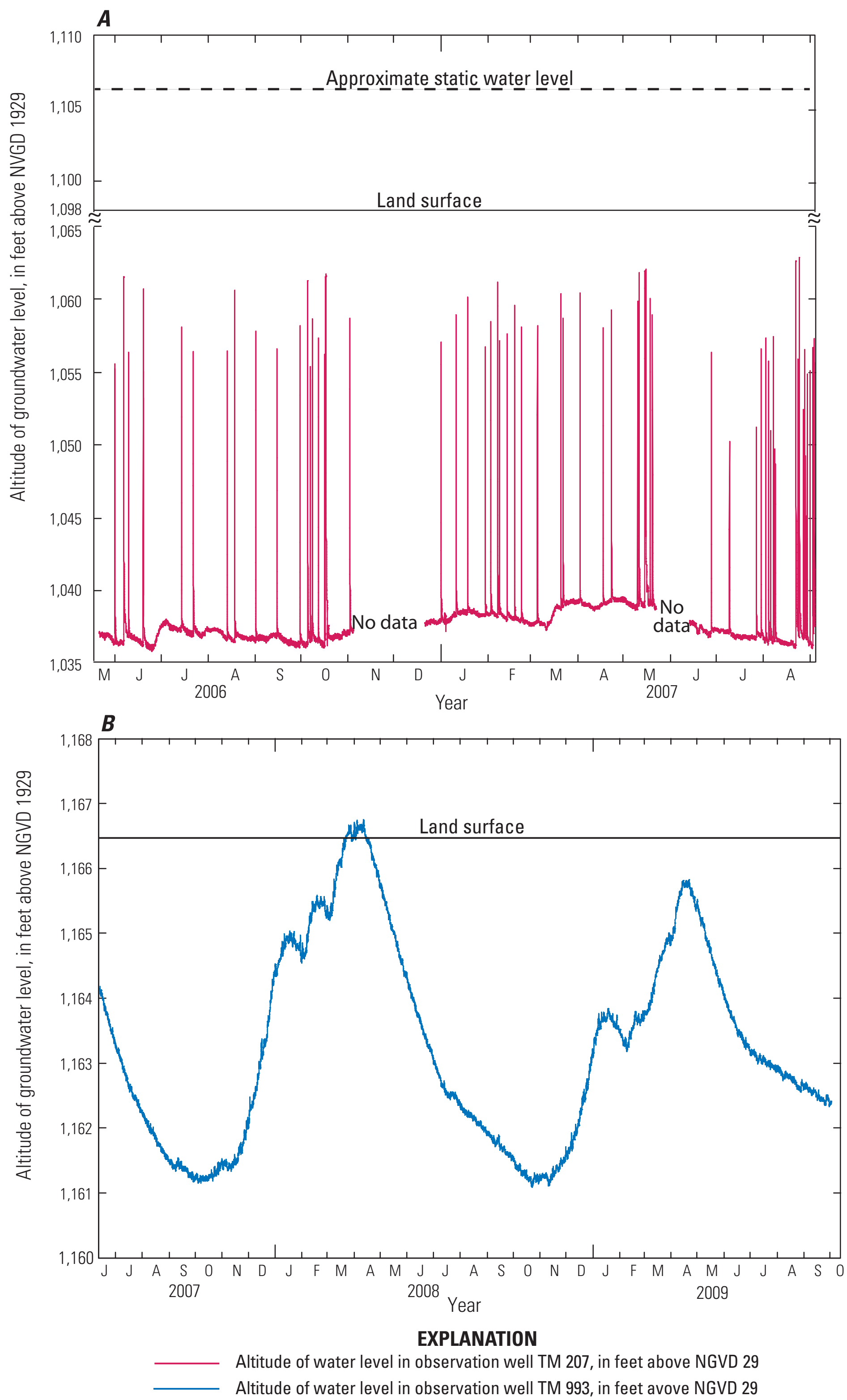


Figure 24. Altitude of the water level from observation wells *A*, TM 207 and *B*, TM 993. Observation well TM 207 at the South Street pumping station, Village of Dryden, New York, has a well depth of 176 feet, is finished in the lower confined aquifer, and was surveyed between May 19, 2006, and September 3, 2007. Observation well TM 993 at Dryden Lake, Town of Dryden, New York, has a well depth of 234 feet, is finished in the lower confined aquifer, and was surveyed between June 13, 2007, and October 2, 2009. Locations of wells shown on figure 8.

pumping conditions. A static water level of 8.5 ft above land surface (artesian flowing condition) was measured during nonpumping conditions in production well TM1046 when the well was drilled in 1986. For the period of water-level record (May 19, 2006, through September 3, 2007), the water-level fluctuation during pumping in observation well TM 207 was 3 ft. Assuming that the static water level has remained about constant since it was measured in 1986, the pumping of municipal production well TM1046 results in drawing down the water level in observation well TM 207 approximately 68 to 71 ft (to altitudes ranging from 1,036 to 1,039 ft).

Observation well TM 993 (fig. 8) is 1.6 mi southeast from the Village of Dryden and is finished in the lower confined aquifer. For the period of water-level record from June 13, 2007, through October 2, 2009, the water-level fluctuation in observation well TM 993 near Dryden Lake was 5.5 ft (fig. 24B), and the water-level data indicate that there were no pumping effects from the municipal pumping wells at Dryden. For the period of record, the hydraulic head in the well was always above the top of the aquifer (171 to 176 ft above the top of the aquifer; figs. 15 and 24B), and the water level was above land surface for 2 months in 2008, indicating that the aquifer was under artesian-flowing conditions during that period (fig. 24B). The recharge period (when groundwater storage in the aquifer is increasing) is shown by rising groundwater levels, which occur mostly during late fall and late winter through early spring when plants are dormant and evapotranspiration is minimal. Little or no recharge occurs during the growing season from late spring through early fall, when the rate of evapotranspiration typically exceeds the rate of precipitation.

Aquifer Properties

Well response to pumping (yield and drawdown) is a function of well construction (pump capacity, casing diameter, screen length and opening size, and well development) and aquifer properties, such as hydraulic conductivity (permeability), storage coefficient, and aquifer thickness. Transmissivity is hydraulic conductivity multiplied by aquifer thickness; and storativity is storage coefficient multiplied by aquifer thickness. Analysis of aquifer-test data allows the calculation of transmissivity and storativity, which are important to characterize the aquifer system and to develop groundwater-flow models.

Aquifer Test at Well TM 981 at the Jay Street Pumping Station

An aquifer test was conducted at Village of Dryden municipal production well TM 981 (well depth 72 ft) at the Jay Street pumping station (figs. 8 and 25) during June 19–21, 2007. Production well TM 981 was drilled in 1998 and is the village's second largest source of groundwater (well TM1046 at the South Street pumping station is the largest source of groundwater). Well TM 981 is finished in the middle confined aquifer, has an 8-inch diameter casing, and is screened from 62 to 72 ft. Screen opening size is 40 slot (0.04 inch). The pumping rate was 104 gal/min for a 24-hour period (the maximum time the Village of Dryden could go without water in their delivery system from this well). Water that was pumped was routed to a holding tank. Water levels were recorded in municipal well TM 981 and in observation wells TM1700 and TM1699 at the Lake Road pumping station (1,150 ft northeast of the pumping well) and TM 207 at the South Street pumping station (1,330 ft northwest of the pumped well, fig. 25). Wells TM1700 and TM1699 are finished in the upper and middle confined aquifers, respectively. Well TM 207 is finished in the lower confined aquifer. Water-level recovery was measured for 24 hours when pumping ceased at municipal well TM 981.

The aquifer test was conducted to (1) determine whether there is hydraulic connection between the upper, middle, and lower confined aquifers and (2) determine the hydraulic properties of the middle confined aquifer at the Jay Street pumping station. The results of the aquifer test were used to input hydraulic conductivity values for the middle aquifer in the numerical groundwater-flow model.

During the 24-hour aquifer test, the pumping rate ranged from 105 gal/min during the early part of the test to 103 gal/min during the latter part of the test and averaged 104 gal/min. The drawdown (difference between static water level and pumping water level) in pumped well TM 981 at the end of 24 hours of pumping was 19.24 ft. Pumping from well TM 981 had no measurable effect on water levels in wells TM 207, TM1699, and TM1700; therefore, only the pumped-well drawdown data were used for quantitative analysis of the aquifer hydraulic properties. It should be noted that although the village's production well TM 204 (125 ft north of wells TM1700 and TM1699; fig. 25) was inadvertently pumped for several hours just before the test (it was turned off when discovered), the water levels in wells TM1700 and TM1699 recovered to with 0.2 ft of static level by the time the aquifer test began. Also, there were no effects on water levels in observation wells TM1700 and TM1699 during the recovery phase of the aquifer test, indicating that pumping from well TM 981 had no measurable effect on water levels in wells TM1700 and TM1699. Because the pumping of production well TM 981 during the aquifer test had no effect on wells TM1700 and TM1699, the pumping of production well TM 204 until several hours just before the test probably did not affect the analysis of the drawdown data of TM 981.

Because of uncertainty on whether the deposits between the upper and middle confined aquifers is a nonleaky confining unit (comprising sediments of low hydraulic conductivity) or is a leaky confining unit (comprising sediments of low to moderate hydraulic conductivity), the hydraulic values were estimated using two methods of analysis (table 2). Results of the aquifer test analysis for a partially penetrating well in a confined aquifer using methods by Dougherty and Babu (1984) indicated that the transmissivity was 1,560 feet squared

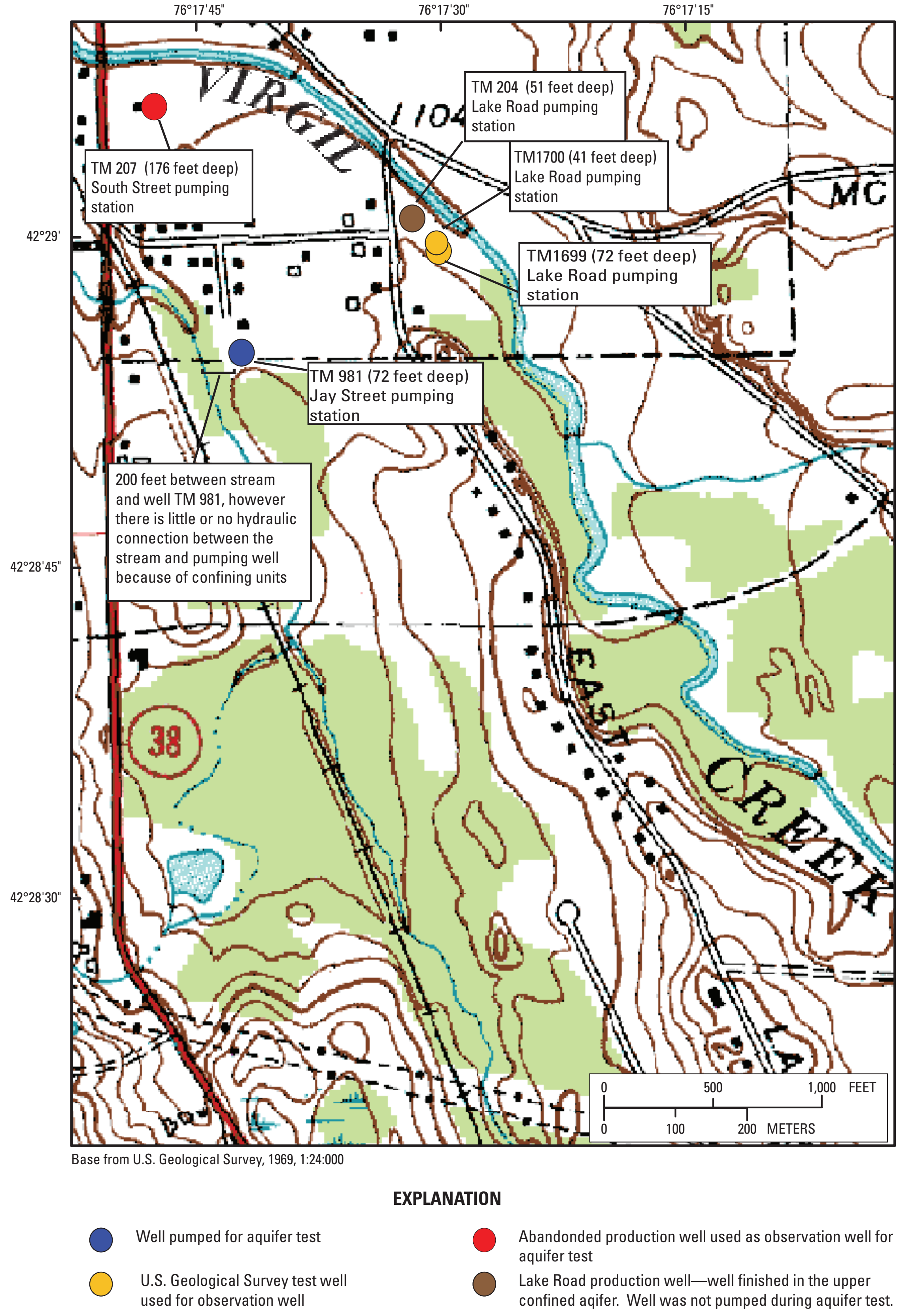


Figure 25. Location of wells in which drawdown was measured for the aquifer test conducted in production well TM 981 in the Village of Dryden, New York, during June 19–21, 2007.

Table 2. Estimated hydraulic values from analyses of aquifer-test data of partially penetrating muncipal well TM 981 at the Jay Street pumping station, Village of Dryden.

[ft, feet; ft/d, feet per day; ft^2/d, feet squared per day]

Method	Casing radius, in ft	Saturated thickness (aquifer thickness), in ft	Transmissivity, in ft^2/d	Horizontal hydraulic conductivity, in ft/d	Storativity[1]
Well TM 981 (Jay Street)					
Method by Dougherty and Babu (1984) for confined aquifer	0.33	18	1,560	87	0.1
Method by Hantush and Jacob (1955) and Hantush (1964) for leaky confined aquifer	0.33	18	1,730	96	0.1

[1]Dimensionless.

per day (ft^2/d) and the horizontal hydraulic conductivity was 87 feet per day (ft/d) based on a saturated thickness of 18 ft (table 2). Results of the aquifer test analysis for a partially penetrating well in a leaky confined aquifer using methods by Hantush and Jacob (1955) and Hantush (1964) indicated that the transmissivity was 1,730 ft^2/d and the horizontal hydraulic conductivity was 96 ft/d based on a saturated thickness of 18 ft (table 2).

Specific Capacity Test in Test Well TM 993 Near Dryden Lake

At the time when well TM 993 (located 450 ft north of Dryden Lake; fig. 8) was drilled, it was noted during development of the well (at a pumping rate of 45 gal/min) that the drawdown was only 0.8 ft, suggesting that a large amount of water could be derived from the aquifer at this site. To investigate the potential water yield at this site, a brief aquifer test (pumping period of 2 hours) was conducted in the test well on January 5, 2005. Well TM 993 is 234 ft deep, 6 inches in diameter, open ended, and finished in coarse gravel that makes up the lower confined aquifer at this site. Specific capacities (a measure of well yield per unit of drawdown that can be used to provide an estimate of the maximum yield for a well and well efficiency) were computed for several pumping rates from the brief aquifer test. At pumping rates of 100, 200, 300, and 400 gal/min, the specific capacities were 28, 27, 24, and 20 gallons per minute per foot of drawdown, respectively (fig. 26). Drawdown was measured in the pumping well (TM 993) during the 2-hour-long pumping interval, and water-level recovery was measured for 4.5 hours afterwards. Drawdown at the end of 2 hours of pumping was 20 ft. There were no wells nearby that were finished in the lower confined aquifer; therefore, drawdown data were only obtainable from the pumping well. The results of the specific-capacity test indicate that, at this site, the confined aquifer could yield large amounts of water (more than 1,000 gal/min) to a properly screened, large-diameter pumping well. Specific capacity decreases with increasing drawdown because of frictional losses associated with the well itself. It is likely that a substantial part of the decreasing specific capacity computed for this test at pumping rates from 300 to 400 gal/min is due to increasing frictional loses as the physical capacity for flow through a 6-inch-diameter casing is approached.

To estimate the potential yield from this site, the transmissivity was first estimated from the specific capacity data using the modified Theis equation (Bradbury and Rothschild, 1985):

$$T = \frac{Q}{4\pi\left(s - s_w\right)}\left[\ln\left\{\frac{2.25Tt}{r_{w^2}S}\right\} + 2sp\right], \qquad (1)$$

where

T = transmissivity;
Q = well discharge, the volume of water discharged over a given time;
s = drawdown in the well;
s_w = well loss;
t = pumping time;
r_w = well radius;
S = storage coefficient (dimensionless); and
sp = partial penetration.

The solution of equation 1 yields an estimate of T that is corrected for well loss and partial penetration. The T computed for the specific capacity test was 142,000 ft^2/d
where

Q = 400 gal/min,
s = 20 ft,
s_w = 1,
t = 2 hours,
r_w = 0.25 ft, and
S = 0.0002.

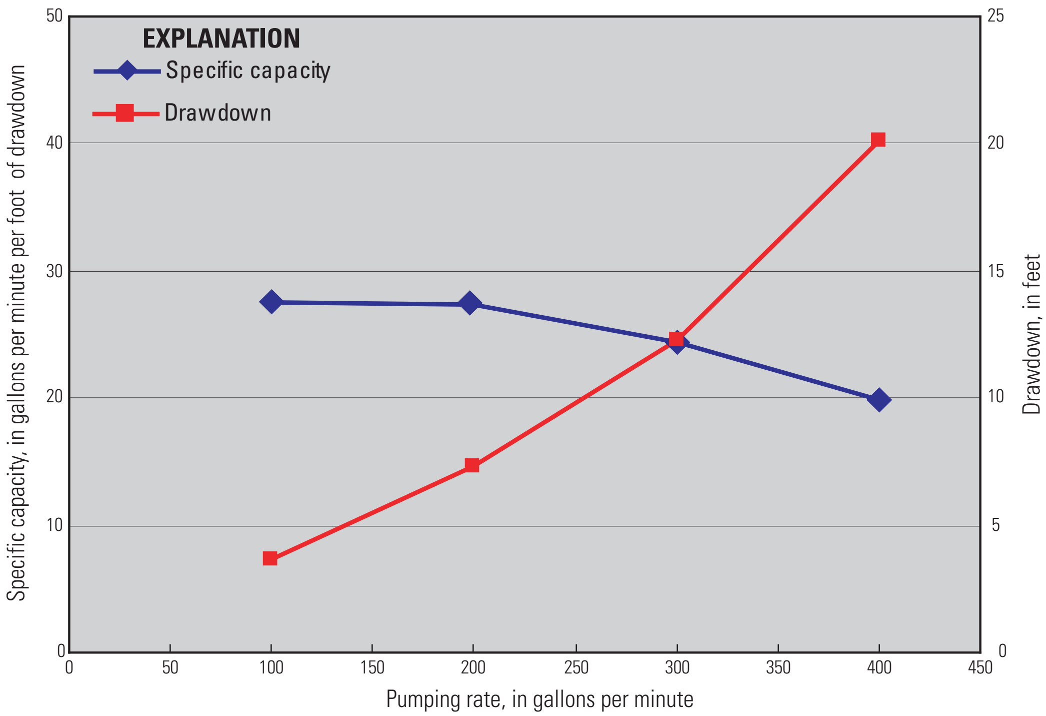


Figure 26. Results of specific capacity test in test well TM 993, 450 feet north of Dryden Lake, Town of Dryden, New York. Well log and well construction details are shown on figure 15; location of well is shown on figure 8.

Using equation 1 to solve for drawdown of a hypothetical large pumping well

where

T = 142,000 ft^2/d,
Q = 2,000 gal/min,
t = 2 hours,
r_w = 0.42 ft (10 in.),
S = 0.0002, and
s = 100 ft.

A drawdown of 100 ft is less than 50 percent of the available head (total available head is about 235 ft). Although well yield can be defined as the maximum pumping rate without lowering the water level in the well below the pump intake (Freeze and Cherry, 1979), there is no set definition of safe yield. However, the British Columbia Ministry of the Environment (2011) suggests that about 70 percent of available drawdown is considered safe available drawdown, which generally leaves sufficient room in the well for a submersible pump and for when groundwater levels are lower than average during drought periods. Computation of the potential yield using a linear equation may provide unreliable results because this computed yield does not actually represent the behavior of the well during pumping. Using equation 1 for extrapolating the pumping rate beyond what is actually observed has risks of overestimating the yield and overdesigning the well. The best method to design a well would include conducting both constant and step tests using a large-diameter screened well (10 to 24 inches in diameter). Ideally, the step test would need to be conducted at a discharge rate up to the maximum possible. A long aquifer test (more than 72 hours) would be needed to accurately determine a sustainable yield.

In addition to the specific-capacity test conducted for this study, several well-performance tests (drawdown tests) had been conducted by hydrologic engineers and drillers in several wells in the Village of Dryden since 1946. Because there were insufficient data on well construction, data from these tests have not been used to compute hydraulic properties of the aquifers, such as transmissivity, hydraulic conductivity, and storativity. Nevertheless, the sources of these data are listed in table 3.

Water Quality

Water-quality samples were collected to characterize the chemical quality of surface water and groundwater in the study area. On various dates from 2003 through 2005, surface-water samples were collected from eight sites, including Virgil Creek, the Dryden Lake outlet, and several tributaries (fig. 27). On various dates from 2003 through 2009, groundwater samples were collected from eight wells (fig. 27). Field measurements were made for pH, specific conductance,

Table 3. Historic well tests from water-supply investigations for the Village of Dryden.

[Surveys conducted by various engineering consultants from 1946 through 2000. BLS, below land sufrace; ft, feet; ft^3/s, cubic feet per second; gal/d, gallons per day; gal/min, gallons per minute; PWS, production well; USGS, U.S. Geological Survey; —, no data; #, number]

Well identifier	USGS well site name	Year of well test	Well type	Hole depth, in ft BLS	Aquifer thickness, in ft	Screened interval, in ft BLS	Static water level, in ft BLS[1]	Aquifer model layer	Pumping rate during test		
									gal/d	gal/min	ft^3/s
South Street, site 1[2]	—	1946	Test	192	7	177–184	+12	3	50,400	35	0.08
South Street supply well[2]	TM 207	1949	PWS	181	23	169–176	+25	3	—	—	—
PWS well # 1 (Lake Road)[3]	TM 202	1964	PWS	45	15	30–45	—	1	—	—	—
Test well (Jay Street)[4]	TM 199	1977	Test	217	—	193–212	—	3	36,000	25	0.06
Kimberly drive test welld	TM1015	1978	Test	97	—	Open end	Flows[6]	2	317,000	220	0.49
Test well (South Street)[3]	—	1986	Test	—	—	173–185	—	3	—	—	—
Test well (Jay Street)[5]	—	—	Test	225	—	—	—	3	—	—	—
Test well (South Street)[4]	—	1998	—	—	—	68–74	—	3	129,000	90	0.20
Lake Street well #2[4]	TM 202	—	PWS	51	—	—	—	1	200,000	140	0.31
Jay Street (initial)[4]	—	—	Test	—	—	170–200	—	3	93,600	65	0.12
Jay Street (final)[4]	—	—	—	—	—	—	—	—	28,800	20	0.04
Jay Street suppy well[4]	TM 981	—	PWS	75	—	62–72	—	2	147,000	102	0.23

[1]Positive values are above land surface.

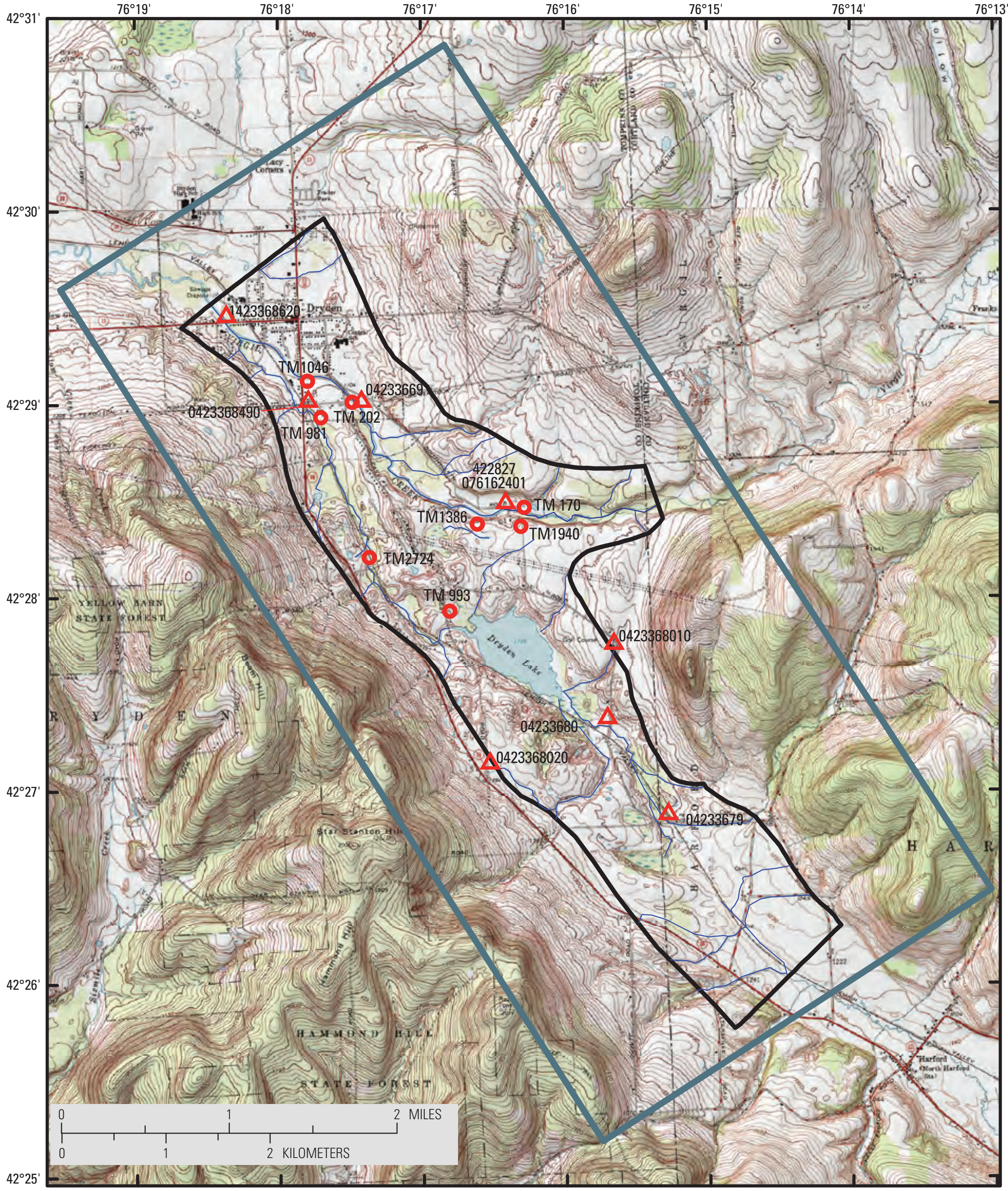
[2]Survey conducted by Lozier engineers.

[3]Survey conducted by Vrooman engineers.

[4]Survey conducted by Foster, Brayton.

[5]Survey conducted by Parrott-Wolf .

[6]Flowing artesian well.



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EXPLANATION

- **Model grid boundary**
- **Boundary of stratified-drift aquifer study area**
- **Stream**
- 0423368020 **Base-flow sampling site and site identification number in which water-quality sample was collected**—Analyses are in table 4
- TM 993 **Well and well site name in which groundwater sample was collected**—Analyses are in tables 6 and 7

Figure 27. Location of groundwater and surface-water sampling sites in Virgil Creek and Dryden Lake Valleys, Town of Dryden, New York.

and water temperature for surface-water samples and groundwater samples. The concentrations of 23 constituents, including inorganic major ions, nutrients, and radiochemicals were measured in surface water; 42 constituents, including nutrients, inorganic major ions, and trace elements were measured in groundwater samples. All samples were analyzed by the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado. Analytical results for selected constituents are compared with Federal drinking-water standards. The standards include maximum contaminant levels (MCLs), secondary maximum contaminant levels (SMCLs), and health advisories (HAs) established by the U.S. Environmental Protection Agency (USEPA; 2006).

Surface Water

A total of 14 surface-water samples were collected by USGS personnel during the study period—7 at roughly seasonal intervals during base-flow conditions at the Virgil Creek streamgage in Dryden (station 0423368620; fig. 27) during 2003–4. Additionally, two samples were collected in 2004 from two tributaries to Virgil Creek in the study area, and four samples were collected in conjunction with Dryden Lake (one each from the inlet and outlet and one each from two tributaries to the lake). Winter samples collected during base flow and non-snowmelt conditions can be an approximation of the chemical quality of groundwater because microbial activity, which can alter the concentrations of some constituents through contact with air and stream biota, is at a minimum. For example, microbial activity (associated with algal growth in the streams during warm seasons) can change dissolved oxygen concentrations or use the nitrogen in the water, potentially causing a decrease in nitrate concentrations. Results of chemical analyses are presented in table 4, and summary statistics for pH and several selected chemical constituents are provided in table 5.

Physicochemical Properties

The pH of surface-water samples ranged from 8.1 to 7.4, with a median value of 7.6 (tables 4 and 5); pH values for all 14 samples were within the accepted USEPA SMCL range of 6.5 to 8.5 (U.S. Environmental Protection Agency, 2006). Specific conductance of the samples ranged from 131 to 402 microsiemens per centimeter (µS/cm) at 25 degrees Celsius (°C), with a median value of 306 µS/cm.

Common Inorganic Constituents

The cation detected in the greatest concentration was calcium, which ranged from 7.46 to 55.1 milligrams per liter (mg/L), with a median value of 40.8 mg/L (tables 4 and 5). Magnesium concentrations ranged from 1.59 to 11.1 mg/L, with a median of 7.99 mg/L. Calcium and magnesium contribute to water hardness, which ranged from 25.2 to 184 mg/L as calcium carbonate ($CaCO_3$), with a median of 134 mg/L. Sodium concentrations ranged from 3.41 to 29.3 mg/L, with a median value of 12.0 mg/L. Potassium concentrations ranged from 0.45 to 1.50 mg/L, with a median value of 1.18 mg/L.

The anion detected in the greatest concentration was bicarbonate, the concentration of which ranged from 17 to 151 mg/L, with a median value of 120 mg/L (tables 4 and 5). Chloride concentrations ranged from 4.54 to 50.3 mg/L, with a median value of 21.2 mg/L. Sulfate concentrations ranged from 7.12 to 17.8 mg/L, with a median value of 12.6 mg/L. Silica concentrations ranged from 1.75 to 6.59 mg/L, with a median value of 4.54 mg/L. Fluoride concentrations were detected in either trace amounts or were below the detection limit (0.17 mg/L). None of the inorganic major constituents collected from surface-water sites in the study area exceeded any Federal or State water-quality standards.

Nutrients

Nitrate was the predominant nitrogen species present in all nutrient samples of surface water, ranging from 0.12 to 5.17 mg/L as nitrogen (table 4). High concentrations of nitrogen can cause excessive plant and algal growth in streams, depleting oxygen and stressing organisms in their aquatic habitat, and it also is a human health concern when the concentration is more than 10 mg/L (U.S. Environmental Protection Agency, 2006). The concentration of nitrate was greater than 2 mg/L in two samples—the tributary to Dryden Lake at West Lake Road (USGS station 0423368020) and in the tributary to Dryden Lake at East Lake Road near Harford (USGS station 04233679)—and may reflect fertilizer use on nearby agricultural areas. Orthophosphate concentrations were not detected above the reporting limit (0.02 mg/L as phosphorus) in any surface-water samples. None of the surface-water samples exceeded Federal or State drinking-water standards for nitrate or nitrite.

Groundwater

Groundwater samples were collected from eight wells—two finished in the upper confined aquifer, two in the middle confined aquifer, and four in the lower confined aquifer (locations shown in fig. 27), including three Village of Dryden municipal wells (TM 202, TM 981, and TM1046), two test wells (TM 993 and TM2724), two domestic wells (TM1386 and TM1940), and one nonmunicipal community well (mobile home park well TM 170). Field measurements were made of pH, specific conductance, and water temperature. Samples were analyzed for inorganic major ions, nutrients, and trace metals by the USGS NWQL in Denver, Colorado. Results of chemical analyses are tabulated in tables 6 and 7, and summary statistics of selected chemical constituents are in tables 5 and 8.

Table 4. Physical properties and concentrations of inorganic major ions, trace metals, and nutrients in surface-water samples from Virgil Creek, inlet and outlet to Dryden Lake, and several tributaries, Town of Dryden, New York, 2003–05

[Sampling site locations are shown in figure 27. conf, confined; e, estimated; ft, feet; ft³/s, cubic feet per second; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; Parm code, USGS National Water Information System (NWIS) parameter code; S&G, sand and gravel; SH, State Highway; trib., tributary; USGS, U.S. Geological Survey; XX, not available; <, less than; —, not analyzed; $CaCO_3$, calcium carbonate; °C, degrees Celsius]

		USGS site name:	Virgil Creek at SH 13 at Dryden						
		Date sampled:	2/11/2003	5/20/2003	8/18/2003	1/13/2004	5/27/2004	6/28/2004	9/14/2004
		USGS station identification number:	0423368620						
Physicochemical properties	Parm code	Units	Values of physical properties						
pH (lab)	00403	pH	7.9	7.5	7.5	7.6	7.8	8.1	8.0
Specific conductance (lab)	90095	µS/cm	394	330	339	292	238	365	300
Dissolved oxygen (field)	00300	mg/L	13.2	12.9	10.8	—	—	—	—
Common inorganic constiuents									
Hardness, filtered, as $CaCO_3$	00900	mg/L	135	139	150	128	105	164	133
Calcium, filtered	00915	mg/L	40.7	41.4	44.7	38.6	31.9	48.9	40.8
Magnesium, filtered	00925	mg/L	8.15	8.71	9.27	7.78	6.26	10.1	7.49
Potassium, filtered	00935	mg/L	1.43	1.31	1.50	1.14	1.26	1.06	1.28
Sodium, filtered	00930	mg/L	29.3	17.8	13.6	11.4	10.0	15.4	12.3
Alkalinity, filtered as $CaCO_3$	39086	mg/L	92	94	98	94	75	125	107
Bicarbonate, filtered, as $CaCO_3$	00453	mg/L	112	115	128	115	90	151	130
Chlorides, filtered	00940	mg/L	50.3	30.1	24.1	20.5	14.0	26.1	19.4
Fluoride, filtered	00950	mg/L	0.03	<0.17	<0.17	<0.17	<0.17	<0.17	<0.17
Silica, filtered	00955	mg/L	4.73	1.75	3.78	4.65	4.08	3.06	5.40
Sulfate, filtered	00945	mg/L	17.8	14.2	12.5	12.6	9.14	14.2	9.80
Dissolved solids, dried at 180°C	70300	mg/L	226	188	198	172	143	208	182
Trace metals									
Iron, filtered	01046	µg/L	30.7	60.1	52.9	23.5	108	37.8	29.3
Manganese, filtered	01056	µg/L	34.2	12.0	9.39	11.9	21.4	11.3	8.17
Nutrients									
Ammonia, as N, filtered	00608	mg/L	0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Nitrate+nitrite, as N, filtered	00631	mg/L	1.37	0.77	0.74	1.48	0.59	1.01	0.78
Nitrite, as N, filtered	00613	mg/L	e0.004	0.008	<0.008	e0.004	0.014	<0.008	<0.008
Ammonia+organic-N, filtered	00623	mg/L	0.15	0.22	0.25	0.12	0.26	0.18	0.20
Ammonia+organic-N, unfiltered	00625	mg/L	0.22	0.30	0.29	0.26	0.36	0.22	0.40
Orthophosphate, as P, filtered	00671	mg/L	<0.02	<0.02	<0.02	<0.02	e0.01	<0.02	<0.02
Phosphorus, filtered	00666	mg/L	0.007	0.009	0.008	0.006	0.020	0.007	0.005
Phosphorus, unfiltered	00665	mg/L	0.014	0.021	0.008	0.019	0.042	0.017	0.027
Stream discharge									
Discharge, instantaneous	00061	ft³/s	35	26	19	50	150	16	43

[a]U.S. Environmental Protection Agency (USEPA) drinking water advisory taste threshold.

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

[c]USEPA secondary maximum contaminant level.

Table 4. Physical properties and concentrations of inorganic major ions, trace metals, and nutrients in surface-water samples from Virgil Creek, inlet and outlet to Dryden Lake, and several tributaries, Town of Dryden, New York, 2003–05.—Continued

Virgil Creek 2,200 ft upstream of SH 38 near Dryden	Virgil Creek at Southworth Road bridge	Dryden Lake outlet upstream of SH 38 at Dryden	Dryden Lake inlet near Dryden	Dryden Lake trib. at West Lake Road near Dryden	Dryden Lake trib. at East Lake Road near Dryden	Dryden Lake trib. at East Lake Road near Harford	Drinking water standard
1/13/2004	8/17/2005	1/13/2004	1/13/2004	1/13/2004	1/13/2004	1/13/2004	
04233669	422827 076162401	0423368490	04233680	0423368020	0423368010	04233679	
Values of physical properties							
7.9	8.1	7.4	7.6	7.4	7.4	7.4	6.5–8.5[c]
313	402	241	216	176	131	361	XX
—	—	—	—	—	—	—	XX
Common inorganic constiuents							
139	184	104	94.2	25.2	58.7	163	XX
42.1	55.1	30.6	27.2	7.46	16.9	47.6	XX
8.23	11.1	6.76	6.23	1.59	4.00	10.8	XX
1.21	1.47	0.91	0.79	0.45	1.03	0.91	XX
11.8	15.5	8.64	7.22	22.3	3.41	11.4	60[a]
102	118	104	60	14	50	110	250[c]
124	144	127	73	17	61	134	XX
21.2	27.3	15.4	12.1	35.0	4.54	21.2	XX
<0.17	e0.05	<0.17	<0.17	<0.17	<0.17	<0.17	2.2[b]
4.95	4.44	4.08	5.63	4.51	4.56	6.59	XX
12.3	13.1	12.7	10.8	7.12	8.01	12.7	250[c]
182	229	140	134	92	84	213	XX
Trace metals							
8.9	e4	44.5	47.2	23.5	68.9	15.7	300[b,c]
8.45	2.7	27.7	36.6	5.84	25.2	8.06	50[c]–300[b]
Nutrients							
<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	XX
1.77	1.19	1.16	2.17	0.22	0.12	5.17	10[a,b]
e0.004	<0.008	0.008	<0.008	<0.008	<0.008	e0.005	1[a,b]
0.12	0.17	0.23	0.10	0.15	0.20	0.20	XX
0.13	0.11	0.20	1.0	0.27	0.32	0.50	XX
<0.02	<0.02	<0.02	<0.02	e0.01	<0.02	<0.02	XX
0.007	0.004	0.006	0.006	0.024	0.016	0.009	XX
0.013	0.005	0.018	0.086	0.05	0.101	0.04	XX
Stream discharge							
26.3	—	14.3	5.64	0.25	0.33	2.5	XX

Table 5. Summary statistics for pH and concentrations of major chemical constituents in surface-water and groundwater samples collected in the Virgil Creek and Dryden Lake valleys, Town of Dryden, New York, 2003–09.

[All samples filtered. mg/L, milligrams per liter; °C, degrees Celsius; —, no drinking-water standard; $CaCO_3$, calcium carbonate; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Constituent	Drinking-water standard	Number of surface-water samples	Number of samples exeeding limit	Surface-water samples			Groundwater samples		
				Minimum	Median	Maximum	Minimum	Median	Maximum
pH (field)	6.5–8.5[a]	14	0	7.4	7.6	8.1	7.0	7.8	8.2
Specific conductance, µS/cm	None	14	—	131	306	402	328	419	487
Hardness, mg/L as $CaCO_3$	None	14	—	25.2	134	184	145	200	257
Alkalinity, mg/L as $CaCO_3$	250[a]	14	0	14	96	125	113	125	161
Common ions									
Cations:									
Calcium, mg/L	None	14	—	7.46	40.8	55.1	39.6	57.8	75.2
Magnesium, mg/L	None	14	—	1.59	7.96	11.1	11.2	13.9	17.2
Potassium, mg/L	None	14	—	0.45	1.18	1.50	0.55	0.80	2.11
Sodium, mg/L	60[a]	14	0	3.41	12.0	29.3	4.80	8.70	12.2
Anions:									
Bicarbonate, mg/L as $CaCO_3$	None	14	—	17	120	151	138	152	196
Chlorides, mg/L	250[a,b]	14	0	4.54	21.2	50.3	5.71	17.0	31.7
Silica, mg/L	None	14	—	1.75	4.54	6.59	5.44	10.6	13.7
Sulfate, mg/L	250[a]	14	0	7.12	12.6	17.8	15.8	29.4	49.0

[a]U.S. Environmental Protection Agency (USEPA) secondary maximum contaminant level.

[b]USEPA drinking water advisory taste threshold.

Physicochemical Properties

The wells that were sampled ranged from 53 to 234 ft deep (table 6). The pH of the samples ranged from 7.0 to 8.2, with a median value of 7.8 (tables 5 and 6); no pH measurement was outside the USEPA SMCL range of 6.5 to 8.5. Specific conductance values of the samples ranged from 328 to 487 µS/cm, with a median value of 419 µS/cm.

Inorganic Major Ions

No samples exceeded any Federal or State drinking-water health advisory standards. The cation that was detected in the greatest concentration was calcium, ranging from 39.6 to 75.2 mg/L, with a median value of 57.8 mg/L (tables 5 and 6). Magnesium concentrations ranged from 11.2 to 17.2 mg/L, with a median value of 13.9 mg/L. Calcium and magnesium contribute to water hardness as $CaCO_3$, which ranged from 145 to 257 mg/L, with a median value of 200 mg/L. Five of the eight sampled wells yielded water with a hardness greater than 180 mg/L, which is classified as very hard, and the hardness of the remaining three samples ranged from 145 to 170 mg/L, which is classified as hard (Hem, 1985).

Sodium concentrations ranged from 4.8 to 12.2 mg/L, with a median value of 8.70 mg/L (tables 5 and 6), for the eight wells sampled. The median concentration of sodium in the four public-supply wells sampled was 8.7 mg/L, which is lower than the median concentration of sodium of 19 mg/L detected in public-supply wells that tap the glacial aquifer systems in the northern United States (Mullaney and others, 2009). The median concentration of sodium in the four domestic and test wells sampled was 8.64 mg/L, which is slightly higher than the median concentration of sodium of 12 mg/L detected in domestic wells that tap the glacial aquifer systems in the northern United States.

The anion detected in the greatest concentration was bicarbonate, the concentration of which ranged from 129 to 181 mg/L, with a median value of 152 mg/L (tables 5 and 6). Bicarbonate values were calculated from alkalinity concentrations, which are given in milligrams per liter of $CaCO_3$. Sulfate concentrations ranged from 15.8 to 49 mg/L, with a median value of 29.4 mg/L. Alkalinity, which results from dissolution of carbonate minerals such as those composing limestone and dolomite and is a measure of the capacity of water to neutralize acid, had concentrations that ranged from 113 to 161 mg/L, with a median of 125 mg/L. Alkalinity lower than 100 mg/L can be corrosive under low pH conditions, and alkalinity greater than 150 mg/L can cause scale (lime) buildup in plumbing pipes (Mechenich and Andrews, 2004). Chloride concentrations ranged from 5.71 to 31.7 mg/L, with median value of 17.0 mg/L (tables 5 and 6). The median concentration of chloride in the four public-supply wells sampled was 14.9 mg/L, which is lower than the median concentration of 26 mg/L that was detected in public-supply wells that tap the glacial aquifer systems in the northern United States (Mullaney and others, 2009). The median concentration of chloride in the four domestic and test wells sampled was 18.3 mg/L, which is slightly higher than the median concentration of 12 mg/L that was detected in domestic wells that tap the glacial aquifer systems in the northern United States (Mullaney and others, 2009). Neither chloride nor sulfate exceeded any Federal or State drinking-water standards in samples from any of the confined aquifer systems.

The major-ion compositions of water from sampled wells from this study and from three other valley-fill aquifer systems in Tompkins County (Lower Sixmile Creek and Willseyville Creek trough, Upper Sixmile Creek and West Branch Owego Creek Valleys, and Upper Buttermilk and Danby Creek Valleys) are presented for comparison using a piper (trilinear) diagram (fig. 28), which shows the relative contributions of major cations and anions, on a charge-equivalent basis, to the total ion content of the water. Percentage scales along the sides of the diagram indicate the relative concentration, in milliequivalents per liter, of each major ion. Cations are shown in the left triangle, and anions are shown in the right triangle. The central diamond integrates the data.

Calcium with some sodium and magnesium generally dominate the cation composition; bicarbonate and, in a few samples, chloride dominate the anion composition in samples from this study area and in most samples from the other three stratified-drift aquifers in Tompkins County where data are available (fig. 28). The exceptions are two samples that were collected in Upper Buttermilk Creek and Danby Creek Valleys and two samples that were collected in Upper Sixmile Creek and West Branch Owego Creek Valleys, which were sodium bicarbonate- to sodium-chloride type waters. The chemistry of water from two wells in Upper Sixmile Creek Valley that were of a sodium bicarbonate- to sodium chloride-type water was a result of enrichment from brackish water in bedrock that locally discharges to the valley fill (Miller, 2009). The water chemistry in the stratified-drift aquifers in all four study areas is similar because the geologic settings of all the areas are similar and comprise Valley Heads glacial drift and Devonian shales and siltstones.

Nutrients

Groundwater samples from each of the three confined aquifers were analyzed for several nitrogen and phosphorus species (table 6). Nitrate was present above the reporting limit of 0.06 mg/L in only one well (TM1940), which had a concentration of 1.78 mg/L. Nitrate concentrations were well below the USEPA MCL of 10 mg/L (U.S. Environmental Protection Agency, 2006). Nitrate concentrations are relatively low in the study area because the major aquifers are confined and not subject to direct recharge from the land surface where there are sources of nitrate from septic systems and fertilizers (agricultural land or golf courses). The impermeable upper confining unit impedes chemicals that are applied on the land surface from readily infiltrating into the upper confined aquifer.

Nitrite was detected in only one well at a concentration above the reporting limit of 0.008 mg/L (0.023 mg/L in well TM1386). All results of nitrite analyses were below the USEPA MCL of 1 mg/L (U.S. Environmental Protection Agency, 2006). Ammonia concentrations ranged from an estimated 0.02 to 0.12 mg/L as nitrogen. Orthophosphate was not detected above the reporting limit (0.02 mg/L) in any groundwater samples (table 6).

Trace Elements

Trace elements detected in every sample included aluminum, arsenic, barium, boron, iron, lithium, manganese, nickel, molybdenum, strontium, uranium, and zinc (table 7). The trace elements detected in the greatest concentrations were barium, boron, iron, lithium, manganese, and strontium. No samples exceeded Federal or State MCLs, but manganese was present in concentrations that exceeded the USEPA SMCL of 50 micrograms per liter (µg/L) in seven of eight wells sampled (table 7). All aluminum concentrations were less than 1.9 µg/L. Arsenic concentrations ranged from less than 0.2 to 9.2 µg/L, with a median of 1.2 µg/L (tables 7 and 8). An arsenic concentration of 9.2 µg/L was detected in Village of Dryden production well TM 981 at Jay Street, which is slightly less than the USEPA MCL for arsenic of 10 µg/L. Barium concentrations ranged from 30.3 to 216 µg/L, with a median of 146 µg/L. Boron concentrations ranged from 10 to 24 µg/L, with a median of 15 µg/L; an MCL has not been established for boron. Iron concentrations ranged from less than 0.6 to 227 µg/L, with a median of 73.8 µg/L. Lead was detected in five of eight samples, but none exceeded the USEPA MCL (15 µg/L). Lithium concentrations ranged from 1.85 to 8.92 µg/L, with a median of 6.96 µg/L; an MCL has not been established for lithium. Strontium concentrations ranged from 75.9 to 415 µg/L, with a median of 176 µg/L; an MCL has not been established for strontium. Uranium concentrations ranged from 0.357 to 0.797 µg/L, with a median of 0.548 µg/L; no samples exceeded the USEPA MCL of 30 µg/L.

Groundwater-Age Dating

Concentrations of chlorofluorocarbons (CFCs) and tritium (^3H) can be used to estimate the age of groundwater (table 9). CFCs are stable and long-lasting synthetic industrial compounds that have been released into the atmosphere since

Table 6. Physical properties and concentrations of inorganic major ions, nutrients, and tritium in groundwater samples from confined aquifers in the Virgil Creek and Dryden Lake Valleys, Town of Dryden, New York, 2003–09.

[Sampling site location is shown in figure 27. conf, confined; e, estimated; ft, feet; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius (°C); Parm code, USGS National Water Information System (NWIS) parameter code; USGS, U.S. Geological Survey; PWS, public supply well; S&G, sand and gravel; TU, tritium unit; XX, not available; <, less than; —, not analyzed; N, nitrogen; $CaCO_3$, calcium carbonate]

		Aquifer sampled	Upper aquifer		Middle aquifer		Lower aquifer				Drinking water standard
		Local name :	Lake Street PWS well	Domestic well	Jay Street PWS well	Domestic well	South Street PWS well	Dryden Lake test well	Keith Lane test well	Pleasant Valley	
		USGS site name:	TM 202	TM1386	TM 981	TM1940	TM1046	TM 993	TM2724	TM 170	
		Date sampled :	7/28/2003	8/31/2005	7/28/2003	8/29/2005	7/28/2003	12/13/2004	12/16/2009	8/17/2005	
		USGS station identification number:	422857 076172701	422821 076163701	422854 076174201	422821 076161901	422905 076144901	422755 076164801	422812 076172201	422828 076161701	
Physiochemical properties	**Parm code**	**Units**	**Values of physical properties**								
Aquifer type			S&G, conf	S&G, conf	S&G, conf	S&G, conf	S&G, conf	S&G, conf	S&G, conf	S&G, conf	XX
Well depth, below land surface	72008	ft	53	68	72	88	180	234	229	104	XX
Dissolved oxygen (field)	00300	mg/L	3.4	1.7	4.3	1.2	2.8	—	0.7	—	XX
Dissolved oxygen (lab)	62971	mg/L	0.1	—	0.3	—	0.4	0.1	—	<0.02	XX
pH (field)	00400	pH	8.1	7.2	8.2	7.8	8.1	7.9	7.0	7.4	6.5–8.5[b]
Specific conductance (field)	00095	µS/cm	475	416	487	427	328	337	339	422	XX
Water temperature	00010	Celsius	10.0	12.4	10.1	11.0	10.7	10.1	7.6	10.3	XX
Common inorganic ions:			**Concentrations of chemical constituents**								
Hardness, filtered, as $CaCO_3$	00900	mg/L	257	211	246	189	169	145	155	217	XX
Calcium, filtered	00915	mg/L	75.2	59.0	70.0	56.7	48.0	39.6	41.6	61.6	XX
Magnesium, filtered	00925	mg/L	16.9	15.3	17.2	11.5	11.9	11.2	12.4	15.3	XX
Potassium, filtered	00935	mg/L	0.73	2.11	0.60	1.07	0.71	0.86	0.55	1.79	XX
Sodium, filtered	00930	mg/L	8.61	6.48	12.2	11.8	8.78	10.8	4.80	6.50	60[a]
Alkalinity, filtered, as $CaCO_3$	29801	mg/L	—	161	—	138	—	115	113	125	250[b]
Bicarbonate, filtered, as $CaCO_3$	29805	mg/L	—	196	—	168	—	140	138	152	XX
Chlorides, filtered	00940	mg/L	16.7	16.4	31.7	17.3	5.71	19.3	21.6	13.1	XX
Fluoride, filtered	00950	mg/L	<0.17	<0.10	<0.17	e0.08	0.24	0.11	0.12	e0.09	2.2[c]
Silica, filtered	00955	mg/L	10.3	6.83	13.1	5.44	13.7	11.0	11.6	10.2	XX
Sulfate, filtered	00945	mg/L	32.9	31.2	45.4	15.8	26.6	27.5	25.3	49.0	250[b]
Dissolved solids, at 180 °C	70300	mg/L	280	258	292	242	198	200	186	256	XX
Nutrients:											
Ammonia, as N, filtered	00608	mg/L	e0.03	<0.04	0.05	<0.04	0.12	<0.04	e0.019	<0.04	XX

Table 6. Physical properties and concentrations of inorganic major ions, nutrients, and tritium in groundwater samples from confined aquifers in the Virgil Creek and Dryden Lake Valleys, Town of Dryden, New York, 2003–09.—Continued

[Sampling site location is shown in figure 27. conf, confined; e, estimated; ft, feet; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius (°C); Parm code, USGS National Water Information System (NWIS) parameter code; USGS, U.S. Geological Survey; PWS, public supply well; S&G, sand and gravel; TU, tritium unit; XX, not available; <, less than; —, not analyzed; N, nitrogen; $CaCO_3$, calcium carbonate]

		Aquifer sampled	Upper aquifer		Middle aquifer		Lower aquifer				Drinking water standard
		Local name :	Lake Street PWS well	Domestic well	Jay Street PWS well	Domestic well	South Street PWS well	Dryden Lake test well	Keith Lane test well	Pleasant Valley	
		USGS site name:	TM 202	TM1386	TM 981	TM1940	TM1046	TM 993	TM2724	TM 170	
		Date sampled :	7/28/2003	8/31/2005	7/28/2003	8/29/2005	7/28/2003	12/13/2004	12/16/2009	8/17/2005	
		USGS station identification number:	422857 076172701	422821 076163701	422854 076174201	422821 076161901	422905 076144901	422755 076164801	422812 076172201	422828 076161701	
Nutrients	**Parm code**	**Units**	**Concentrations of nutrients**								
Nitrate, as N, NO2+NO3, filtered	00631	mg/L	<0.060	e0.04	<0.060	1.78	<0.06	<0.060	e0.02	<0.060	10[a,c]
Nitrite, as N, filtered	00613	mg/L	<0.008	0.023	<0.008	<0.008	<0.008	<0.008	<0.002	<0.008	1[a,c]
Ammonia+organic-N, filtered	00623	mg/L	e0.06	0.14	e0.08	0.14	0.15	<0.10	e0.06	<0.1	XX
Ammonia+organic-N, unfiltered	00625	mg/L	e0.09	e0.09	0.11	e0.06	0.16	<0.10	—	0.18	XX
Orthophosphate, as P, filtered	00671	mg/L	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	e0.004	<0.02	XX
Phosphorus, filtered	00666	mg/L	e0.003	0.015	0.006	<0.004	0.011	0.004	—	0.018	XX
Phosphorus, unfiltered	00665	mg/L	e0.003	<0.004	0.006	<0.004	0.011	0.007	—	0.028	XX
Radiochemical, tritium, unfiltered	07000	TU	9.9	—	9.9	—	7.1	11.1	—	10.0	XX

[a]U.S. Environmental Protection Agency (USEPA) drinking water advisory taste threshold.

[b]USEPA secondary maximum contaminant level.

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

Table 7. Concentrations of trace metals in groundwater samples from confined aquifers in the Virgil Creek and Dryden Lake Valleys, Town of Dryden, New York, 2003–09.

[Sampling site location is shown in figure 27. conf, confined; USGS, U.S. Geological Survey; e, estimated; µg/L, micrograms per liter; MHP, mobile home park; Parm code, USGS National Water Information System (NWIS) parameter code; PWS, public water supply; XX, not available; <, less than; —, not analyzed]

		Aquifer sampled:	Upper aquifer		Middle aquifer		Lower aquifer				Drinking water standard
		Local name:	Lake Street PWS well	Domestic well	Jay Street PWS well	Domestic well	South Street PWS well	Dryden Lake test well	Keith Lane test well	Pleasant Valley MHP	
		USGS station name:	TM 202	TM1386	TM 981	TM1940	TM1046	TM 993	TM2724	TM 170	
		Date sampled:	8/23/2005	8/31/2005	7/28/2003	8/29/2005	7/28/2003	12/13/2004	12/16/2009	8/17/2005	
		USGS station identification number:	422857 076172701	422821 076163701	422854 076174201	422821 076161901	422905 076144901	422755 076164801	422812 076172201	422828 076161701	
Trace metals	Parm code	Units	Concentrations of chemical constituents								
Aluminum, filtered	01106	µg/L	e0.9	e1.1	e0.8	<1.6	e1.2	—	e1.9	e1.3	50[a]
Antimony, filtered	01095	µg/L	<0.200	0.242	<0.200	<0.200	e0.176	—	e0.035	e0.142	6[b,c]
Arsenic, filtered	01000	µg/L	4.7	e0.1	9.2	<0.2	5.9	—	0.59	1.2	10[b]
Barium, filtered	01005	µg/L	176	61.4	216	30.3	179	—	146	63.3	2,000[b,c]
Beryllium, filtered	01010	µg/L	<0.060	<0.060	<0.060	<0.060	<0.060	—	<0.012	<0.060	4[b,c]
Boron, filtered	01020	µg/L	17	10	16	10	24	—	—	14	XX
Cadmium, filtered	01025	µg/L	0.103	0.118	0.105	0.244	0.232	—	<0.020	0.086	5[b,c]
Chromium, filtered	01030	µg/L	<0.8	e0.02	<0.8	0.04	<0.8	—	<0.12	<0.8	100[b,c]
Cobalt, filtered	01035	µg/L	0.117	0.114	0.112	0.117	0.068	—	0.235	0.124	XX
Copper, filtered	01040	µg/L	1.5	4.3	0.5	8.8	0.9	—	<1.0	0.6	1,000[a]
Iron, filtered	01046	µg/L	70.5	77.2	43.0	<6.0	92.1	105	227	56.6	300[a,b]
Lead, filtered	01049	µg/L	0.326	0.093	0.104	e0.049	0.296	—	e0.015	<0.080	15d
Lithium, filtered	01130	µg/L	7.84	8.91	8.92	1.85	4.84	—	—	6.07	XX
Manganese, filtered	01056	µg/L	152	54.7	173	4.20	144	114	146	222	50[a]–300[c]
Molybdenum, filtered	01060	µg/L	1.09	e0.263	0.933	<0.400	2.53	—	1.73	0.859	XX
Nickel, filtered	01065	µg/L	1.66	1.44	1.33	1.96	1.17	—	1.20	2.68	XX
Selenium, filtered	01145	µg/L	<0.4	<0.4	<0.4	<0.4	0.6	—	0.04	<0.4	50[b,c]
Silver, filtered	01075	µg/L	<0.200	<0.200	<0.200	<0.200	<0.200	—	<0.010	<0.200	100[b,c]
Strontium, filtered	01080	µg/L	216	75.9	236	80.5	415	—	—	137	XX
Thallium, filtered	01057	µg/L	<0.040	<0.040	<0.040	<0.040	<0.040	—	—	<0.040	XX
Vanadium, filtered	01085	µg/L	1.0	0.2	0.8	e0.1	0.9	—	—	0.4	XX
Uranium, natural, filtered	22703	µg/L	0.548	0.468	0.741	0.357	0.662	—	0.478	0.797	30[b]
Zinc, filtered	01090	µg/L	4.3	8.0	2.8	8.6	12.4	—	e2.3	5.4	5,000[a,c]

[a]U.S. Environmental Protection Agency (USEPA) secondary maximum contaminant level.

[b]USEPA maximum contaminant level.

[c]New York State Department of Health (NYSDOH) maximum contaminant level.

[d]USEPA treatment technique.

[e]USEPA proposed maximum contaminant level.

Table 8. Summary statistics for concentrations of trace elements in groundwater samples collected in the Virgil Creek and Dryden Lake valleys, Town of Dryden, New York, 2003–09.

[All concentrations are in micrograms per liter (µg/L); e, estimated; <, less than; —, not applicable]

Constituent	Drinking-water standard	Number of samples	Number of samples exeeding limit	Groundwater samples		
				Minimum	Median	Maximum
Aluminum	50[a]	7	0	<1.6	e1.1	e1.9
Antimony	6[b,c]	7	0	<0.200	e0.035	0.242
Arsenic	10[b]	7	0	<0.2	1.2	9.2
Barium	2,000[b,c]	7	0	30.3	146	216
Beryllium	4[b,c]	7	0	<0.012	<0.060	<0.060
Boron	None	7	—	10	15	24
Cadmium	5[b,c]	7	0	<0.020	0.105	0.244
Chromium	100[b,c]	7	0	<0.12	<0.8	0.04
Cobalt	None	7	—	0.068	0.117	0.235
Copper	1,000[a]	7	0	<1.0	0.900	8.8
Iron	300[a,b]	8	0	<0.6	73.8	227
Lead	15d	7	0	<0.080	0.093	0.326
Lithium	None	7	—	1.85	6.96	8.92
Manganese	50[a]–300[c]	8	7[a]–0[c]	4.2	145	222
Molybdenum	None	7	—	<0.400	0.933	2.53
Nickel	None	7	—	1.17	1.44	2.68
Selenium	50[b,c]	7	0	<0.4	<0.4	0.6
Silver	100[b,c]	7	0	<0.010	<0.200	<0.200
Strontium	None	7	—	75.9	176	415
Thallium	None	7	—	<0.040	<0.040	<0.040
Vanadium	None	7	—	e0.1	0.6	1.0
Uranium	30[b]	7	0	0.357	0.548	0.797
Zinc	5,000[a,b]	7	0	e2.3	5.4	12.4

[a]U.S. Environmental Protection Agency (USEPA) secondary maximum contaminant level.

[b]USEPA maximum contaminant level.

[c]New York State Department of Health (NYSDOH) maximum contaminant level.

[d]USEPA treatment technique.

[e]USEPA proposed maximum contaminant level.

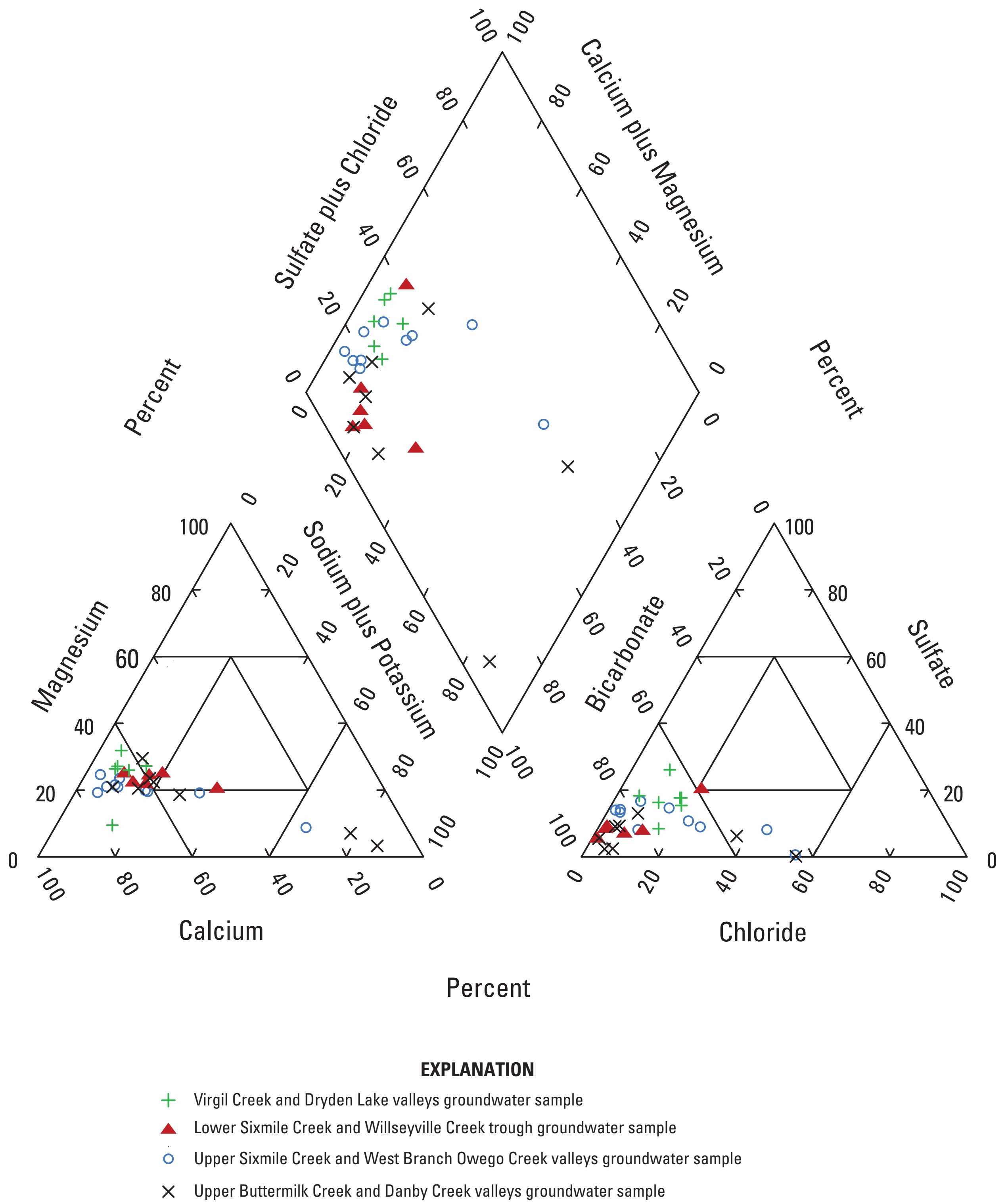


Figure 28. Piper diagram illustrating variability in major ion composition of groundwater in Virgil Creek Valley, Lower Sixmile Creek and Willseyville Creek trough, Upper Sixmile Creek and West Branch Owego Creek Valleys, and Upper Buttermilk and Danby Creek Valleys, Tompkins County, New York.

Table 9. Apparent groundwater ages from groundwater samples collected from five wells that tap the confined stratified-drift aquifers in the Virgil Creek and Dryden Lake valleys, Town of Dryden, Tompkins County, New York

[^3H, tritium; CFC, chlorofluorocarbon; NP, not possible; pptv, parts per trillion; USGS, U.S. Geological Survey; °C, degrees Celsius]

Sample site name and location	USGS site identification number	Sample bottle	Recharge temperature, in °C	Sampling date	Calculated atmospheric mixing ratio, in pptv			Model piston dates			Piston flow age, in years			^3H, in tritium units	Estimated ^3H age	Comments on CFC apparent age
					CFC–11	CFC–12	CFC–113	CFC–11	CFC–12	CFC–113	CFC–11	CFC–12	CFC–113			
TM1046, Village of Dryden production well at South Street	422905076144901	1	8.1	7/28/2003	20.4	0.0	0.0	1963.5	1940	1955	40	NP	NP	7.1	Late 1950s	Earlier than 1940s to early 1960s.
		2			14.8	0.0	0.0	1961.5	1940	1955	42	NP	NP			
		3			9.2	0.0	0.0	1959	1940	1955	45	NP	NP			
TM 981, Village of Dryden production well at Jay Street	422854076174201	1	9.4	7/28/2003	33.3	1.5	0.0	1966	1944.5	1955	38	NP	NP	9.9	Early 1970s or younger	Mid-1940s to mid-1960s; possible mixture.
		2			3.9	0.0	0.0	1955	1940	1955	49	NP	NP			
		3			27.6	1.1	0.0	1965	1943.5	1955	39	NP	NP			
TM 202, Village of Dryden production well at Lake Street	422857076172701	1	10.	7/28/2003	7.3	0.0	0.0	1957.5	1940	1955	46	NP	NP	9.9	Early 1970s or younger	Early 1940s to mid-1960s; possible mixture.
		2			23.1	0.78	0.0	1964	1942.5	1955	40	NP	NP			
		3			22.2	1.1	0.0	1964	1943.5	1955	40	NP	NP			
TM 993, USGS test well at Dryden Lake	422755076164801	1	4.0	12/13/2004	3.3	7.3	0.0	1954.5	1950	1953	50	55	52	11.1	Early 1970s or younger	Late 1940s to l ate 1950s.
		2			4.9	4.7	1.1	1956	1948	1958.5	49	57	46			
		3			4.7	6.5	1.0	1955.5	1949	1957.5	49	56	47			
TM 170, Pleasant View Mobile Home Park well at Southworth Road	422828076161701	1	8.8	8/17/2005	175.2	2.5	1.2	1980.5	1946	1958.5	25	60	47.1	10.0	Early 1970s or younger	Mid-1940s or older Contamination of CFC–11; note: CFC–11 and CFC–113 concentrations decreased with time.
		2			89.2	1.2	0.0	1972.5	1944	1953	33	62	52.6			
		3			20.5	2.3	0.0	1963.5	1946	1953	42	60	52.6			

the mid-1940s and are present in precipitation. In North America, the air mixing ratios of CFC–11 and CFC–113 peaked in about 1993 and 1994, respectively, and the CFC–12 air mixing ratio peaked in mid-1999 (Elkins and others, 1993). Concentrations of CFCs in precipitation and those present in groundwater recently derived from precipitation correspond to that present in the contemporaneous atmosphere. Atmospheric CFC concentrations have been recorded since about 1945 (Plummer and Busenberg, 2000). The comparison of CFC concentrations in a water sample to historical records of atmospheric CFC concentrations can indicate the year (after 1945) in which the water entered the water table. However, the estimated age of a groundwater sample can also reflect mixing of older and younger water within an aquifer.

Recharge temperature is an important component in the interpretation of the age of the water, along with concentrations of CFCs (Heaton, 1981; Heaton and Vogel, 1981; Stute and Schlosser, 1999). The recharge temperatures calculated for water from three wells in this study ranged from 4 to 10 °C (table 9).

Tritium is a radioactive isotope of hydrogen with a half-life of 12.32 years (Lucas and Unterweger, 2000). Based on releases to the atmosphere from nuclear testing, ^{3}H can be used as a tracer to estimate whether groundwater has been recharged before or after 1953. The standard unit of measure for ^{3}H is a tritium unit (TU), in which 1 TU is equivalent in terms of radioactivity to 3.2 picocuries per liter (pCi/L). The greatest concentrations of ^{3}H (greater than 500 TU) occurred following periods of atmospheric testing of nuclear weapons, which began in 1952 and peaked in 1963–4 (Clark and Fritz, 1997). Atmospheric concentrations have gradually declined since 1963–4, and present-day groundwater typically contains less than 1 to 10 TU (Clark and Fritz, 1997). Natural (prenuclear age) levels of ^{3}H in precipitation are on the order of 1 to 5 TU. The relative age of the groundwater (time since it entered the aquifer and ceased contact with the atmosphere) can be estimated through a comparison of the ^{3}H concentration in a water sample with the recorded historical changes in concentration in the atmosphere, taking into account the half-life decay. Groundwater that does not contain detectable ^{3}H (less than 0.8 TU) can be assumed to have been recharged before 1953, and groundwater that does contain detectable ^{3}H (more than 0.8 TU) is assumed to contain some component of groundwater that was recharged after 1953 (Cordy and others, 2000).

Five samples were collected and analyzed for CFCs, dissolved gases, and ^{3}H to estimate the age of the groundwater in the study area. Three samples were collected on July 28, 2003, from the Village of Dryden municipal wells (TM1046, TM 981, and TM 202), one sample was collected on December 13, 2004, from the test well at Dryden Lake (TM 993), and one sample was collected on August 17, 2005, from a mobile home park well at Southworth Road (TM 170). Concentrations of ^{3}H in the five groundwater samples from this study ranged from 7.1 to 11.1 TU (table 9). The ^{3}H concentrations were used along with concentrations of CFCs to estimate the apparent age of groundwater. The results of the age-dating samples are listed in table 9.

Based on the CFC and ^{3}H analyses for the three Village of Dryden production wells, the apparent groundwater ages were as follows: before the 1940s to early 1960s for the well finished in the lower confined aquifer (TM1046) and early 1970s or younger for the wells finished in the middle and upper confined aquifers (TM 981 and TM 202, respectively). The results also indicated that the groundwater sampled from the middle and upper confined aquifers were possibly mixtures of water of different ages.

The results of the CFC analyses for the test well at Dryden Lake (TM 993, lower aquifer) indicated that the apparent age of water was late 1940s to late 1950s; however, the ^{3}H concentration of 11.1 TU (table 9) indicated that the water was 1970s or later. Samples with values between 5 and 15 TU indicate that the water probably entered the aquifer sometime after 1970. Because of the disagreement of ages determined by CFC and the ^{3}H dating methods, the age of water sampled from TM 993 is uncertain.

The results of the CFC analyses for the mobile home park well at Southworth Road (TM 170) indicated that the apparent age of water was probably mid-1940s or older based on the CFC–12 and CFC–113 concentrations. However, the CFC–11 concentration indicated that the apparent age was mid-1960s to early 1980s, but the laboratory noted there may have been CFC–11 contamination in this sample (enrichment that results in an apparent age younger than in actuality) and that the concentrations of CFC–11 in the three samples that were analyzed decreased with time, both phenomena suggesting the results may not be reliable. The ^{3}H concentration of 10 TU indicated that the water was 1970s or later. It is possible that the CFC–12 and CFC–113 concentrations have also decreased because they have undergone degradation, which results in apparent ages that are older than in actuality. Although there is no evidence for aerobic degradation of CFCs in groundwater, CFC–11, CFC–12, and CFC–113 can all be degraded in sulfate-reducing and methanogenic anaerobic environments (Plummer and Busenberg, 2000).

Simulation of Groundwater Flow

The groundwater flow through the stratified-drift aquifer system in the Virgil Creek and Dryden Lake Valleys in the Town of Dryden and in part of the Owego Creek Valley, Town of Harford was simulated using the computer program MODFLOW–2000, a three-dimensional, cell-centered, finite-difference, saturated-flow model developed by the U.S. Geological Survey (McDonald and Harbaugh, 1988). Areas that potentially contribute recharge to the Village of Dryden municipal production wells were calculated using the computer program MODPATH (Pollock, 1989), a semianalytical particle-tracking program that uses groundwater heads and fluxes predicted through steady-state groundwater-model simulation to trace the flow lines in the aquifer.

Model Design

A preprocessing and postprocessing program, Groundwater Modeling System (GMS) version 7.1 (build date October 11, 2010; Aquaveo, 2010), was used to input data for MODFLOW–2000 and MODPATH and generate output graphics and statistical analyses. Because the Village of Dryden has been withdrawing water for a long period of time (since the 1940s) at a relatively small rate (in 2008, the rate was 0.192 Mgal/d or 133 gal/min) and the interest of this study is in long-term trends rather than seasonal or other short-term effects, the aquifer system is assumed to be near steady-state. Therefore, a steady-state simulation was used to compute the hydraulic-head distribution and groundwater budgets and to estimate the rate of groundwater flow. The model was calibrated to measured groundwater levels made throughout the study area and to flow rates in a reach of Virgil Creek in the vicinity of the Virgil Dam.

The model was based on the generalized geologic and hydrologic sections presented previously in this report (figs. 13, 14, 18, and 19). The model is only a simplified representation of actual aquifer conditions because (1) the geology is complex, (2) the distribution of hydraulic properties is unknown in most of the simulated area, and (3) there is a scarcity of geohydrologic data in some parts of the study area. However, the model is a valuable tool that can be used to better understand how the hydrologic system works and to estimate the sources of recharge within areas contributing recharge to the Village of Dryden production wells.

Model Grid and Layers

The three confining layers and the three aquifers that form the geohydrologic framework of the valley-fill deposits (figs. 18 and 19) were represented by six model layers (fig. 29). Water-bearing zones in the bedrock were not explicitly simulated in the model because (1) studies in other areas indicate that the Devonian shales and siltstones transmit relatively little groundwater compared with the overlying sand and gravel units in this area and (2) there is little information on the hydraulic properties of the bedrock or the hydraulic-head relation between the bedrock and the unconsolidated deposits within the study area.

The model represents an area of 5.4 mi^2 and extends from 5.3 mi southeast of the Village of Dryden to 1.3 mi northwest of the Hamlet of Harford (fig. 30*A*). The model grid included 159 rows and 73 columns in each of the six layers, with a uniform cell size of 200 by 200 ft.

Model layers 1, 3, and 5 represent the upper, middle, and lower confining units, respectively (figs. 18, 19, and 29). Layers 1 and 3 each represent a 10- to 60-ft-thick till unit, whereas layer 5 represents a 60- to 100-ft-thick confining unit comprising mostly fine-grained lacustrine sediments and some till (figs. 13 and 14). Model layers 2, 4, and 6 (fig. 29) represent confined sand and gravel aquifer units (figs. 18 and 19) of unknown origin. The model does not include surficial unconfined units because they are small, discontinuous, and thinly saturated; it would have been difficult to prevent these cells from becoming dry cells, which would result in model instability, and attempting to include these deposits would not have substantially improved the results.

Model layers 1 through 6 contain 21,497 active cells. Layer thicknesses were initially assigned by using the Solid module of GMS to a construct a three-dimensional model of stratigraphy using borehole data. Subsequently, the thicknesses of model layers in some areas were changed manually upon visual inspection of well logs and using geological concepts and knowledge of the hydrostratigraphy of other similar confined aquifers in the county (Miller, 2009; Miller and Karig, 2010).

Boundary Conditions

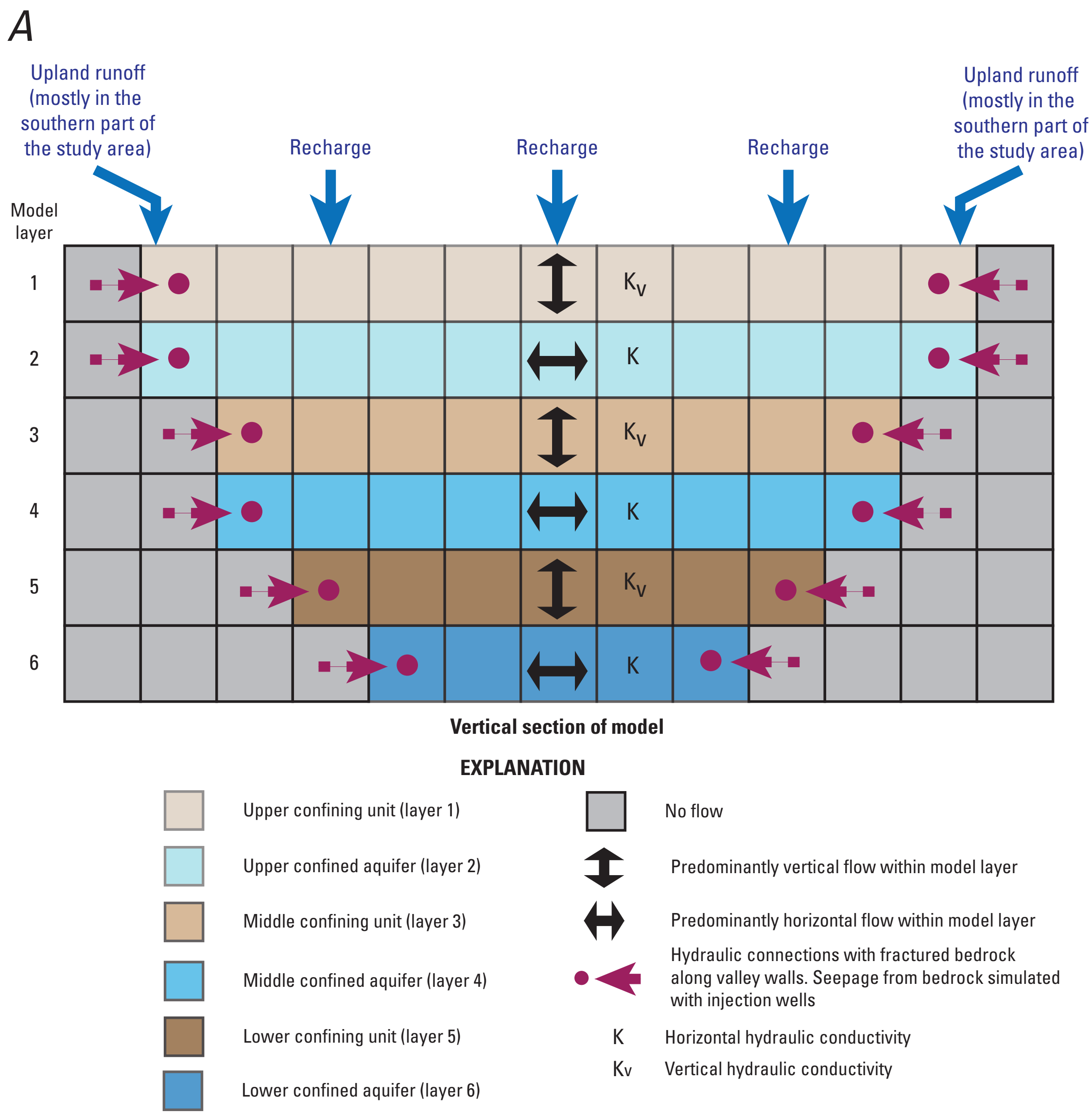
Several types of boundary conditions that represent inflows and outflows of water to and from the aquifer system were specified in the model (figs. 29 and 30). Natural boundaries were used where possible, but arbitrary boundaries were used to limit the northern, southern, and eastern extents of the model.

No-Flow Boundaries

No-flow lateral boundaries were used in model layers 1 through 6 to represent the contact between the aquifer system and the shale bedrock at the valley wall. However, a specified flux was included to represent a small amount of seepage from the adjacent bedrock to the simulated valley-fill units.

Specified-Flux Boundaries

A specified-flux boundary (Recharge package) was used to represent direct recharge from precipitation to the upper confining unit (layer 1) and to the upper confined aquifer unit (layer 2) where the upper confining unit had been removed by erosion near the Virgil Creek Dam area (figs. 14 and 19). Groundwater recharge was nonuniformly distributed over the model area to the topmost active layer. The average annual recharge from direct precipitation was estimated to be 0 inches per year (in/yr) in low areas in the northern part of the study area where the hydraulic head in the upper aquifer is near or above the top of the upper confining unit (rejected recharge due to artesian flowing conditions), 2.2 in/yr (0.0005 ft/d) where the upper confining unit is above the altitude of the hydraulic head in the upper aquifer in the north part of the study area, 8.3 in/yr (0.0019 ft/d) where the upper confining unit consists of a thin weathered till at land surface in the south and central part of the valley, 11 in/yr (0.0025 ft/d)



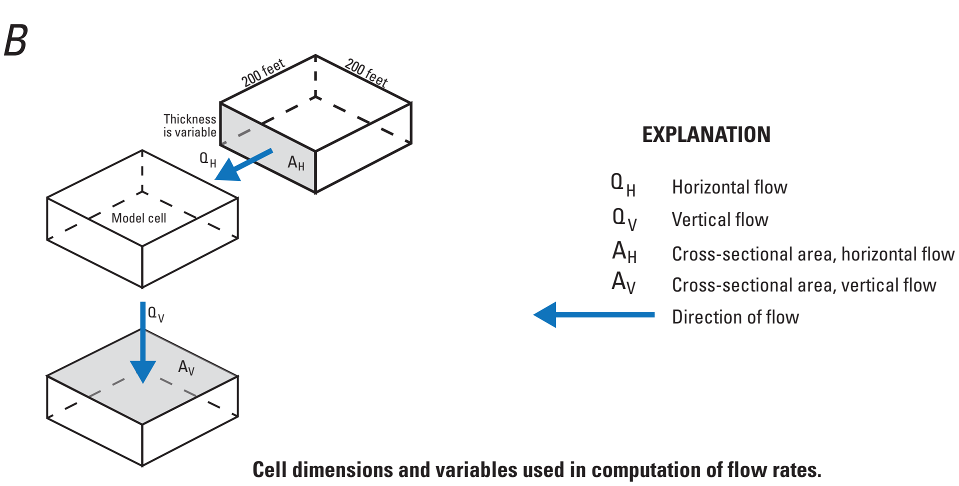
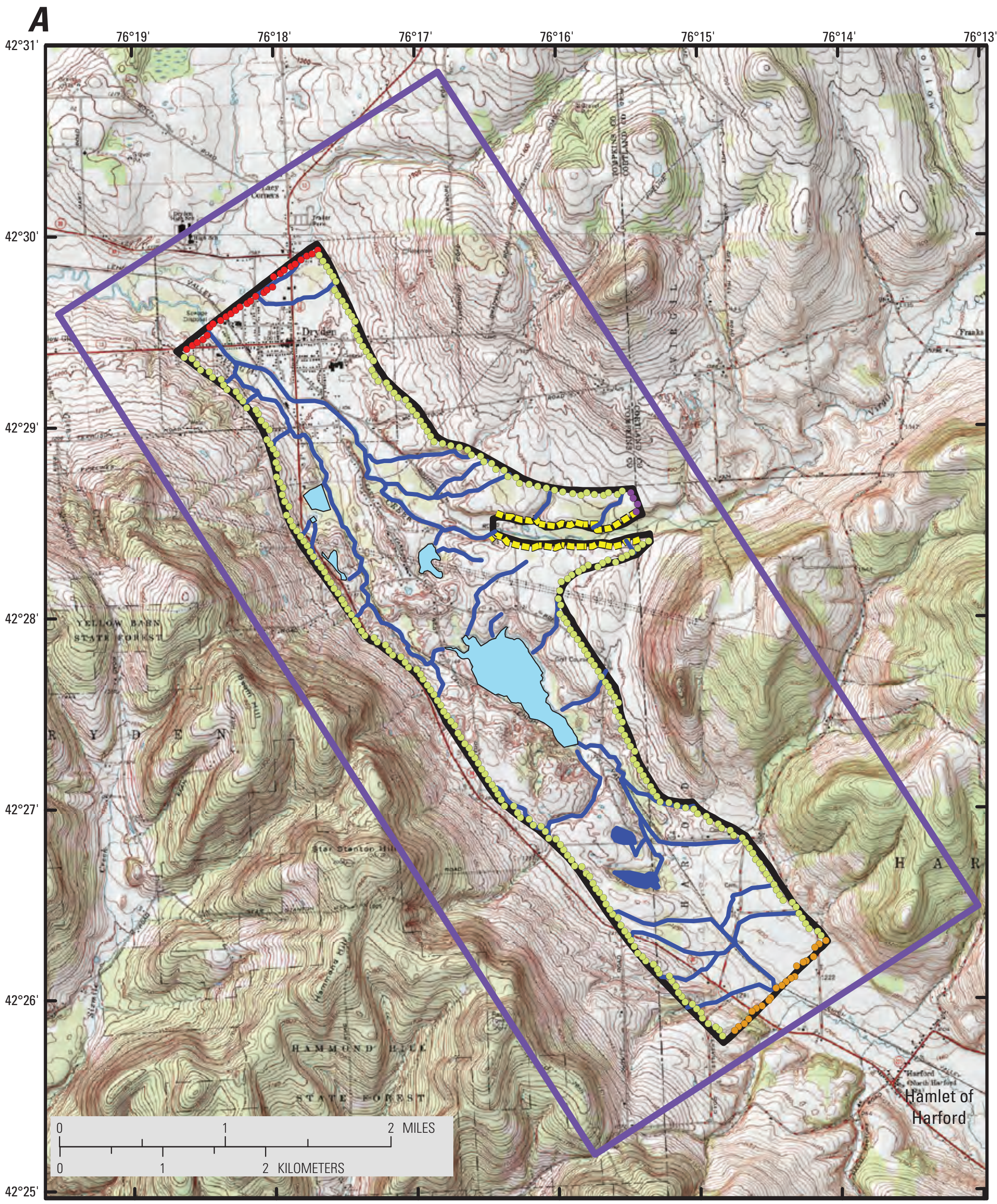


Figure 29. Schematic diagrams of the model used in the study of the stratified-drift aquifer system in Virgil Creek and Dryden Lake Valleys, Town of Dryden, Tompkins County, New York: *A,* vertical cross-section of model and representation of hydraulic connections between model layers and bedrock valley walls and *B,* cell dimensions and variables used in computation of flow rates between cells.



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EXPLANATION

Boundary of model grid

Boundary of stratified-drift aquifer

Head-dependent boundaries

General head cells (lakes, ponds, and wetlands)

River cells (streams and bogs)

Drain cells (bluffs along eroded stream gorge)

Specified-flux boundaries

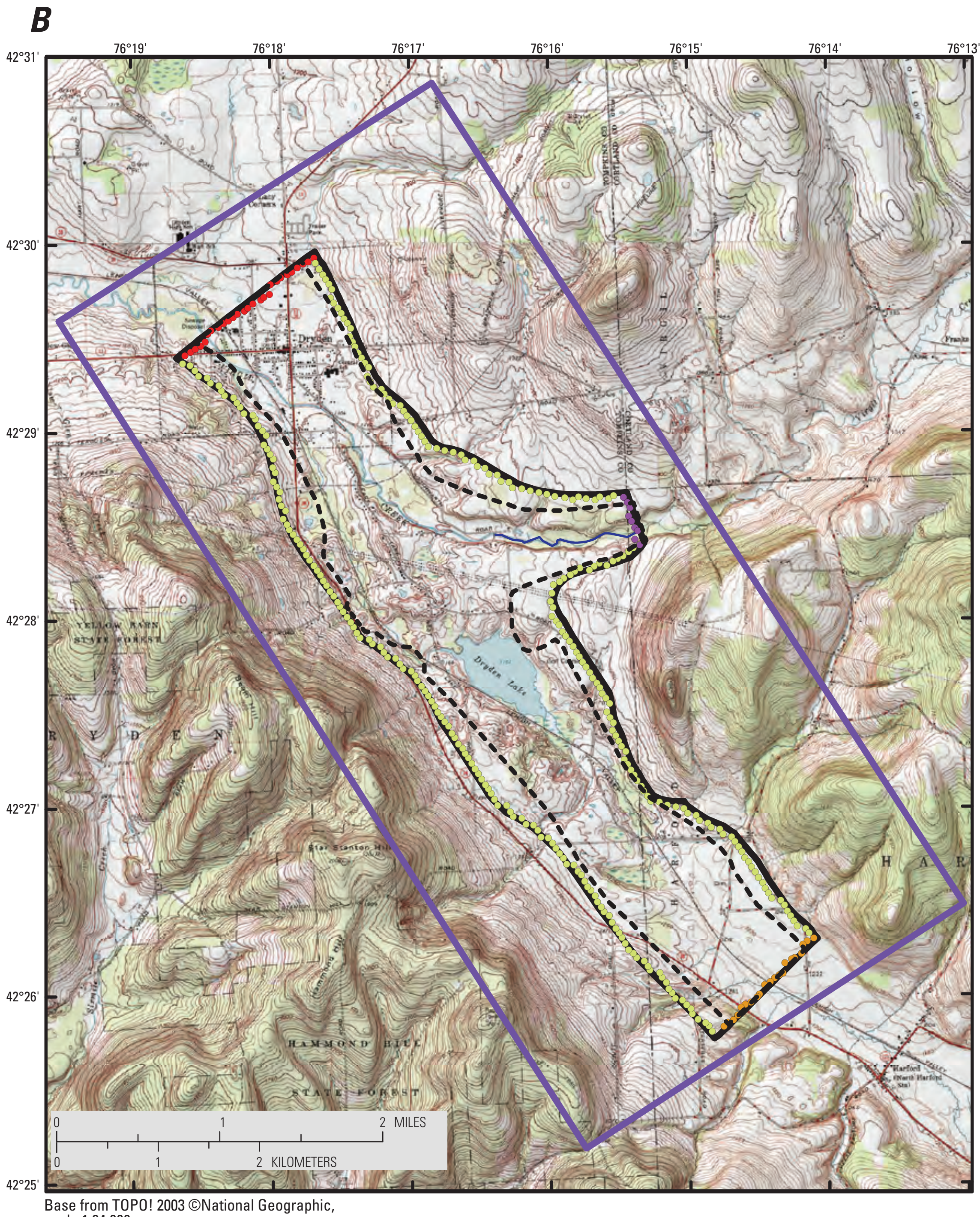
Well cell that simulates groundwater outflow through the northern end of the model

Well cell that simulates groundwater inflow through the eastern end of the model

Well cell that simulates groundwater outflow through the southern end of the model

Well cell that simulates recharge from groundwater inflow from bedrock along the valley walls and runoff and from unchanneled uplands

Figure 30. Boundary conditions in groundwater-flow model in stratified-drift aquifer study area in the Virgil Creek, Dryden Lake, and Owego Creek Valleys, Tompkins and Cortland Counties, New York: *A,* Upper confining unit (model layer 1), *B,* middle and lower confining units (model layers 3 and 5) and upper, middle, and lower confined aquifer units (model layers 2, 4, and 6).



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EXPLANATION

Boundary of model grid

Boundary of layers 2 through 5

Model boundary (layer 6)

Head-dependent boundaries

River cells in layer 2 where Virgil Creek is in a gorge and where layer 1 is absent (has been removed by erosion)

Specified-flux boundaries

Well cell that simulates recharge from groundwater inflow from bedrock along the valley walls and runoff and from unchannel uplands

Well cell that simulates groundwater outflow through the southern end of the model

Well cell that simulates groundwater outflow through the northern end of the model

Well cell that simulates groundwater inflow through the eastern end of the model

Figure 30. Boundary conditions in groundwater-flow model in stratified-drift aquifer study area in the Virgil Creek, Dryden Lake, and Owego Creek Valleys, Tompkins and Cortland Counties, New York: *A,* Upper confining unit (model layer 1), *B,* middle and lower confining units (model layers 3 and 5) and upper, middle, and lower confined aquifer units (model layers 2, 4, and 6).—Continued

where relatively permeable but poorly sorted kame deposits lie along the east side of the valley, and 17.5 in/yr (0.004 ft/d) at the moraine in the southern part of the study area where the upper confining unit consists of heterogeneous material (reworked sand and gravel mixed with till consisting of a fine-grained matrix) and locally contains windows of permeable sediment that can readily transmit recharge from precipitation and tributaries that lose water as they flow over the valley floor. There was no recharge from precipitation included (1) in low-lying areas of the northern part of the study area where the hydraulic head is above the top of the upper aquifer and upper confining unit, (2) in areas of large ponds and wetlands, and (3) where Dryden Lake occupies the valley.

A specified-flux boundary, represented by discharging wells (pumped wells), was used to represent the Village of Dryden municipal production wells. Pumping is distributed between three pumping stations—TM1046 at South Street, TM 981 at Jay Street, and TM 202 at Lake Road (fig. 25). During 2005–7, the total daily average groundwater withdrawal from the village municipal pumping wells was about 242,000 gal/d (32,350 cubic feet per day (ft^3/d)); about 125,000 gal/d (16,700 ft^3/d) was from South Street pumping station, about 93,500 gal/d (12,500 ft^3/d) from the Jay Street pumping station, and about 23,500 gal/d (3,140 ft^3/d) from Lake Road pumping station. Domestic and apartment wells were not included as discharging wells because most of that pumped water is returned to the groundwater system via septic systems.

Although bedrock was not formally represented in this model because of the assumption that shale transmits relatively little groundwater, a small amount of inflow from the bedrock to the valley-fill deposits probably does occur (Yager and others, 2001). Therefore a specified flux boundary, represented by injection wells, was used in active cells that border the bedrock valley walls to represent the groundwater inflow from bedrock (layers 1 through 6). In addition to the hydraulic gradient and cross-sectional flow area, the amount of groundwater flux from the bedrock uplands to the valley-fill geohydrologic units is controlled by the unit that has the lowest hydraulic conductivity—that of the weathered and fractured bedrock or that of the valley-fill sediments. For the confining units, the hydraulic conductivity is lower than that of the weathered and fractured shale. A hydraulic conductivity value of 2.5 ft/d was used for the study area; the value is based on the weathered and fractured bedrock in the Genesee Valley of central New York as estimated by Yager and others (2001). The horizontal hydraulic conductivity of the upper confining unit (weathered till) in this study area is estimated to be 1 ft/d, and those of the unweathered middle and lower confining units are estimated to be 0.25 ft/d and 0.3 ft/d, respectively. Therefore, the groundwater flux from the bedrock uplands is controlled, in large part, by the confining units because they all have lower hydraulic conductivities than the bedrock. Darcy's law (equation 2) was used to estimate the flux of groundwater inflow from the adjacent valley walls into the confining beds in the simulated study area:

$$Q = KIA, \tag{2}$$

where

- Q = discharge, the volume of water discharged over a given time;
- K = hydraulic conductivity;
- I = hydraulic gradient, measured as change in height (Δh) over change of length (Δl) or rise over run or slope (dimensionless); and
- A = cross-sectional flow area.

Using the above equation, the estimated flux into the confining units (represented by injection wells in cells along the valley walls) ranged from 6 ft^3/d for the middle and lower confining units to 25 ft^3/d for the upper confining unit, where

- K = 1 ft/d, 0.25 ft/d, and 0.3 ft/d for the upper, middle, and confined aquifers, respectively,
- I = 0.005 ft/ft, and
- A = 5,000 ft^2.

In areas where the aquifers abut the valley walls, the flux of groundwater inflow from the adjacent valley walls into the confined aquifers is controlled, in large part, by the hydraulic conductivity of the weathered bedrock (about 2.5 ft/d), which is lower than that of the aquifer units (120 ft/d for the upper confined aquifer, 100 to 130 ft/d for the middle confined aquifer, and 30 to 300 ft/d for the lower confined aquifer). Using Darcy's equation above, the estimated groundwater flux from bedrock into the aquifer units was computed and represented in the model by injection wells in cells along the valley walls. The computed recharge for a cell along the valley wall was 100 ft^3/d for the upper confining unit and ranged from 35 to 75 ft^3/d for the middle and lower confining units, where

- K = 2.5 ft/d for the bedrock,
- I = 0.005 ft/ft, and
- A ranged from 3,000 to 8,000 ft^2.

In some places in the southern part of the study area, recharge from upland sources can be more than in the northern part of the study area because, in addition to groundwater inflow from adjacent bedrock, some unchanneled runoff from adjacent hillsides seeps into the upper aquifer where the upper confining unit is thin, discontinuous, or absent, such as at some kame terraces along the valley walls and at the Valley Heads Moraine. The recharge from uplands in the southern part of the study area is at least equal to and, in some places, greater than that in the northern part of the study area where the confining units abut the valley walls and prevent runoff from entering the upper aquifer. The maximum recharge to the model from the upland areas in the southern part of the study area was determined by (1) dividing the uplands into surface-water subbasins, (2) determining the drainage area that contributes runoff to the valley in each subbasin, (3) multiplying the contributing upland area by the average unit-area base flow, and (4) dividing this flow by the number of perimeter cells of the modeled area adjacent to the subbasin and applying the result to these cells. During calibration, the extra recharge from unchanneled runoff from adjacent hillsides was reduced in the southern part of the study area because simulated water levels were too high. The recharge (represented in the model by injection wells in cells in layer 2 along the valley walls) from upland sources in the southern part of the study area is estimated to range from 100 to 200 ft^3/d.

A specified-flux boundary, represented by discharging wells, was used to simulate groundwater outflow through the northern and southern boundaries in the Dryden Lake Valley. The flux was initially estimated using Darcy's law (equation 2) and then modified during the calibration process. The final calibrated groundwater fluxes for the three confined aquifer layers—2, 4, and 6—out for each cell at the northern boundary of the model are 500 ft^3/d, 1,500 ft^3/d, and 1,000 ft^3/d, respectively, and at the southern boundary of the model, 400 ft^3/d, 400 ft^3/d, and 1,000 ft^3/d, respectively.

A specified-flux boundary, represented by injection wells, was used to simulate groundwater inflow into the eastern (upgradient) boundary in the Virgil Creek Valley (1,500 ft east of the Virgil Creek Dam). The flux was initially estimated using Darcy's law (equation 2) and then modified during the calibration process. The final calibrated groundwater fluxes for each cell at the eastern boundary of the model for the three confined aquifer layers—2, 4, and 6—are 500 ft^3/d, 700 ft^3/d, and 2,000 ft^3/d, respectively.

Head-Dependent Boundaries

The General Head package in MODFLOW–2000 was used to simulate flow in or out of a cell that represents lakes, ponds, and wetlands. General head conditions are specified by assigning a head and a conductance to a selected set of cells. If the water-table altitude rises above the specified head, then water flows out of (discharges from) the aquifer. If the water-table altitude falls below the specified head, then water flows into (recharges) the aquifer. In both cases, the flow rate is proportional to the head difference and the conductance. The altitude of the water surface of Dryden Lake was determined through leveling. The water-surface altitudes of small ponds and wetlands were derived from LiDAR data with 3.28-ft (1 meter) horizontal resolution and about 1-ft vertical accuracy. The conductance (C) for model cells representing head-dependent boundaries was computed from the relation:

$$C = K \frac{A}{l}, \qquad (3)$$

where

- C = conductance,
- K = hydraulic conductivity,
- A = cross-sectional flow area, and
- l = length of flow path between cell center and model boundary.

Flow between the aquifer and the surface-water body (Q) is referred to as a head-dependent flux and is governed by the following equation (McDonald and Harbaugh, 1988):

$$Q = C\,(H - h), \qquad (4)$$

where

- Q = discharge, flow between the aquifer and stream;
- C = conductance of the streambed material;
- H = altitude of head in the stream; and
- h = altitude of head in the aquifer.

The River package in MODFLOW–2000 was used to simulate flow of water between the upper confining unit and streams and, where the upper confining unit was removed in the area of the Virgil Creek Dam, between the upper aquifer (locally unconfined in this area) and Virgil Creek. The rate at which water moves between stream and aquifer is dependent on the head difference between the two, as well as on the vertical conductance of the streambed material. Stream-stage estimates were computed from land-surface altitudes derived from leveling at several sites and from LiDAR data (about 1-ft vertical accuracy). The thickness and hydraulic conductivity of the riverbed were not known, and stream widths were approximated between locations where measurements were made. The thickness of the riverbed was assumed to be 1 ft. The hydraulic conductivity of the riverbed was not measured but was estimated to range from 1 to 25 ft/d on the basis of values used for other groundwater modeling studies done in the northeastern United States (Miller and others, 1998; Miller, 2000a; Carleton and Gordon, 2007). Flow between the aquifer and the stream is referred to as a head-dependent flux and is governed by equations 3 and 4.

The K values for river cells representing flows to and from streams were assumed to be as follows:

- 50 ft/d, where Virgil Creek flows on coarse-grained alluvium and in a channel that has been dredged and reworked in the vicinity of Virgil Creek Dam;
- 1 to 2 ft/d, where Virgil Creek flows on till or alluvium downstream from Virgil Creek Dam;
- 1 ft/d, for the inlet and outlet to Dryden Lake;
- 1 to 10 ft/d for tributary streams that lose water where they flow on coarse alluvial fans and morainal deposits; and
- 0.1 to 0.5 ft/d, for small tributary streams that lose water where they flow on kame terraces, alluvium, or till.

The ratio A/l in equation 3 was based on the length, width, and thickness of the stream channel as follows:

- cells representing Virgil Creek: 0.125 ft,
- cells representing inlet to Dryden Lake: 0.05 ft,
- cells representing outlet to Dryden Lake: 0.0125 ft, and
- cells representing small tributaries: 0.015 to 0.05 ft.

The Drain package in MODFLOW was used to simulate groundwater that seeps out from the till bluffs (layer 1) in the eroded gorge cut by Virgil Creek in the vicinity of the Virgil Creek Dam (fig. 30*A*). The Drain package allows water to leave the model domain if the head in a cell containing a drain is higher than the designated drain stage. Drains are active only when the water table in the layer is higher than the altitude of the drain. The altitude of the drains used in the model ranged from 1,163 ft to 1,211 ft. The model calculates the rate of seepage between the drain and the aquifer using the following equation (McDonald and Harbaugh, 1988):

$$Q = C\,(h - d), \tag{5}$$

where

Q = discharge, seepage rate;
C = hydraulic conductance of the interface between the modeled layer and the drain;
h = altitude of the hydraulic head in the model cell; and
d = altitude of the drain.

A C value of 20 ft^3/d (computed using equation 3) was used in equation 5, where vertical K value was 1 ft/d, A value was 4,000 ft^2 (thickness of geohydrologic unit of 20 ft multiplied by the width of model cell of 200 ft), and the value of l was 200 ft.

Model Calibration

The model was calibrated using a combination of automated parameter estimation and trial-and-error techniques. Simulated and measured water levels throughout the study area and loss of streamflow in a reach of Virgil Creek near the dam were compared to determine the combination that resulted in the lowest cumulative error. The model was calibrated using estimated average annual recharge conditions and average groundwater withdrawals by the Village of Dryden for 2005–7. The average daily pumping rates for 2005–7 for the Village of Dryden production wells TM1046, TM 993, and TM 202 were 125,300 gal/d (16,750 ft^3/d), 93,900 gal/d (12,550 ft^3/d), and 30,600 gal/d (4,100 ft^3/d), respectively. Because groundwater has been withdrawn from the aquifer system by Village of Dryden production wells since the mid-1940s and there are no water-level data for the time before pumping began, the model could not be calibrated to steady-state, nonpumping conditions.

Model Parameters

Initially 52 model parameters were estimated from precipitation records, results of aquifer tests, examination of drill cuttings and split-spoon cores during test drilling, and interpretation of drillers' logs. Then 39 (horizontal and vertical hydraulic conductivities, recharge, and streambed conductance of Virgil Creek in the vicinity of the dam) of the 52 parameter values were adjusted using a nonlinear, parameter-estimation, inverse model (PEST, version 12.0; Doherty and Hunt, 2010), and the remaining 13 parameters (streambed conductance, specified flux along the valley walls, and porosity) were fixed (table 10). Some parameters (horizontal hydraulic conductivities and streambed conductances) were further changed when improvements in model results were identified through improvement of the sum of the root-mean-squared errors. Adjustments continued until the model-computed values (residuals) matched the field-observed values to an acceptable level of agreement of less than 5 ft. The final values of parameters used in the model are given in table 11 and the zones of horizontal hydraulic conductivity of the upper (layer 2), middle (layer 4), and lower (layer 6) confined aquifers used in the numerical simulation are shown on figure 31.

The model was most sensitive to changes in recharge and horizontal hydraulic conductivity in model layers 2 and 4 (upper and middle confined aquifers, respectively) in the northern part of the study area and to bed conductance of Virgil Creek in the vicinity of Virgil Creek Dam (figs. 31 and 32). The model was slightly less sensitive to changes in recharge in the central part of the study area and in horizontal hydraulic conductivity of layer 6 (lower confined aquifer) and vertical hydraulic conductivity of layer 1 (upper confining unit) in the northern part of the study area. The model was less sensitive to changes in vertical hydraulic conductivity of layer 5 and to horizontal hydraulic conductivities of layers 2, 4, and 6 in the southern part of the study area. The model was insensitive to vertical hydraulic conductivity in layer 1 in the central and southern parts of the study area, to vertical hydraulic conductivity of layer 3, and to horizontal hydraulic conductivity of layer 6 in the southern part of the study area.

Steady-state simulations were used to produce a model that would approximate the water levels for (1) long-term average groundwater-level conditions, (2) average municipal well pumping rates for 2005–7, and (3) streamflow measured in Virgil Creek at the Virgil Creek Dam on May 10, 2007, which was near the median annual base-flow conditions as determined by a hydrograph-separation analysis of a nearby streamgage of similar hydrologic setting. Because precipitation was above average for 2005–7, the model was calibrated to some heads that represent a slightly wetter than average period.

Table 10. Numbers of parameters that represent the stratified-drift aquifer system in the Virgil Creek and Dryden Lake valleys, Tompkins County, New York, as estimated and fixed in the nonlinear, parameter-estimation inverse model.

[—, no parameter specified; X, fixed parameter]

Aquifer property	Model layer					
	1	2	3	4	5	6
	Upper confining unit	Upper confined aquifer	Middle confining unit	Middle confined aquifer	Lower confining unit	Lower confined aquifer
Horizontal hydraulic conductivity:						
Estimated	—	4	—	3	—	12
Fixed	—	—	—	—	—	—
Vertical hydraulic conductivity:						
Estimated	7	—	1	—	1	—
Fixed	—	—	—	—	—	—
Recharge, estimated	7	1[a]	—	—	—	—
Streambed conductance, estimated (near dam only)	—	3	—	—	—	—
Other fixed head-dependant and specified-flux properties and porosity:						
Streambed conductance	X	—	—	—	—	—
Specified flux along valley walls	X	X	X	X	X	X
Porosity	X	X	X	X	X	X
Total:						
Estimated (39)	14	8	1	3	1	12
Fixed (13)	3	2	2	2	2	2

[a]Recharge specified in area of layer 2 where layer 1 is absent (removed by erosion).

Table 11. Parameter values estimated for the groundwater-flow model of the stratified-drift aquifer system in the Virgil Creek and Dryden Lake Valleys, Tompkins County, New York.

[gal/d, gallons per day; ft/d, feet per day; ft^2/d, square feet per day; ft^3/d, cubic feet per day; in/yr, inches per year]

Variable	Value
Specified-flux boundary:	
Recharge package:	
Moraine, in/yr (ft/d)	17.5 (0.004)
Backside of moraine, in/yr (ft/d)	3.5–8.3 (0.0008–0.0019)
Floodplain at Virgil Creek Dam, in/yr (ft/d)	8.8 (0.002)
Well package:	
Large withdrawal wells	
Village of Dryden South Street pumping station, gal/d (ft^3/d)	125,000 (16,700)
Village of Dryden Jay Street pumping station	93,500 (12,500)
Village of Dryden Lake Road pumping station	23,000 (3,140)
Upland sources of recharge[a]	
Groundwater inflow from adjacent bedrock (represented by injection wells)	
Groundwater inflow into upper confining unit (layer 1) (ft^3/d)	25
Groundwater inflow into the middle (layer 3) and lower confining units (layer 5) (ft^3/d)	6
Groundwater inflow into upper confined aquifer (layer 2) (ft^3/d)	100
Groundwater inflow into the middle and upper confined aquifers (layers 4 and 6) (ft^3/d)	35–75
Groundwater outflow through confined aquifers at the northern and southern boundaries in the Dryden Lake valley	
Groundwater fluxes out of each cell at the northern boundary of the model for the three aquifers—layers 2, 4, and 6 (ft^3/d)	500, 1,500, 1,000, respectively
Groundwater fluxes out of each cell at the southern boundary of the model for the three aquifers—layers 2, 4, and 6 (ft^3/d)	400, 400, 1,000, respectively
Groundwater inflow through the confined aquifers at the eastern boundary in the Virgil Creek valley	
Groundwater fluxes into each cell at the eastern boundary of the model for the three aquifers—layers 2, 4, and 6 (ft^3/d)	500, 700, 2,000, repectively
Head-dependent boundaries:	
General-head package:	
Vertical hydraulic conductivity of Dryden Lake (ft/d)	250,000
Vertical hydraulic conductivity of small ponds and wetlands (ft/d)	0.01–0.3
River package:	
Vertical hydraulic conductivity of Virgil Creek in the vicinity of Virgil Creek Dam (ft/d)	50
Vertical hydraulic conductivity of Virgil Creek downstream of the Virgil Creek Dam (ft/d)	1–2
Vertical hydraulic conductivity of the inlet and outlet to Drydan Lake (ft/d)	1
Vertical hydraulic conductivity of tributary streams that lose water where they flow on alluvial fans and morainal deposits (ft/d)	1–10
Vertical hydraulic conductivity of small tributary streams that lose water where they flow on kame terraces, alluvium, or till (ft/d)	0.1–0.5
Drain package, conductance of drain cell (ft^2/d)/(ft)	20
Hydraulic conductivity (ft/d):	
Layer 1 (vertical hydraulic conductivity)	1
Layer 2 (horizontal hydraulic conductivity):	

Table 11. Parameter values estimated for the groundwater-flow model of the stratified-drift aquifer system in the Virgil Creek and Dryden Lake Valleys, Tompkins County, New York.—Continued

[gal/d, gallons per day; ft/d, feet per day; ft^3/d, cubic feet per day; in/yr, inches per year]

Variable	Value
Moraine	210
Backside of moraine	70–120
Layer 3 (vertical hydraulic conductivity)	0.025
Layer 4 (horizontal hydraulic conductivity)	100–130
Layer 5 (vertical hydraulic conductivity)	0.03
Layer 6 (horizontal hydraulic conductivity):	
Southern part (moraine area)	300
Northern part (backside of moraine)	35–200
Model error, root mean square error	3.8

[a]Recharge derived from 11.3 square miles of upland area

A hydrograph-separation analysis was not done to determine the median annual base flow at the Virgil Creek at State Highway 13 streamgage site because of the following limitations at that site: (1) a flood-control reservoir (Virgil Creek Dam) that slowly releases runoff after a storm, which would result in an apparent decrease in surface runoff and an apparent increase in base flow, and (2) a short period of record (2 years; a long-term station (more than 10 years) is more representative of long-term climatological conditions than a short-term station and provides a more reliable base-flow estimate because extremes have less weight in the determination of base-flow characteristics). Because of these limitations, the median annual base flow was computed using discharge data from the Sixmile Creek at Bethel Grove, New York (USGS station 4233300, not shown on map), 11 mi southeast of Dryden. The Sixmile Creek at Bethel Grove station has more than 10 years of record and contains no dams or lakes in the upgradient drainage basin. The Sixmile Creek at Bethel Grove and Virgil Creek at State Highway 13 have similar-size drainage areas (39 mi^2 and 30 mi^2, respectively) and similar geologic settings: both drain the backside of the Valley Heads Moraine, have predominantly till at land surface, and contain multiple confined aquifers (Miller and Karig, 2010). The median base flow of Sixmile Creek at Bethel Grove, as determined through a hydrograph-separation analysis using the HYSEP computer program (Sloto and Crouse, 1996), was 36.8 ft^3/s from 1996 to 2007. On the day that the seepage measurements were made in Virgil Creek at the dam site (May 10, 2007), the flow at the Sixmile Creek at Bethel Grove was 39 ft^3/s, which was close to annual median base-flow conditions.

Model Fit

Hydraulic heads computed from the steady-state simulation were compared with the water-table altitudes measured in 57 wells (fig. 33), and groundwater discharges computed from the steady-state simulation were compared with base flow estimated from stream discharge measured at Virgil Creek on May 10, 2007 (fig. 12A). A set of calibration targets was created to provide feedback on the magnitude, direction (high or low), and spatial distribution of the calibration error. Water-level residuals (measured minus simulated water-level altitudes) for the stratified-drift aquifer system are shown on figures 33 and 34 and table 12. The calibration target (fig. 33) is drawn such that the height of the target is equal to twice the confidence interval (plus interval on top, minus interval on bottom). The center of the target corresponds to the observed value. The top of the target corresponds to the observed value plus the interval and the bottom corresponds to the observed value minus the interval. The colored bar represents the error. If the bar lies entirely within the target (plus or minus (±) 5 ft), the color bar is drawn in green. A simulated head within the ±5-ft confidence interval was considered a good agreement with the measured value because the average annual fluctuation of water levels in the aquifers in the study area ranges from 5 to 6 ft (figs. 23 and 24*B*) and the water-level measurements used to calibrate the model (that were taken during various seasons and years) would be within ±5 ft of representing long-term average annual water-level conditions. Therefore, a model calibration target of less than a 5-ft residual is a reasonable goal, and the residual plots for heads indicate that the model simulates the

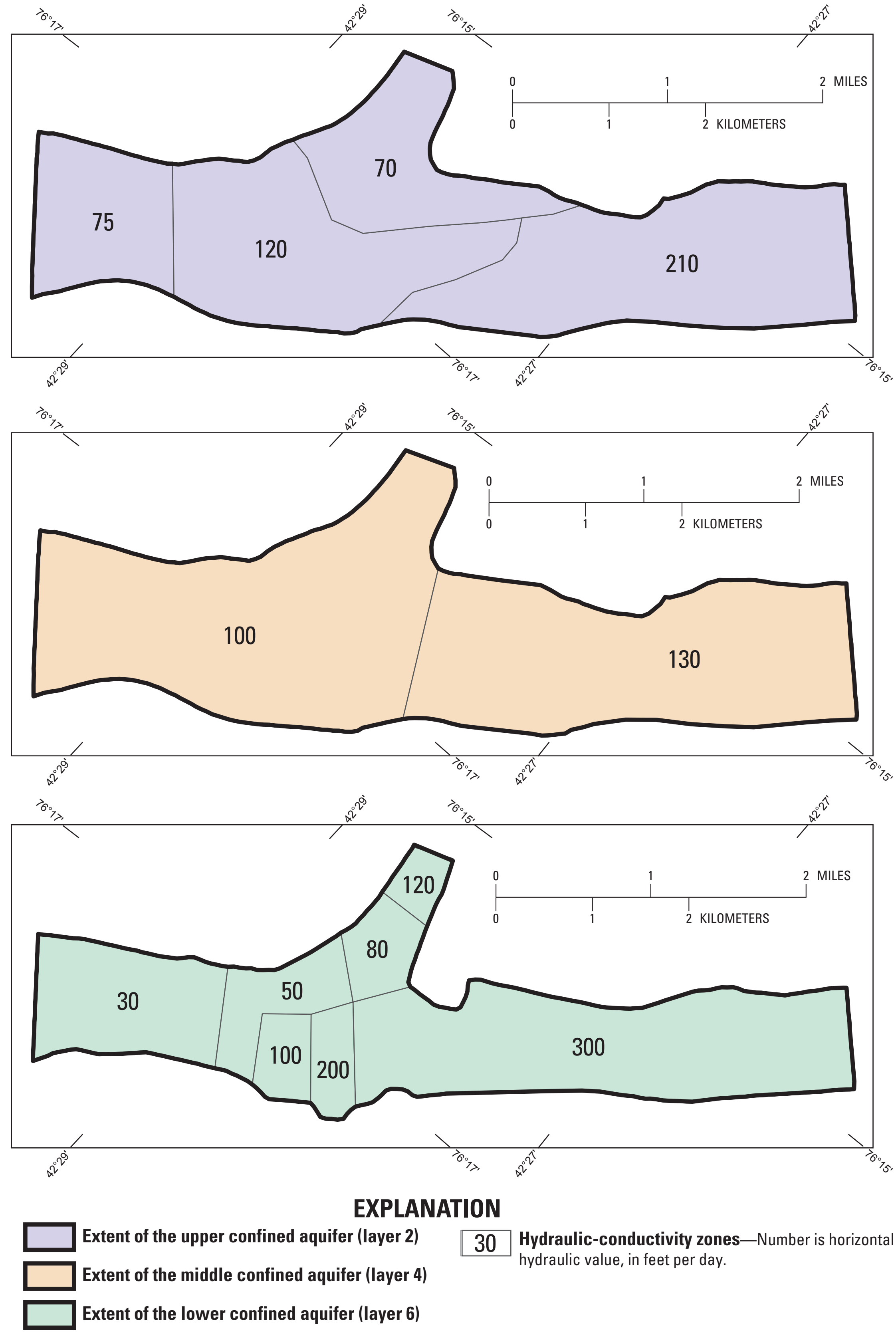


Figure 31. Zones of horizontal hydraulic conductivity of the *A*, upper, *B*, middle, and *C*, lower confined aquifers used in the numerical simulation of groundwater flow in the stratified-drift aquifer system in Virgil Creek and Dryden Lake Valleys, Tompkins County, New York.

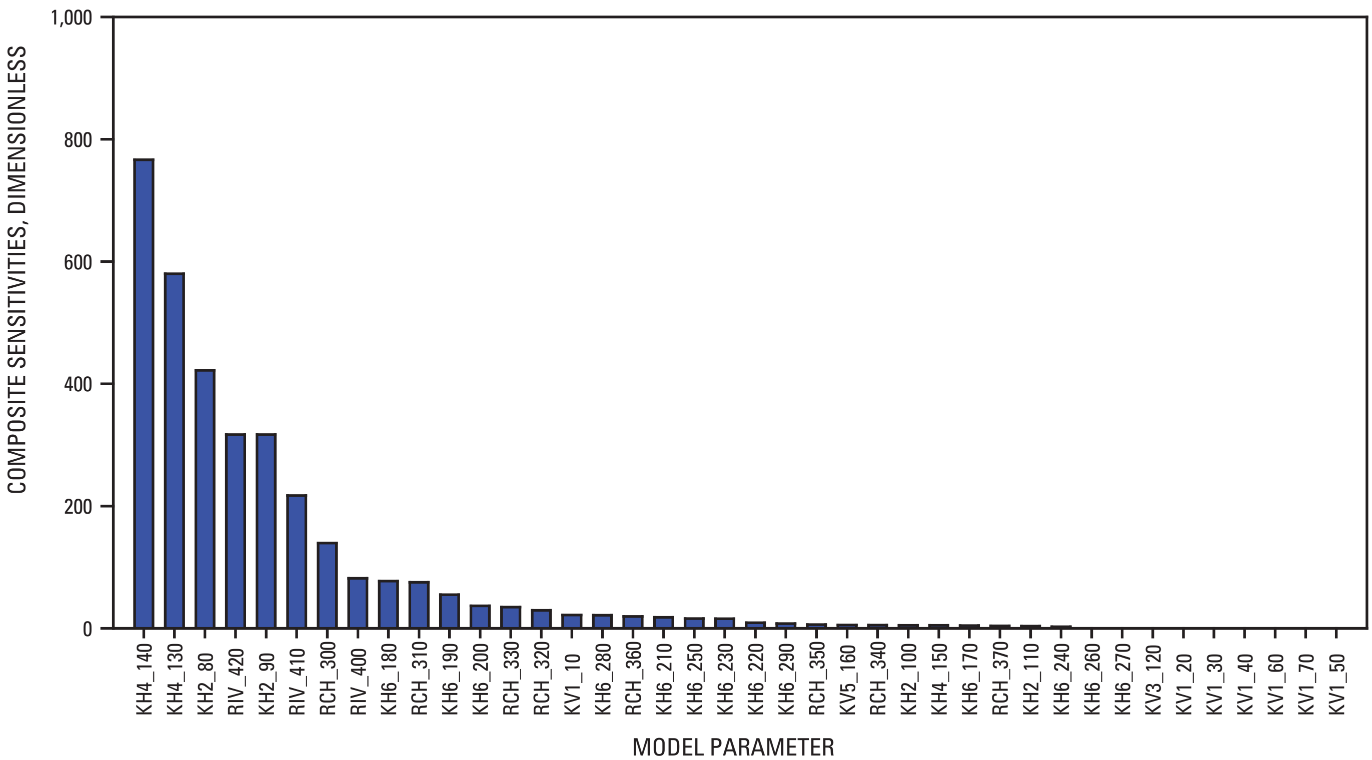


Figure 32. Composite sensitivity of groundwater-flow model output to changes in input parameters, stratified-drift aquifer system in the Virgil Creek, Dryden Lake, and Owego Creek Valleys, Tompkins and Cortland Counties, New York. KH, horizontal hydraulic conductivity; KV, vertical hydraulic conductivity; RCH, recharge; and RIV, river. Single-digit number following KH, KV, RCH, and RIV designates model layer number; underscore followed by a number designates subareas within a model layer.

groundwater-flow system reasonably well (fig. 33). Residual plots for heads show little bias in model error with the mean residual near zero (fig. 34).

A simulated head within the 10-ft confidence interval (±5 ft of the target) was considered a good agreement with the measured value (observation sites shown with green bars in fig. 33). A simulated head between the 10- and 20-ft confidence intervals (more than ±5 ft but less than ±10 ft) was considered a moderate agreement with the measured value (observation sites shown with yellow bars in fig. 33). A simulated head greater than the 20-ft confidence intervals (greater than ±10 ft of the target) would have been considered a poor agreement, and the bar would have been drawn in red. All 57 well observations (figs. 33 and 34; table 12) were less than the 20-ft confidence interval (±10 ft of the target). Of the 57 observation sites (green bars in fig. 33), 46 were entirely within 100 percent of the 10-ft confidence interval (plus or minus 5 ft of the target), and 11 were between 100 and 200 percent of the confidence interval (±5 to 10 ft of the target, shown as yellow bars in fig. 33). The moderate agreement at the 11 sites that were between 100 and 200 percent of the confidence interval may be a result of inaccurately reported data, such as wrong well location (erroneous latitude and longitude coordinates or wrong reported address) or erroneous measured or reported water-level measurements. Alternatively, the moderate agreement may be a result of local geohydrologic heterogeneities or complexities that the model does not include because glacial stratigraphy is typically complex and the numerical groundwater-flow model is a simple representation of the groundwater-flow system of the study area.

Model calibration was considered satisfactory when (1) simulated heads were less than ±10 ft of the measured heads and (2) the root-mean-square error (a statistical measure of the magnitude of a varying quantity, which is especially useful when variations are positive and negative between differences of measured and simulated heads) for all observation wells was less than 4 ft (the root-mean-square error for the final model was 3.8 ft, table 12). However, the model-computed loss of discharge (0.89 ft^3/d) for Virgil Creek near the dam was less than the loss (1.19 ft^3/d) as measured on May 10, 2007. The root-mean-square error for water levels in the upper, middle, and lower confined aquifers (model layers 2, 4, and 6) were 4.3, 3.7, and 2.3, respectively. Most

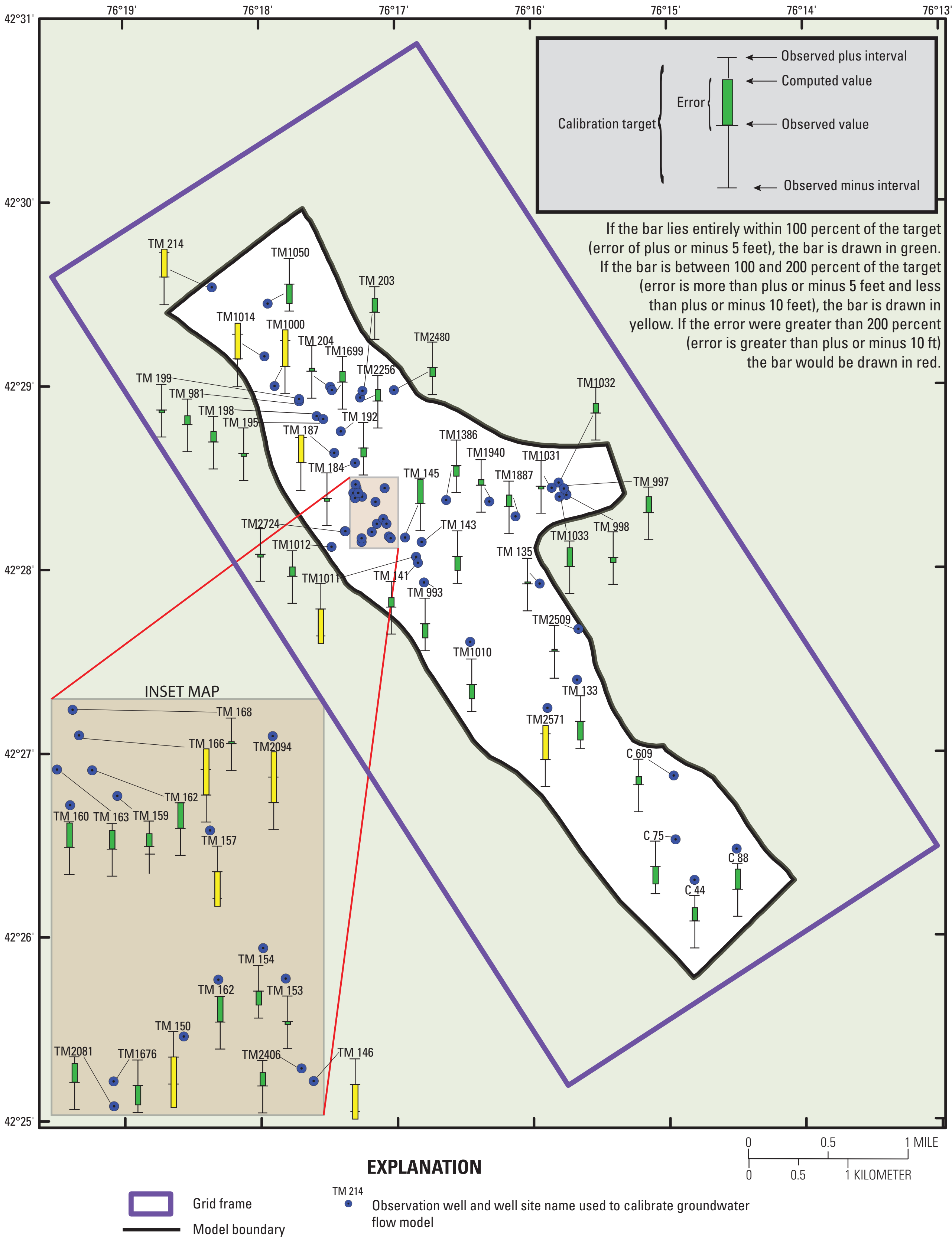


Figure 33. Groundwater-level residuals for simulated heads in the numerical groundwater-flow model of the stratified-drift aquifer system in Virgil Creek and Dryden Lake Valleys, Town of Dryden, Tompkins County, New York.

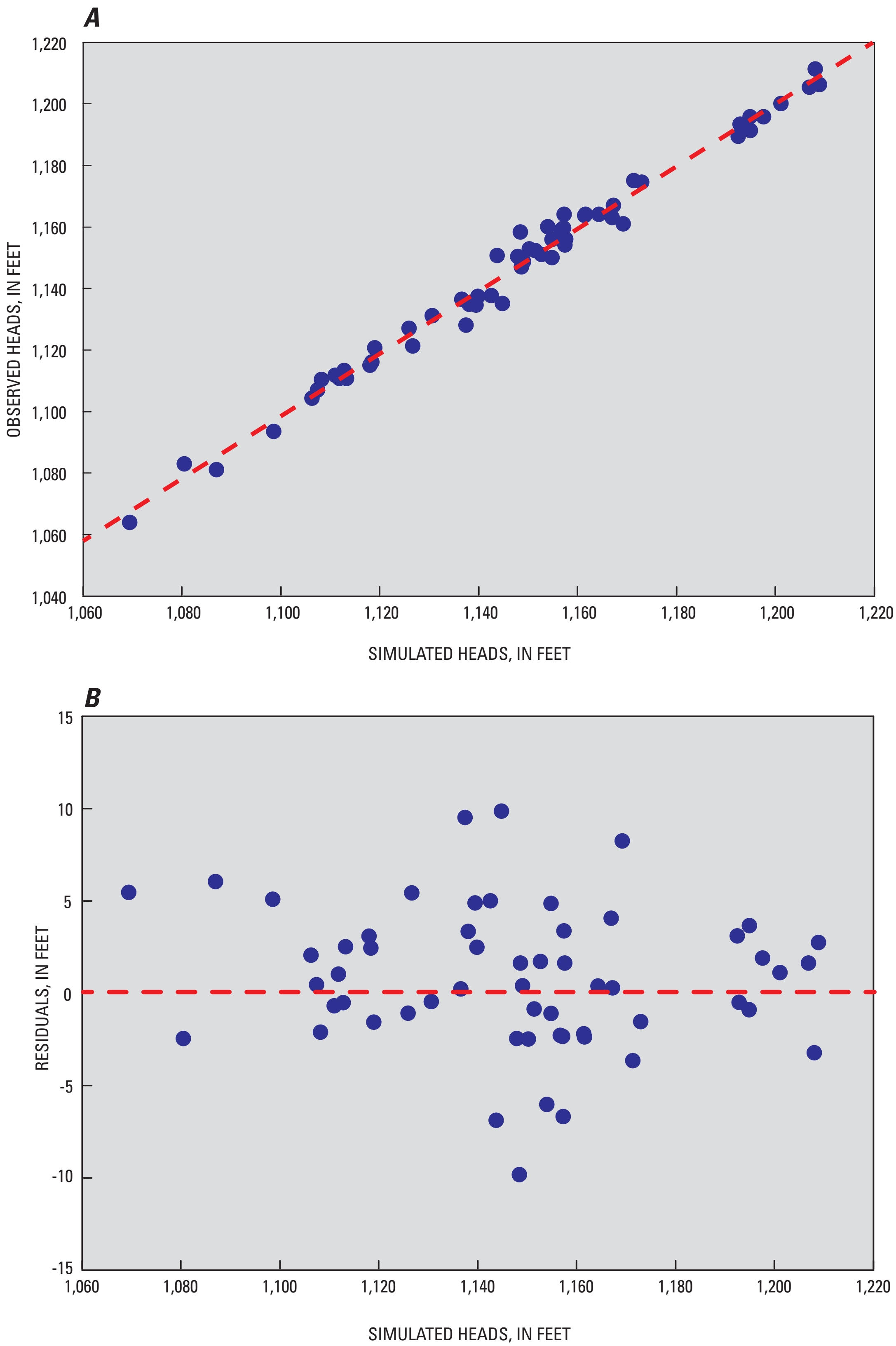


Figure 34. Plots showing residuals for simulated heads in the numerical groundwater-flow model, showing relation between *A*, simulated and observed values and *B*, simulated values and residuals.

Table 12. Measured and simulated water levels in wells open to the stratified-drift aquifers in the Virgil Creek, Dryden Lake, and Owego Creek Valleys, Towns of Dryden and Harford, Tompkins and Cortland Counties, New York.

[NGVD29, National Geodetic Vertical Datum of 1929; TM, Tompkins County well; C, Cortland County well]

Well name	Model layer	Water level altitude in feet above NGVD29		Residual (measured minus simulated) in feet above NGVD29
		Measured	Simulated	
TM 133	4	1,175.0	1,171.3	3.7
TM 135	4	1,164.0	1,164.4	-0.4
TM 141	4	1,156.0	1,157.6	-1.6
TM 143	4	1,159.0	1,156.7	2.3
TM 145	4	1,150.0	1,154.8	-4.8
TM 146	2	1,160.0	1,154.0	6.0
TM 150	4	1,158.3	1,148.5	9.8
TM 152	4	1,148.7	1,149.1	-0.4
TM 153	4	1,152.3	1,151.4	0.9
TM 154	4	1,152.8	1,150.3	2.5
TM 157	2	1,150.7	1,143.9	6.8
TM 159	2	1,137.4	1,139.9	-2.5
TM 160	2	1,134.6	1,139.5	-4.9
TM 162	4	1,137.6	1,142.6	-5.0
TM 163	2	1,134.8	1,138.1	-3.3
TM 166	2	1,128.0	1,137.5	-9.5
TM 168	2	1,136.4	1,136.6	-0.2
TM 184	2	1,131.1	1,130.6	0.5
TM 187	4	1,121.3	1,126.7	-5.4
TM 192	2	1,120.6	1,119.0	1.6
TM 195	2	1,113.3	1,112.8	0.5
TM 198	4	1,110.8	1,113.3	-2.5
TM 199	6	1,111.7	1,111.0	0.7
TM 203	2	1,115.0	1,118.1	-3.1
TM 204	2	1,107.0	1,107.4	-0.4
TM 214	4	1,064.0	1,069.4	-5.4
TM 993	6	1,163.7	1,161.5	2.2
TM 981	4	1,104.3	1,106.3	-2.0
TM 997	6	1,189.4	1,192.5	-3.1
TM 998	4	1,195.8	1,194.9	0.9
TM1000	2	1,093.5	1,098.6	-5.1
TM1010	4	1,164.0	1,161.6	2.4
TM1011	2	1,164.0	1,157.3	6.7
TM1012	2	1,147.0	1,148.6	-1.6
TM1014	2	1,081.0	1,087.0	-6.0
TM1031	4	1,193.4	1,192.9	0.5
TM1032	2	1,195.7	1,197.6	-1.9

Table 12. Measured and simulated water levels in wells open to the stratified-drift aquifers in the Virgil Creek, Dryden Lake, and Owego Creek Valleys, Towns of Dryden and Harford, Tompkins and Cortland Counties, New York.—Continued

[C, Cortland County well; NGVD29, National Geodetic Vertical Datum of 1929; TM, Tompkins County well]

Well name	Model layer	Water level altitude in feet above NGVD29		Residual (measured minus simulated) in feet above NGVD29
		Measured	Simulated	
TM1033	2	1,191.3	1,194.9	-3.6
TM1386	2	1,159.6	1,157.2	2.4
TM1699	4	1,110.8	1,111.8	-1.0
TM1887	4	1,174.5	1,172.9	1.6
TM2081	6	1,154.1	1,157.5	-3.4
TM2256	1	1,116.0	1,118.4	-2.4
TM2480	1	1,127.0	1,125.9	1.1
TM2571	2	1,161.0	1,169.2	-8.2
C 44	4	1,205.3	1,206.9	-1.6
C 88	2	1,206.2	1,208.9	-2.7
Median				-0.4
Maximum				9.8
Root mean square error				3.8

observation wells were in the upper and middle confined aquifers (25 and 26 observation wells, respectively). Only five observation wells were in the lower confined aquifer.

Water-level residuals (measured minus simulated water-level altitudes) for the stratified-drift aquifers are listed in table 12. Statistics were calculated for the water-level residuals, including median (-0.4 ft), mean (-0.8 ft), root-mean-square error (3.8 ft), maximum (9.8 ft), and minimum (-9.8 ft). Of the water-level residuals, 33 percent are less than zero, 24 percent are greater than zero, and 50 percent range from -2 to 2 ft.

Model Applications

The model was used as a tool to (1) better understand the groundwater-flow system in the stratified-drift aquifer system in Virgil Creek and Dryden Lake Valleys in Tompkins County, (2) estimate the areas contributing recharge to the production wells in the Village of Dryden in the northern part of the study area and to a hypothetical pumping well at the site of test well TM2724 near Keith Lane in the central part of the study area (location shown in fig. 8), and (3) compute a water budget.

Groundwater-Flow Directions

The numerical groundwater-flow model outputs cell-by-cell water levels from which maps of the potentiometric surfaces of the aquifers can be made and used to show the direction of groundwater flow. The distribution of water levels and the generalized groundwater-flow directions (shown by arrows) in plan view for the three confined aquifers (model layers 2, 4, and 6) are shown on figures 35A, B, and C, respectively. The distribution of water levels and the generalized groundwater-flow directions in a longitudinal hydrologic sectional view are shown on figure 36. The direction of groundwater flow is perpendicular to potentiometric contours.

North of the drainage divide separating the Dryden Lake Valley from the Owego Creek Valley, the horizontal component of groundwater flow in the upper and middle aquifers is generally to the northwest (figs. 35A, B). In the Virgil Creek Valley, the horizontal component of groundwater flow in the upper and middle confined aquifers initially flows westward from the eastern boundary of the model to the junction of Virgil Creek Valley with Dryden Lake Valley, where it then flows to the northwest (figs. 35A, B).

The horizontal and vertical components of groundwater-flow directions in the upper and middle confined aquifers are locally controlled by the distribution of surface-water bodies such as Dryden Lake, Virgil Creek downstream from the dam, and the stream that drains Dryden Lake (figs. 35A, B, and 36), which are groundwater-discharge zones. In the central part of the study area, most groundwater in the upper and middle confined aquifers discharges into these surface-water bodies listed above. In the northern part of the study area, groundwater discharges to Virgil Creek, to the Village of Dryden production wells TM 981 (which taps the middle confined aquifer) and TM 202 and TM 204 (which tap the upper confined aquifer), and as underflow out through the northern boundary of the study area.

In the Dryden Lake Valley, the horizontal component of groundwater flow in the lower confined aquifer is predominantly to the northwest from the drainage divide in the southern part of the study area to the northern end of the model (figs. 35C and 36), where some groundwater discharges to the Village of Dryden production well TM1046 at the South Street pumping station and the remainder discharges as underflow out through the northern boundary of the study area. In the Virgil Creek Valley, the horizontal component of groundwater flow in the lower confined aquifer is predominantly westward from the eastern boundary of the model to the junction of Virgil Creek Valley with Dryden Lake Valley, where it then flows to the northwest and leaves the study area as underflow out through the northern boundary of the study area (figs. 35C and 36).

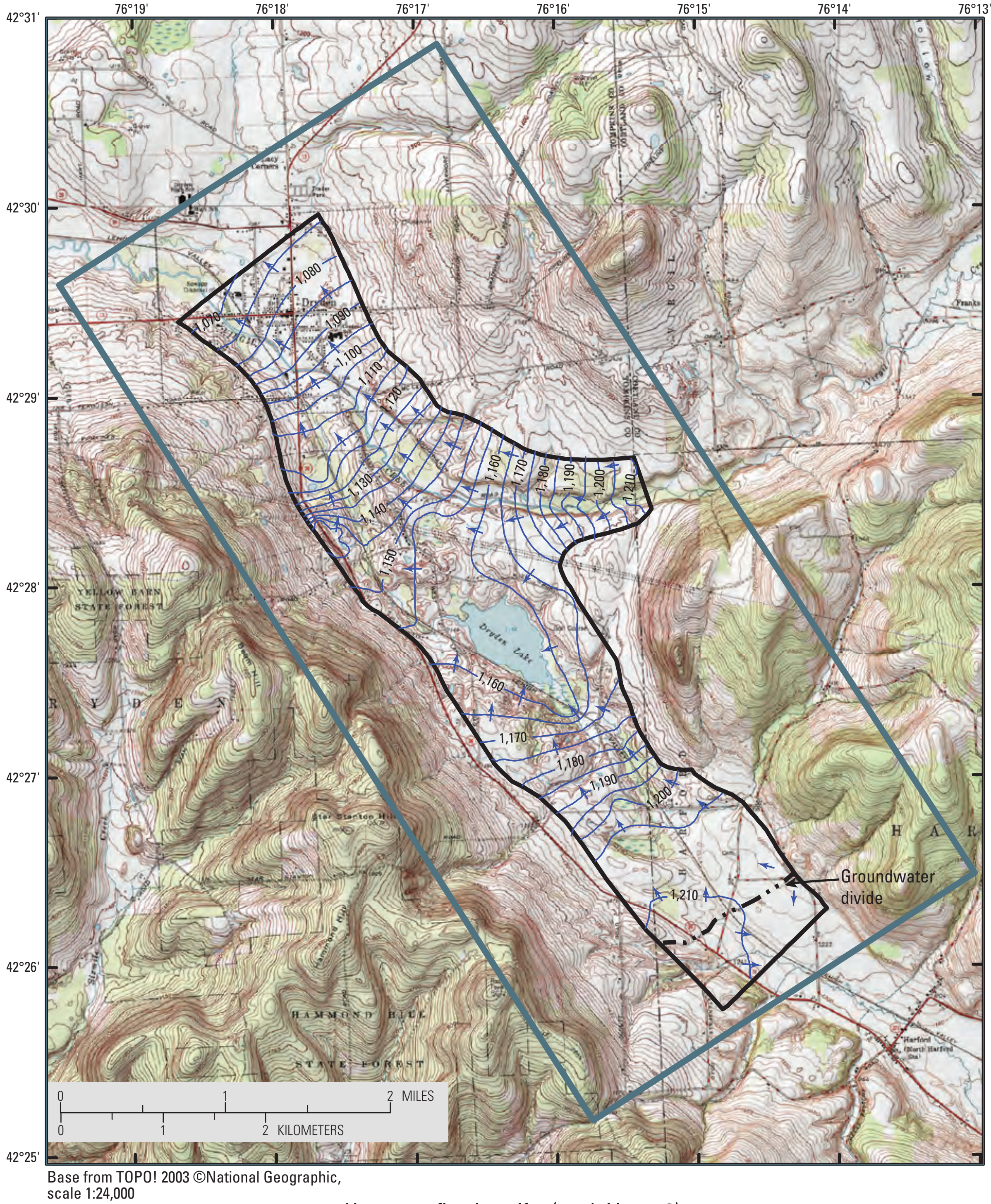
The general vertical component of groundwater flow in the aquifer system is downward in the southern part (where large amounts of recharge occur at the Valley Heads Moraine), upward southwest of Dryden Lake in the central part (a major discharge area), and slightly upward in most of the northern part of the study area, except near the northern boundary, where flow is predominantly horizontal (fig. 36).

Areal Extent of the Zones of Groundwater Contribution to the Village of Dryden Municipal Production Wells

The areal extent of the zones of groundwater contribution to three Village of Dryden municipal production wells TM 202, TM 981, and TM1046 and to one hypothetical well at test well site TM2724 near Keith Lane were delineated through MODPATH, a particle-tracking program that computes three-dimensional flow paths using the output from the steady-state MODFLOW–2000 program. These delineations provide the Village of Dryden, the Town of Dryden, and Tompkins County with the approximate boundaries of the parts of the aquifer system that need to be managed to protect the water quality of this drinking-water resource. The MODPATH particle-tracking analyses were done with simulations that assumed average annual recharge conditions and average pumping conditions for 2005–7. During 2005–7, the average daily pumping rates for the Village of Dryden production wells TM1046, TM 981, and TM 202 were 125,300 gal/d (16,750 ft^3/d or 87 gal/min), 93,900 gal/d (12,550 ft^3/d or 65 gal/min), and 30,600 gal/d (4,100 ft^3/d or 21 gal/min), respectively. Although the daily average pumping rate for TM 202 (which was pumped intermittently for 2005–7) was 30,600 gal/d (4,100 ft^3/d or 21 gal/min), for the purposes of determining the areal extent of the zones of groundwater contribution under conditions that the well would be used more regularly, a simulated pumping rate of 72,000 gal/d (9,600 ft^3/d or 50 gal/min) was used (pump capacity is estimated to range from 50 to 60 gal/min). The simulated pumping rate for the hypothetical well was 288,000 gal/d (38,500 ft^3/d or 200 gal/min). Backward tracking simulations were used to track imaginary particles starting from the pumping wells to where the recharge enters the aquifer system. The average traveltime for groundwater flow in the aquifers was estimated using a porosity of 0.3 (30 percent) for sand and gravel, which is an assumed median aquifer porosity used for other stratified-drift model studies in upstate New York (Zarriello, 1993; Coon and others, 1997; Miller, 1998). Porosity was held constant at 0.3 for the entire system; any variability in porosity, which likely occurs because of the complex glacial geology, will change the calculated traveltimes.

Plan views of the areal extent of the zones of groundwater contribution to Village of Dryden production wells TM 202 (Lake Road pumping station, finished in the upper confined aquifer) and TM 981 (Jay Street pumping station, finished in the middle confined aquifer) are shown on figure 37. The areal extent of the zones of groundwater contribution to production wells TM 202 and TM 981 are 0.51 mi^2 and 0.94 mi^2, respectively. The areal extent of the

A



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Upper confined aquifer (model layer 2)

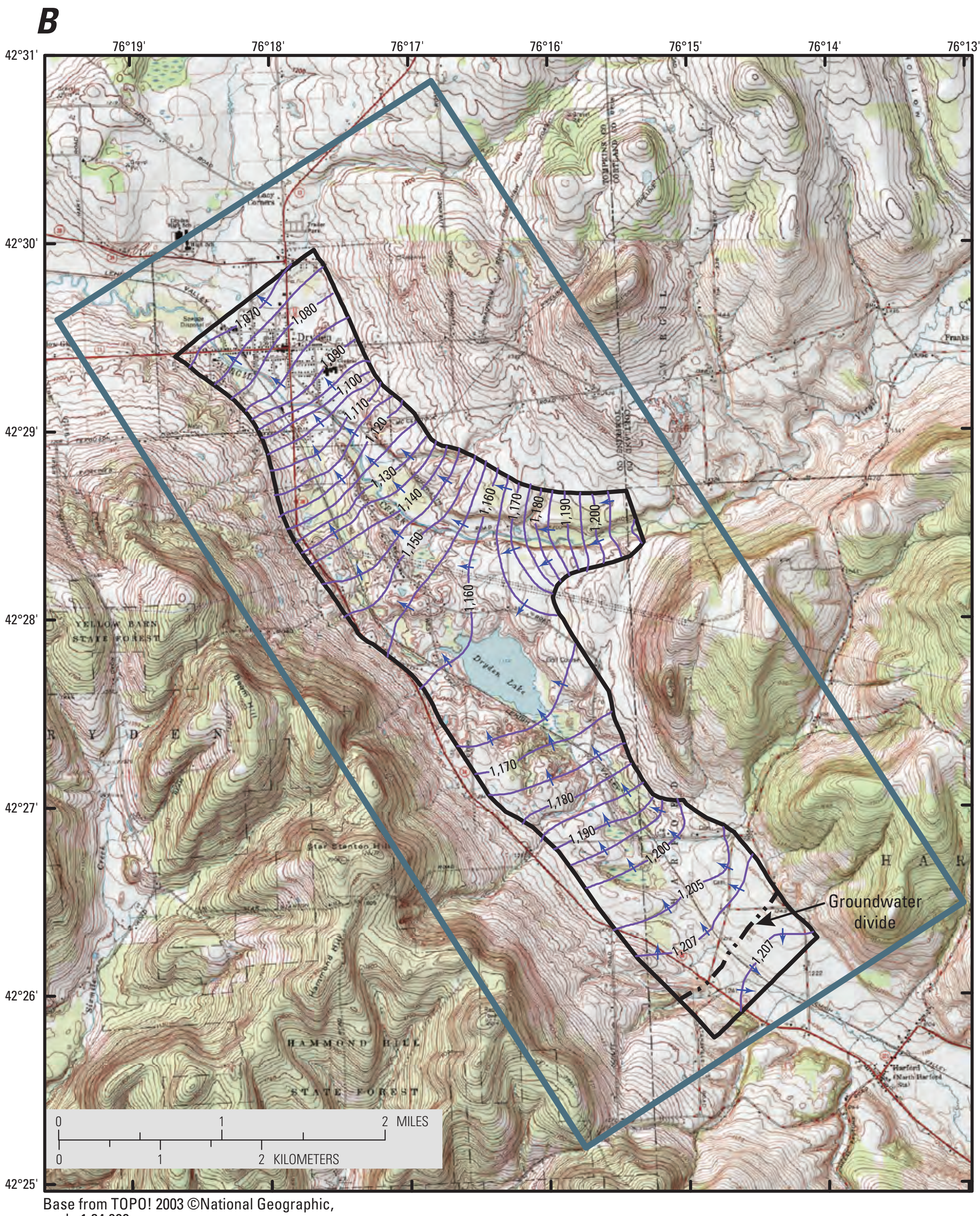
EXPLANATION

Grid frame

Model boundary

1,190 **Potentiometric contour**— Contour interval 5 feet. Datum is National Geodetic Vertical Datum of 1929. Arrow indicates direction of groundwater flow.

Figure 35. Distribution of hydraulic head computed by steady-state simulation for the stratified-drift aquifer system in Virgil Creek and Dryden Lake Valleys in Tompkins County and the headwaters of Owego Creek Valley in Cortland County, New York: *A,* upper confined aquifer (model layer 2), *B,* middle confined aquifer (model layer 4), and *C,* lower confined aquifer (model layer 6).



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Middle confined aquifer (model layer 4)

EXPLANATION

Grid frame

Model boundary

1,190 **Potentiometric contour**— Contour interval 5 feet except noted differently near drainage divide. Datum is National Geodetic Vertical Datum of 1929. Arrow indicates direction of groundwater flow.

Figure 35. Distribution of hydraulic head computed by steady-state simulation for the stratified-drift aquifer system in Virgil Creek and Dryden Lake Valleys in Tompkins County and the headwaters of Owego Creek Valley in Cortland County, New York: *A,* upper confined aquifer (model layer 2), *B,* middle confined aquifer (model layer 4), and *C,* lower confined aquifer (model layer 6).—Continued

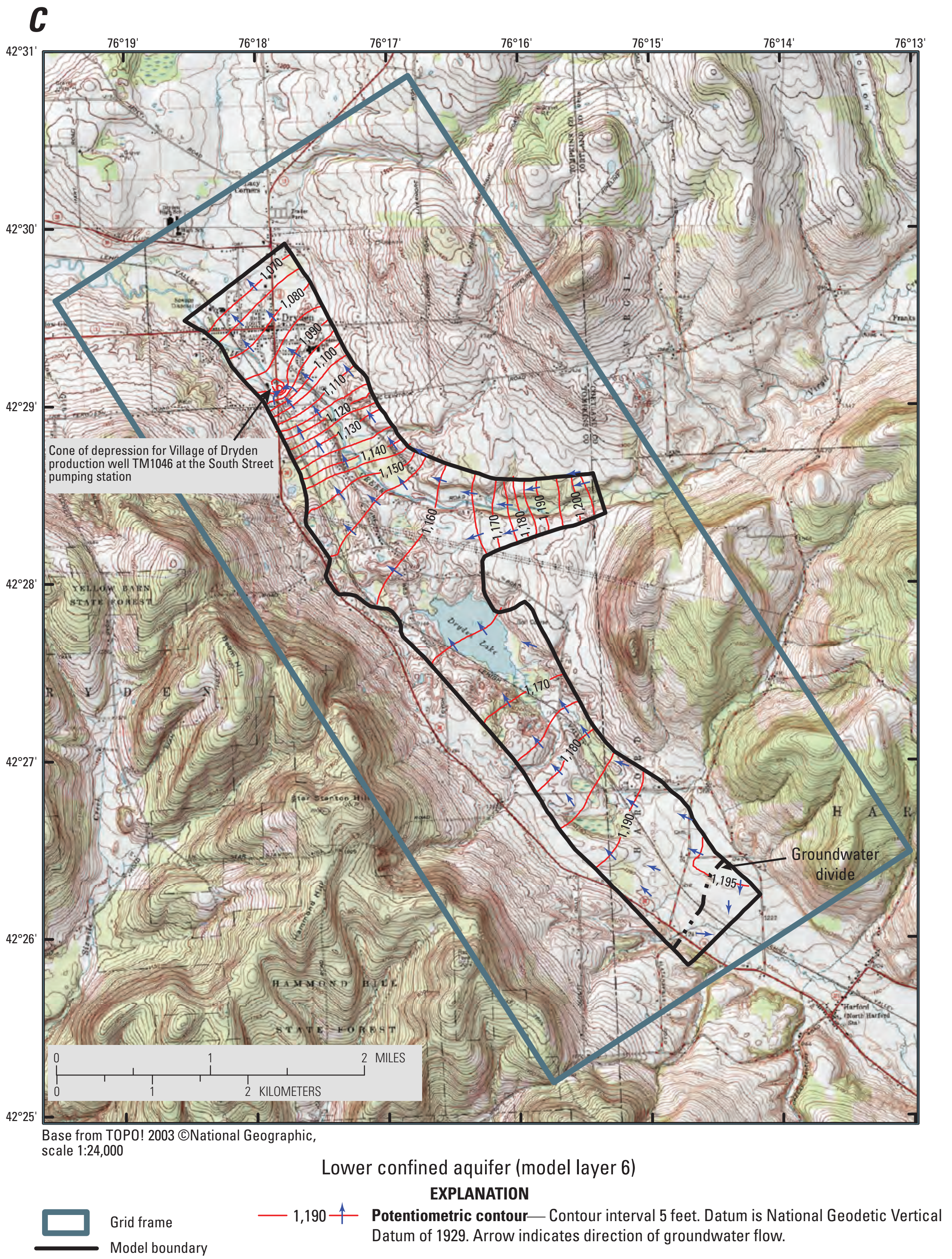


Figure 35. Maps showing distribution of hydraulic head computed by steady-state simulation for the stratified-drift aquifer system in Virgil Creek and Dryden Lake Valleys in Tompkins County and the headwaters of Owego Creek Valley in Cortland County, New York. *A,* Upper confined aquifer (model layer 2). *B,* Middle confined aquifer (model layer 4). *C,* Lower confined aquifer (model layer 6).

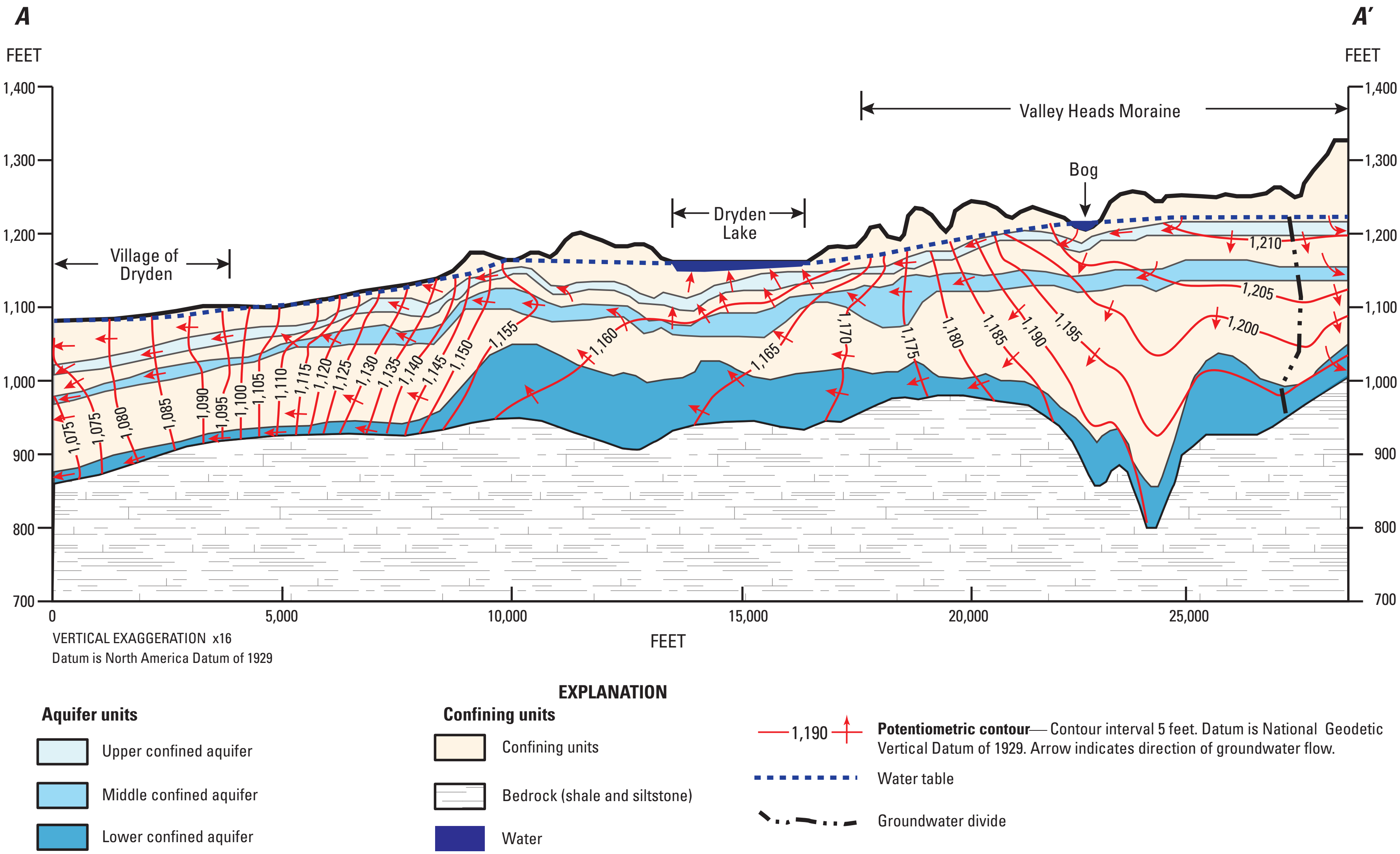
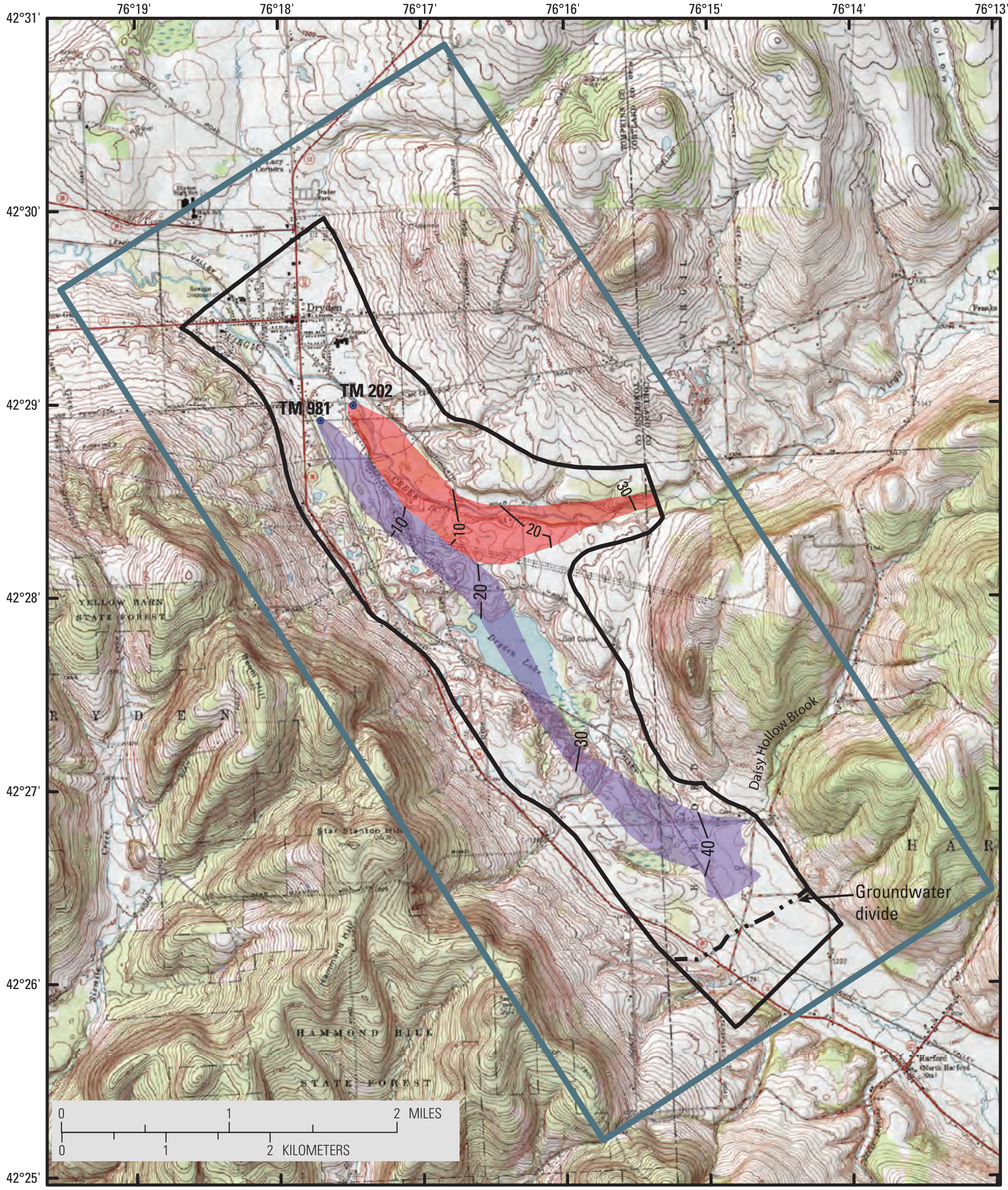


Figure 36. Groundwater flow in a longitudinal hydrologic cross-section A–A′ in the central part of the numerical groundwater model study area, Town of Dryden, Tompkins County, and Town of Harford, Cortland County, New York. Location of line of section shown on figure 8.



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EXPLANATION

Grid frame

Model boundary

—10— **Areal extent of the zone of groundwater contribution to the Village of Dryden production well TM 202 at Lake Street**—Contour interval is the time, in years, for groundwater to travel to the well.

—10— **Areal extent of the zone of groundwater contribution to the Village of Dryden production well TM 981 at Jay Street**—Contour interval is the time, in years, for groundwater to travel to the well.

Figure 37. The estimated areal extent of the zones of groundwater contribution and time of travel to Village of Dryden production wells TM 202, which is finished in the upper confined aquifer (model layer 2), and TM 981, which is finished in the middle confined aquifer (model layer 4), in the Dryden Lake and Virgil Creek Valleys, Tompkins County, New York.

zone of groundwater contribution to well TM 202 extends 2.2 mi southeast into the Virgil Creek Valley, while the areal extent of the zone of groundwater contribution to well TM 981 extends 3.8 mi south in the Dryden Lake Valley. The furthest starting points for pathlines that simulate flow to well TM 202 (Lake Road production well) are where Virgil Creek loses water to (recharges) the upper aquifer near the Virgil Creek Dam. Model results indicate that it takes approximately 30 years for groundwater to flow from the eastern end of the model boundary (in the vicinity of the Virgil Creek Dam) to pumping well TM 202. The furthest starting points for pathlines that simulate flow to well TM 981 (Jay Street production well) are near the groundwater divide between the Susquehanna River Basin and Great Lakes Basin in the southern part of the Dryden Lake Valley. Model results indicate that it takes approximately 40 years for groundwater to flow from the southern end of the model boundary (near the groundwater divide between the Susquehanna River Basin and Great Lakes Basin) to pumping well TM 981.

The plan view of the areal extent of the zone of groundwater contribution to the Village of Dryden municipal production well TM1046 (South Street pumping station, finished in the lower confined aquifer) is shown on figure 38. The areal extent of the zone of groundwater contribution to this well is 1.4 mi^2 and extends 2.4 mi southeast into the Dryden Lake Valley and 0.5 mi east into the Virgil Creek Valley. In the Dryden Lake Valley, the furthest starting points for pathlines that simulate flow to production well TM1046 are at Daisy Hollow Brook and the groundwater divide between the Susquehanna River and Great Lakes Basins. In the Virgil Creek Valley, the furthest starting points for pathlines that simulate flow to production well TM1046 are at Virgil Creek at the Virgil Creek Dam area. The actual zone of groundwater contribution may extend beyond the southern model boundary; however, there were insufficient data on the flow conditions in the lower confined aquifer in the southern part of the study area to determine whether that is the case.

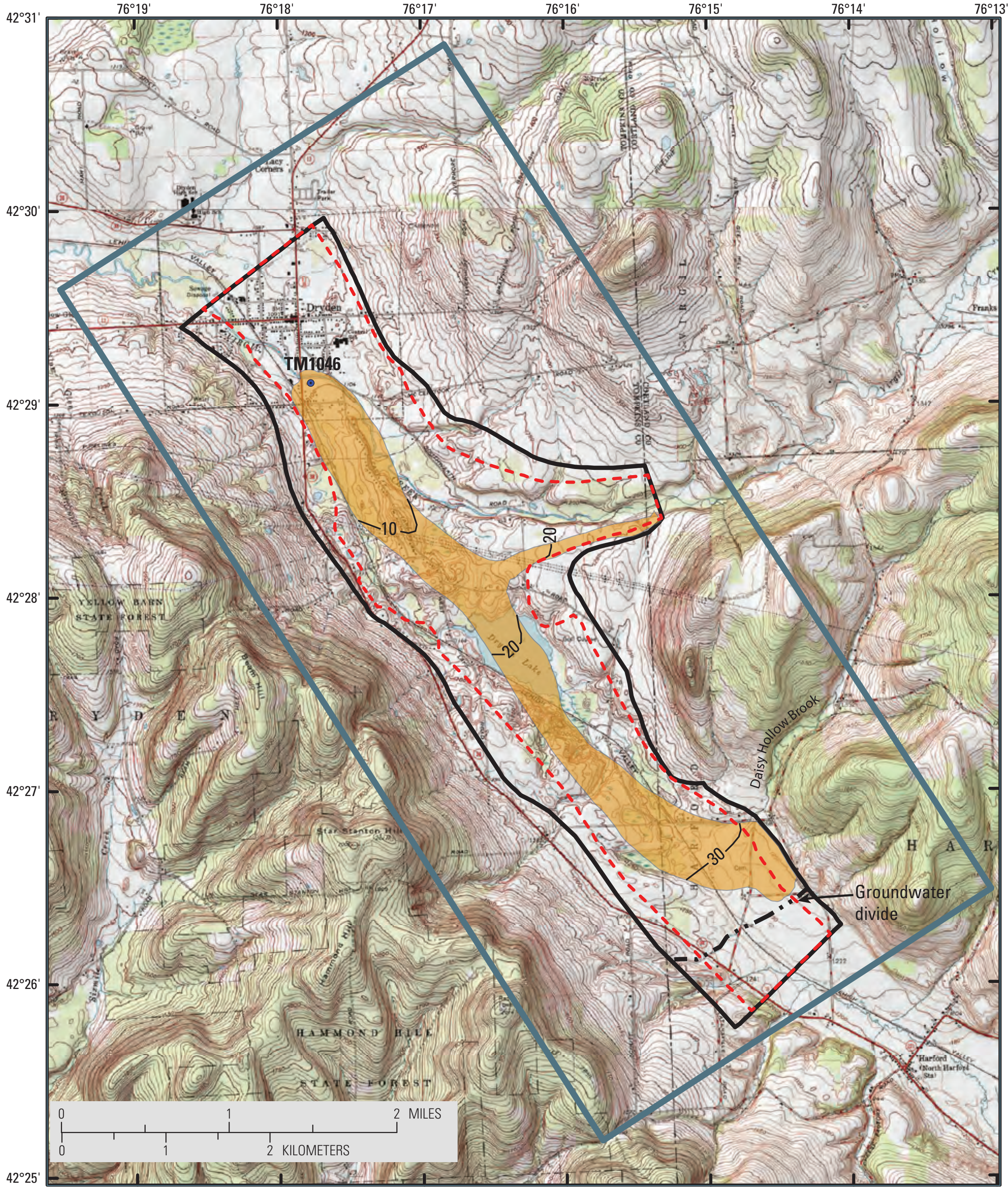
As development increases in the Town of Dryden, the need for more water will increase. One potential location for a production well is at test-well site TM2724 (on the Jim Schug trail near Keith Lane in the central part of the study area), where relatively thick aquifer units were encountered. A particle-tracking analysis was conducted for a hypothetical well finished in the lower confined aquifer at this site and for existing Village of Dryden municipal production well TM1046 at the South Street pumping station, also finished in the lower confined aquifer. Plan views of the zones of groundwater contribution to Village of Dryden municipal production well TM1046 and to a hypothetical well at test-well site TM2724 are shown on figure 39. The simulated pumping rate for the Village of Dryden municipal production well TM1046 was 125,300 gal/d (87 gal/min), and the simulated pumping rate for the hypothetical well at test-well site TM2724 was 288,000 gal/d (200 gal/min). The zones of groundwater contribution to municipal production well TM1046 and to a hypothetical well pumped at test-well site TM2724 are 1.2 mi^2 and 0.86 mi^2, respectively. The zone of groundwater contribution for municipal production well TM1046 extends 4 mi down the eastern part of the Dryden Lake Valley and 0.5 mi into Virgil Creek Valley, while the zone of groundwater contribution for the hypothetical well near Keith Lane extends 3.4 mi down the western part of the Dryden Lake Valley. The results of the simulation with municipal production well TM1046 and the hypothetical well (both finished in the lower confined aquifer) indicate that the wells would interfere with one another. With the simulated hypothetical well pumping at a rate of 200 gal/min, the zone of groundwater contribution for municipal production well TM1046 shifted 500 ft to the east (figs. 38 and 39).

In the Dryden Lake Valley, the furthest starting points for pathlines that simulate flow to well TM1046 are at Daisy Hollow Brook and at the groundwater divide between the Susquehanna River and Great Lakes Basins (fig. 37). In the Virgil Creek Valley, the furthest starting points for pathlines that simulate flow to well TM1046 are at Virgil Creek at the Virgil Creek Dam area (fig. 39). In the Dryden Lake Valley, the furthest starting points for pathlines that simulate flow to the hypothetically pumped well (TM2724) are at the groundwater divide between the Susquehanna River and Great Lakes Basins (fig. 39). The actual areal extent of the zone of groundwater contribution may extend beyond the southern model boundary; however, there are not sufficient data on the flow conditions in the lower confined aquifer in the southern part of the study area to corroborate this hypothesis.

Water Budget

The water budget for simulated average annual, steady-state conditions with three simulated discharging wells representing the Village of Dryden municipal production wells is given in table 13. The model-computed water budget indicated that the sources of recharge to the confined aquifer system are precipitation that falls directly on the valley-fill sediments (40 percent of total recharge), stream leakage (35.5 percent), seepage from wetlands and ponds (12 percent), unchanneled runoff and groundwater inflow from the uplands (8.5 percent), and groundwater underflow into the eastern end of the modeled area (4 percent).

Most groundwater discharges to surface-water bodies (table 13), including (1) streams (33 percent of total discharge), (2) Dryden Lake (33 percent), and (3) wetlands and ponds (10 percent), but some groundwater discharges (4) as underflow out the northern end (11 percent) and southern end (4 percent) of the simulated area, (5) to simulated pumping wells (4.5 percent), and (6) to drains that represent seepage from the bluffs exposed in the gorge in the vicinity of the Virgil Creek Dam (4.5 percent). More water discharges as underflow out of the northern end of the study area than the southern end because the majority of recharge occurs in the Virgil Creek and Dryden Lake parts of the system and the simulated groundwater divide is close to the surface-water divide near the southern end of the study area.



Base from TOPO! 2003 ©National Geographic, scale 1:24,000

EXPLANATION

Grid frame

Model boundary (layers 1 through 5)

Model boundary (layer 6)

10 **Areal extent of the zone of groundwater contribution to Village of Dryden production well TM 1046 at South Street**—Contour interval is the time, in years, for groundwater to travel to the well.

Figure 38. The estimated areal extent of the zone of groundwater contribution and time of travel to Village of Dryden production well TM1046, which is finished in the lower confined aquifer (model layer 6), in the Dryden Lake and Virgil Creek Valleys, Tompkins County, New York.

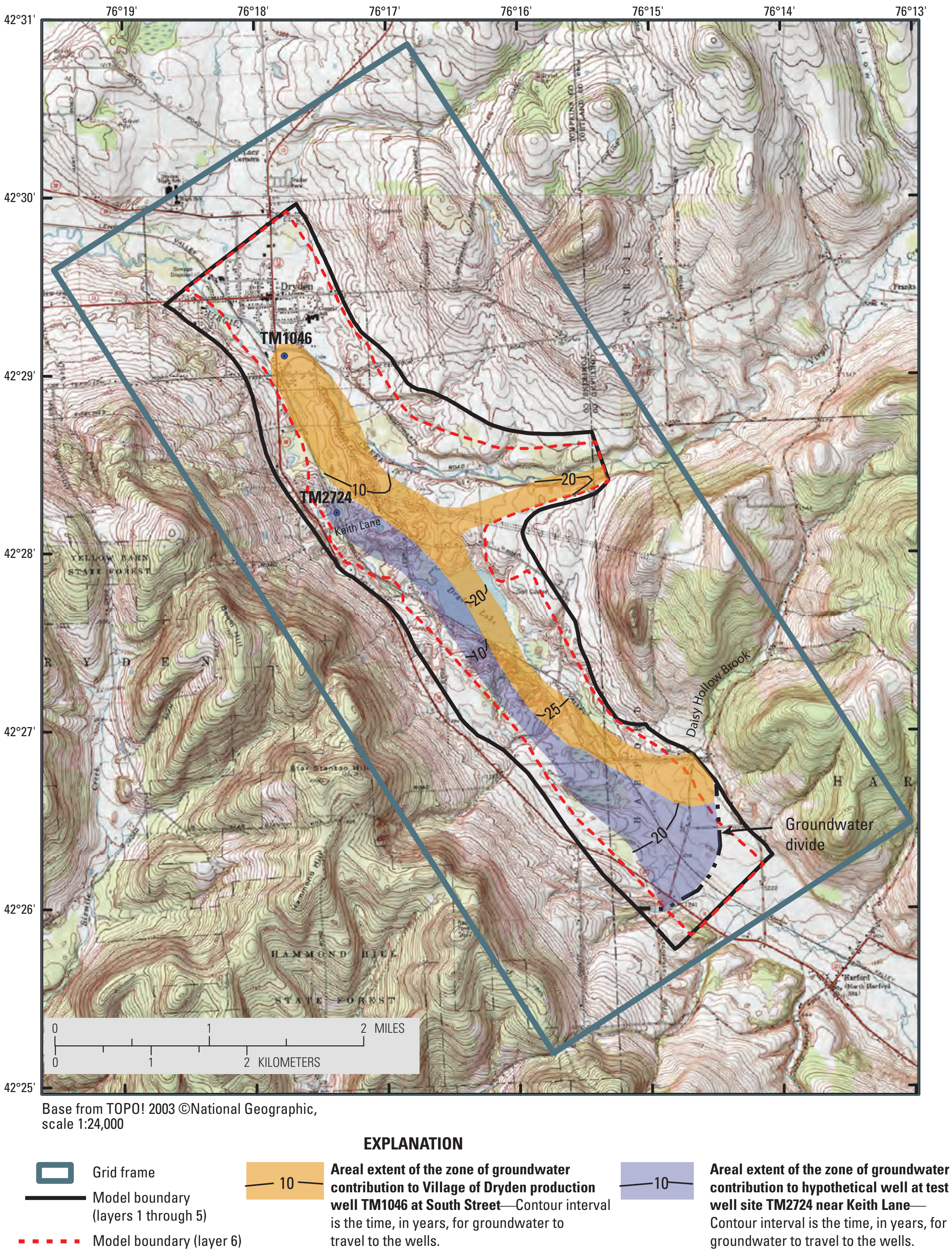


Figure 39. Estimated areal extent of the zones of groundwater contribution and time of travel to Village of Dryden production well TM1046, which is finished in the lower confined aquifer (model layer 6), and to a hypothetical well at test-well site TM2724 near Keith Lane, also finished in the lower confined aquifer, in the Dryden Lake and Virgil Creek Valleys, Tompkins County, New York.

Table 13. Simulated water budget for the stratified-drift aquifer system in the Virgil Creek and Dryden Lake Valleys, Town of Dryden, Tompkins County, and in part of the Owego Creek Valley, Town of Harford, Cortland County, New York

[ft^3/d, cubic feet per day; ft^3/s, cubic feet per second

	Inflow volume, in ft^3/d	Inflow volume, in ft^3/s	Percent
Recharge			
Precipitation that falls directly over the valley-fill sediments	286,500	3.32	40
Upland sources:			
Seepage losses from streams	253,200	2.93	35.5
Unchanneled runoff and underflow from uplands	60,300	0.69	8.5
Leakage from wetlands and ponds	87,900	1.02	12
Groundwater underflow entering Virgil Creek valley	27,500	0.32	4
Total	715,400	8.28	100
Discharge			
Streams	233,000	2.70	33
Dryden Lake	237,600	2.75	33
Groundwater flow out ends of the modeled area:			
Northern end	78,200	0.90	11
Southern end	31,900	0.37	4
Wetlands and ponds	70,500	0.82	10
Pumping wells	32,000	0.37	4.5
Drains along the Virgil Creek gorge near the dam	32,200	0.37	4.5
Total	715,400	8.28	100

Model Limitations

The numerical simulations of the stratified-drift aquifer system in Virgil Creek and Dryden Lake Valleys in Tompkins County and a small part of the headwaters in Owego Creek Valley in Cortland County offer a means of examining geohydrologic features that affect groundwater flow and the areal extent of the zones of groundwater contribution to several large pumping wells. However, to appraise the reliability of these simulations requires additional field data to refine the calibration and verify the model. Specifically, more wells would be needed to obtain head information in the aquifer for model calibration, to determine the thickness of the geohydrologic units, and to conduct additional aquifer tests that would be needed to estimate hydraulic properties. Although large amounts of recharge are believed to occur through windows in the confining units in the southern part of the study area (this assumption was made to match observed heads with modeled simulated heads), it has not been verified by field evidence. To confirm this hypothesis that windows in the confining units are present, a number of closely spaced wells would need to be drilled or large open pits would need to be excavated (similar to sand and gravel mines).

The use of the model as a quantitative predictive tool would be inappropriate without further data acquisition and calibration. The model at its present stage would be considered useful for estimating the general effects of changes in hydraulic values and boundary conditions on the size and shape of the areal extent of the zones of groundwater contribution. The accuracy of the flow lines generated by the particle-tracking program (MODPATH) depends largely on how realistically the flow model represents the system. The limitations inherent in modeling due to the uncertainty of parameter values and boundary conditions need to be considered if the model is to be used effectively.

Because the steady-state calibration period (2005–7) included years of above-average precipitation, the model was calibrated to pumping rates and some water levels that represent a wet cycle. The steady-state model results would change in drier years; for example, water levels would be lower and simulated areal extent of the zones of groundwater contribution would be larger during dry years.

For the three Village of Dryden production wells TM1046, TM 981, and TM 202, the age of groundwater was simulated by calculating the time of travel along the simulated flow paths back to the point of recharge and by CFC and ^{3}H-age dating methods. The ages determined from a CFC measurement at the Village of Dryden production well TM1046 at South Street (finished in the lower aquifer, layer 6) range from more than 60 to 40 years (earlier than 1940s to early 1960s; table 9), and from a ^{3}H-age measurement it was about 35 years (late 1950s; table 9). The simulated time of travel calculated from the Village of Dryden production well TM1046 at South Street back to the point of recharge is a little more than 30 years (fig. 38), which is considered a good match with the ^{3}H age (about 35 years) but less of a good match with the CFC age (60 to 40 years).

The ages determined from CFC measurements at Village of Dryden production wells TM 981 at Jay Street (finished in the middle aquifer, layer 4 in model) and at Village of Dryden production well TM 202 at Lake Road (finished in the upper confined aquifer, layer 2 in model) range from more than 60 years to approximately 40 years (from mid-1940s to mid-1960s) and from 60 to approximately 40 years (early 1940s to mid-1960s), respectively. The simulated times of travel that were computed for wells TM 981 and well TM 202 (fig. 38) were approximately 40 and 30 years, respectively. However, the CFC ages for wells TM 981 and TM 202 may not be reliable because these ages differed substantially from ^{3}H-age measurements of 30 years or younger for both wells (early 1970s or younger; table 9) and because the CFC laboratory reported that these samples possibly were affected by mixing of waters of different ages. Therefore, because of the reasons stated above and because of the wide range in measured ages and inherent uncertainties of age-dating techniques, the CFC ages were not used to calibrate the numerical groundwater model.

Summary

In 2002, the U.S. Geological Survey, in cooperation with the Tompkins County Planning Department and the Town of Dryden, began a study of the stratified-drift aquifer system in the Virgil Creek and Dryden Lake Valleys in the Town of Dryden, Tompkins County, New York. Because this area is undergoing increasing development and the aquifers underlying the valleys are the most used in the county, this study was undertaken to characterize the geohydrology of the stratified-drift aquifer system in the Virgil Creek and Dryden Lake Valleys and provide the geohydrologic data needed by the Town of Dryden and Tompkins County to develop a strategy to manage and protect their water resources. In this study area, there are three extensive confined sand and gravel aquifers (upper, middle, and lower confined aquifers) that are tapped by most wells. The Dryden Lake Valley is a glaciated valley oriented parallel to the direction of ice movement. Erosion by ice extensively widened and deepened the valley, truncated bedrock hillsides, and formed a nearly straight, U-shaped bedrock trough. The maximum thickness of the valley fill in the central part of the Dryden Lake Valley is about 400 ft. The Virgil Creek Valley in the eastern part of the study area underwent less severe erosion by ice than the Dryden Lake Valley, hence it has a bedrock floor that is several hundred feet higher in altitude than that in the Dryden Lake Valley and contains less than 150 ft of sediments.

The sources and amounts of recharge were difficult to identify in most areas because the confined aquifers are overlain by confining units. However, near the Virgil Creek Dam, the upper confined aquifer crops out at land surface in the floodplain of a gorge eroded by Virgil Creek, and this is where the aquifer receives large amounts of recharge from precipitation that directly falls over the aquifer and from seepage losses from Virgil Creek. The results of streamflow measurements in Virgil Creek in the gorge indicated that the stream lost 1.2 cubic feet per second (ft^3/s; 0.78 million gallons per day) of water in the reach extending from 1,200 feet (ft) upstream from the dam to 220 ft downstream from the dam.

Large amounts of recharge also replenish the aquifer system in the southern part of the study area at the Valley Heads Moraine, which consists of heterogeneous sediments that include coarse-grained outwash and kame sediments as well as zones that contain till with a fine-grained matrix. In this area, the till probably contains zones of coarse-grained material that form local windows of permeable sediment. These windows are where local large amounts of recharge (from precipitation that directly falls over the aquifer and from seepage losses from tributaries that flow over the valley floor) replenish the aquifers.

Most groundwater in the northern part of the study area discharges to the Village of Dryden municipal production wells, to the outlet to Dryden Lake, to Virgil Creek, and as groundwater underflow that exits the northern boundary of the study area. Most northward-flowing groundwater in the southern part of the study area discharges to Dryden Lake, to the inlet to Dryden Lake, to homeowner, nonmunicipal community wells (a mobile home park and several apartments), and to commercial wells. Most of this pumped water is eventually returned to the groundwater system via septic systems. In the southern part of the study area, most of the southward-flowing groundwater discharges to the headwaters of Owego Creek and to agricultural wells, and some exits as groundwater underflow out of the southern boundary of the study area.

The largest user of groundwater in the study area is the Village of Dryden. It is estimated that Village of Dryden production wells supply water to about 1,800 village residents, 3,800 college students, 1,900 high school students, and several small businesses. Water use in the village has approximately tripled since the early 1970s, when withdrawals ranged between 18 and 30 million gallons per year (Mgal/yr), to 2000 through 2008, when withdrawals ranged between 75 and 85 Mgal/yr. The estimated groundwater use by homeowners, nonmunicipal communities, and small commercial facilities outside the Village of Dryden service area is estimated to be

about 18.4 Mgal/yr, but much of this pumped water is returned to the groundwater system via septic systems.

For this investigation, an aquifer test was conducted at the Village of Dryden production well TM 981 (well depth 72 ft and finished in the middle aquifer) at the Jay Street pumping station during June 19–21, 2007. The aquifer test consisted of pumping production well TM 981 at 104 gallons per minute (gal/min) over a 24-hour period. The drawdown in well TM 981 at the end of 24 hours of pumping was 19.2 ft. Results of the aquifer-test analysis for a partially penetrating well in a confined aquifer indicated that the transmissivity was 1,560 feet per day (ft/d), and the horizontal hydraulic conductivity was 87 ft/d, based on a saturated thickness of 18 ft.

During 2003–5, surface-water samples were collected at eight sites, including Virgil Creek, Dryden Lake outlet, and several tributaries. During 2003–9, groundwater samples were collected from eight wells, including three municipal production wells, two test wells, and three domestic wells. Calcium dominates the cation composition and bicarbonate dominates the anion composition in most groundwater and surface-water samples, and none of the common inorganic constituents collected exceeded any Federal or State water-quality standards. Concentrations of calcium in groundwater samples ranged from 39.6 to 75.2 milligrams per liter (mg/L). Hardness ranged from hard to very hard. Sodium values ranged from 4.8 to 12.2 mg/L. Bicarbonate concentrations ranged from 138 to 196 mg/L, with a median of 152 mg/L, followed by sulfate and chloride, concentrations of which ranged from 15.8 to 49 mg/L and 5.71 to 31.7 mg/L, respectively.

Results from a three-dimensional, finite-difference, groundwater-flow model were used to compute a water budget and to estimate the areal extent of the zones of groundwater contribution to the Village of Dryden municipal production wells. The model-computed water budget indicated that the sources of recharge to the confined aquifer system are precipitation that falls directly on the valley-fill sediments (40 percent of total recharge), stream leakage (35.5 percent), seepage from wetlands and ponds (12 percent), unchanneled runoff and groundwater inflow from the uplands (8.5 percent), and groundwater underflow into the eastern end of the model area (4 percent). Most groundwater discharges to surface-water bodies, including Dryden Lake (33 percent), streams (33 percent), and wetlands and ponds (10 percent). In addition, some groundwater discharges as underflow out of the southern and northern ends of the model area (15 percent), to simulated pumping wells (4.5 percent), and to drains that represent seepage from the bluffs exposed in the gorge in the vicinity of the Virgil Creek Dam (4.5 percent).

The areal extent of the zones of groundwater contribution to three Village of Dryden municipal production wells TM 202, TM 981, and TM1046 and to one hypothetical well at test-well site TM2724 near Keith Lane were delineated through the software program MODPATH. These delineations provide the Village of Dryden, the Town of Dryden, and Tompkins County with the approximate boundaries of the parts of the aquifer system that need to be managed in order to protect the water quality of this drinking-water resource. The areal extent of the zones of groundwater contribution to Village of Dryden municipal production wells TM 202 (Lake Road pumping station, finished in the upper confined aquifer) and TM 981 (Jay Street pumping station, finished in the middle confined aquifer) are 0.5 square mile (mi^2) and 0.9 mi^2, respectively. The areal extent of the zone of groundwater contribution to well TM 202 extends 2.2 miles (mi) southeast into the Virgil Creek Valley, whereas the areal extent of the zone of groundwater contribution to TM 981 extends 3.8 mi south in the Dryden Lake Valley. The areal extent of the zone of groundwater contribution to production well TM1046 (South Street pump station) is 1.4 mi^2 and extends 2.4 mi into Dryden Lake Valley and 0.5 mi into Virgil Creek Valley. The areal extent of the zone of groundwater contribution of the hypothetical well at test-well site TM2724 near Keith Lane (which was identified as a potential future municipal-well site) is 0.86 mi^2 and extends 3.4 mi down the western part of the Dryden Lake Valley. The results of the simulation with municipal production well TM1046 and the hypothetical well pumping (both finished in the lower confined aquifer) indicate that there would be well interference (the lowering of the water level in one well due to pumping of another well). Also, the simulated pumping of the hypothetical well at a rate of 200 gal/min altered the zone of groundwater contribution for municipal production well TM1046 by shifting its zone 500 ft to the east.

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Appendix 1. Selected Wells in the Stratified-Drift Aquifer System in Virgil Creek and Dryden Lake Valleys, Tompkins County, and in Owego Creek Valley, Cortland County, New York

Table 1–1. Selected wells in the stratified-drift aquifer system in Virgil Creek and Dryden Lake Valleys, Tompkins County, and in Owego Creek Valley, Cortland County, New York

[ft, feet; gal/min, gallons per minute; S&G, sand and gravel; --, no data; >, greater than; WL, water level]

Well site name	Date drilled	Well depth, in ft	Depth of casing, in ft	Casing diameter, in inches	Altitude land surface, in ft	Aquifer type (aquifer layer)	Water level below land surface, in ft	Altitude water level, in ft	Date water level measured	Depth to bedrock, in ft	Altitude top of bedrock, in ft	Reported yield, in gal/min	Remarks
TM 125	11/6/1980	180	50	6	1,308	Shale	--	--	--	50	1,258	10	0–10 till, 10–20 gravel (dry), 20–30 till, 30–50 gravel (dry), 50–180 ft shale.
TM 133	10/23/1961	52	52	6	1,160	S&G (middle)	25	1,135	10/23/1961	--	--	24	
TM 134	6/5/1973	171	45	6	1,215	Shale	--	--	--	45	1,170	5	0–45 dry gravel and till, 45–171 ft shale.
TM 135	5/16/1905	82	82	6	1,240	Sand (middle)	76	1,164	5/16/1905	--	--	5	
TM 138	10/16/1974	82	82	6	1,175	S&G (lower)	--	--	--	--	--	15	0–30 dry coarse gravel, 30–50 gravel and sand, 50–64, till, 64–70 gravel and sand, 70–79 dry, till, 79–82 ft S&G.
TM 141	--	79	79	6	1,206	S&G (middle)	50.6	1,155.4	10/25/1985	--	--	--	
TM 143	9/22/1980	102	102	6	1,200	S&G (middle)	41	1,159	9/22/1980	--	--	30	0–10 sand, 10–25 till, 25–38 till and gravel, 38–61, clayey sand, 61–69 clay with stones (till?), 69–72 gravel and clay, 72–85 clay, 85–99 clay and gravel (till?), 99–100 sand, 100–102 S&G, another hole drilled to depth 195 ft did not, penetrate a signifiant aquifer.
TM 144	7/7/1963	267	31	6	1,230	Shale	135	1,095	7/7/1963	31	1,199	5	0–31 S&G, 31–267 ft shale.
TM 145	10/15/1961	98	98	6	1,200	S&G (middle)	50	1,150	10/15/1961	--	--	24	0–21 S&G, 21–41 till, 41–46 S&G, 46–87 silt and clay, 87–98 ft S&G.
TM 146	1972	42	42	6	1,188	S&G (upper)	24	1,164	10/16/1984	--	--	--	0–34 till, 34–42 ft S&G.

Table 1–1. Selected wells in the stratified-drift aquifer system in Virgil Creek and Dryden Lake Valleys, Tompkins County, and in Owego Creek Valley, Cortland County, New York

[ft, feet; gal/min, gallons per minute; S&G, sand and gravel; --, no data; >, greater than; WL, water level]

Well site name	Date drilled	Well depth, in ft	Depth of casing, in ft	Casing diameter, in inches	Altitude land surface, in ft	Aquifer type (aquifer layer)	Water level below land surface, in ft	Altitude water level, in ft	Date water level measured	Depth to bedrock, in ft	Altitude top of bedrock, in ft	Reported yield, in gal/min	Remarks
TM 149	5/16/1978	157	157	6	1,145	S&G (lower)	--	Flows	--	--	--	20	0–30 gravel, 30–50 till, 50–100 clay, sand, gravel, 100–103 clay and gravel,103–110 clay, 110–137 clay and gravel, 137–144 quicksand,144–145 sandy, clayey, 154–157 ft S&G, flowing well.
TM 150	9/6/1968	58	58	6	1,179.5	S&G (middle)	21.2	1,158.3	10/29/1985	--	--	15	0–34 ft till, 34–40 S&G, 40–57 till, 57–58 ft S&G.
TM 152	10/28/1968	69	69	6	1,184.7	S&G (middle)	36	1,148.7	10/28/1968	--	--	13	0–50 clay and gravel (till), 50–59 gravelly till, 59–67 S&G, 67–70 gravel, 70 ft clay.
TM 153	4/29/1966	62	62	6	1,189.6	S&G (middle)	37.3	1,152.3	10/17/1985	--	--	20	0–8 topsoil, 8–45 till, 45–46 gravel, 46–60 till, 60–62 ft gravel. WL = 30 ft, 4/29/1966.
TM 154	3/29/1968	78	78	6	1,195.8	S&G (middle)	43	1,152.8	3/29/1968	--	--	20	0–30 till, 30–44 sandy fine gravel, 44–58 S&G, 58–70 fine sand, 70–78 ft S&G.
TM 156	4/24/1975	62	40	6	1,200	Shale	--	--	4/24/1975	40	1,160	12	0–40 till and gravel, 40 ft bedrock.
TM 157	9/16/1967	65	65	6	1,203.7	S&G (upper)	53	1,150.7	10/25/1985	--	--	20	0–45 S&G, 45–60 clay, 60–68 S&G, 68 ft clay.
TM 159	10/17/1968	99	99	6	1,167	S&G (middle)	29.6	1,137.4	10/29/1985	--	--	15	0–20 S&G, 20–50 clay (till?), 50–60 S&G, 60–70 S&G and clay,70–75 S&G, 75–80?, 80–90, sand and clay, 90–99 ft S&G.

Table 1–1. Selected wells in the stratified-drift aquifer system in Virgil Creek and Dryden Lake Valleys, Tompkins County, and in Owego Creek Valley, Cortland County, New York

[ft, feet; gal/min, gallons per minute; S&G, sand and gravel; --, no data; >, greater than; WL, water level]

Well site name	Date drilled	Well depth, in ft	Depth of casing, in ft	Casing diameter, in inches	Altitude land surface, in ft	Aquifer type (aquifer layer)	Water level below land surface, in ft	Altitude water level, in ft	Date water level measured	Depth to bedrock, in ft	Altitude top of bedrock, in ft	Reported yield, in gal/min	Remarks
TM 160	4/7/1971	43	43	6	1,151	S&G (upper)	16.4	1,134.6	10/29/1985	--	--	25	0–43 clay and gravel (till), 43 ft gravel.
TM 161	6/28/1971	57	57	6	1,245	S&G (upper)	--	--	--	--	--	20	0–10 gravel, 10–50 till, 50–57 ft gravel.
TM 162	5/4/1970	113	113	6	1,162	S&G (middle)	24.4	1,137.6	10/30/1985	--	--	--	0–7 topsoil, 7–21 till, 21–101 clay, 101–113 ft S&G.
TM 163	5/1/1970	42	42	6	1,152.2	S&G (upper)	17.4	1,134.8	10/29/1985	--	--	12	0–30 sandy clay and fine gravel (till?), 30–40 hard clay and coarse gravel (till?), 40–42 ft S&G.
TM 164	5/7/1970	160	79	6	1,335	Shale	9	1,326	5/7/1970	79	1,256	6	0–79 till, 79–160 ft shale.
TM 166	8/17/1970	40	40	6	1,154	S&G (upper)	26	1,128	8/17/1970	--	--	12	0–30 sandy clay and gravel (till?), 30–38 gravelly clay (till?), 38–40 ft S&G.
TM 168	3/24/1971	31	31	6	1,150.4	S&G (upper)	14	1,136.4	3/24/1971	--	--	30	0–10 sand, 10–20 till, 20–28 clay and grave (till?)l, 28–31 ft S&G.
TM 169	8/21/1976	185	60	6	1,305	Shale	65	1,240	8/21/1976	60	1,245	5	0–60 till, 60–185 ft shale.
TM 170	8/29/1980	104	104	6	1,175	S&G (lower)	Flows	--	--	--	--	20	0–15 till, 15–70 clay, 70–90 fine sand, 90–96 fine sand, some gravel 96–100 S&G, 100–104 ft coarse gravel. Flowing well.
TM 171	4/12/1971	98	98	6	1,150	S&G (middle)	--	--	--	--	--	20	0–40 till, 40–48 clay and gravel, 80–97 clay and gravel (till), 97–98 ft gravel.

Table 1–1. Selected wells in the stratified-drift aquifer system in Virgil Creek and Dryden Lake Valleys, Tompkins County, and in Owego Creek Valley, Cortland County, New York

[ft, feet; gal/min, gallons per minute; S&G, sand and gravel; --, no data; >, greater than; WL, water level]

Well site name	Date drilled	Well depth, in ft	Depth of casing, in ft	Casing diameter, in inches	Altitude land surface, in ft	Aquifer type (aquifer layer)	Water level below land surface, in ft	Altitude water level, in ft	Date water level measured	Depth to bedrock, in ft	Altitude top of bedrock, in ft	Reported yield, in gal/min	Remarks
TM 172	4/15/1972	97	97	6	1,137	S&G (middle)	--	--	--	--	--	30	0–20 S&G, 20–50 fine sand, 50–80 clay and cobbles (till), 80–97 ft S&G.
TM 174	3/31/1984	175	80	6	1,275	Shale	65	1,210	3/31/1971	75	1,200	--	0–55 till, 55–75 clay, 75–79 weathered shale, 79–175 ft shale.
TM 177	4/2/1975	62	62	6	1,180	S&G (upper)	5	1,175	4/2/1975	--	--	20	0–20 gravel, 20–60 S&G, 60–62 ft gravel.
TM 178	5/7/1970	52	52	6	1,255	Gravel (uplands)	25	1,230	5/7/1970	--	--	15	0–20 till, 20–50 ft gravel.
TM 179	4/14/1971	57	57	6	1,275	Gravel (uplands)	32	1,243	4/14/1971	--	--	45	0–57 ft till and gravel.
TM 184	3/1/1967	50	50	6	1,164.1	S&G (upper)	33	1,131.1	3/1/1967	--	--	15	
TM 187	10/31/1980	92	92	6	1,139.3	S&G (middle)	18	1,121.3	10/31/1980	--	--	25	0–5 sand, 5–8 till, 8–36 gravel 12 gal/min, 36–64 S&G 30 gal/min, 64–73 sand, 73–88 sand, silt, and till, 88–92 ft S&G.
TM 189	12/15/1983	53	53	6	1,150	S&G (lower)	20	1,130	12/15/1983	--	--	30	0–20 gravel (dry), 20–40 S&G (some water), 40–50 gravel, 50–53 S&G.
TM 192	1965	97	97	6	1,157.6	S&G (middle)	37	1,120.6	8/1/1965	--	--	24	
TM 193	9/21/1978	96	96	6	1,127	S&G (middle)	14	1,113	9/21/1978	--	--	15	0–4 gravel (dry), 4–40 ?, 40–70 silt and clay, 70–80 till, 80–88 gravel and till, 88–96 ft gravel.
TM 195	8/14/1978	52	52	6	1,133.3	S&G (upper)	20	1,113.3	8/14/1978	--	--	15	0–3 sandy topsoil, 3–10 till, 10–30, sandy clay, 30–52 ft S&G.

Table 1–1. Selected wells in the stratified-drift aquifer system in Virgil Creek and Dryden Lake Valleys, Tompkins County, and in Owego Creek Valley, Cortland County, New York

[ft, feet; gal/min, gallons per minute; S&G, sand and gravel; --, no data; >, greater than; WL, water level]

Well site name	Date drilled	Well depth, in ft	Depth of casing, in ft	Casing diameter, in inches	Altitude land surface, in ft	Aquifer type (aquifer layer)	Water level below land surface, in ft	Altitude water level, in ft	Date water level measured	Depth to bedrock, in ft	Altitude top of bedrock, in ft	Reported yield, in gal/min	Remarks
TM 198	9/13/1978	103	103	6	1,126.8	S&G (middle)	16	1,110.8	9/13/1978	--	--	30	0–5 till and gravel, 5–15 till,15–45 clay and gravel, 45–65 sandy clay, 65–70 sandy clay and some gravel, 70–100 silty gravel, 100–103 ft coarse to fine sand.
TM 199	3/7/1977	217	217	--	1,105.7	S&G (lower)	-6	1,111.7	6/4/1905	--	--	50	Abandoned Village of Dryden production well (Jay St. pumping station). Flows (head = +6 ft above land surace). Screened 193–212 ft.
TM 202	1963	53	41	--	1,100	S&G (upper)	--	--	--	--	--	100	Village of Dryden municipal production well. Screened 41–53 ft. Yield has declined to about 65–75 gal/min (1998).
TM 203	1978	47	47	6	1,135	S&G (upper)	29	1,106	10/16/1984	--	--	--	Well deepened from 34 to 47 ft.
TM 204	1964	51	39	--	1,114.5	S&G (upper)	7.5	1,107	--	--	--	115	Village of Dryden municipal production well. Screened 39–51 ft. Yield has declined to about 65–75 gal/min (1998).

Table 1–1. Selected wells in the stratified-drift aquifer system in Virgil Creek and Dryden Lake Valleys, Tompkins County, and in Owego Creek Valley, Cortland County, New York

[ft, feet; gal/min, gallons per minute; S&G, sand and gravel; --, no data; >, greater than; WL, water level]

Well site name	Date drilled	Well depth, in ft	Depth of casing, in ft	Casing diameter, in inches	Altitude land surface, in ft	Aquifer type (aquifer layer)	Water level below land surface, in ft	Altitude water level, in ft	Date water level measured	Depth to bedrock, in ft	Altitude top of bedrock, in ft	Reported yield, in gal/min	Remarks
TM 207	1949	176	169	8	1,090	S&G (lower)	Flows	--	--	--	--	85	Abandoned Village of Dryden production well. Screened 169–176 ft. 0–23 silty S&G, 23–68 till, 68–75 S&G, 75–80 clay, 80–82 S&G, 82–90 (till?), 90–120 silty sand, 120–157 till(?), 157–167 silty S&G, 167–175 S&G, 175–181 ft clay. Static water level = + 25 ft above land surface (8/18/1949).
TM 214	1/25/1972	67	67	--	1,076	S&G (upper)	12	1,064	1/25/1972	--	--	48	0–20 silty S&G, 20–30 S&G, 30–57 till, 57–61 till and gravel, 61–67 ft S&G.
TM 981	8/17/1998	72	62	8	1,111	S&G (middle)	6.7	1,104.3	6/13/2007	--	--	104	Village of Dryden production well (Jay St. pumping station). 0–5 sand, 5–29 till, 29–33 S&G, 33–42 coarse sand, 39–41 S&G, 41–50 silty and clayey sand with some pebbles, 50–54 sand and silt, 54–56 S&G, 56–60 fine to coarse with some silt, 60–72 ft S&G. Screened 62–72 ft.

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[ft, feet; gal/min, gallons per minute; S&G, sand and gravel; --, no data; >, greater than; WL, water level]

Well site name	Date drilled	Well depth, in ft	Depth of casing, in ft	Casing diameter, in inches	Altitude land surface, in ft	Aquifer type (aquifer layer)	Water level below land surface, in ft	Altitude water level, in ft	Date water level measured	Depth to bedrock, in ft	Altitude top of bedrock, in ft	Reported yield, in gal/min	Remarks
TM 993	12/9/2004	234	234	6	1,167	S&G (lower)	2.82	1,163.7	12/13/2004	--	--	400	Test well at Dryden Lake. 0–2 S&G, 2–40 till, 40–55 silty clay, 55–65 fine sand, 65–75 S&G, 75–96 clay, 96–99 S&G, 99–105 clay, 105–110 S&G, 110–140 silt and clay, 140–177 clay with stones, 177–245 ft S&G.
TM 997	11/17/2005	84	110	6	1,209	S&G (lower)	19.6	1,189.4	11/21/2005	109	1,100	5	Test well at Virgil Creek Dam. 0–48 S&G, 48–57 silty clay, 57–77 till, 77–86 S&G, 86–100 silty clay, 100–109 till, 109–113 ft shale. Casing perforated from 79–84 ft.
TM 998	11/17/2005	37	37	6	1,209	S&G (upper)	13.2	1,195.8	11/21/2005	--	--	--	Test well at Virgil Creek Dam. 0–37 ft S&G.
TM1000	7/12/1996	35	--	--	1,100.5	S&G (upper)	7	1,094	7/9/1996	--	--	--	Test boring. 0–12 fill, 12–24 sand, 24–28 silt, 28–32 S&G, 32–35 ft till.
TM1005	6/21/1984	103	--	--	1,230	S&G (middle)	--	--	--	--	--	--	Test boring. 0–5 S&G, 5–33 till, 33–45 silty S&G, 45–47 till, 47–55 silt, 55–97 till, 97–103 ft S&G.
TM1006	6/12/1970	71	71		1,188	S&G (middle)	23	1,165	6/15/1984	--	--	--	
TM1007	6/19/1984	88	--	--	1,168	Till	--	--	--	--	--	--	Test boring. 0-19 gravel, 19-32 till, 32-70 fine sand, 70-74 silty gravel, 74-88 ft till.

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[ft, feet; gal/min, gallons per minute; S&G, sand and gravel; --, no data; >, greater than; WL, water level]

Well site name	Date drilled	Well depth, in ft	Depth of casing, in ft	Casing diameter, in inches	Altitude land surface, in ft	Aquifer type (aquifer layer)	Water level below land surface, in ft	Altitude water level, in ft	Date water level measured	Depth to bedrock, in ft	Altitude top of bedrock, in ft	Reported yield, in gal/min	Remarks
TM1010	4/15/1985	102	--	--	1,162	S&G (middle)	Flows	1,164	4/15/1985	--	--	--	Test boring. 0-2 cinders, 2-11 gravel, 11-23 till, 23-28 gravel, 28-41 silty fine sand, 41-102 ft silty S&G. Just barely flows above land surace.
TM1011	11/12/1987	92	--	--	1,213	S&G (upper)	49	1,164	11/12/1987	--	--	--	Test boring. 0-21 sand, 21-48 till, 48-56 silty sand, 56-59 till, 59-62 S&G, 62-81 till, 81-88 silt, 88-91 till, 91-92 ft S&G.
TM1012	11/13/1987	73	--	--	1,177	S&G (middle)	30	1,147	11/13/1987	--	--	--	Test boring. 0-8 sand, 8-18 till, 18-32 S&G, 32-35 till, 35-50 silty very fine sand, 50-55 S&G, 55-73 ft till. Water leveled measured at hole depth = 55 ft.
TM1013	4/12/1985	106	--	--	1,180	Till	--	--	--	--	--	--	Test boring. 0-2 gravel, 2-10 till, 10-18 sand, 18-35 till, 35-42 S&G, 42-54 till, 54-58 S&G, 58-64 till, 64-190 clay and silt, 90-106 ft till.
TM1014	6/22/1984	73	--	--	1,092	S&G (unconfined)	11	1,081	6/22/1984	--	--	--	Test boring. 0-26 S&G, 26-28 silt, 28-58 till, 58-60 silt, 60-63 fine to coarse sand, 63-73 ft till. Water level measured at boring depth = 17 ft.

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[ft, feet; gal/min, gallons per minute; S&G, sand and gravel; --, no data; >, greater than; WL, water level]

Well site name	Date drilled	Well depth, in ft	Depth of casing, in ft	Casing diameter, in inches	Altitude land surface, in ft	Aquifer type (aquifer layer)	Water level below land surface, in ft	Altitude water level, in ft	Date water level measured	Depth to bedrock, in ft	Altitude top of bedrock, in ft	Reported yield, in gal/min	Remarks
TM1015	5/15/1978	95	95	6	1,120	S&G (middle)	Flows (+3.8)	1,123.8	5/15/1978	--	--	--	Test well. Flows. 0-31 till, 31-41 S&G, 41-51 sand, 51-71 till, 71-73 S&G, 73-85 till, 85-95 clay, 95-97.5 S&G, 97.5-98 ft fine sand.
TM1016	--	170	170	6	1,095	S&G (lower)	Flows	--	--	--	--	30	Abandoned. Old milk plant well.
TM1030	7/14/1987	44	--	--	1,234.5	S&G (upper)	24	1,210.5	7/14/1987	--	--	--	Test boring. 0-33 till, 33-44 ft S&G.
TM1031	7/14/1987	70	--	--	1,200.2	S&G (middle)	6.8	1,193.4	7/14/1987	--	--	--	Test boring. 0-41 S&G, 41-70 ft till.
TM1032	7/27/1987	69	--	--	1,202.9	S&G (upper)	7.2	1,195.7	7/27/1987	--	--	--	Test boring. 0-18 S&G, 18-29 till, 29-41 S&G, 41-65 silt, 65-70 ft till.
TM1033	7/21/1987	71	--	--	1,198.5	S&G (upper)	7.2	1,191.3	7/21/1987	--	--	--	Test boring. 0-30 S&G, 30-71 ft till.
TM1034	7/28/1987	30	--	--	1,242.5	S&G (upper)	22	1,220.5	7/28/1987	--	--	--	Test boring. 0-30 ft S&G. water level measured at boring depth = 30 ft.
TM1046	1986	180	155	12	1,098	S&G (lower)	+8.5	1,116.6	1986	--	--	90	Village of Dryden production well at South St. pumping station. Screened 155-180 ft. Static water level - +8.5 ft above land surface (1986).
TM1050	9/9/2010	12	--	--	1,087	S&G (unconfined)	4	1,083	9/9/2010	--	--	--	Test hole for Village of Dryden library expansion.

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[ft, feet; gal/min, gallons per minute; S&G, sand and gravel; --, no data; >, greater than; WL, water level]

Well site name	Date drilled	Well depth, in ft	Depth of casing, in ft	Casing diameter, in inches	Altitude land surface, in ft	Aquifer type (aquifer layer)	Water level below land surface, in ft	Altitude water level, in ft	Date water level measured	Depth to bedrock, in ft	Altitude top of bedrock, in ft	Reported yield, in gal/min	Remarks
TM1334	7/11/2001	115	43	6	1,224	Shale	40	1,184	7/11/2001	43	1,181	3	0-10 clay and fine sand, 10-18 S&G, 18-20 clay, 20-37 gravel, 37-39 fine sand, 39-40 coarse sand, 40-43 clay, 43-115 ft shale.
TM1374	8/13/2001	57	57	6	1,180	S&G (middle)	18	1,162	8/13/2001	--	--	15	0-10 till, 10-28 clay and sand, 28-30 S&G, 30-40 fine sand, 40-58 ft gravel.
TM1384	9/5/2001	78	78	6	1,130	S&G (outside study area)	10	1,120	9/5/2001	--	--	20	0-30 till, 30-35 silty sand, 35-75 clay, 75-78 ft gravel.
TM1386	9/7/2001	68	68	6	1,207.3	S&G (upper)	47.7	1,159.6	8/29/2005	--	--	30	0-50 till and lacustrine silt, 50-68 ft gravel.
TM1432	1/10/2002	48	48	6	1,171	S&G (unconfined)	30	1,141	1/10/2002	--	--	20	0-48 ft S&G.
TM1524	7/6/2002	129	20	6	1,205	Shale	26	1,179	7/6/2002	20	1,195	2	0-11 till, 11-13 clay, 13 18 till, 18-130 ft shale.
TM1543	7/28/2002	110	23	6	1,268	Shale	17	1,251	7/28/2002	23	1,245	10	0-21 till, 21-110 ft shale.
TM1580	8/21/2002	140	58	6	1,530	Shale	58	1,472	8/21/2002	58	1,472	7	0-55 till, 55-140 ft shale.
TM1629	10/30/2002	140	79	6	1,170	Shale	70	1,100	10/30/2002	79	1,091	4	0-40 till, 40-68 clay, 68-75 S&G, 75-76 till, 76-140 ft shale.
TM1676	5/8/2003	50	50	6	1,170.6	S&G (middle)	20.2	1,150.4	5/19/2009	--	--	7	0-10 sandy clay, 10-20 S&G, 20-33 clay, 33-36 gravel, 36-49 till, 49-50 ft S&G.
TM1695	5/27/2003	396	300	6	1,115	Shale	7.3	1,107.7	5/27/2003	387	728	--	Test well. Well deepened in 2003 (from 300 to 396 ft). Plugged and abandoned. Well log (see figure 8).

Table 1–1. Selected wells in the stratified-drift aquifer system in Virgil Creek and Dryden Lake Valleys, Tompkins County, and in Owego Creek Valley, Cortland County, New York

[ft, feet; gal/min, gallons per minute; S&G, sand and gravel; --, no data; >, greater than; WL, water level]

Well site name	Date drilled	Well depth, in ft	Depth of casing, in ft	Casing diameter, in inches	Altitude land surface, in ft	Aquifer type (aquifer layer)	Water level below land surface, in ft	Altitude water level, in ft	Date water level measured	Depth to bedrock, in ft	Altitude top of bedrock, in ft	Reported yield, in gal/min	Remarks
TM1699	5/28/2003	72	72	4	1,114.9	S&G (middle)	4.07	1,110.8	6/10/2003	--	--	--	Observation well. Screened 62 to 72 ft. Well log (see figure 8).
TM1700	5/29/2003	41	41	6	1,115.2	S&G (lower)	4.82	1,110.4	6/10/2003	--	--	--	Observation well. Well log (see figure 8)
TM1725	7/31/2003	240	76	6	1,257	Shale	6	1,251	7/31/2003	76	1,181	5	0-66 till, 66-240 ft shale.
TM1735	8/8/2003	360	111	6	1,247	Shale	65	1,182	8/8/2003	111	1,136	2	0-43 till, 43-45 gravel, 45-70 till with gravel layers, 70-100 till, 100-105 sand, 105-109 till, 109-360 ft shale.
TM1779	9/24/2003	79	79	6	1,205	S&G (upper)	--	--	--	--	--	10	0-43 S&G, 43-53 clay, 53-79 ft gravel.
TM1855	5/21/2004	110	23	6	1,235	Shale	10	1,225	5/21/2004			6	0-23 till, 23-110 ft shale.
TM1887	7/13/2004	78	78	6	1,234.5	S&G (middle)	60	1,174.5	7/13/2004	--	--	20	0-30 till, 30-55 silt and clay, 55-60 S&G, 60-75 till, 75-78 ft S&G.
TM1920	9/24/2004	90	90	6	1,105	S&G (outside study area)	50	1,055	9/24/2004	--	--	12	0-10 gravel, 10-20 clay, 20-40 clay with S&G layers, 40-70 till, 70-90 ft gravel.
TM1940	11/2/2004	88	88	6	1,224.5	S&G (middle)	61.5	1,163	8/29/2005	--	--	15	0-40 till, 40-60 dry gravel, 60-70 dirty gravel (till?), 70-88 ft gravel, water bearing.
TM1965	12/22/2004	49	49	6	1,120	S&G (upper)	30	1,090	12/22/2004	--	--	10	0-45 till, 45-49 ft S&G.
TM2001	4/25/2005	296	101	6	1,283.5	Shale	93	1,190.5	4/25/2005	96	1,188	4	0-96 boulders and clay, 96-296 ft shale.
TM2020	5/14/2005	260	28	6	1,400	Shale	50	1,350	5/14/2005	28	1,372	4	0-8 till, 8-260 ft shale.
TM2063	8/1/2005	300	88	6	1,290	Shale	85	1,205	7/28/2005	88	1,202	2	0-88 boulders and gravel, 88-300 ft shale.

Table 1–1. Selected wells in the stratified-drift aquifer system in Virgil Creek and Dryden Lake Valleys, Tompkins County, and in Owego Creek Valley, Cortland County, New York

[ft, feet; gal/min, gallons per minute; S&G, sand and gravel; --, no data; >, greater than; WL, water level]

Well site name	Date drilled	Well depth, in ft	Depth of casing, in ft	Casing diameter, in inches	Altitude land surface, in ft	Aquifer type (aquifer layer)	Water level below land surface, in ft	Altitude water level, in ft	Date water level measured	Depth to bedrock, in ft	Altitude top of bedrock, in ft	Reported yield, in gal/min	Remarks
TM2070	9/8/2005	52	52	6	1,192	S&G (upper)	7	1,185	9/8/2005	--	--	12	0-4 sand, 4-30 S&G, 30-48 clay (till?), 48-52 ft S&G.
TM2081	8/17/2005	164	164	6	1,173.4	S&G (lower)	19.3	1,154.1	8/17/2005	--	--	15	0-10 sandy clay, 10-20 S&G, 20-33 clay, 33-36 gravel, 36-49 till, 49-64 S&G, 64-160 clay, 160-164 ft coarse gravel.
TM2094	9/19/2005	70	70	6	1,184	S&G (middle)	49	1,135	9/19/2005	--	--	12	0-35 sandy clay, 35-37 gravel, 37-50 clay, 50-70 S&G.
TM2103	7/21/2005	300	44	6	1,260	Shale	--	--	--	35	1,225	2	0-10 till, 10-30 S&G, 30-35 till, 35-300 ft shale.
TM2118	10/28/2005	200	120	6	1,160	Clay	--	--	--	--	--	--	0-45 dry sand, 45-70 till, 70-85 clay, 85-200 clay with some fine gravel (till?).
TM2256	8/16/2006	30	30	6	1,122	S&G (unconfined)	8	1,114	8/16/2006			12	0-30 ft S&G.
TM2406	7/19/2007	69	69	6	1,186	S&G (middle)	35	1,151	7/19/2007	--	--	20	0-20 sand, 20-30 S&G, 30-48 till, 48-56 clay, 56-69 ft S&G.
TM2444	9/10/2007	104	99	6	1,244	Shale	85	1,159	9/10/2007	99	1,145	10	0-10 till and gravel layers, 10-90 till, 90-99 till and broken shale, 99-104 ft shale.
TM2480	12/19/2007	60	60	6	1,169	S&G (upper)	42	1,127	12/19/2007	--	--	6	0-10 sandy clay, 10-45 clay, 45-60 ft S&G.
TM2509	4/30/2008	98	98	6	1,247	S&G (middle)	80	1,167	4/30/2008	--	--	10	0-15 till, 15-20 till with seams of sand, 20-60 till, 60-80 dry gravel, 80-99 S&G, 99-104 ft till.

Table 1–1. Selected wells in the stratified-drift aquifer system in Virgil Creek and Dryden Lake Valleys, Tompkins County, and in Owego Creek Valley, Cortland County, New York

[ft, feet; gal/min, gallons per minute; S&G, sand and gravel; --, no data; >, greater than; WL, water level]

Well site name	Date drilled	Well depth, in ft	Depth of casing, in ft	Casing diameter, in inches	Altitude land surface, in ft	Aquifer type (aquifer layer)	Water level below land surface, in ft	Altitude water level, in ft	Date water level measured	Depth to bedrock, in ft	Altitude top of bedrock, in ft	Reported yield, in gal/min	Remarks
TM2571	8/20/2008	60	60	6	1,206	S&G (upper)	45	1,161	8/20/2008	--	--	60	0-20 gravel, 20-58 till, 58-60 ft gravel.
TM2724S	12/16/2009	95	95	6	1,147.9	S&G (middle)	Flows	1,154.9	12/16/2009	--	--	100	
TM2724D	12/16/2009	229	229	6	1,147.9	S&G (lower)	Flows	1,155.9	12/16/2009	218	930	>100	Test well. Well log (fig. 15). Yields >100 gallons per minute at zones 88-106 and 152-187 ft.
C 44	12/1970	65	0	--	1,216	Sand (upper)	10.8	1,205.3	4/11/1983	--	--	--	0-5 sand, 5-30 gravelly till, 30-85 ft sand.
C 57	--	204	204	6	1,231.9	Sand (lower)	46.8	1,185.2	8/7/1980	--	--	--	Former creamery well.
C 75	04/06/1974	38	35	--	1,224	S&G (middle)	12.7	1,211.3	4/6/1974	--	--	--	0-15 till, 15-19 S&G, 19-28 till, 28-38 ft S&G.
C 88	11/1978	51	41	--	1,238.4	S&G (upper)	32.2	1,206.2	11/16/1978	--	--	--	Test well. 0-8 S&G, 8-12 tll, 12-51 ft S&G.
C 122	5/8/1974	40	38	--	1,237.7	Sand (upper)	29.8	1,207.9	5/8/1974	--	--	--	Test well. 0-12 S&G, 12-23 till, 23-40 ft sand.
C 123	5/8/1974	12	9	--	1,237.7	S&G (unconfined)	--	--	--	--	--	--	Test hole.
C 609	9/10/2002	68	68	6	1,245	S&G (middle)	45	1,200	9/10/2002	--	--	10	0-7 gravel, 7-20 clay, 20-30 till, 30-64 gravel and hardpan, 64-68 ft gravel.

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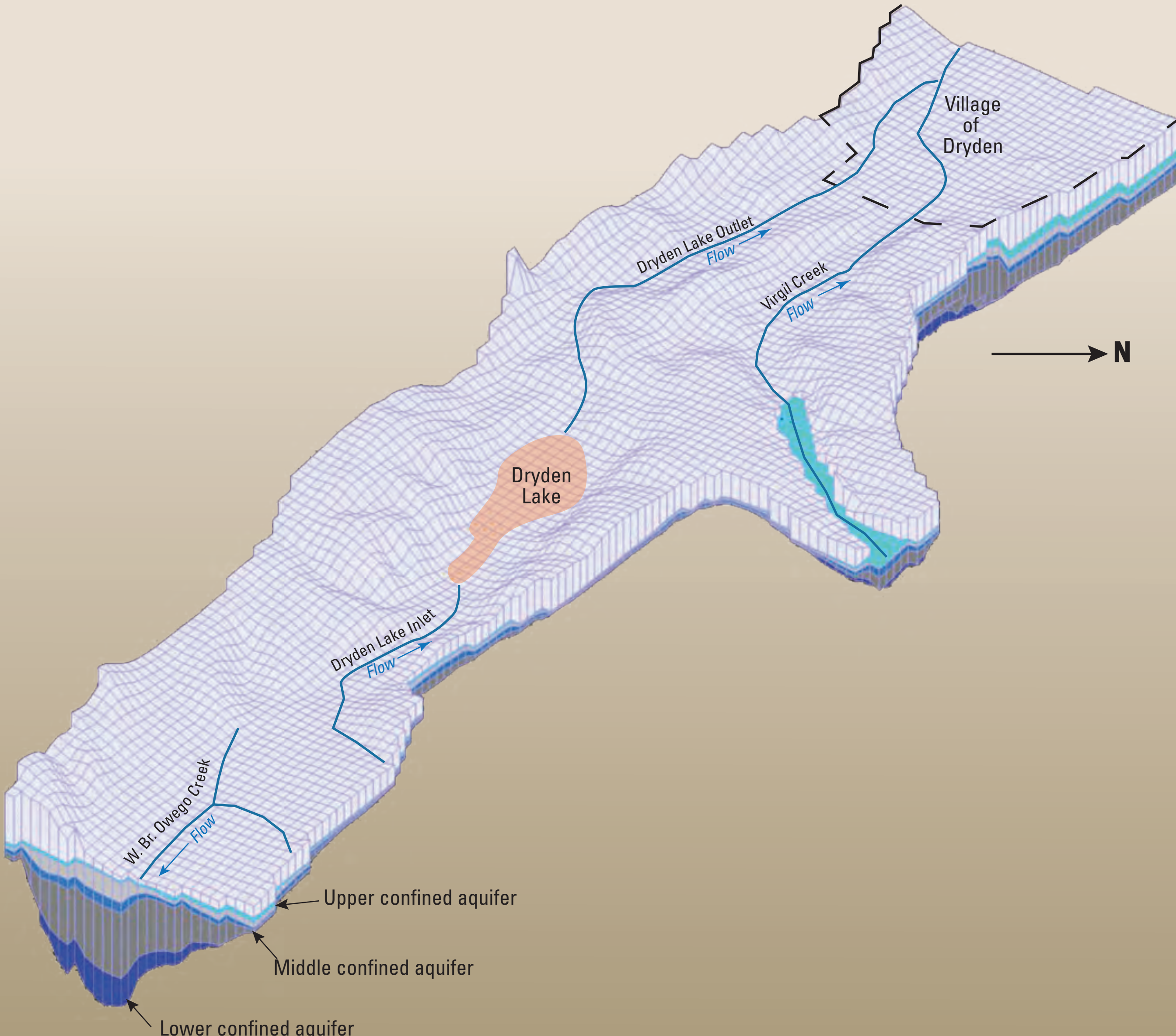

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