GEOLOGY AND HYDROLOGY OF THE ONONDAGA AQUIFER IN EASTERN ERIE COUNTY, NEW YORK, WITH EMPHASIS ON GROUND-WATER-LEVEL DECLINES SINCE 1982

By Ward W. Staubitz and Todd S. Miller

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CONVERSION FACTORS AND ABBREVIATIONS

The following factors may be used to convert the inch-pound units used in this report to metric (International System) units.

Multiply inch-pound unit	By	To obtain metric unit
	Length	
inch (in.)	2.54	centimeter (cm)
	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.59	square kilometer (km^2)
	Combined Units	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	0.64632	million gallons per day (Mgal/d)
cubic foot per second per square mile ($ft^3/s/mi^2$)	0.01093	cubic meter per second per square kilometer ($m^3/s/km^2$)
gallons per minute (gal/min)	0.06308	liters per second (L/s)
million gallons per day (Mgal/d)	43.81	liter per second (L/s)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
foot per day (ft/d)	0.3048	meter per day (m/d)
gallon per day per foot ((gal/d)/ft)	12.42	liter per day per meter ((L/d)/m)

Other Abbreviations

milligrams per liter (mg/L)
microsiemens per centimeter at 25° C (µS/cm)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "mean sea level."

Geology and Hydrology of the Onondaga Aquifer in Eastern Erie County, New York, with Emphasis on Ground-Water-Level Declines Since 1982

By Ward W. Staubitz and Todd S. Miller

ABSTRACT

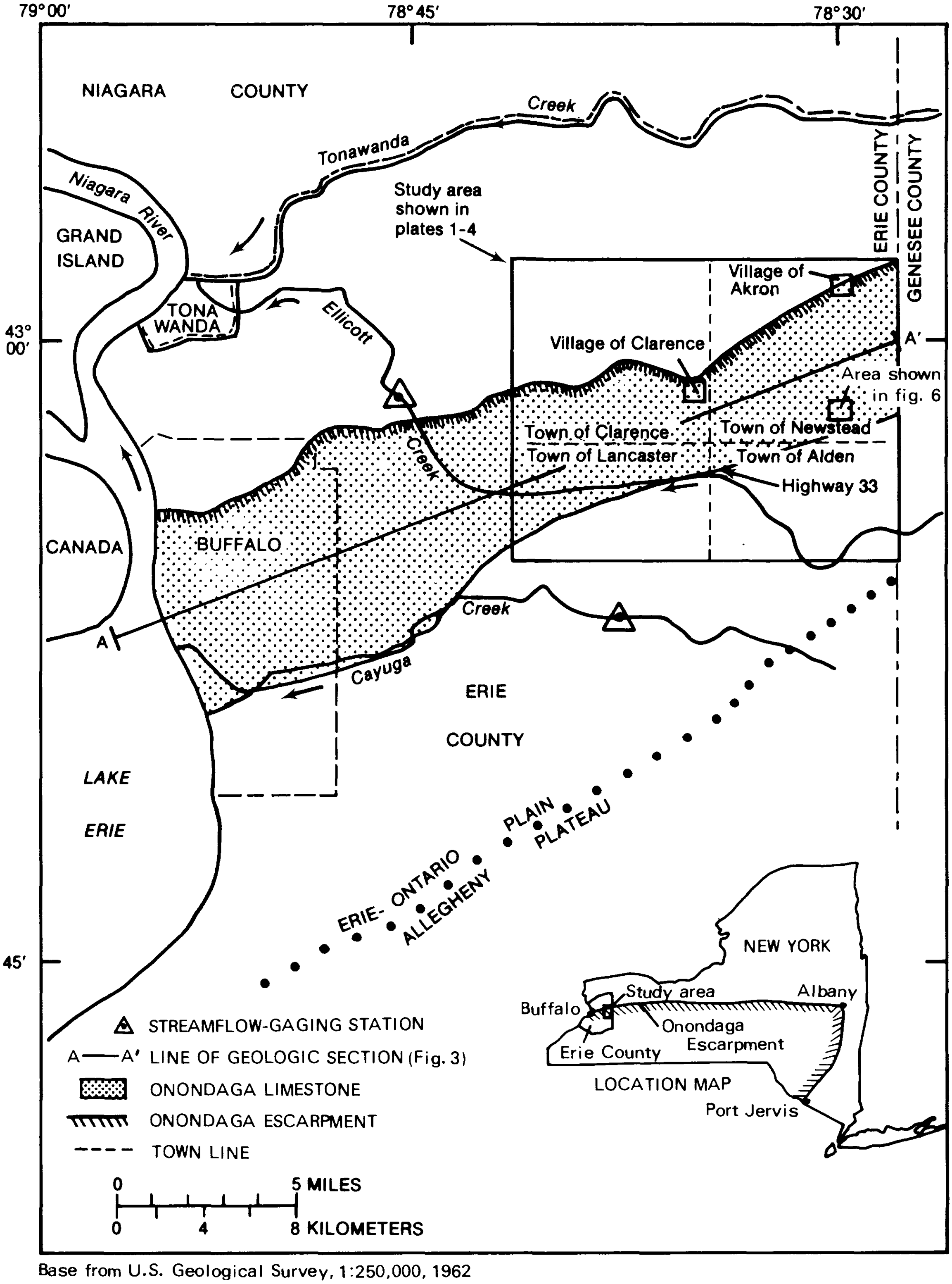
The Onondaga aquifer is a nearly flat-lying, 25- to 110-foot-thick, cherty limestone with moderately developed karst features such as sinkholes, disappearing streams, and solution-widened joints. Most ground water moves through solution-widened bedding planes, and some moves through vertical joints. Yield of water to 42 wells ranges from 3 to 100 gallons per minute and averages 20 gallons per minute.

Ground-water levels in the Onondaga aquifer declined during the fall of 1981 and summer and fall of 1982-85 near a 2.2-mile-long and 800-foot-wide land-surface depression in the eastern part of Erie County. More than 60 wells and several wetlands went dry, and at least three sinkholes developed. Ground-water levels were measured in 150 wells during a high-water-level period in April 1984 and a low-water period in October 1984. Water levels fluctuated 20 to 50 feet near the depression and near quarries but fluctuated only 5 to 10 feet elsewhere. The water-level decline is caused by the combined effect of ground-water removal by pumpage from a quarry (the water is then discharged to Dorsch Creek) and by the diversion of some water of Dorsch Creek since 1981 away from swallets in the 2.2-mile-long depression area, which are recharge points for the aquifer. In 1982, sinkholes formed in a surface-depression area in Harris Hill. The enlargement of sinkholes in the Harris Hill area seems unrelated to the water-level decline in the eastern part of the county and is probably caused by local drainage alterations.

INTRODUCTION

Ground-water levels in some parts of the Towns of Newstead and Clarence in eastern Erie County (fig. 1) declined greatly during the fall of 1981 and each summer and fall during 1982-85. More than 60 wells went dry during this period, most of which were then drilled deeper. Some of the redrilled wells went dry in subsequent years, and others have nearly gone dry. Several wetlands in the central part of the Towns of Newstead and Clarence reportedly dried up during the summer of 1982, and at least three sinkholes developed or enlarged in the Harris Hill area in the Town of Clarence (pl. 1).

The area where water levels declined is underlain by the Onondaga Limestone--an important aquifer that, in eastern Erie County, supplies water to approximately 750 households, 20 commercial and industrial facilities, and many farms. The Onondaga aquifer is a major source of water supply elsewhere in New York State (fig. 1) and is particularly important because it provides water of suitable quality for most uses. Water in the underlying Akron and Bertie Dolomites and Camillus Shale is less desirable for most uses because it contains elevated levels of hydrogen sulfide and dissolved iron and manganese.



Base from U.S. Geological Survey, 1:250,000, 1962

Figure 1.--Location and major geographic features of Newstead-Clarence area, Erie County, N.Y.

Purpose and Scope

In October 1983, the U.S. Geological Survey began a 2-year study, in cooperation with the Erie County Department of Environment and Planning and the Towns of Clarence and Newstead, to describe the hydrologic conditions in the Onondaga aquifer in eastern Erie County and to identify the extent and cause of ground-water-level declines and increased sinkhole formation. This report summarizes results of the study; it describes the hydrologic conditions in the Onondaga aquifer from October 1982 through September 1985 and explains the probable cause of water-level declines and the processes and causes of sinkhole formation in the area. It also presents physiographic and water-level maps, hydrographs, water-quality data, and a geologic section of rock units in the study area.

Description of Study Area

The area studied encompasses 36 mi^2 in the Towns of Clarence and Newstead in eastern Erie County (fig. 1) that are underlain by the Onondaga Limestone. The area is bounded on the east by the Erie-Genesee County line, on the west by the western border of the Town of Clarence, on the north by the Onondaga Escarpment, and on the south by New York State Highway 33 (pl. 1).

The study area is in the Erie-Ontario Plain physiographic province. The land surface is slightly undulating and rises gently from an elevation of 700 ft above sea level in the west to 850 ft in the east. The land surface is characterized by moderately developed karst features such as sinkholes, swallets, solution-widened joints, and disappearing streams. The area is drained by tributaries of Tonawanda Creek, which flows into the Niagara River at Tonawanda (fig. 1).

The climate is humid continental with warm summers and cold winters. Precipitation is fairly uniform throughout the year and averages 37.6 in/yr (U.S. Department of Commerce, 1984). Most precipitation during the winter falls as snow.

Land use in the Town of Newstead consists mostly of dairy farms and low-density residential areas with some commercial properties and light industries along Main Street (New York State Route 5), a limestone quarry at the Erie-Genesee County line, and a sand- and gravel-mining operation in the western part of the town (pl. 1). The Town of Clarence is more developed and contains medium-density residential areas, commercial properties and light industry, two limestone quarries, a landfill, a sand- and gravel-mining operation, and a few dairy farms. Interstate 90 (New York State Thruway) traverses the area from east to west. Major features of the area are indicated on plate 1.

Acknowledgments

Special thanks are extended to Harold Bloodsworth of Clarence, N.Y., for his assistance in measuring daily precipitation and monthly water levels; to the citizens of the Towns of Clarence and Newstead for providing access to their wells for water-level measurements, to County Line Stone and Buffalo Crushed Stone for access to their quarries and for supplying information on pumpage from the quarries, to the Erie County Laboratory for chemical

analyses of ground-water samples, and to Frey Well Drillers for information on deepened wells.

METHODS AND APPROACH

The approach taken in this study was to (1) describe the geohydrologic conditions, including ground-water levels and ground-water flow patterns in the Onondaga aquifer, (2) delineate areas of reported water-level declines and sinkhole formation, and (3) identify the causes of water-level declines and sinkhole formation. The study entailed a well inventory, water-level measurements, chemical analysis of water from selected wells, a survey of springs in the area, and discharge measurements on Dorsch Creek, which drains the southeastern part of the study area (pl. 1).

Well Inventory

Information on wells, including the location, owner, depth of well, depth to water, yield, date drilled, and whether redrilled because of declining water levels, was compiled from well data provided by Frey Well Drillers and from a 1984 field survey by the U.S. Geological Survey. Locations of wells, including redrilled wells, were plotted on 7.5-minute quadrangle maps to identify any patterns among wells that had gone dry. Well locations are shown on plate 1; well data are presented in table 12 (at end of report).

Water-Level Measurements

Water levels were measured in 33 wells twice monthly from September 1982 through September 1985 and at 150 wells twice--once during a high-water-level period in April 1984 and once during a low-water-level period in October 1984.

Chemical Analyses

Twenty-two water samples were collected from wells and springs in the area to compare the quality of water from the respective geologic formations, to compare the relative residence time of ground water in different parts of the Onondaga aquifer, and to determine the potential for dissolution of the Onondaga Limestone. Water samples were collected during a high water-level period in April 1984, a low-water period in August 1985, and during a pumping test in the Gunnville Road area (pl. 1) in February 1984. The samples were analyzed by the Erie County Laboratory for dissolved calcium, magnesium, sodium, silica, sulfate, and chloride. Specific conductance, pH, water temperature, and alkalinity were measured in the field at the time of sample collection.

Stream-Discharge Measurements

A stream-gaging station was installed on Dorsch Creek, 0.4 mi west of Crittenden Road, in the Town of Newstead (pl. 1), to record stream stage continuously from June 1984 through September 1985. Discharge measurements were used to develop a stage-to-discharge relationship (Kennedy, 1984) to calculate the quantity of flow in Dorsch Creek.

Discharge measurements also were made at several locations along Dorsch Creek downstream from the gaging station and along several small streams that flow over the escarpment to locate sites of ground-water discharge to the streams and where the streams lose water to the aquifer.

Survey of Springs

The locations of springs were plotted on a map, and discharge, pH, water temperature, and specific conductance of most springs were measured to identify ground-water discharge areas. Specific conductance and pH indicate whether the water is from the Onondaga aquifer or the underlying Camillus Shale. (The latter has higher specific conductance and lower pH.) The discharge indicates whether the source of the spring is a diffuse flow system through small joints (discharge less than 0.5 ft^3/s) or from a cave-conduit or solution-widened joint system (discharge greater than 0.5 ft^3/s).

Dye-Tracer Study

Two dye-tracer studies were conducted at a swallet (sinkhole into which a stream disappears) in the Harris Hill area in the western part of the Town of Clarence in April 1984 and October 1985 in an attempt to determine the velocity and direction of ground-water flow. In April 1984, fluoroscene dye was mixed with stream water that flowed into the swallet, and activated-charcoal packets that adsorb the dye were placed in 14 springs considered likely discharge areas at the base of the Onondaga Escarpment. The charcoal packets were replaced periodically and analyzed in the laboratory by fluorometer to detect the dye (Aley and Fletcher, 1976). In October 1985, dye was again mixed with stream water that flowed into the swallet, but this time, charcoal packets were placed along seepage faces in a quarry 0.9 mi south of the swallet and in a drainage ditch that receives pumpage from the quarry.

Precipitation and Evapotranspiration Measurements

Monthly, annual, and long-term average precipitation values in the study area were tabulated from data from the U.S. Weather Service station at the Buffalo International Airport (2 mi southwest of the study area, pl. 1) and from a local observer in Clarence. Potential evapotranspiration in the study area was calculated through Hamon's method (1961) and long-term average monthly temperature data from the airport.

GEOLOGY

The study area is underlain by Devonian and Silurian sedimentary rocks that trend east-west and dip slightly to the south-southwest at about 40 ft/mi. The bedrock in most of the area is overlain by unconsolidated deposits. The western and eastern ends of the study area are mantled by a thin cover of till and (or) lacustrine silt and clay, generally 3 to 15 ft thick, and the central part by sand and gravel, sand, and till deposits 25 to 50 ft thick that fill a north-south-trending buried valley (Miller and Staubitz, 1985) shown on plate 1. The uppermost formation in the study area is the Onondaga Limestone, which is underlain by the Bois Blanc Limestone (locally absent) and the Akron and Bertie Dolomites, which overlie the Camillus shale (table 1).

Table 1.--Summary of geologic units in Newstead-Clarence area, Erie County, N.Y. (Modified from Oliver, 1966.)

Period	Formation	Member	Thickness (feet)	Description
Devonian	Onondaga Limestone	Seneca	40	Olive-gray, massive bedded limestone, contains sparse tabulate and rugose corals and abundant dark nodular chert (5 to 25 percent). Exposures are few because the upper part of the Onondaga Limestone is eroded.
		Moorehouse	55	Olive-gray and light olive-gray, fine-grained, massive bedded limestone, contains brachiopods, sparse tabulate and rugose corals, and abundant nodular chert (5 to 50 percent).
		Clarence	40	Olive-gray, fine-grained, massive bedded limestone, contains few fossils and extremely abundant chert (25 to 75 percent).
		Edgecliff	5	Light-gray, coarsely crystalline, massive bedded limestone, numerous corals, and some nodular chert (5 to 25 percent).
	Bois Blanc Limestone		0-4	Gray, fine-grained, discontinuous limestone.
Silurian	Akron Dolomite		8	Greenish-gray to light buff, mottled and banded fine-grained dolomite.
	Bertie Dolomite		55	Gray to dark gray, thin to medium-bedded, fine-grained dolomite, dolomitic limestone, and shaly dolomite.
	Camillus Shale		400	Gray to brownish gray, thin to massive-bedded, shale with some interbedded limestone and dolomite, contains abundant gypsum with beds up to 5 ft thick. No fossils. Gypsum is mined near Akron.

The study area is characterized by minor development of karst features such as sinkholes, solution-widened joints, and swallets. Sinkholes are surface depressions, typically several feet to several tens of feet in diameter, that form when surficial unconsolidated sediments subside into enlarged subsurface openings produced by solution of carbonate rocks such as limestones and dolomites, or when the roof of a subsurface cave in the rock collapses. Solution-widened joints are secondary openings in the rock, such as horizontal bedding joints or vertical fractures, that have been enlarged by the dissolution of the carbonate rock by circulating ground water. Swallets are sinkholes into which a stream flows; thus, the streamflow recharges the groundwater reservoir. Swallets generally form over solution-widened joints in the limestone.

Onondaga Limestone

In New York, the Onondaga Limestone outcrop extends east-west from Lake Erie to just south of Albany, then south to Port Jervis. (See inset in fig. 1). It is a nearly flat-lying complex of massive, cherty, and argillaceous limestones deposited in a marine environment during Middle Devonian time. In Erie County, the outcrop area is 4 mi wide and 23 mi long and extends east-west from Lake Erie to the Erie-Genesee County border (fig. 1). The gentle south-southwestward dip of the Onondaga Limestone gives rise to a 20- to 50-ft-high escarpment that trends roughly east-west and marks the northern extent of the Onondaga. South of the escarpment, the land surface parallels the gently dipping surface of the Onondaga. The escarpment separates a low-lying plain to the north from a higher plain to the south.

The formation is 140 ft thick (Oliver, 1966) south of the study area, where it is buried and protected from erosion by more recent overlying formations. Where it crops out within the study area, however, it ranges from only 25 to 110 ft in thickness because erosion has removed its upper levels.

In western New York, the Onondaga is divided into four members, which are, in descending order, the Seneca, Moorehouse, Clarence, and Edgecliff. The northward-facing cliff of the Onondaga Escarpment consists chiefly of the Edgecliff and Clarence. The stratigraphy of the Onondaga and deeper formations is depicted in table 1.

The Onondaga Limestone is an important source of crushed stone in Erie County. Currently, three quarries operate in the study area (pl. 1).

Bois Blanc Limestone

Underlying the Onondaga Limestone is the Bois Blanc Limestone, a gray, fine-grained limestone that was deposited in a marine environment during Devonian time. It ranges in thickness from a few inches to 4 ft but is discontinuous within the study area and may be absent in many places.

Akron and Bertie Dolomites

Underlying the Bois Blanc Limestone and, in places, the Onondaga Limestone, are the Akron and Bertie Dolomites, which are fine-grained dolomites, shaly dolomites, and dolomitic limestones that were deposited in a marine environment during Silurian time. The Akron and Bertie Dolomites are exposed in the lower part of the falls of Murder Creek at Akron and the falls of Ellicott Creek at Williamsville (pl. 1). Some streamflow on top of the escarpment seeps down through the Onondaga Limestone and discharges from bedding planes at the base of the Onondaga and in the upper parts of the Akron and Bertie Dolomites at the face and along the sides of the falls. In some other places, the Akron and Bertie Dolomites are exposed in the lower parts of the escarpment.

Camillus Shale

Underlying the Akron and Bertie Dolomites is the Camillus Shale, which consists of shale, limestone, dolomite, and gypsum beds that were deposited in a marine environment during Silurian time (LaSala, 1968). The Camillus Shale crops out north of the Onondaga escarpment and underlies most of the low-relief area in the Tonawanda Creek basin (fig. 1), where it is covered by 10 to 50 ft of till, lacustrine silt and clay, and some sand and gravel.

The Camillus Shale dips to the south-southwest at 17 to 60 ft/mi. The formation is slightly folded, with fold amplitudes of a few feet and spacings of a few hundred feet between crests. The fold axes generally trend east-west (LaSala, 1968). Gypsum beds in the Camillus have been extensively mined, but of the four mines north of the study area, only one (near Akron) is active today.

Where the Camillus crops out north of the escarpment, the top 3 to 10 ft is moderately weathered and fractured, probably by dissolution of the gypsum by water and by freeze-thaw mechanical weathering. South of the escarpment, where the Akron and Bertie Dolomites overlie the Camillus, core samples revealed the top of the Camillus to be extremely fractured and weathered such that it resembles a coarse gravel (Goldberg-Zoino Associates, 1984). Dissolution of some of the gypsum, limestone, and dolomite beds by percolating ground water has left a residue of broken shale. The greater weathering of the Camillus south of the escarpment may be due to the greater seepage of water (with potential to dissolve the gypsum in the Camillus) through the Onondaga and Akron and Bertie than through the less permeable clay and till that overlies the Camillus north of the escarpment.

HYDROLOGY

Precipitation

Mean annual precipitation at the Buffalo International Airport is 37.6 inches (U.S. Department of Commerce, 1984) and is fairly uniformly distributed throughout the year. The mean monthly precipitation is 3.13 inches, with slightly larger amounts in August, September, November, and December, and slightly smaller amounts in February and June. Precipitation generally falls as rain from April through November and as snow from December through March. The snowpack generally reaches its maximum depth in February and decreases in March and early April (Dethier, 1966). Surface-water runoff and ground-water recharge both increase appreciably during snowmelt periods.

Total rainfall measured by a local observer in Clarence during the 11 snow-free months from June 1984 through August 1985 was 29.3 inches, whereas rainfall measured at the Buffalo International Airport was 34.02 inches, a difference of 14 percent (table 2). Measurement error of precipitation is ± 5 percent (Winter, 1981) at each measuring site, which leaves an unexplained difference of 4 to 9 percent. This suggests that, although the precipitation measured at the Buffalo Airport may be somewhat higher than that in the study area, it is representative of the study area on an annual basis.

Table 2.--Monthly precipitation at U.S. Weather Service station at the Buffalo International Airport and at Clarence, reported by a local observer.

[All values are in inches]

Year	Month	Clarence	Buffalo	Difference
1984	June	4.7	6.9	-2.2
	July	1.3	1.4	- .1
	August	4.0	4.2	- .2
	September	4.0	3.7	+ .3
	October	1.0	.9	+ .1
	November	3.1	2.7	+ .4
1985	January			
	February			
	March			
	April	1.4	1.3	+ .1
	May	3.1	3.5	- .4
	June	2.8	3.2	- .4
	July	2.4	1.8	+ .6
	August	1.5	4.6	-3.1
	Total for period	29.3	34.2	-4.9

The mean annual precipitation measured at the Buffalo International Airport during 1979-84 was 10 percent greater than normal (table 3); however, precipitation during some months and seasons was below normal. The mean precipitation for May through October of 1979-84, when water levels in the study area reached annual lows, was 17 percent above normal.

Evapotranspiration

Evapotranspiration is the loss of water through evaporation from the soil and other surfaces and through transpiration by plants. In the study area, the monthly potential evapotranspiration exceeds the monthly precipitation during summer and fall, which greatly reduces both surface-water runoff and ground-water recharge (table 4). Potential evapotranspiration is the maximum evapotranspiration that occurs if the amount of water in the soil is unlimited. Where soil moisture is limited, actual evapotranspiration is less than the potential evapotranspiration. The long-term annual potential evapotranspiration in the study area is 25.7 inches of water, and, for the growing season of May through September, it is 16.1 inches.

Table 3.--Monthly precipitation and departure from normal at U.S. Weather Service station at the Buffalo International Airport.

[All values are in inches]

Month	1979		1980		1981		1982		1983		1984		1985	
	Total	Departure	Total	Departure	Total	Departure	Total	Departure	Total	Departure	Total	Departure	Total	Departure
January	5.43	2.53	1.97	-.93	1.11	-1.79	6.88	3.98	1.44	-1.58	1.54	-1.48	4.27	1.25
February	2.03	-.52	1.08	-1.47	3.50	.95	1.04	-1.51	1.30	-1.10	3.59	1.19	3.34	.94
March	2.48	-.37	4.05	1.20	1.70	-1.15	2.64	-.21	3.20	.23	1.77	-1.20	4.42	1.45
April	3.16	.01	2.43	-.72	3.09	-.06	2.33	-.82	2.55	-.51	2.53	-.53	1.33	1.73
May	1.63	-1.34	1.60	-1.37	2.56	-.41	3.66	.69	3.28	.39	4.67	1.78	3.46	.57
June	2.18	-.05	5.82	3.59	3.68	1.45	3.14	.91	2.99	.27	6.86	4.14	3.21	.49
July	3.51	.58	3.55	.62	5.05	2.12	1.50	-1.43	2.01	-.95	1.37	-1.59	1.81	-1.15
August	6.26	2.73	3.58	.05	3.13	-.40	4.62	1.09	3.51	-.65	4.16	00	4.63	.47
September	5.61	2.36	4.53	1.28	4.24	.99	3.37	.12	2.11	-1.26	3.73	.36	1.20	-2.53
October	3.88	.87	4.69	1.68	3.31	.30	2.06	-.95	4.62	1.69	.87	-2.06		
November	4.14	.40	2.36	-1.38	2.22	-1.52	6.31	2.57	5.19	1.57	2.66	-.96		
December	3.43	.43	2.65	-.35	2.87	-.13	3.32	.32	7.30	3.88	3.67	.25		
TOTAL	43.74	7.63	38.31	2.20	35.46	0.35	40.87	4.76	39.50	1.98	37.42	-.10		
May-Oct.	23.07	5.15	23.77	5.85	21.97	4.05	18.35	.43	18.52	-.51	21.66	2.63		

Table 4.--Long-term, average monthly precipitation and estimated potential evapotranspiration in the Clarence-Newstead area.

[Precipitation data from U.S. Weather Service Station at Buffalo International Airport. All values are in inches.]

Month	Precipitation	Potential Evapotranspiration
January	3.06	.46
February	2.40	.43
March	2.97	.89
April	3.06	1.69
May	2.89	3.13
June	2.72	4.26
July	2.96	5.31
August	4.16	4.32
September	3.37	2.55
October	2.93	1.51
November	3.62	.71
December	3.42	.48
TOTAL	37.56	25.74

Surface Water

The study area is drained by streams tributary to Tonawanda Creek, which flows westward to the Niagara River at Tonawanda (fig. 1). The northern part of the study area is drained by several intermittent streams and by two perennial streams, Gott and Ransom Creeks, which originate from springs at the Onondaga escarpment (pl. 1). The southern and central parts of the study area are drained by Dorsch and Ellicott Creeks and several intermittent streams.

In the central part of the study area, several intermittent streams flow from east to west and disappear into swallets (pl. 1), where they recharge the Onondaga aquifer. During the 1982-85 study, most of the streams draining into swallets dried up in May and June and then resumed continuous flow from November through April. The outlet of Gunnville wetland just east of Harris Hill (pl. 1) is an exception in that it continues to flow late into the summer. Many of these intermittent streams flow for short periods after heavy rains during the summer and fall.

Ellicott Creek

The southern part of the study area is drained by Ellicott Creek, which flows to the west-northwest. The Ellicott Creek drainage basin is bordered on the east by the Murder Creek drainage basin and on the south by the Cayuga Creek drainage basin (pl. 1). Ellicott Creek is fed by several small tributaries and by water pumped from the three quarries--two near Harris Hill and the other at the Erie-Genesee County border (pl. 1). The New York State Department of Environmental Conservation (written commun., 1985) estimates that the quarries discharge an average of 7.2 Mgal/d (11.1 ft^3/s) to Ellicott Creek, which amounts to 9.2 percent of the 121-ft^3/s mean daily discharge of Ellicott Creek measured at the U.S. Geological Survey stream-gaging station near Williamsville from July 1984 through June 1985. The flow in Ellicott Creek is well sustained throughout the summer, partly by the contribution from quarry pumpage.

Dorsch Creek

Dorsch Creek, a tributary to Ellicott Creek, drains the southeastern part of the study area. Near its headwaters, it receives water pumped from a quarry between Crittenden and County Line Roads (pl. 1). From the rated discharge of the pump, the New York State Department of Environmental Conservation (written commun., 1985) estimates that the quarry discharges an average of 3 Mgal/d (4.64 ft^3/s) of water into Dorsch Creek. The U.S. Geological Survey operated a stream-gaging station on Dorsch Creek at Dorsch Road 0.4 mi west of Crittenden Road (pl. 1) from June 1984 through September 1985 to measure the quantity and seasonal distribution of flow and to estimate the amount of water pumped from the quarry. The surface-drainage area of Dorsch Creek above the gage is 1.14 mi^2. Mean daily discharges of Dorsch Creek are listed in table 5.

Quarry discharge.--The quarry discharge to Dorsch Creek is estimated as the difference between unit runoff of Dorsch Creek and that of Ellicott and Cayuga Creeks. (Cayuga Creek is the next stream south of Ellicott Creek, fig. 1.) The average monthly discharge per unit area for Dorsch Creek, Ellicott Creek, and Cayuga Creek are given in table 6. The mean-daily discharge per square mile measured in Dorsch Creek from July 1984 through June 1985, 8.8 $(ft^3/s)/mi^2$, is much greater than that of either Ellicott Creek, 1.48 $(ft^3/s)/mi^2$, or Cayuga Creek 1.57 $(ft^3/s)/mi^2$. The daily average discharge per square mile of Ellicott Creek and Cayuga Creek are, respectively, 17 and 18 percent of the Dorsch Creek value; therefore, approximately 82 percent of the daily average streamflow of Dorsch Creek (10.0 ft^3/s), or 8.2 ft^3/s, is water pumped from the quarry. The difference in daily average discharge is even greater from April through October, when the drainage-area-adjusted discharges of Ellicott Creek and Cayuga Creek were 11 percent and 9 percent, respectively, of the Dorsch Creek value. The New York State Department of Environmental Conservation's estimated 4.6 ft^3/s of quarry pumpage into Dorsch Creek, is 44 percent lower than the value calculated from streamflow records from July 1984 through June 1985.

The effect of water pumped from the quarry and then discharged into Dorsch Creek is evident from the hydrographs shown in figure 2. The daily stage and associated discharge of Dorsch Creek fluctuates regularly and rapidly, depending on when and how many pumps are operating in the quarry. As described in an unpublished report by Dunn Geoscience (written commun., 1981), the quarry generally operates one pump continuously at approximately 1.8 Mgal/d (2.8 ft^3/s) and one additional pump intermittently at 0.5 Mgal/d (0.8 ft^3/s). During periods of low water levels, only one pump may operate intermittently, and during high-water periods, as many as three pumps may be operated to pump 6 to 10 Mgal/d (9.2 to 15.4 ft^3/s).

Table 5.--Mean daily discharge of Dorsch Creek at station 04218452.

[Values are in cubic feet per second]

	1984						1985								
)ay	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September
1	7.5	2.7	2.3	2.9	2.1	3.3	49	6.9*	17	47	5.9	18	12*	4.4	2.4
2	6.5	2.4	2.3	2.7	3.4	3.3	17	6.9*	18	23	5.3	15	12*	5.7	2.2
3	6.5	2.9	3.1	2.5	1.9	4.4	14	6.9*	13	22	5.3	15	12*	3.3	4.4
4	6.5	1.6	2.4	2.7	4.4	3.4	13	6.9*	37	17	5.7	13	12*	1.9	2.9
5	4.4	2.9	2.4	2.4	3.9	3.0	13	6.9*	31	22	8	12	12*	3.9	3.0
6	6.3	1.9	2.4	2.4	2.9	3.0	12	6.9*	18	11	21	12	11*	4.1	2.5
7	9.1	2.3	2.4	2.5	2.7	3.3	12	6.9*	25	16	13	11	11*	8.0	1.9
8	4.7	1.9	2.3	2.4	3.3	3.5	10	6.9*	65	16	12	10	11*	5.1	2.2
9	4.3	2.2	2.3	2.2	3.4	3.4	9.7	6.9*	29	13	12	13	11*	4.7	4.6
10	4.1	1.9	2.1	2.4	3.9	3.5	8.8	6.9*	24	11	10	14	11*	2.4	5.3
11	4.6	1.6	6.8	2.3	4.9	4.3	9.7	6.9*	28	11	11	15	11*	2.4	4.3
12	4.7	1.9	2.7	2.3	3.4	6.3	8.8	6.9*	65	10	10	26	10*	3.3	4.7
13	4.3	2.0	3.4	2.1	3.3	5.5	10	6.9*	22	7.2	12	22	10*	2.9	4.3
14	4.3	3.9	3.5	2.5	2.9	4.9	8.5	6.9*	17	6.1	12	16	10*	2.9	1.9
15	4.3	3.5	3.5	2.1	3.1	6.5	7.7	6.9*	22	11	13	12	10*	2.8	1.9
16	3.3	2.2	2.8	2.4	3.0	5.7	6.8	6.9*	31	10	13	22	10*	2.8	5.7
17	3.7	2.2	2.4	1.3	2.8	4.9	7.2	6.9*	32	6.5	12	31	10*	2.3	11
18	3.9	2.2	2.4	1.6	3.0	4.6	7.0	6.9*	28	7.5	14	33	10	1.8	9.1
19	2.9	2.4	2.4	2.0	2.9	4.4	7.0	6.8	26	16	14	29	9.7	2.8	6.5
20	3.1	1.9	2.3	1.6	2.4	4.1	7.0*	6.8	28	11	14	25	10	2.7	3.5
21	2.2	2.1	2.5	1.8	3.0	5.7	7.0*	6.5	26	8.5	15	20	10	2.7	2.5
22	3.1	2.6	2.4	2.3	3.0	9.4	7.0*	17.4	26	6.8	13	17	8.8	2.8	1.8
23	3.0	2.7	2.5	2.1	3.0	6.1	7.0*	114	26	7.5	12	16	9.4	1.8	3.8
24	3.3	2.2	2.5	1.8	3.0	4.9	7.0*	117	26	6.8	14	17	8.0	1.6	2.5
25	2.9	2.1	2.5	2.3	3.0	5.1	7.0*	24	26	6.8	13	13	2.7	1.3	2.7
26	2.5	2.2	3.5	2.5	3.0	4.4	7.0*	15	22	6.5	13	13*	3.1	3.0	2.2
27	2.9	2.1	2.7	2.1	3.0	4.7	7.0*	13	23	6.1	13	13*	2.2	2.0	2.2
28	2.9	2.0	2.4	1.6	3.3	10	7.0*	13	39	6.1	16	13*	2.1	1.6	2.0
29	2.9	2.2	2.5	1.6	3.3	94	7.0*	--	28	5.9	13	13*	3.9	2.2	2.0
30	1.9	1.9	2.4	1.6	3.3	24	7.0*	--	24	5.7	13	13*	3.3	3.9	1.9
31	3.0	--	--	1.8	--	15	7.0*	--	56	--	22		4.7	2.7	--
'OTAL	129.6	68.6	82.1	66.8	94.5	268.6	315.2	457.7	898	361	380.2	512	273.9	95.8	107.9
IEAN	4.2	2.3	2.7	2.2	3.2	8.66	10.2	16.3	29	12	12.3	17.1	8.84	3.09	3.60
'T³/S/MI²	3.68	2.02	2.37	1.93	2.81	7.60	8.95	14.30	25.44	10.53	10.79	15.00	7.75	2.71	3.16

Record missing; value estimated.

Table 6.--Monthly discharge of Dorsch Creek, Ellicott Creek, and Cayuga Creek.

[Locations are shown in fig. 1.]

		Stream name, station number, and drainage area, in mi^2					
		Dorsch Creek 04218452 (1.14)		Ellicott Creek 04218518 (81.6)		Cayuga Creek 04215000 (96.4)	
Year	Month	ft^3/s	$(ft^3/s)/mi^2$	ft^3/s	$(ft^3/s)/mi^2$	ft^3/s	$(ft^3/s)/mi^2$
1984	July	4.2	3.7	39.4	.48	45.6	.47
	August	2.3	2.0	26.7	.33	21.6	.22
	September	2.7	2.4	40.7	.50	74.3	.77
	October	2.2	1.9	22.9	.28	19.7	.20
	November	3.2	2.8	57.1	.69	78.7	.82
	December	8.7	7.6	196	2.40	349	3.62
1985	January	10.2	8.9	115	1.41	127	1.32
	February	16.3	14.3	348	4.26	450	4.67
	March	29	25.4	319	3.91	383	3.97
	April	12	10.5	169	2.07	169	1.75
	May	12.3	10.8	65.8	.81	43.9	.46
	June	17.1	15.0	50.7	.62	41.1	.43
Average July-June		10.0	8.8	121	1.48	150	1.57
Average April-Oct.		7.5	6.6	59.3	.73	59.3	.61

Seepage loss.--Stream-discharge measurements downstream from the gage at Dorsch Creek indicate that some of the flow is lost as seepage through the stream bottom to ground water or through the channel banks to adjacent wetlands. Discharge measured on September 18, 1984 at the gage was 1.84 ft^3/s; 0.66 mi downstream at Ayers Road (pl. 1) it was 1.52 ft^3/s, and 0.53 mi further downstream at Dorsch Road it was 1.56 ft^3/s. Loss of streamflow in the reach between the gage and Ayers Road was 0.28 ft^3/s, or 15 percent of the discharge measured at the gage. Discharge measured on October 28, 1985, was 2.84 ft^3/s at the gage, and 1.5 mi downstream at South Newstead Road it was 2.48 ft^3/s. The loss of streamflow between the gage and South Newstead Road was 0.36 ft^3/s, or 13 percent of the discharge measured at the gage. At the time that the discharge measurements were made, no flow was observed in intermittent tributaries, no withdrawals from Dorsch Creek were observed between measuring sites, and pumped water from the quarry to Dorsch Creek had been steady for several hours. The discharge measurements were estimated to be accurate to within 8 percent of the actual value. Duplication of the results from two different sets of measurements indicates a probable loss of streamflow from Dorsch Creek.

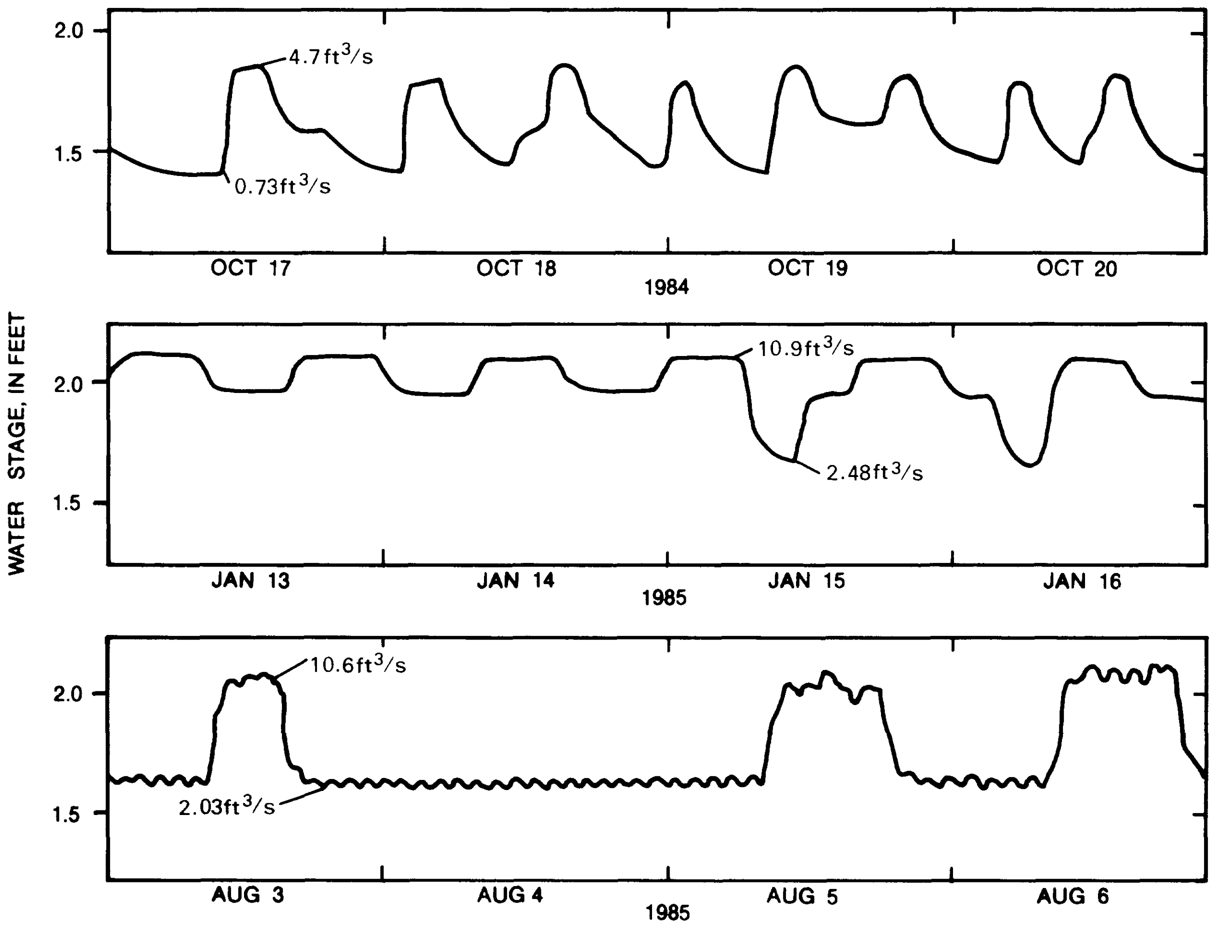


Figure 2.--Stream stage in Dorsch Creek at the gaging station on October 17-20, 1984; January 13-16, 1985; and August 3-6, 1985.

Ground Water

Water Quality

Onondaga Limestone.--Water withdrawn from wells that tap the Onondaga aquifer generally is lower in total dissolved solids and therefore more desirable as a water supply than water in the underlying formations. Water samples collected periodically from six wells that tap the Onondaga aquifer in eastern Erie County (Miller and Staubitz, 1985) had a lower mean value of specific conductance, 698 µS/cm, (a measure of total dissolved solids) and lower mean concentrations of dissolved calcium (Ca), magnesium (Mg), bicarbonate (HCO_3), and sulfate (SO_4) than water from underlying formations (table 7). The only undesirable characteristic of water from the Onondaga Limestone is that it is relatively hard and commonly requires softening for domestic uses.

Akron and Bertie Dolomites.--The quality of water from the Akron and Bertie Dolomites, which lie between the Onondaga Limestone and Camillus Shale,

Table 7.--Quality of water in the Onondaga Limestone, Akron and Bertie Dolomites, and Camillus Shale.

[All concentrations are mean values, in milligrams per liter; a dash indicates no available data.]

Characteristic or constituent	Formation, data source, and number of samples				
	Onondaga Limestone (Miller and Staubitz, 1985)	Akron and Bertie Dolomites (Miller and Staubitz, 1985)	Camillus Shale		
			(LaSala, 1968)	(Goldberg-Zoino, 1984)	(Goldberg-Zoino, 1984)
	25	2	1	1	1
Specific conductance (µS/cm)	698	1,270	1,820	2,420	1,400
pH	7.7	7.4	7.1	7.2	7.5
Calcium	88	243	300	--	--
Magnesium	28	55	96	--	--
Sodium	32	5.9	17	40	42
Chloride	26	20	20	26	79
Bicarbonate	132	140	240	167	130
Sulfate	114	494	914	1,990	480
Iron	.08	.06	.07	.90	2.9
Manganese	.03	.07	.03	.04	.10
Hydrogen sulfide	--	--	--	3.2	3.4

is variable. An observation well installed in the upper part of the dolomite yielded relatively fresh water with a specific conductance of 580 µS/cm and dissolved Ca, Mg, SO_4, and HCO_3 concentrations similar to those of water in the overlying Onondaga Limestone (well 38-59, table 8). Another well installed near the bottom of the dolomite (table 7) had a specific conductance of 1,270 µS/cm and dissolved Ca and SO_4 values characteristic of the underlying Camillus Shale (well 56-59, table 8). The molar calcium-to-magnesium ratios in both samples were relatively high (3.3 and 2.6, respectively). Hem (1970, p. 143) states that water from dolomite at or below saturation should contain nearly equal molar concentrations of calcium and magnesium. Because dolomite is less soluble than calcite or gypsum, the quality of water within the formation is probably controlled by the hydrogeologic character of the system and by the origin of the water. Water in the upper part of the dolomite is derived from leakage from the overlying limestone, and its quality is similar to that of water in the limestone. Water in the lower part of the dolomite may, in places, be derived from upwelling from the underlying Camillus Shale, and its quality is similar to that of water in the Camillus Shale.

Camillus Shale.--Water in the Camillus Shale has high concentrations of total dissolved solids; specific-conductance values as high as 2,420 µS/cm were reported (table 7). Water from the Camillus Shale has particularly high concentrations of dissolved Ca and SO_4, which are derived from the dissolution of gypsum ($CaSO_4 \cdot 2H_2O$) beds within the shale. This water also tends to have a strong hydrogen sulfide (H_2S) odor and appreciable concentrations of dissolved iron (Fe) and manganese (Mn). The presence of these constituents, which result from reducing conditions within the shale, makes water from the Camillus generally objectionable for domestic purposes.

Mineral saturation.--Water samples were collected from 18 wells and 4 springs in the study area. Results of the water-quality analyses were entered as input to the U.S. Geological Survey's WATEQF computer program (Plummer, and others, 1976), and the saturation indices were calculated for calcite, dolomite, gypsum, and other minerals commonly found in carbonate rock. The saturation indices shown in table 8 indicate that water from wells in areas of severe water-level declines (wells 53-20, 40-20, 13-07, 36-13, 31-11, and 39-48; see pl. 1) was similar to that in adjacent areas in which water levels had not declined significantly (wells 09-44, 49-47, and 30-59). Water from these wells was undersaturated with respect to all carbonate minerals and had specific-conductance values between 630 and 870 μS/cm, dissolved Ca concentrations between 80 and 125 mg/L, Mg between 12.4 and 46 mg/L, Na (sodium) between 10.6 and 36 mg/L, and Cl (chloride) between 7.5 and 72 mg/L.

Water from two wells (24-48 and 34-24, pl. 1) in the vicinity of a channellike depression where it crosses South Newstead Road and the New York State Thruway, differed significantly from water elsewhere in the Onondaga aquifer. These wells had specific conductance of 1,300 to 1,600 μS/cm, and the following dissolved ion concentrations: Ca, 95 to 150 mg/L; Mg, 35 to 53 mg/L; Na, 65 to 158 mg/L; Cl, 135 to 325 mg/L; and SO_4, 66 to 236 mg/L. Particularly high Na and Cl concentrations were noted at wells sampled in April 1984, shortly after the spring thaw. These wells are adjacent to the New York State Thruway, where drainage from the Thruway seeps into the ground at nearby swallets. The high values of Na and Cl at these wells may be due to the migration of deicing salts from the Thruway. Samples collected from these wells in August 1985 (table 8), a nonsalting period, had significantly lower concentrations of Na and Cl. The seasonal fluctuation in the quality of water at these wells indicates that water travels relatively quickly through this part of the Onondaga aquifer.

The water samples collected in August from wells 24-48 and 34-24 had nearly the same dissolved Ca concentrations as samples collected in April, but the concentrations of HCO_3 were lower and SO_4 significantly greater. The higher SO_4 concentrations in August may be derived from water upwelling from the Camillus shale during periods of low water levels and limited freshwater recharge within the Onondaga Limestone. The August samples from wells 24-48 and 34-24 also were more saturated with gypsum--a common mineral found in the Camillus Shale--than the April samples from those wells. The large number of swallets in the vicinity indicates the presence of numerous solution-widened joints and fractures that could serve as a path for upwelling water from the Camillus Shale.

Water samples from springs in the area had low concentrations of dissolved constituents and were less saturated with respect to carbonate minerals than samples from wells. This indicates that water discharging from springs has had a relatively short residence time and, therefore, probably drains a relatively shallow flow system. The specific conductance of water from the springs ranged from 430 to 600 μS/cm, and dissolved-ion concentrations were: Ca, 68 to 92 mg/L; Mg, 11.3 to 5.8 mg/L; and SO_4, 19.3 to 23.2 mg/L.

Table 8.--Chemical analyses of water from selected degree of saturation of each water sample

[Concentrations are in milligrams per liter.

Constituent or characteristic	Well or spring number[1], formation[2],									
	09-44 OLS (4-84)	49-47 OLS (4-84)	39-48 OLS (4-84)	53-20 OLS (8-85)	40-20 OLS (8-85)	13-07 OLS (8-85)	36-13 OLS (8-85)	31-11 OLS (8-85)	23-39 OLS (8-85)	34-24 OLS (4-84)
					Concentration					
Specific conductance (µS/cm)	790	783	636	790	730	870	760	710	1,100	1,610
pH	7.5	7.1	7.3	7.1	6.9	7.0	6.9	6.9	6.9	7.0
Calcium (mg/L)	94	97	80	116	98	126	106	106	135	155
Magnesium (mg/L)	46	36	38	20	16	19	35	23	46	34
Sodium (mg/L)	13	30	13	21	26	36	6.8	11	68	158
Chloride (mg/L)	55	72	28	38	53	68	7.5	23	75	325
Sulfate (mg/L)	77	47	47	196	101	161	98	75	89	66
Bicarbonate (mg/L)	176	172	174	113	118	123	172	168	261	188
Mineral					Saturation Index[3]					
Anhydrite ($CaSO_4$)	-2.0	-2.2	-2.24	-1.40	-1.78	-1.56	-1.76	-1.90	-1.77	-1.95
Aragonite ($CaCO_3$)	-.165	-.55	-.41	-.50	-.83	-.69	-.64	-.71	-.39	-.47
Calcite ($CaCO_3$)	-.01	-.396	-.26	-.35	-.68	-.54	-.49	-.56	-.24	-.32
Dolomite [$CaMg(CO_3)_2$]	-.195	-1.09	-.70	-1.14	-1.93	-1.71	-1.18	-1.57	-.67	-1.16
Gypsum ($CaSO_4.2H_2O$)	-1.60	-1.79	-1.85	-1.16	-1.45	-1.19	-1.47	-1.55	-1.48	-1.55
Magnesite ($MgCO_3$)	-.50	-1.00	-.76	-1.15	-1.59	-1.50	-1.05	-1.35	-.78	-1.16

[1] Well numbers and locations of wells are described in table 12; spring numbers and locations of springs are listed in table 10.

[2] OLS = Onondaga Limestone, BDL = Akron and Bertie Dolomites, CMS = Camillus Shale

Ground Water in the Onondaga Limestone

Ground water occurs in bedding planes and vertical joints and fractures in the Onondaga Limestone, some of which have been widened by dissolution. The upper 5 to 15 ft of the limestone contains the most joints, all of which are widened by the more intense weathering that occurs near land surface.

Bedding planes.--Bedding planes, which transmit most of the water in the Onondaga Limestone, are planar openings parallel to the nearly horizontal bedding in the rock. They were formed by the expansion of the rock during removal of weight by erosion of overlying rock units and by the retreat of *wells and springs in the Newstead-Clarence area and with respect to selected minerals.*

Analyses by Erie County Laboratory.]

and date (month-year) of samples											
								Spring	Spring	Spring	Spring
34-24	24-48	24-48	55-48	55-48	38-59	56-59	30-59	22	9	8	12
OLS	OLS	OLS	OLS	OLS	BDL	CMS	OLS				
(8-85)	(4-84)	(8-85)	(4-84)	(8-85)	(2-84)	(2-84)	(2-84)	(4-84)	(4-84)	(4-84)	(4-84)
					Concentration						
1,300	1,600	1,400	1,090	1,100	580	1,020	640	490	597	481	433
7.2	6.8	7.1	7.1	7.1	7.5	7.5	7.5	7.0	6.8	6.7	7.1
141	150	150	110	126	79	160	81	75	92	76	68
35	53	42	49	50	14	28	12	11	9.1	8.3	5.8
92	125	65	44	61	17	4	33	23	35	20	22
170	275	135	10	145	36	9.4	68	40	65	40	43
236	121	230	93	118	33	310	31	37	22	23	19
137	250	187	176	226	124	130	114	95	119	104	88
					Saturation Index						
-1.3	-1.71	-1.40	-1.86	-1.61	-2.33	-1.24	-2.4	-2.3	-2.5	-2.5	-2.61
-.28	-.55	-.34	-.48	-.13	-.31	-1.11	-.34	-.63	-1.04	-1.26	-.95
-.134	-.40	-.19	-.48	+.02	-.16	+.40	-.19	-.47	-.88	-1.11	-.79
-.537	-1.08	-.70	-.82	+.02	-.90	-.49	-1.05	-1.69	-2.69	-3.09	-2.54
-1.08	-1.34	-1.05	-1.50	-1.42	-1.96	-.87	-1.98	-1.90	-2.07	-2.09	-2.19
-.77	-1.08	-.851	-.82	-.38	-1.07	-.86	-1.20	-1.52	-2.11	-2.29	-2.06

[3] Saturation index (SI) <0 indicates the water is undersaturated with respect to the mineral,
SI = 0 indicates the water is in theoretical equilibrium with the mineral.
SI >0 = indicates the water is oversaturated with respect to the mineral.

glaciers from the area. Major bedding planes extend at least several miles, which makes them effective conduits for ground water. Although the separation along bedding planes is generally small (less than 1/4 inch), dissolution has widened them to several inches in some places. Bedding planes widened by dissolution were observed in quarries and along the escarpment at the bottom of the Onondaga and at the top of the Clarence Member of the Onondaga. These planes undergo a greater rate of dissolution than smaller joints because they form a preferential path for horizontal ground-water flow. The downward migration of water is inhibited by the relatively impermeable underlying Akron and Bertie Dolomites and some massive beds within the Onondaga, especially the Clarence Member of the Onondaga, 50 to 75 percent of which is highly insoluble chert.

The walls of quarries show where prominent joints occur in the Onondaga Limestone. A quarry in the southwestern part of the study area (pl. 1) has large seeps of water from two prominent bedding planes; one was observed on top of the cherty Clarence Member (altitude about 625 ft), and the other was reported by the quarry operator to be at the base of the Onondaga (altitude 565 ft), where water cascades into a sump pit.

Vertical joints.--Vertical joints are planar openings roughly perpendicular to bedding planes but are generally less extensive and therefore form less significant water-bearing openings except where dissolution has widened them. Vertical joints in the study area are typically 5 to 18 ft apart, penetrate 10 to 25 ft, and are preferentially oriented N75°E, N40°W, and N5°E (Goldberg-Zoino Associates, 1984). Most vertical joints extend several tens of feet laterally, but some extend for several miles. A quarry that previously occupied the site of Spaulding Lake, north of Main Street in the Town of Clarence (pl. 1), was abandoned when mining intercepted a major vertical joint from which large volumes of water flooded the quarry. The joint's trend is N43°W and is traceable on air photos from the escarpment at County Route 216 (Old Goodrich Road) to Tillman Swamp.

The separation along vertical joints ranges from less than 1/16 inch to 0.5 ft. The wider separations are in the upper 5 to 15 ft of the Onondaga Limestone, where dissolution is most rapid, and at the escarpment, where tension-release stresses from the absence of supporting rock mass has caused the rock to expand away from the cliff. Vertical joints become narrower, less numerous, and less continuous with depth.

Well yields.--The reported yield of 42 wells with open-hole construction that tap the Onondaga aquifer indicated that the yields of wells range from 3 to 100 gal/min and average 20 gal/min. The yield of water to a well depends on how many saturated bedding planes and vertical joints with significant openings are penetrated. The highest reported well yields in the study area are near the channellike depression in the central part of Newstead (pl. 1), which indicates the presence of numerous, continuous, solution-widened joints beneath the depression area.

Recharge.--The ultimate source of recharge is precipitation, which reaches the saturated zone in the Onondaga aquifer by (1) direct areal infiltration of rain and snow-melt through the overlying unconsolidated deposits (lake deposits and till), (2) flow of stream water into swallets and into vertical joints that intersect stream channels, and (3) seepage of water from wetlands through the underlying organic debris and glacial deposits into the Onondaga aquifer. Recharge occurs over most of the study area except at the base of the escarpment, in quarries where water is pumped, in the upgradient parts of wetlands during periods of high water levels, and in the channellike depression during periods of low water levels. The rate of recharge to the aquifer depends on the amount of precipitation and streamflow available for recharge, the amount of water lost through evapotranspiration, and the permeability of the Onondaga Limestone and overlying unconsolidated deposits. Each of these factors is described below.

Infiltration of precipitation. If the amount of water available for recharge either exceeds the rate at which water can move to the water table, or the rate at which water can flow through the aquifer, recharge either becomes ponded at land surface or is lost as runoff. This occurs in many places in the spring, when large amounts of snowmelt and rain exceed the infiltration capacity of the area. During this period, intermittent streams flow from a few weeks to several months, and water accumulates in low areas, such as wetlands and the channellike depression areas in Newstead and Harris Hill.

Conversely, when the amount of water available for recharge is less than the discharge from the aquifer, ground-water levels decline. Comparison of the long-term average monthly precipitation with the corresponding estimated potential evapotranspiration (table 4) reveals that the 19.6 inches of potential evapotranspiration exceeds the 16.1 inches of precipitation from May through September, which means that little of the precipitation during this period is available for ground-water recharge, so that ground-water levels decline. Intermittent streams flow and water ponds in low areas only during heavy rains and snowmelt. After periods of significant precipitation, ground-water levels rise for a time (from several hours to 3 days). Hydrographs of water levels in wells measured during 1983-85 (pl. 4) show that water levels declined from May through October and rose from November through April.

Infiltration from streams. Streamflow that seeps into swallets provides a significant amount of recharge to the Onondaga aquifer. At least 14 swallets were identified in the study area, the majority of which are clustered within the channellike depression near South Newstead Road, Steiner Road, and Ayers Road in the Town of Newstead (pl. 1). Individual swallets were observed to accept streamflow at rates of 0.1 to 1.5 ft^3/s without overflowing; a cluster of swallets, such as those within the channellike depression in the Newstead area, could probably accept several times that amount before ponding would occur. Immediately after snowmelt or particularly heavy rains, however, the swallets may not accept all of the incoming streamflow if the carrying capacity of the aquifer is exceeded and ground-water levels rise. During these periods, the swallet may overflow and produce runoff to tributaries that drain outside the study area. During the summer and fall, intermittent streams that flow into swallets dry up.

At the top of the escarpment, some streamflow seeps downward through vertical joints exposed in the stream channels. These joints have been enlarged by tension-release stresses, ice wedging, and dissolution; they range in width from 0.25 to 8 inches. Most of the water that seeps into the Onondaga aquifer at the top of the escarpment discharges to springs and streams at the base of the escarpment, where more impermeable bedrock units (Akron and Bertie Dolomites) that underlie the Onondaga Limestone retard further vertical seepage.

<u>Regional flow and discharge</u>.--Ground water in the Onondaga aquifer moves from areas of higher head (recharge areas) to areas of lower head (discharge areas) through a network of joints and bedding planes. The direction of ground-water movement in the Onondaga aquifer during a period of high ground-water levels (April 1984) and low ground-water levels (October 1984) is shown by arrows on the potentiometric-surface maps in plates 2 and 3, respectively. Water levels in approximately 150 wells were measured once during each of

these two months to document the seasonal fluctuation of ground-water levels and the changes in direction of ground-water flow. Ground water discharges to wells, springs, wetlands, the channellike depressions, and quarries.

Ground-water movement in the Onondaga aquifer generally follows the east-to-west slope of the Erie-Niagara basin--that is, it moves from the higher parts of the basin in eastern Erie County to lower areas further west and eventually discharges to Lake Erie or the Niagara River (fig. 3). In the central part of the study area, flow paths in the underlying Akron and Bertie Dolomites and Camillus Shale are similar to those of the Onondaga aquifer (Goldberg-Zoino and Associates, 1984), except that the Akron and Bertie Dolomites have a larger downward component of flow than the Onondaga aquifer (fig. 3).

The differences in hydraulic conductivity (permeability) of the four formations have a significant effect on the regional flow system. Hydraulic conductivity values for the Onondaga Limestone, Akron Dolomite, Bertie Dolomite, and Camillus Shale are summarized in table 9. The Camillus Shale is the most permeable aquifer. As a result of dissolution of gypsum, the shale is 2 to 3 times more permeable than the Onondaga Limestone, which is, in turn, 4 to 10 times more permeable than the Akron and Bertie Dolomites.

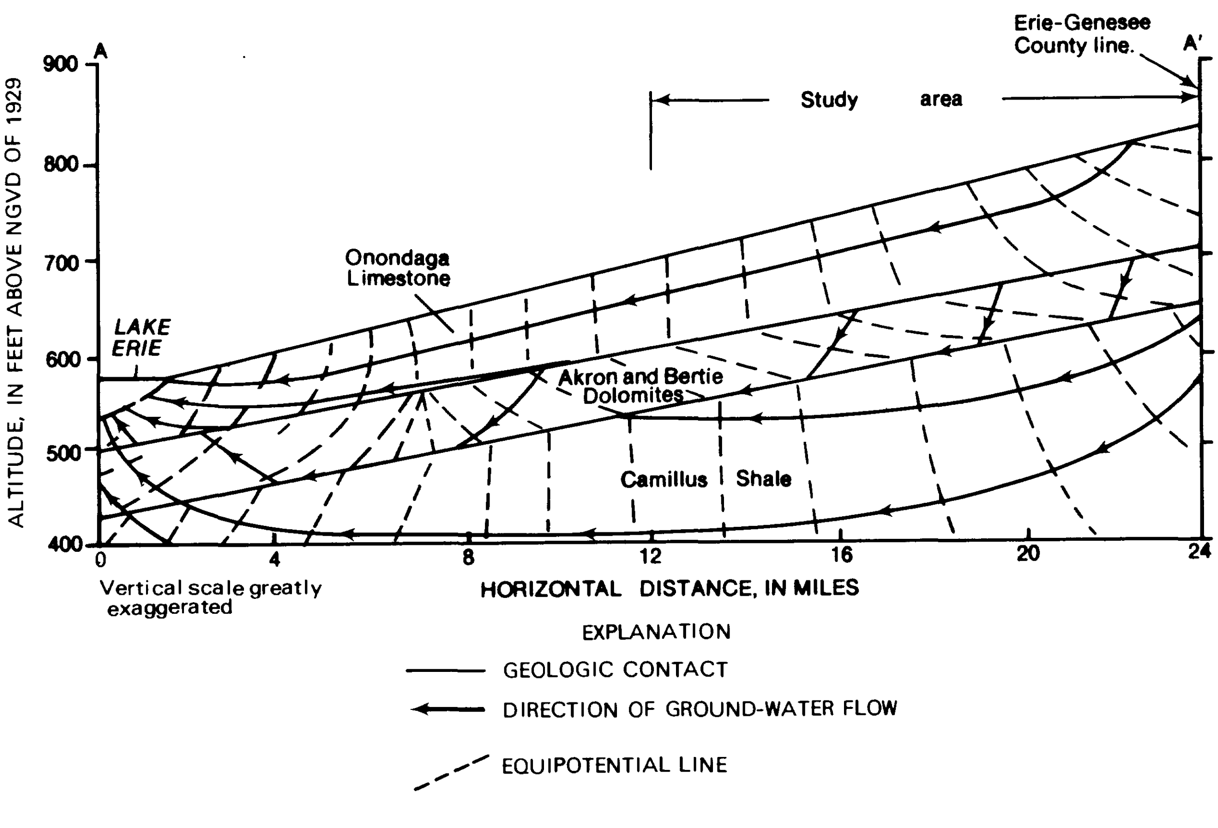


Figure 3.--Generalized regional ground-water movement from study area to Lake Erie.

Table 9.--Hydraulic conductivity of bedrock aquifers in the study area.

Aquifer	Hydraulic conductivity range (ft/d)	Source of data
Onondaga Limestone	8 to 50	LaSala, 1968
	1.25 to 4.5	Goldberg-Zoino, 1984
Akron Dolomite	≈ 2	Goldberg-Zoino, 1984
Bertie Dolomite	0.4	Goldberg-Zoino, 1984
Camillus Shale	23 to 60	LaSala, 1968, and Goldberg-Zoino, 1984

In the central part of the study area, the progressive decrease in water levels (potentiometric surfaces) from each aquifer to the one below indicates a vertical downward component of ground-water flow. The water level in the Onondaga aquifer was about 10 ft higher than that in the Bertie Dolomite, which in turn was 10 ft higher than that in the Camillus Shale. Because the potentiometric surface in Camillus Shale in this area is as high as the middle part of the Onondaga, the Camillus aquifer is artesian. Artesian flow occurs in wells installed in the Camillus Shale in low areas, such as along the base of the escarpment at Clarence and Williamsville and in the bottom of the quarry south of Harris Hill, where a major vertical joint extends downward from the bottom of the quarry to the Camillus Shale and allows water from the Camillus to flow up and into the quarry.

Results of a pumping test conducted in the central part of the study area by Goldberg-Ziono and Associates in February 1984 indicated the transmissivity of the Camillus Shale to be about 8,800 (gal/d)/ft of aquifer thickness (Goldberg-Zoino, 1984). LaSala (1968) reported transmissivities ranging from 7,000 to 70,000 (gal/d)/ft. The Akron and Bertie Dolomites have relatively low hydraulic conductivities (2.0 and 0.4 ft/d, respectively) and thus form a leaky confining bed over the Camillus Shale. The vertical hydraulic conductivity of the Bertie Dolomite is 0.004 ft/d (Goldberg-Zoino, 1984), and this aquifer contributes 1.7 Mgal/d to the Camillus Shale.

Local flow and discharge.--The potentiometric surface of the Onondaga aquifer generally parallels the slightly undulating land surface (pls. 2 and 3). Highlands are recharge areas, and lowlands are discharge areas. Ground water that enters the flow system in high areas moves radially away and is discharged either to the nearby low areas (such as the base of the escarpment or wetlands), to more permeable rock zones (such as areas with a high density of solution-widened joints), to major pumping centers at quarries, or to Lake Erie and the Niagara River.

Escarpment. The sharp decline of land surface at the escarpment has produced an east-west-trending ground-water divide that lies 0.5 to 1.0 mi south of the escarpment (pls. 2 and 3). Ground water north of the divide flows north to the base of the escarpment and discharges to springs and headwater tributaries of Tonawanda Creek, whereas ground water south of the divide flows southwestward to the central and southern parts of the aquifer (pls. 2 and 3, and fig. 4). The northward direction of ground-water flow north of the divide is verified by (1) the similarity of pH and specific conductance of springs and headwater tributaries at the base of the escarpment to those of ground water in the Onondaga aquifer (water from the Camillus Shale has significantly higher specific conductance, ranging from 1,500 to 2,000 μS, see table 7); and (2) the progressive decline of water levels in the direction of the escarpment.

Springs. Most springs along the base of the Onondaga escarpment (pl. 1) flowed during the wet periods and had relatively low discharges of 0.02 to 0.3 ft^3/s, which suggests a relatively small catchment area (from the escarpment to the ground-water divide about 1 mi south) and diffuse flow through small bedding planes in the aquifer rather than through large, extensive conduits,

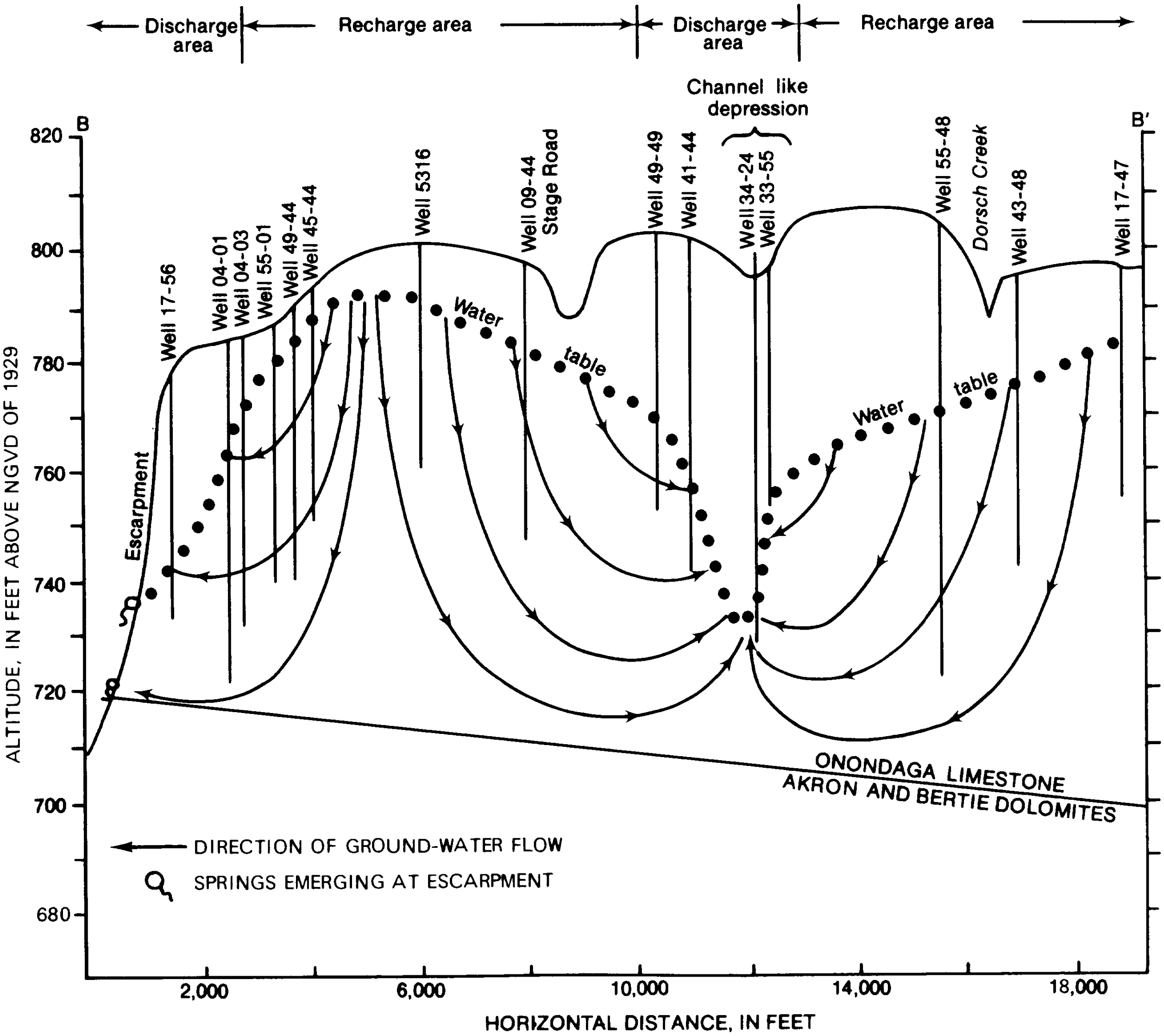


Figure 4.--North-south vertical section through the Onondaga Limestone showing two-dimensional flow of ground water. (Location of section B-B' is shown on pl. 1.)

which indicates a larger catchment area and larger openings. Large quantities of water can discharge where major vertical joints intercept significant bedding planes, both of which may be enlarged by dissolution. The largest spring found in the study area, at Old Goodrich Road (no. 11 in table 10, see pl. 1), had a discharge of 1.0 ft^3/s on May 14, 1984. The relatively large discharge from this spring is attributed to a major vertical joint, visible on air photos, that extends southeast from the escarpment at Old Goodrich Road to Spaulding Lake and then to Tillman Swamp, where it is covered by unconsolidated deposits (pl. 1). The second largest spring is at Cummings Road, Town of Newstead (pl. 1), where water seeps from abandoned mines. A description of 22 springs along the Onondaga escarpment is given in table 10.

Large discharges from springs elsewhere, such as 14 to 35 ft^3/s measured in limestones in the Mohawk River basin in east-central New York, have been attributed to outflow from large cavernous drainage systems (Baker, 1976). The absence of extremely large springs in the study area would thus suggest a lack of significant cavernous drainage systems with outlets at the escarpment.

Wetlands. Wetlands are in low areas and are generally ground-water discharge areas except during the summer and early fall, when the water table declines below their level, allowing them to recharge the underlying Onondaga aquifer. The following observations are evidence that wetlands are ground-water discharge areas from late fall to spring: (1) springs drain into the wetlands along their perimeter, (2) outflow from the wetlands is nearly continuous, (3) ground-water levels in wells in and around the wetland are higher than or the same as the standing water in the wetland, and (4) ground-water levels peak when discharge from the wetland is greatest.

In the Gunnville wetland (pl. 1), water levels in wells 54-11 and 51-41, installed in the underlying Onondaga aquifer, were the same as the standing-water level in the wetland from November through June of 1985 and 1986, which indicates that the wetland is a discharge area during this period. From July through October of those years, water levels in the Onondaga aquifer were several feet lower than in the wetland, which indicates a potential for water in the wetland to recharge the Onondaga aquifer. The wetland is probably perched above the water table from July through October. Most of the water loss in the wetland during this period occurs through evapotranspiration, although some infiltration to the Onondaga aquifer probably occurs also.

Channellike depressions. The study area contains two large, channellike depressions of high permeability that drain water rapidly from adjacent parts of the Onondaga aquifer and create a depression in the water table during summer and fall. These depressions, which contain many sinkholes and swallets, resemble abandoned, sinuous stream channels and range from 200 to 800 ft in width and 3 ft to more than 10 ft in depth (pl. 1 and fig. 5).

One of these depressions is in Harris Hill, in the Town of Clarence, and extends 0.75 mi west from well 02-00 near Main Street to the edge of the escarpment near Harris Hill Road (pl. 1). In 1982, several sinkholes formed in this depression, and an older one became enlarged.

Table 10.--Location and general characteristics of springs.

[Dashes indicate missing values.]

Spring no. on pl.	Location: Latitude ° ' "	Location: Longitude ° ' "	Elevation, in feet above NGVD	Discharge (cubic feet per second)[1]	Discharge: Date measured	Temperature (°C)	pH	Specific conductance (µS/cm)
1	42 58 16	78 44 04	650	0.2 (e)	5-21-84	11	7.3	1,000
2	42 58 28	78 42 56	670	.1 (e)	5-21-84	12	7.7	810
3	42 58 47	78 42 35	605	.5 (e)	5-14-84	10	7.9	950
4	42 58 46	78 42 14	605	.3 (e)	5-14-84	11	7.9	760
5	42 59 08	78 41 34	615	.3 (e)	5-14-84	14	7.9	420
6	42 58 55	78 41 28	615	.5 (e)	5-14-84	14	8.0	600
7	42 59 09	78 40 52	640	.2 (e)	4-24-84	8	7.2	600
				.1 (e)	5-14-84	16	7.8	400
8	42 58 34	78 40 23	675	.216 (m)	4-19-84	8	--	--
				.140 (m)	4-30-84	7.6	6.7	481
9	42 58 34	78 40 22	675	.146 (m)	4-19-84	8	--	--
				.191 (m)	4-30-84	7.5	7.5	597
10	42 58 58	78 39 23	660	--	4-25-84	10	7.2	380
				.2 (e)	5-14-84	16	8.0	400
11	42 59 03	78 38 20	675	.82 (m)	5- 1-84	10	7.4	420
				1.0 (e)	5-14-84	10	7.4	400
12	42 59 19	78 37 38	700	.2 (e)	4-26-84	9	7.1	430
14				--	4-26-84	9	7.2	650
15	42 58 58	78 35 09	720	.1 (e)	5-21-84	11	7.0	1,200
16	42 59 03	78 34 41	725	.01 (m)	5-21-84	11	7.2	900
17	42 59 04	78 34 36	725	.05 (e)	5-22-84	10	7.3	820
18	42 59 14	78 34 12	730	.02 (m)	5-22-84	18	7.5	880
19	42 59 21	78 33 59	730	.10 (m)	5-22-84	11	7.0	880
20	42 59 26	78 33 50	730	.03 (m)	5-22-84	--	--	--
21	43 00 21	78 30 32	750	.20 (m)	9- 6-84	--	7.45	900
22	42 58 38	78 33 21	760	--	5- 1-84	7.0	7.40	490

[1] e = estimate, m = measured

The other depression, in the Town of Newstead, extends 2.2 mi west from Ayers Road to at least the intersection of Schutt and Stage Roads (pl. 1). West of this intersection, the surficial expression of the depression is less developed because unconsolidated deposits overlie the depression. Ground-water levels near this depression fluctuate as much as 50 ft, and more than 60 wells went dry during the summers of 1982-85.

These depressions may be the surficial expression of (1) preglacial or interglacial stream channels that survived the erosional effects of glaciation, (2) areas where unconsolidated deposits have slowly subsided into solution-widened fractures in the Onondaga Limestone, or (3) areas where the abrupt collapse of the upper bedrock surface into solution-widened channels or caverns has caused subsidence of the overlying unconsolidated deposits. In any case, the many sinkholes and swallets in these depressions indicate that the underlying bedrock has a highly developed network of interconnected solution-widened joints and thus constitutes a zone of high permeability.

Indications that these depressions are zones of high permeability are that: (1) wells in the vicinity of the depression have the highest yields in the study area, (2) ground-water levels within the depressions fluctuate as much as 50 ft annually, whereas wells elsewhere fluctuate only 10 to 15 ft, (3) many sinkholes are present, (4) swallets within the depression accept large amounts of surface runoff during spring snowmelt and summer rainstorms, and (5) large amounts of circulation water were lost during the 1984 rotary drilling of two test holes in the depression.

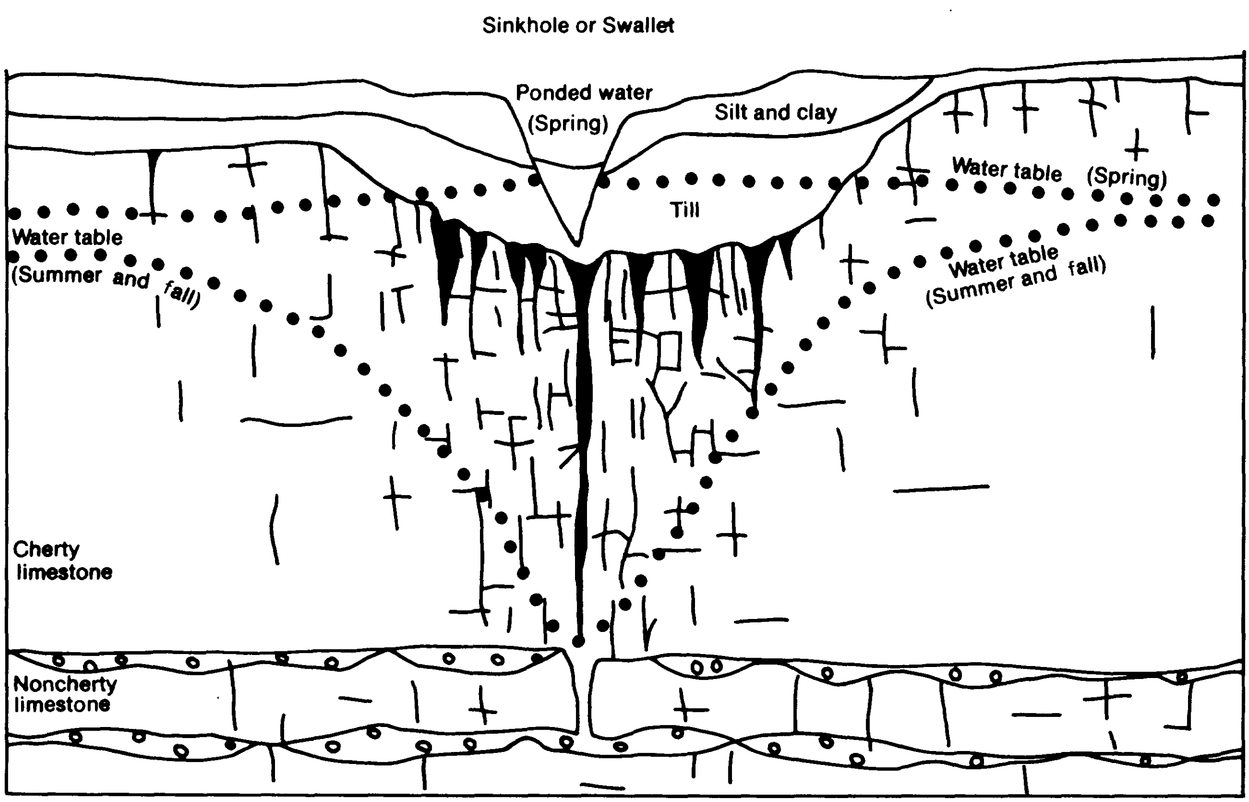


Figure 5.--Idealized vertical section showing a swallet in a channellike depression.

The depressions may be areas of ground-water recharge or ground-water discharge, depending on the season. During the spring, after snowmelt, intermittent streams drain to the depressions, where the water seeps into swallets and recharges the Onondaga aquifer. During this period, ground-water levels near the depressions are as high or nearly as high as in the surrounding areas (pl. 2). Recharge ceases when the intermittent streams dry up in the late spring. Ground-water levels in the vicinity of the depressions then decline rapidly and become lower than in other areas, as seen in well hydrographs (pl. 4) and on the potentiometric-surface map for October 1984 (pl. 3).

The greatest water-level fluctuations and the lowest water levels observed during the study occurred in the depressions (pl. 4). The fluctuations decrease with distance from the depressions. During most of the year, water levels decline toward the depression, which indicates that ground water from surrounding areas flows toward the depressions. Also, velocity of ground-water flow increases near the depression, as evidenced by the steep slope of the potentiometric surface at the edge of the depression area (pl. 3). Ground water within the depression generally flows westward, although some probably seeps to deeper bedrock units, and some may discharge in the area of the buried valley near the Tillman wetland (pl. 1). Ground water also may leave the system as seepage to springs that feed Ransom and Gott Creeks or may flow farther west and discharge to quarries near Harris Hill or to Lake Erie.

Quarries. Pumping for dewatering at three quarries that mine the Onondaga Limestone results in significant ground-water discharge from the Onondaga. Two quarries are in the southwestern part of the study area, and one is in the eastern part (pl. 1). Two quarries are pumped all year (the eastern and extreme southwestern quarries); the other is not pumped during the summer and early fall, when ground-water levels are below the quarry floor. Water pumped from the two southwestern quarries is discharged to Ellicott Creek through drainage ditches (pl. 1), and water pumped from the eastern quarry is discharged into Dorsch Creek, which flows 5.0 mi southwestward to Ellicott Creek.

The daily average pumpage from the quarry in the eastern part of the area (at the Genesee-Erie County border) from June 1984 to July 1985 was 5.3 Mgal/d. Water levels indicate a 5- to 25-ft-deep cone of depression within 1,000 ft of the quarry (pl. 3). Ground water flows into the quarry from the north, east, south, and southwest. On July 24, 1985, water levels in wells within 500 ft of the quarry ranged from 784 to 788 ft above sea level. Since quarry operations began in 1958, several wells close to the quarry have been deepened (pl. 1) because pumping from the quarry had caused the water level to fall below the pump intakes. Projecting the regional hydraulic gradient of unaffected areas to the quarry indicates that the natural water levels in the area would be 800 to 810 ft above sea level during the summer. Without the pumping, the natural direction of ground water flow would be northwestward and westward.

The combined pumping capacity from the two quarries in the western part of the study area may be as high as 23 Mgal/d but usually ranges from 1.5 to 6.0 Mgal/d (Todd Giddings and Associates, 1980, and Dunn Geoscience, 1981). Pumpage varies during the year and depends on the season and amount of precipitation and snowmelt. Generally, pumpage is greatest in the winter and spring, when water levels in the Onondaga aquifer are highest, and is lower in summer and fall but can be increased after an exceptionally wet period, such as November 1982, when 6.3 inches of rain was recorded at the Buffalo International Airport. Pumpage from the westernmost quarry near Harris Hill during that time was increased from 1.80 Mgal/d on October 27, 1982, to 8.62 Mgal/d on November 29, 1982. Pumpage at the westernmost quarry near Harris Hill was measured usually once a month (table 11). The average annual pumpage of 1,225 Mgal is derived by multiplying the average of the measurements in table 11 by 365 days.

The pumping has lowered ground-water levels by 5 to 35 ft within 3,000 ft of the quarries (pl. 3). During the winter, when the pumps are shut down at the quarry east of Barton Road, water levels rise to altitudes from 700 to 710 ft (Todd Giddings and Associates, 1980), which is 5 to 15 ft below land surface.

Table 11.--Pumpage from quarry in western part of study area, February 1981 through June 1985.

[Location is shown in pl. 1; values are in million gallons per day.]

Date and pumpage 1981		Date and pumpage 1982		Date and pumpage 1983		Date and pumpage 1984		Date and pumpage 1985	
Feb. 26	5.1	Feb. 4	2.9	Jan. 28	2.2	Jan. 25	5.1	Jan. 31	2.3
Mar. 25	2.3	Feb. 11	2.0	Apr. 27	1.6	Mar. 27	5.0	Feb. 26	5.1
Apr. 23	3.9	Mar. 23	5.5	May 25	2.1	Apr. 24	4.7	Mar. 28	5.0
May 28	3.6	Apr. 26	4.2	July 29	1.4	May 23	5.4	Apr. 29	4.4
June 29	.03	May 11	3.9	Aug. 31	1.4	June 22	5.0	May 30	4.6
July 30	3.3	June 19	3.8	Sept. 27	1.7	July 23	1.9	June 21	5.5
Aug. 7	2.3	June 28	4.1	Oct. 25	1.5	Aug. 29	1.8		
Aug. 19	1.9	July 20	1.9	Dec. 2	4.6	Sept. 28	1.8		
Sept. 21	2.0	July 30	3.3	Dec. 28	6.6	Oct. 31	1.4		
Oct. 30	3.4	Aug. 30	3.6			Nov. 30	4.1		
Nov. 18	2.5	Sept. 28	3.7			Dec. 28	2.6		
Nov. 30	2.1	Oct. 27	1.8						
		Nov. 29	8.6						
		Dec. 28	4.0						

Dye tracing. The direction and velocity of ground-water flow in solution-channel flow systems have sometimes been successfully identified through dye-tracing techniques (Thrailkill, 1983). The many sinkholes and the disappearance of streamflow into swallets in the Harris Hill area of Clarence indicates the presence of continuous, solution-widened openings. Dye-tracer studies were conducted at a swallet near Main Street in Harris Hill in the spring of 1984 and fall of 1985 to identify the point of discharge from the solution-widened openings.

In April 1984, dye was injected into a stream that enters the swallet. Fourteen springs that emerge along the base of the escarpment north of the injection site were sampled periodically for 8 weeks, but no dye was detected. In October 1985, dye was reinjected at the same site, and this time sampling packets were placed at seepage faces along the northern wall of the quarry

0.9 mi south of the swallet and at the drainage ditch that receives quarry pumpage (pl. 1). Once again, after 8 weeks, no dye was detected. This indicates that water entering the swallet and flowing within any underlying solution-widened openings does not flow northward to discharge at the escarpment or southward to the quarry. Thus, the swallet and sinkholes in the Harris Hill area are probably not within the cone of depression of the quarry.

The water that transported the dye may have moved vertically downward to deeper formations or flowed westward in the Onondaga aquifer along the direction of regional ground-water flow. Unfortunately, no sampling sites were available to detect dye that may have moved westward or downward into the deeper formations.

Ground-Water-Level Declines

Water levels in parts of the Onondaga aquifer declined during the fall of 1981, and several wells became dry. Water levels declined again during the summer and fall of 1982-85, and more than 60 wells and several wetlands became dry. The depth of wells that went dry ranged from 30 ft to 77 ft and averaged 50 ft. Most of the wells that went dry were deepened another 25 to 80 ft; the average was 45 ft. The depth of redrilled wells now ranges from 72 to 130 ft and averages 95 ft. Most of the deepened wells are completed in the lower part of the Onondaga, but several of the deeper ones are in the Akron and Bertie Dolomites.

Areas Affected by Water-Level Declines

To identify areas that have severe water-level declines, water levels were measured twice at 150 wells--once in April 1984, a period of high-water levels, and once in October 1984, a period of low water levels. The measurements showed water-level fluctuations to be greatest at the channellike depression and at quarries (pl. 4).

The water-level measurements revealed that water levels declined 30 to 50 ft during the summers and falls of 1982-85 in the vicinity of the channellike depression in the eastern part of the study area and in an apparent extension of the channel into the central part of the study area. Water levels elsewhere declined less than 10 ft. Most of the wells that became dry and were redrilled since 1981 are within 2,500 ft of the center of the depression and extend as a belt at least 3 mi long from Ayers Road to North Millgrove Road (pl. 4). The channel may extend west another 2 mi to Tillman wetland, but west of North Millgrove Road it may be buried by unconsolidated deposits.

<u>Causes of water-level declines in the channellike depression area.</u>--The decline of water levels and the resultant loss of storage within the aquifer since 1981 indicates that the equilibrium of the aquifer was stressed at that time. Although precipitation during some months was below normal, precipitation during periods of water-level declines was at or above normal (table 3). Thus, the repeated water-level declines probably were not caused by a lack of precipitation.

Before the quarry at the Erie-Genesee County line was opened, ground water flow probably followed land surface and the direction of surface drainage--westward and northwestward to and then beneath the channellike depression. Although the quarry is upgradient of the depression area and intercepts some of the ground water that would have flowed to it, no significant water-level declines were reported west of the quarry from 1958 to 1981. However, at least part of the water pumped from the quarry and discharged to Dorsch Creek during this period flowed northwestward in a small channel that branches off Dorsch Creek near Ayers Road; the water then flowed back into the Onondaga aquifer through several swallets in the easternmost extension of the depression area (fig. 6). Some of the water pumped from the quarry was, in effect, returned to the aquifer through the swallets in the channellike depression and thus did not constitute a major loss from the system. During the summer of 1981, however, channel clearing routed all flow in Dorsch Creek

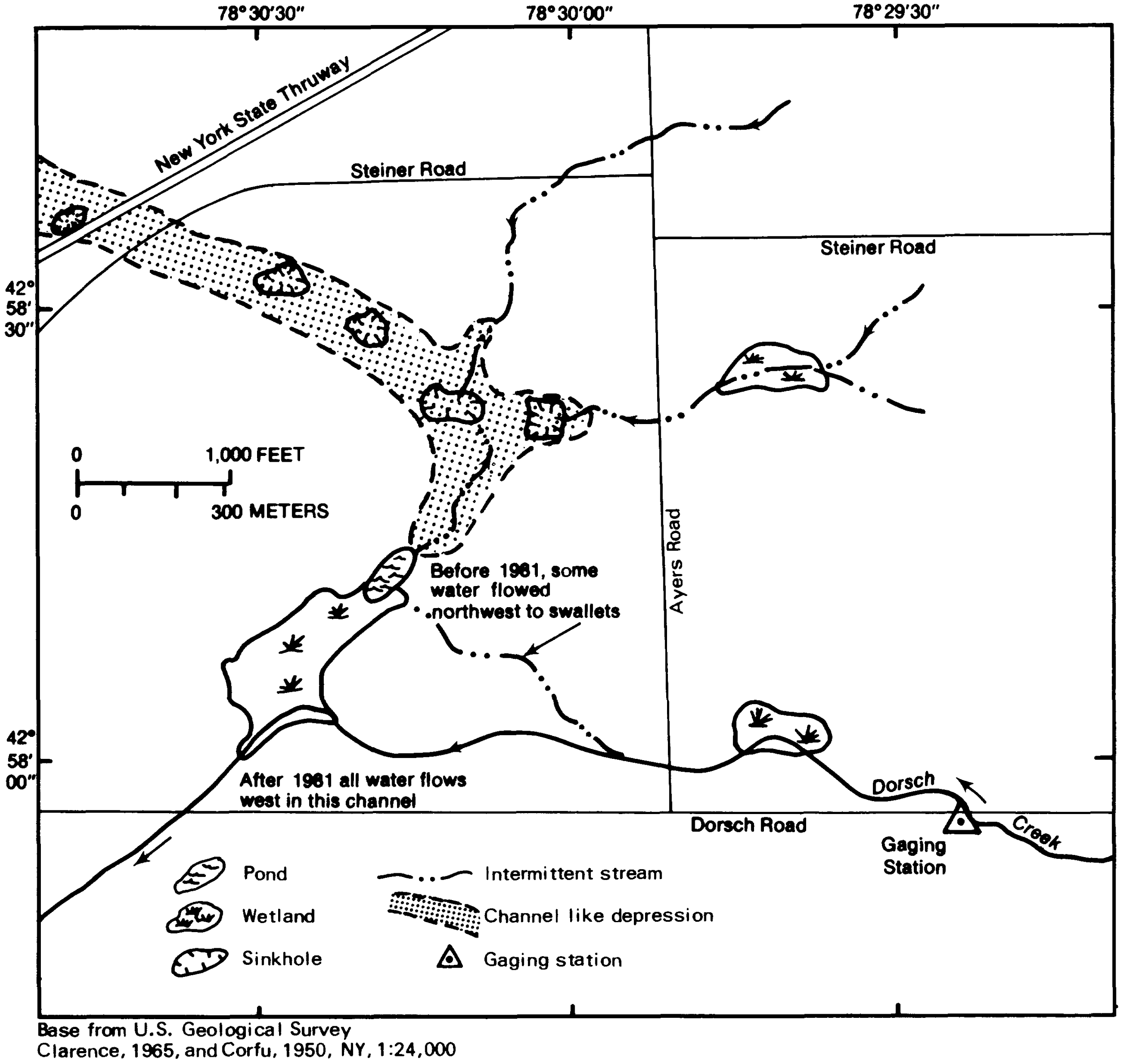


Figure 6.--Hydrologic features of channellike-depression area in the Town of Newstead. (Location is shown in fig. 1.)

southwestward, away from the swallets in the channellike depression area. Since then, all quarry pumpage carried by Dorsch Creek has flowed into Ellicott Creek and none flows through the now-abandoned channel to the swallets. Therefore, since 1981, none of the water removed from the quarry returns to recharge the ground water in the Onondaga aquifer in the depression area.

Shortly after the 1981 diversion of water in Dorsch Creek from the swallets, several wells near the channellike depression were reported to go dry. During the summers and falls of 1982-85, ground-water levels near the depression again declined, but more severely than in 1981, and caused several wetlands and more than 60 wells to go dry. The diversion of recharge away from the depression area evidently has stressed the equilibrium of this part of the aquifer and caused a loss of storage in the aquifer, as reflected by the water-level declines. The reason that ground-water fluctuations near the depression are greater than in the surrounding areas is that the bedrock within the channel area has a high density of solution-widened joints and is therefore more permeable than elsewhere.

Causes of water-level declines near the quarries.--Water levels declined 5 to 30 ft in the vicinity of the three quarries as a result of the dewatering operations. The seasonal dewatering affected water levels within a 3,000-ft radius of the western quarries and within 1,000 ft the eastern quarry. Several wells near the eastern quarry (at the Erie-Genesee County line, fig. 1) had to be deepened as a result of water-level declines after the quarry began operation in 1958.

Sinkhole Development

Sinkholes form almost exclusively in areas underlain by carbonate bedrock. Dissolution of the carbonate bedrock along joints and fractures by ground water over thousands of years forms solution channels. Sinkholes form either with the collapse of bedrock into a solution-widened joint or cavity or by slumping of unconsolidated sediments into bedrock openings. The distribution of sinkholes is controlled by the location of underground solution cavities and the trend or direction of solution-widened joints.

Although sinkholes have developed naturally throughout geologic time, they have formed with increased frequency in the past 50 years as a result of large ground-water withdrawals. For example, in some areas underlain by carbonate rocks in Alabama, where sinkhole formation has been extensively studied, an estimated 4,000 individual sinkholes and areas of subsidence have developed since 1900 (Newton, 1977). All but about 50 of these are defined as human-induced sinkholes and are associated with ground-water declines caused by the withdrawal of large quantities of water by high-yield wells and by pumping from quarries and mines (Newton, 1976).

The formation of sinkholes is usually preceded by or coincident with the lowering of ground-water levels or an increase in the range of water-table fluctuations. Initially, when the water levels are high, solution-widened openings are filled with water and residual particles of chert, clay, and other insoluble minerals as well as particles from overlying unconsolidated deposits. Both the water and residual material in the solution-widened openings serve to support the overlying bedrock and unconsolidated deposits, and their presence tends to restrict infiltration of water from above. When ground-water levels are lowered, such as through heavy pumping, the potentiometric gradient is increased, and the velocity of ground-water flow accelerates toward the discharge area, which results in the dewatering of the openings and subsurface erosion of the residual material within them (Newton, 1977).

The loss of structural support (hydrostatic pressure) in the solution-widened openings and in pore spaces in unconsolidated deposits by evacuation of water may cause a collapse of the opening or collapse of unconsolidated sediments into openings of the underlying bedrock, which results in abrupt subsidence at land surface. If the unconsolidated deposits consist primarily of sand and gravel, this process generally results in a gradual subsidence at land surface that forms a depression with low-angle slopes, but if they consist of silt and clay, this process results in the sudden formation of steep-sided, conical sinkholes, as depicted in figure 7. Clayey silt or clay are relatively cohesive and can support a substantial weight, but as the sediment in the lower part of the deposit gradually spalls into the openings in the bedrock, a cavity is formed that becomes larger until the weight of overlying material can no longer be supported, at which time it collapses, forming a sinkhole.

If unconsolidated clayey deposits above a vertical joint are subjected to repeated wetting and drying, such as by a widely fluctuating water table, desiccation cracks develop, and spalling will occur more rapidly. An increased range of water-level fluctuations has been reported to be caused by seasonal dewatering of quarries and mining (Newton, 1976) and also by diversion of storm runoff into sinkholes (Reitz and Eskridge, 1977), both of which occur in Clarence.

In 1982, a sinkhole, a swallet, and an area of subsidence formed at approximately the same time along and 500 ft north of Main Street in the channellike depression in the Harris Hill area of Clarence (pl. 1). The sinkhole formed under a bowling alley along Main Street, and an area subsided under Main Street in front of the bowling alley. The swallet formed in a seasonally flooded, wooded area about 500 ft northeast of the bowling alley. The bowling alley became structurally unstable and was demolished, and the sinkhole and the subsidence area in the roadway were filled in. The swallet, which is fed by an intermittent stream, has increased in size through slumping of its steep sides and downcutting by the stream. (Discharge of the intermittent stream was 0.40 ft^3/s in April 1984.) Another sinkhole formed adjacent to the swallet in the spring of 1985 and grew larger during the summer. As long as the stream flows unobstructed into the swallet, it is likely to continue downcutting, and the swallet will probably continue to enlarge. In October 1985, the swallet was 30 ft in diameter and 16 ft deep, and the new sinkhole that formed beside it in 1985 was 18 ft in diameter and 12 ft deep.

Geologic logs of wells in the study area did not reveal large solution conduits or caves, but some well logs indicated several zones with small solution channels and zones with broken, highly weathered rock (Goldberg-Zoino, 1984). These channels are probably solution-widened fractures and joints, and such zones are likely to be highly permeable, preferential paths of ground-water flow.

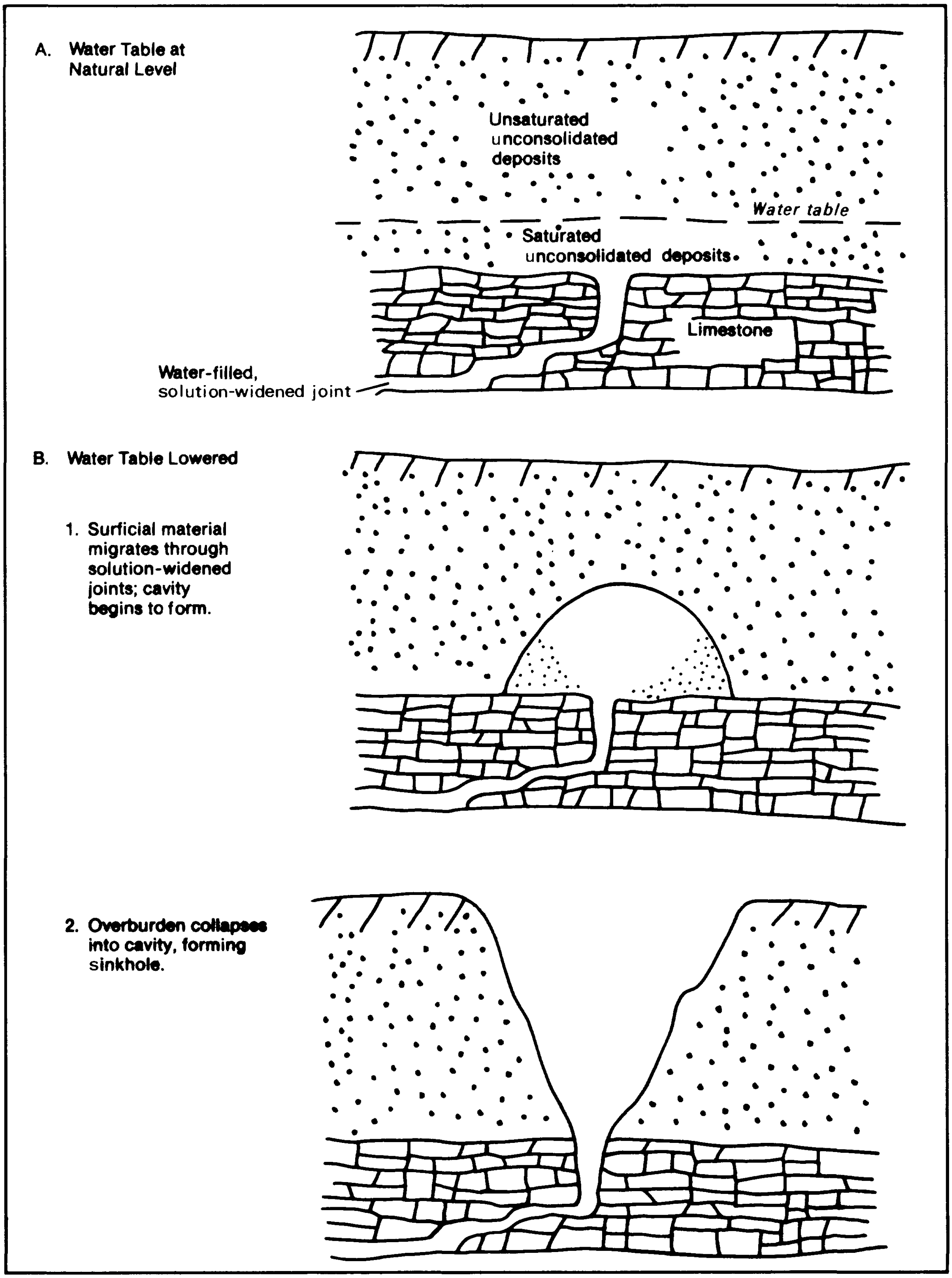


Figure 7.--Development of a collapse-type sinkhole.

The formation of the swallet and sinkholes along Main Street resulted from the collapse of a cavity in the surficial deposits, as described earlier and shown in figure 7. The swallet and sinkholes are steep sided and funnel shaped, and the swallet has an outlet at its bottom, into which the stream flows. The exposed sides of the swallet and sinkholes consist of a cohesive, plastic silty clay. The log of a well drilled 10 ft from the swallet indicates that 16 ft of silty clay overlies the Onondaga Limestone at the site (Goldberg-Zoino Associates, 1984). The generalized soil map of Erie County (U.S. Department of Agriculture, 1979) identifies the soil in this area as a Minoa-Cosad, in which the Cosad is underlain by deep clayey sediments and prone to piping and sloughing when excavated. Fortunately, in Harris Hill, this soil type occupies only a very small (0.13 mi^2) area, most of which remains undeveloped at this time. The soils of the surrounding area are described to be of the Benson and Wassaic groups, both of which are underlain by the limestone bedrock at a depth of 20 to 40 inches. These soils are too thin to form collapse-type sinkholes of any appreciable size.

No decline or increased fluctuation in water levels in the Onondaga aquifer near Harris Hill was evident immediately before the formation of the sinkholes. The dye-tracer study indicated that the sinkholes are probably not within the cone of depression of the quarry to the south and were, therefore, unlikely to have been induced by quarry pumpage. However, land development, such as drainage of wetlands and alteration of local surface-drainage patterns, may have lowered water levels that seasonally fluctuate in the unconsolidated deposits and, over the long term, could have contributed to the formation of sinkholes in the Harris Hill area. The formation of sinkholes in the Harris Hill area does not appear to be related to water-level declines in the eastern part of the study area.

SUGGESTIONS FOR FURTHER STUDY

Diversion of some flow from Dorsch Creek into the swallet area in the channellike depression has been proposed by local interests as a method to mitigate declining ground-water levels during the summer and fall. If part of the flow in Dorsch Creek is diverted to the swallets west of Ayers Road (fig. 6), it would be useful to (1) monitor the amount and quality of water diverted and the response of ground-water levels; (2) install a recording stream gage along the diversion ditch between the swallet and the diversion structure; and (3) measure ground-water levels monthly at the same wells that were monitored during this study. A data-collection period of 8 months would be needed, from 1 month before the beginning of the diversion (about April) until diversion ceases (about late November). This type of monitoring would indicate whether the diversion of water to the swallets has an appreciable effect on ground-water levels west of Ayers Road and, if so, the quantity of water needed for diversion to raise and maintain ground-water levels at a particular height.

SUMMARY

The Onondaga aquifer is a nearly flat-lying, 25- to 110-ft-thick, cherty limestone with moderately developed karst features such as sinkholes, swallets, and solution-widened joints. Most ground water moves through solution-widened bedding planes, although some moves through vertical joints. Yield of water to 42 wells in the study area ranged from 3 to 100 gal/min and averaged 20 gal/min.

Ground-water levels declined sharply during the fall of 1981 and each summer and fall from 1982 through 1985 in some parts of the Onondaga aquifer in the Towns of Newstead and Clarence. Several wetlands and more than 60 wells went dry, and at least three sinkholes formed. The area contains two large, channellike surface depressions--one in Harris Hill and one in the Town of Newstead. Sinkholes formed in the depression in Harris Hill in 1982, and wells went dry near the depression in Newstead.

Water-level measurements during periods of high and low water levels indicate that greater annual fluctuations (20 to 50 ft) occur near the depressions than in the surrounding area (5 to 10 ft). During periods of low water levels in summer and fall, ground water drains toward the depression in the Newstead area and then flows westward. Water-level fluctuations in the vicinity of the channellike depression are greater than in other areas because the depression has a high density of solution-widened joints that can quickly drain the area. Water-level fluctuations decrease with distance from the depression. The area of severe water-level declines is within 2,500 ft of the center line of the depression in the Newstead area.

An average of 5.3 Mgal/d of water is pumped into Dorsch Creek from a quarry 1.5 mi east of the channellike depression. Before 1981, some of this water reentered the ground when part of the discharge of Dorsch Creek flowed into swallets within the depression. The water entering the swallet was a major source of ground-water recharge during the summer and fall. When the channel of Dorsch Creek was improved and its flow diverted from the swallets, a significant part of the summer and fall recharge was lost, and ground-water levels declined within the aquifer.

The formation of sinkholes in the Harris Hill area is caused by slumping of unconsolidated deposits into solution-widened openings in the bedrock. The sinkholes are in a surface-depression area and are underlain by a relatively thick (up to 16 ft) deposit of cohesive silty clay; sinkholes are less likely to form where the surficial deposits are thin or absent. The enlargement of sinkholes in the Harris Hill area seems unrelated to the water-level decline in the eastern part of the study area and is likely the result of local drainage alteration in the Harris Hill area.

Water in the Onondaga aquifer is generally of good quality and is suitable for most domestic and agricultural purposes. Water in the underlying Akron and Bertie Dolomites and Camillus Shale tends to be of poorer quality, especially in the Camillus Shale, where the water contains appreciable concentrations of dissolved iron and manganese and has a strong hydrogen sulfide odor. Water from wells close to the depression in Newstead had elevated sulfate concentrations during a low-water period. This indicates that water from the Camillus Shale may upwell through the Bertie and Akron Dolomites into the Onondaga aquifer during low-water periods in the areas affected by severe water-level declines and may degrade the quality of water from wells in those areas.

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Table 12.--Records of Selected Wells in Eastern Erie County, N.Y.

NUMBERING AND ARRANGEMENT OF WELLS

All wells and borings are identified by latitude and longitude to the nearest second, as measured from 7 1/2-minute topographic maps, scale 1:24,000. The location of each well or boring record was plotted on these maps by U.S. Geological Survey staff during a visit to the site or from large-scale engineering drawings.

The location of each well and boring is shown on plate 4 and on additional maps within the text. The four numbers used to identify each well on these illustrations are the seconds of latitude and longitude. For example, a well located at 42°45'38" latitude and 78°34'31" longitude is identified in illustrations as well 38-31. Data are arranged in 1-minute strips of latitude and longitude, and well numbers are placed near the well symbols. The first well in this listing is in the southernmost strip and is followed by other strips successively farther north.

ABBREVIATIONS

1. Type of well

Drl = drilled
Dug = dug
Drv = driven
Aug = augered

2. Well finish

S = screen
O = open hole

3. Aquifer type

On = Onondaga Limestone
AB = Akron and Bertie Dolomites
Cm = Camillus Shale
S&G = Sand and gravel

4. Land-surface elevation

in feet above sea level, estimated from topographic maps.

Table 12.--Records of selected wells in eastern Erie County, N.Y.

[A dash indicates no data available]

Location latitude-longitude	Owner	Date drilled	Type of well	Well depth (ft)	Casing or hole diam. (in.)	Well finish	Aquifer type	Land-surface elevation (ft)	Water level, Depth below land surface (ft), April 24-25, 1984	Water level, Depth below land surface (ft), Oct. 11-12, 1984	Well yield (gal/min)	Remarks
4256 38 7834 31	U.S. Geological Survey	1981	Aug	58	2	S	S & G	775	33.0	43.8		
4256 40 7837 57	Toby Greenhouse	--	Drl	155	6	O	On,Ab,Cm	735	63.6	72.4		
4256 42 7837 06	C. Kicak	--	Drl	--	6	O	On	765	19.9	28.9		
4256 47 7839 07	J. Pawlak	--	Drl	--	6	O	On	715	7.6	12.2		
4257 00 7841 28	G. Wojcki	--	Drl	20	6	O	On	710	10.1	13.8		
4257 06 7833 10	Jacks	--	Drl	45	6	O	On	774	9.6	--		
4257 07 7833 10	Fosmer	--	Drl	61	6	O	On	774	9.7	21.3		
4257 11 7835 31	Auction House	--	Drl	--	6	O	On	790	38.4	41.0		
4257 14 7831 53	--	1982	Drl	66	6	O	On	781	--	28.5	10	
4257 16 7841 24	E. Walters	--	Drl	20	6	O	On	712	12.7	--		
4257 17 7830 47	H. Smith	8/82	Drl	42	6	O	On	796	2.8	--		Redrilled, old depth = 36 ft
4257 19 7836 49	Lancaster Landfill	1980	Drl	66	4	O	On	762	32.0	33.4	2	
4257 20 7841 05	Rose Garden	--	Drl	--	6	O	On	720	14.4	18.5		
4257 24 7839 11	Londos	8/80	Drl	66	6	O	On	725	25.2	36.2	30	
4257 26 7828 44	R. Kiegler	1982	Drl	72	6	O	On	828.6	4.5	6.0	10	
4257 26 7838 05	Bender	--	Drl	--	6	O	On	730	8.3	32.4		
4257 29 7831 51	Johnson	10/83	Drl	65	6	O	On	783	8.6	25.4	25	Redrilled
4257 30 7837 59	Harris	7/82	Drl	52	6	O	On	733	8.6	31.5	10	
4257 31 7838 41	P. Tresp	--	Drl	30	6	O	On	728	8.3	22.3		
4257 35 7834 31	U.S. Geological Survey	1981	Aug	16	2	O	On	798	1.5	3.4		
4257 36 7833 10	Kurpita	--	Drl	40	6	O	On	778	3.4	14.7		
4257 37 7839 26	Scarpello	--	Drl	45	6	O	On	721	13.5	18.2		
4257 38 7834 20	Schabert	10/82	Drl	102	6	O	On	794.5	33.8	65.8	10	Redrilled, old depth = 72 ft
4257 38 7839 12	Majewski	--	Drl	77	6	O	On	727	8.8	16.1		
4257 38 7839 59	GZA	1984	Drl	102	6	O	Ab	737.3	--	--		
4257 39 7835 36	Minnick	--	Drl	40	6	O	On	791	36.8	36.8		
4257 40 7834 20	D. Crist	--	Drl	90	6	O	On	795.8	66.9	66.9		Redrilled, old depth = 68 ft
4257 40 7836 02	D. Volker	1981	Drl	50	6	O	On	763	43.3	43.3	10	Redrilled
4257 41 7835 55	DePaolo	9/82	Drl	89	6	O	On	769	50.5	50.5	10	Redrilled
4257 42 7834 20	Marek	10/82	Drl	90	6	O	On	793.7	65.0	65.0	10	Redrilled, old depth = 60 ft

Table 12.--Records of selected wells in eastern Erie County, N.Y. (continued).

Location latitude-longitude	Owner	Date drilled	Type of well	Well depth (ft)	Casing or hole diam. (in.)	Well finish	Aquifer type	Land-surface elevation (ft)	Water level, Depth below land surface (ft): April 24-25, 1984	Water level, Depth below land surface (ft): Oct. 11-12, 1984	Well yield (gal/min)	Remarks
4257 42 7837 58	A. Pfuelb	--	Drl	--	6	O	On	736.3	15.0	15.0		
4257 43 7830 48	K. Smith	--	Drl	54	6	O	On	796	11.3	20.2		
4257 45 7834 20	L. Wisniewski	1983	Drl	96	6	O	On	793.2	32.3	64.4		Redrilled, old depth = 72 ft
4257 47 7834 21	Massinger	--	Drl	95	6	O	On	792.1	32.5	63.1		Redrilled, old depth = 70 ft
4257 47 7834 25	B. McCumber	--	Drl	95	6	O	On	790.6	31.9	60.9		Redrilled, old depth = 60 ft
4257 50 7834 20	Remington	10/82	Drl	100	6	O	On	791.9	30.9	62.8	10	Redrilled
4257 51 7838 41	--	1981	Drl	38	0.75	S	On	722	+0.1	3.5		
4257 52 7833 42	--	--	Drl	54	6	O	On	798	23.6	Dry		
4257 53 7834 20	Reinecki	10/82	Drl	110	6	O	On	792.1	31.1	63.2	50	Redrilled
4257 54 7838 11	--	1981	Drl	35	.75	S	On	723	1.2	3.3		
4257 55 7829 45	Tarboy	--	Drl	50	6	O	On	809	7.0	13.7		
	Richardson	9/82	Drl	94	6	O	On	807	--	--		Redrilled
4257 55 7830 28	D. Mileham	--	Drl	70	6	O	On	800	5.8	12.7		
4257 55 7830 48	Guidie	7/83	Drl	82	8	O	On	803	21.9	32.4	10	
4257 55 7834 20	Hoffman	1982	Drl	102	6	O	On	791.4	30.6	62.5	20	
4257 56 7837 59	GZA	1984	Drl	175	6	S	Cm	727.7	--	--		
4257 57 7829 01	Brzuszkicwicz	--	Drl	30	2	O	On	813	4.1	3.9		
4257 57 7834 23	Tagbiarino	--	Drl	125	6	O	On,Ab	801	--	72.1	1	Redrilled, old depth = 77 ft
4257 59 7836 29	U.S. Geological Survey	1981	Aug	12	.75	S	S & G	763.7	8.1	9.9		
4258 01 7830 48	Vohwinkel	--	Drl	32	6	O	S & G	805	7.1	--	30	
4258 02 7840 00	--	1981	Drl	41	6	S	On	694.9	30.6	45.6		
4258 05 7830 45	Schoenthal	--	Drl	22	6	O	S & G	803	2.7	--		
4258 05 7830 48	Koelles	--	Drl	20	6	O	S & G	805	3.5	--		
4258 09 7839 42	Burdette	--	Drl	--	6	O	On	705	--	11.0		
4258 09 7839 46	Laugs	--	Drl	--	6	O	On	705	4.7	11.3		
4258 11 7828 42	Goodhue	--	Drl	--	2	O	On	832.9	32.2	32.3	5	
4258 11 7834 03	T. Wende	--	Drl	--	6	O	On	783.9	21.0	33.0		
4258 11 7834 23	U.S. Geological Survey	--	Aug	32	2	S	S & G	798.4	14.8	18.7		
4258 13 7833 07	Schultz	--	Drl	100	6	O	On	784.4	15.2	48.6	75	Redrilled, old depth = 57 ft
4258 15 7834 51	Town of Clarence	--	Drl	>100	2	S	Ab,Cm	801.9	52.1	74.0		
4258 16 7832 51	Burke	--	Drl	86	6	O	On	791.0	21.3	54.5		Redrilled, old depth = 56 ft
4258 18 7835 30	U.S. Geological Survey	1981	Aug	43	2	S	S & G	770.1	23.3	32.1		
4258 19 7835 07	Melbourne	--	Drl	40	6	O	On	790.1	24.8	24.3		
4258 20 7831 39	Neiman	--	Drl	105	6	O	On	788	—	35.6		Redrilled, old depth = 37 ft
4258 20 7831 54	Thompson	--	Drl	--	6	O	On	785	11.0	27.8		
4258 20 7832 01	Ferris	8/83	Drl	170	6	O	On,Ab,Cm	785	12.0	--	20	Redrilled, old depth = 60 ft

Table 12.--Records of selected wells in eastern Erie County, N.Y. (continued).

Location latitude-longitude	Owner	Date drilled	Type of well	Well depth (ft)	Casing or hole diam. (in.)	Well finish	Aquifer type	Land-surface elevation (ft)	Water level: Depth below land surface (ft) April 24-25, 1984	Water level: Depth below land surface (ft) Oct. 11-12, 1984	Well yield (gal/min)	Remarks
4258 21 7831 32	Werner	8/83	Drl	81	6	O	On	789	14.0	--		Redrilled, old depth = 29 ft
4258 21 7835 20	H. Bloodsworth	--	Drl	49	6	O	On	779.5	32.5	40.5		
4258 21 7835 23	R. Bickert	--	Drl	50	6	O	On	776.6	31.4	39.4		
4258 22 7833 08	D. Buganhagen	--	Drl	95	6	O	On	782.9	13.5	46.1		
4258 22 7833 42	G. Dorr	8/82	Drl	110	6	O	On	767.0	2.1	31.6	10	Redrilled, old depth = 28 ft
4258 22 7839 42	G. Compton	--	Drl	--	6	O	On	713	5.6	15.7		
4258 23 7827 51	Jarudzin	--	Drl	72	6	O	On	843.1	--	51.0		Redrilled, old depth = 50 ft
4258 23 7831 39	Browdy	--	Drl	--	6	O	On	795	--	--		
4258 23 7832 17	J. Weaver	--	Drl	86	6	O	On	782.4	11.5	41.1	10	Redrilled
4258 23 7833 34	A. Buganhagen	8/82	Drl	100	6	O	On	772.0	7.3	31.8		Redrilled, old depth = 40 ft
4258 23 7841 14	--	8/81	Drl	34	0.75	S	On	703	8.2	17.5		
4258 24 7830 48	Richardson	9.82	Drl	94	6	O	On	807	--	--		Redrilled, old depth = 81 ft
4258 24 7839 38	K. Metz	--	Drl	--	6	O	On	714	5.1	14.2		
4258 29 7827 50	Jarudzin	7/78	Drl	84	6	O	On	842.7	28.1	51.6	10	Redrilled
4258 29 7828 46	Carlson	9/76	Drl	73	6	O	On	817.7	17.2	--		
4258 29 7837 34	Stephan	--	Drl	--	6	O	On	731	6.2	13.5		
4258 30 7832 16	Szpylmans	9/83	Drl	131	6	O	On, Ab	781.9	9.4	43.9	3	Redrilled
4258 31 7827 41	Fisher	--	Drl	110	6	O	On	821	23.2	38.3		
4258 31 7829 11	Raduns	8/85	Drl	76	6	O	On	807.4	10.4	25.6		Redrilled from 32 to 76 ft, yield = 20 gal/min
4258 32 7829 46	Casseri	--	Drl	--	6	O	On	800	11.3	23.6		
4258 33 7830 55	U.S. Geological Survey	7/84	Drl	40	2	S	On	790	--	38.9		
4258 34 7828 14	Hyde	--	Drl	90	6	O	On	823	20.8	24.0		
4258 34 7828 32	Fosmer	1972	Drl	50	6	O	On	822.5	23.8	31.6		
4258 34 7828 35	Kuhn	--	Drl	--	6	O	On	823.0	--	38.8	15	
4258 35 7830 25	Baumler	--	Drl	72	6	O	On	802	27.5	62.5		Redrilled
4258 34 7833 07	D. Berghom	9/82	Drl	96	6	O	On	719.2	15.9	32.3	10	
4258 35 7829 55	W. Nadrowski	--	Drl	52	6	O	On	798.3	10.6	23.9		
4258 35 7830 25	Baumler	--	Drl	75	6	O	On	802	26.9	dry		
4258 35 7833 10	Rebrovitch	--	Drl	40	6	O	On	770.3	12.9	22.3		
4258 35 7835 55	Twele	7/82	Drl	62	6	O	On	732	15.8	21.5	25	Redrilled
4258 36 7828 43	Ballow	--	Drl	--	6	O	On	823.6	24.2	--		
4258 36 7829 50	S. Nagy	--	Drl	--	6	O	On	798.6	16.4	29.1		
4258 36 7832 13	Eckert	8/82	Drl	91	6	O	On	781.9	11.6	43.7	10	Redrilled
4258 36 7838 49	McLaughlin	--	Drl	97	6	O	On	726	12.8	23.6		
4258 37 7828 43	Bednarek	--	Drl	--	6	O	On	819.2	17.4	28.6	10	

Table 12.--Records of selected wells in eastern Erie County, N.Y. (continued).

Location latitude-longitude	Owner	Date drilled	Type of well	Well depth (ft)	Casing or hole diam. (in.)	Well finish	Aquifer type	Land-surface elevation (ft)	Water level: Depth below land surface (ft) April 24-25, 1984	Water level: Depth below land surface (ft) Oct. 11-12, 1984	Well yield (gal/min)	Remarks
4258 38 7833 03	Theilman	9/82	Drl	86	6	0	On	777.5	17.4	28.9	4	Redrilled, old depth = 48 ft
4258 38 7838 52	Miller	--	Drl	--	6	0	On	720	47.3	56.1		
4258 38 7840 24	--	8/81	Drl	23	0.75	0	Ab	668	8.4	18.2		
4258 39 7838 34	Scavone	11/83	Drl	113	6	0	On,Ab	732	30.2	41.3		
4258 39 7830 48	Schoenthal	--	Drl	60	6	0	On	803	--	--		
4258 40 7833 01	Hofner	--	Drl	75	6	0	On	782.7	21.1	30.4		
4258 40 7830 44	Pouthier	--	Drl	60	6	0	On	801	27.8	43.6		
4258 41 7833 06	Blumont	6/81	Drl	67	6	0	On	766.7	8.8	17.7	7	
4258 43 7835 10	--	--	Drl	--	6	0	On	752	15.6	24.2		
4258 43 7837 10	D. Hughes	--	Drl	70	6	0	On	738	6.4	12.4		
4258 45 7832 13	Laver	11/82	Drl	97	6	0	On	788.4	18.1	50.0	10	Redrilled, old depth = 57 ft
4258 47 7832 27	Antolik	2/82	Drl	100	6	0	On	785.2	13.0	45.3	5	Redrilled, old depth = 55 ft
4258 49 7830 47	Pingitore	8/56	Drl	52	6	0	On	800	20.0	29.0	55	
4258 49 7832 12	Trapp	9/83	Drl	100	6	0	On	785.0	12.6	46.3	25	Redrilled, old depth = 57 ft
4258 50 7828 40	--	--	Drl	--	6	0	On	820	--	14.2		
4258 51 7832 13	Richards	9/83	Drl	100	6	0	On	784.3	11.7	44.6		Redrilled
4258 52 7838 33	Smith	--	Drl	--	6	0	On	705	21.8	25.8		
4258 56 7835 49	Rouse	1954	Drl	35	6	0	On	710	8.1	14.0		
4258 56 7836 31	L. Stott	1958	Drl	58	6	0	On	736	14.1	30.6		
4259 02 7832 02	Kempler	10/83	Drl	92	6	0	On	781.6	--	40.5	10	Redrilled, old depth = 62 ft
4259 03 7828 43	Holmes	--	Drl	24	6	0	On	822	--	9.7		
4259 03 7829 39	Knop	--	Drl	32	6	0	On	812	8.4	10.9		
4259 04 7831 59	D. Roper	--	Drl	100	6	0	On	781.5	13.9	39.4		Redrilled, old depth = 55 ft
4259 04 7835 50	Erikson	--	Drl	--	6	0	On	696	1.1	--		
4259 05 7828 55	J. Finch	--	Drl	50	6	0	On	826	--	26.6		
4259 05 7828 56	J. Finch	--	Drl	150	6	0	On,Ab	824	7.3	25.6	12	
4259 07 7834 12	Parker	--	Drl	--	6	0	On	770	38.1	50.4		
4259 08 7838 09	Koehler	--	Drl	--	6	0	On	741	51.0	55.7		
4259 09 7830 44	Statler	--	Drl	--	6	0	On	796	8.6	14.2		
4259 16 7828 42	Wight	--	Drl	--	6	0	On	824	11.4	29.2		
4259 16 7828 43	Wight	4/80	Drl	58	6	0	On	824	11.3	29.0	20	
4259 20 7837 54	Torak	--	Drl	110	6	0	On	699	0.0	26.6		
4259 23 7832 50	Quarry Hill	--	Drl	140	6	0	On,Ab	775	--	35.4	75	
4259 26 7830 45	--	--	Drl	62	6	0	On	811	--	11.7		
4259 31 7833 00	Schlects	--	Drl	75	6	0	On	770	19.0	31.6		

Table 12.--Records of selected wells in eastern Erie County, N.Y. (continued).

Location latitude-longitude	Owner	Date drilled	Type of well	Well depth (ft)	Casing or hole diam. (in.)	Well finish	Aquifer type	Land-surface elevation (ft)	Water level Depth below land surface (ft) April 24-25, 1984	Oct. 11-12, 1984	Well yield (gal/min)	Remarks
4259 34 7833 09	Martin	--	Drl	--	6	O	On,Ab	745	17.7	15.7		
4259 36 7833 09	Stein	--	Drl	75	6	O	On	720	6.0	22.3		
4259 38 7833 42	Hernandez	--	Drl	27	6	O	On	805	1.7	12.9		
4259 45 7830 44	Hammond	--	Drl	40	6	O	On	799	3.0	7.8		
4259 49 7830 44	--	--	Drl	--	6	O	On	799	4.2	8.6		
4259 51 7830 09	JW Gunsmith	--	Drl	36	6	O	On	810	1.6	9.0	15	
4259 52 7830 36	MGA	--	Drl	49	6	O	On	799	3.5	6.2		
4259 53 7928 50	Shaff	1977	Drl	38	6	O	On	815	7.7	14.3	50	
4259 53 7829 25	--	--	Drl	62	6	O	On	811	2.8	9.7		
4259 54 7828 18	Groneas	7/79	Drl	37	6	O	On	815	11.8	16.7	15	
4259 55 7831 01	Machelski	--	Drl	--	6	O	On	790	7.5	10.1		
4300 01 7831 01	Popelski	--	Drl	49	6	O	On	788	9.7	--		
4300 04 7831 01	Newstead Fire Station	10/62	Drl	65	6	O	On	790	--	25.0		
4300 04 7831 03	Newstead Fire Station	--	Drl	53	6	O	On	793	--	19.8		
4300 05 7828 43	--	--	Drl	62	6	O	On	811	2.8	11.2		
4300 17 7830 56	Edwards	11/83	Drl	47	6	O	On	780	27.1	36.5	10	