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QUALITY AND MOVEMENT OF GROUND WATER IN OTTER CREEK-DRY CREEK BASIN, CORTLAND COUNTY, NEW YORK

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 78-3
Open-File Report

Prepared in cooperation with

Cortland County, New York

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

"Quality and Movement of Ground Water
in Otter Creek-Dry Creek Basin,
Cortland County, New York"

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ERRATA

The following corrections should be noted:

Page 20	Table 3, heading: Discharge at station 01508940 (not 01508962)
Page 33	Second paragraph, last line: ...indicated in figure 16 (not 10)
Page 40	Table 8, constituent heading: Nitrite + Nitrate (as N) (not Nitrate + Nitrate (as N))
Page 44	Side heading: Chloride concentrations in milligrams per liter (not micrograms)
Page 45	Explanation: Line of equal approximate chloride concentration (not nitrate)
Page 48	Table 10, column heading: Sampling site - delete "wells"

QUALITY AND MOVEMENT OF GROUND WATER IN OTTER CREEK - DRY CREEK BASIN, CORTLAND COUNTY, NEW YORK

By William Buller, W. J. Nichols, and J. F. Harsh

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Albany, New York
1978

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

H. William Menard, Director

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FACTORS FOR CONVERTING U.S. CUSTOMARY UNITS TO INTERNATIONAL SYSTEM (SI) UNITS

U.S. customary units	Multiply by	To obtain SI units
	Length	
inches (in)	25.4	millimeters (mm)
feet (ft)	.3048	meters (m)
miles (mi)	1.609	kilometers (km)
	Area	
acres	.405	hectares (ha)
square miles (mi^2)	2.590	square kilometers (km^2)
	Flow	
cubic feet per second (ft^3/s)	28.32	liters per second (L/s)
gallons per minute (gal/min)	.06309	liters per second (L/s)
million gallons per day (Mgal/d)	43.81	liters per second (L/s)
gallons per day per foot [(gal/d)/ft]	.00014	liters per second per meters [(L/s)/m]
	Hydraulic Units	
transmissivity, feet squared per day (ft^2/d)	.0929	meters squared per day (m^2/d)
hydraulic conductivity, feet per day (ft/d)	.3048	meters per day (m/d)
feet per mile (ft/mi)	.1894	meters per kilometer
	Volume	
cubic feet (ft^3)	.02832	cubic meters (m^3)
fluid ounces (fl. oz.)	29.57	milliliters (mL)
	Weight	
pound (lb)	.453	kilogram (kg)
ton	907.2	kilogram (kg)
	Concentration	
--	--	milligrams per liter (mg/L)
	Rate	
tons per square mile (ton/mi^2)	350.27	kilograms per hectare (kg/ha)
inches per year (in/yr)	2.54	centimeters per year (cm/yr)

DEFINITION OF TERMS

Aquifer.--A water-bearing stratum of permeable earth material that will yield significant quantities of water to wells and springs.

Aquifer characteristics (specific yield and transmissivity).--Terms that describe, respectively, the ability of earth materials to store and transmit ground water.

Digital hydrologic model.--A computer program designed to simulate movement of water within an aquifer.

Discharge.--The volume of water that passes a given point in a stream within a given period of time.

Evapotranspiration.--Water withdrawn from a land area by evaporation from water surfaces and moist soil and by plant transpiration.

Gaining reach.--A reach of a stream where flow is supplemented by inflow of ground water.

Drift.--All deposits resulting from glacial activity.

Head, static.--The height of the surface of a column of water above a standard datum that can be supported by the static water pressure at a given point.

Hydraulic conductivity.--Ratio of flow velocity to driving force (hydraulic gradient) for viscous flow of a specified liquid in a porous medium under saturated conditions.

Hydraulic gradient.--The change in static head per unit length of flow path in the direction of maximum rate of decrease in head.

Losing reach.--A reach of a stream in which stream water seeps into the ground.

Outwash aquifer.--An aquifer that consists mainly of sand and gravel that was deposited by glacial meltwater.

Potentiometric map.--A map that shows the altitude of the water table or, in a confined aquifer, the level to which water would rise in an uncapped well.

Proglacial deposits.--Deposits made beyond the limits of the glacier.

DEFINITION OF TERMS (cont'd)

Saturated thickness.--The thickness of subsurface material through which ground water flows; the part between the water table and the lower confining unit.

Specific yield.--Ratio of (a) the amount of water that a given volume of saturated rock or soil will yield by gravity to (b) the volume of rock or soil.

Storage coefficient.--Volume of water an aquifer releases or takes into storage per unit surface area of the aquifer per unit change in head.

Stream-gaging station.--A stream site where a record of discharge is obtained. Within the U.S. Geological Survey, this term refers only to sites where a continuous record of discharge is obtained.

QUALITY AND MOVEMENT OF GROUND WATER IN OTTER CREEK-DRY CREEK BASIN, CORTLAND COUNTY, NEW YORK

BY

William Buller, W. J. Nichols, and J. F. Harsh

ABSTRACT

A steady increase in the chloride and nitrate content of water in a sand and gravel aquifer of glacial origin in the Cortland area prompted a study to obtain data on the extent and source of these constituents. Chloride concentration in the upper part of the aquifer increased generally from 2 mg/L in 1930 to 20 milligrams per liter (mg/L) in 1976, and nitrate concentration (as nitrogen) in the upper part of the aquifer increased from 1 mg/L in 1930 to an average of 4 mg/L in 1976. Although the ground water is normally very hard (more than 180 mg/L as calcium carbonate), its quality generally meets State standards for source waters used for drinking.

The most likely threat to the quality of water is continued increase in the concentrations of chloride and nitrate. Concentrations of chloride and nitrate (as nitrogen) locally may be as high as 80 mg/L and 7 mg/L, respectively. Concentrations of these constituents are generally less than 10 mg/L chloride and 2 mg/L nitrate (as nitrogen) along the aquifer boundary. Input/output budgets indicate that in wet years such as 1976, output may exceed input of these constituents. Road salting and farming seem to be the primary cause of chloride increases, although septic systems may be a major source locally. Farm-animal waste, sewage systems, and fertilizers are the major contributors of nitrate to ground water.

Flow in the aquifer system was simulated with a digital-computer model. The model was calibrated by comparing measured water levels in the aquifer with those determined by the model. The major sources of recharge are from precipitation and seepage from losing reaches of the streams. In the uplands, ground water generally moves in the same direction as surface runoff--toward and into streams, which generally have gaining reaches in the uplands. On the valley floor the ground water moves in a general downvalley direction, parallel to the main streams, and ultimately discharges into the West Branch Tioughnioga River and Tioughnioga River.

INTRODUCTION

A marked increase in chloride and nitrate concentrations in ground water since the mid-1930's in the Cortland area indicates that further population growth and urbanization may cause a deterioration in the quality of water supplies. The aquifer underlying the Cortland area is an excellent ground-water reservoir that provides water for the municipalities of Cortland and Cortlandville, several industries, and private supplies. Total (1976) pumpage from the aquifer was 6 Mgal/d and is expected to reach nearly 10 Mgal/d by the year 2020 (Stearns and Wheler, 1970).

In 1975, the County of Cortland requested the U.S. Geological Survey to study the hydrologic characteristics of the aquifer and the drainage area that provides recharge to the aquifer. The study was undertaken as part of an Areawide Waste Treatment Management Plan, Section 208, of the Federal Water Quality Pollution Act. Its objectives were to:

(1) Establish a network of observation wells and stream-sampling stations to obtain sufficient basic data to define present water-quality conditions and to provide a baseline against which future water-quality data may be compared;

(2) Develop and verify a digital hydrologic model of the aquifer for county water-use planning;

(3) Provide a hydrologic data base for land-use management.

The study, from August 1975 to January 1977, was not of sufficient duration or scope to determine the sources, movement, or long-term trends of ground-water contamination. However, suggested procedures for future determination of these factors are given at the end of the report in the section, "Suggestions for Further Investigations."

After the necessary hydrologic data had been collected, flow of water in the aquifer was simulated on a digital model to develop a better understanding of the integrated surface-water/ground-water system. This report describes the hydrogeology of the basin, presents in tabular form the basic hydrologic data used in developing the model, and interprets the results obtained from the model together with field observations as they relate to movement and quality of surface water and ground water in the basin. A companion report explains the development, calibration, and application of the model (Cosner and Harsh, in press).

Acknowledgments

This study was done in cooperation with the County of Cortland. Cooperation and assistance were provided by James Feuss and Hayne Smith of the Cortland County Department of Health, Walker Banning of the Central

New York Region Planning and Development Board, and Randolph Well and Pump Company. Special mention is given to local governments who permitted the drilling of test holes on their land. The authors express thanks to David Bouldin, Department of Agronomy, Cornell University, Ithaca, N.Y.; Olin Vanderslice and John Peters of the Agway Farm Research Center, Tully, N.Y.; and the Cortland County Cooperative Extension, Agricultural Division, for providing technical information. Special thanks are extended to James Bugh, Department of Geology, State University College at Cortland, for his contribution to the section on glacial geology.

Location and Description of Study Area

The 10-mi^2 study area, hereafter called Otter Creek-Dry Creek basin, encompasses principally the valley floor and lower stream reaches of Otter Creek basin and Dry Creek basin, and includes the city of Cortland and the surrounding Town of Cortlandville. The location and major geographic features of the study area are shown in figure 1. The western and southern parts are drained by Otter Creek, the northern part by Dry Creek. Both streams drain the central part and are tributary to the West Branch of the Tioughnioga River.

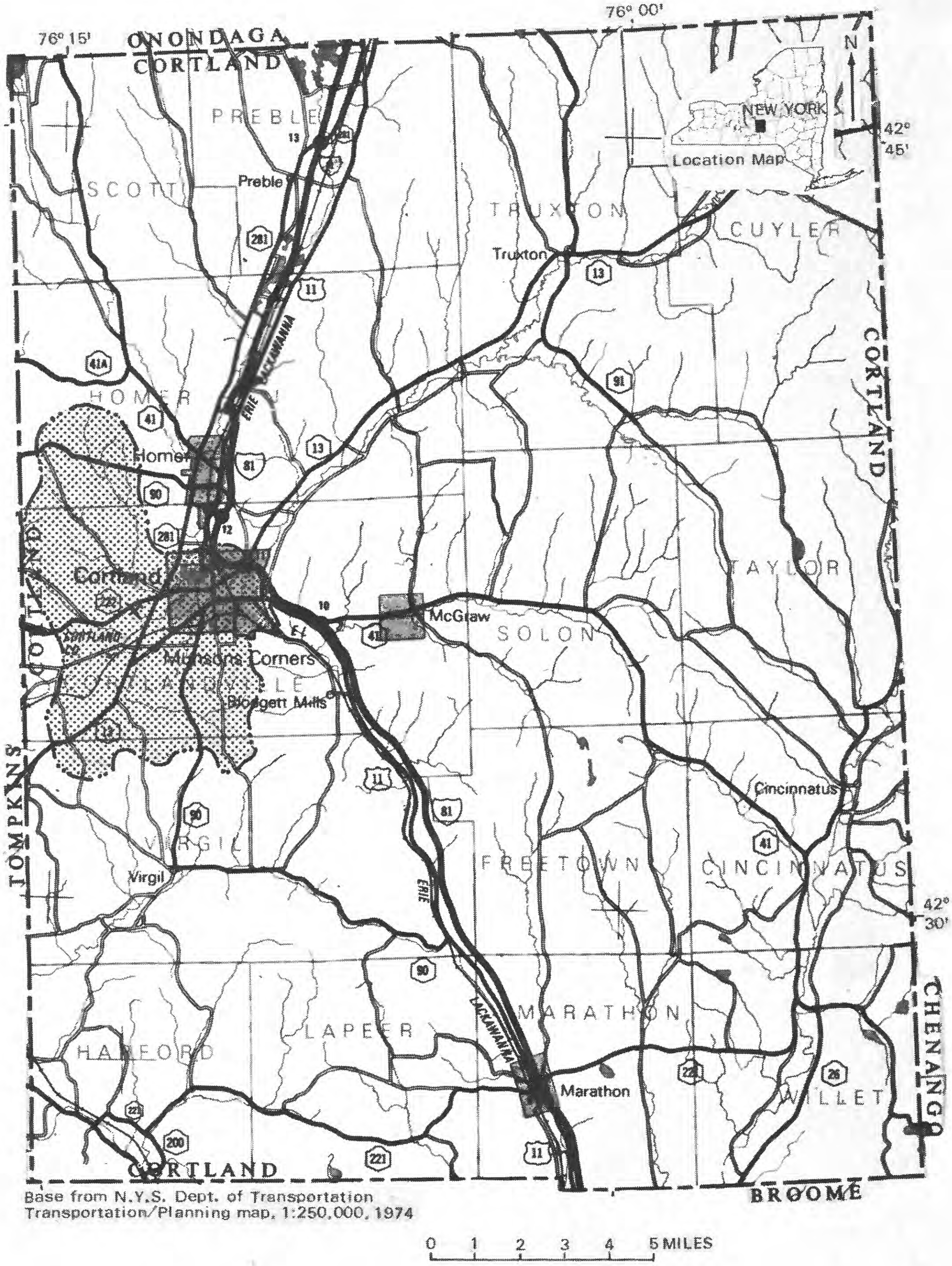
The area has been glaciated and consists of a broad, flat valley surrounded by hills that, except in the west, rise to nearly 700 ft above the valley floor. The western part of the valley is moderately undulating and contains many lowland depressions.

The city of Cortland is a fairly industrialized, growing, urban community; the surrounding areas of South Cortland and Cortlandville are agricultural and residential. At present (1977), the population of Cortland is about 20,000, and the total population of Otter Creek-Dry Creek basin is nearly 36,000 (Stearns and Wheler, 1970).

Average annual precipitation is about 40 inches, of which 70 percent occurs from March through November. Winters are severe; air temperatures frequently reach below 0°F, and annual snowfall averages 60 inches. Winter precipitation is stored as snow until the spring thaw. Summers are moderate with temperatures seldom exceeding 90°F (Stearns and Wheler, 1970).

Previous Investigations

Major contributors to the literature on the glacial geology in central New York are Fairchild (1932), MacClintock and Apfel (1944), von Engeln (1961), Denny and Lyford (1963), and Coates (1966). Asselstine (1946), Hollyday (1969), Weist and Giese (1969), and MacNish, Randall, and Ku (1969) describe the geology and water resources of the study area.



Base from N.Y.S. Dept. of Transportation
Transportation/Planning map, 1:250,000, 1974

Figure 1.--Location and major geographic features of Otter Creek-Dry Creek basin.

Stearns and Wheler (1970) made a comprehensive water-supply study of Cortland County that describes part of the study area. Barth and others (1974) evaluated the growth patterns and ground-water-management policies within the Tioughnioga River basin, which includes the Otter Creek-Dry Creek basin.

Methods of Investigation

Data for this study were collected and analyzed during August 1975 to January 1977.

First steps entailed a literature review and refinement of earlier concepts of the glacial geology of the Cortland area and of the hydrologic system. The principal aquifer system investigated is in the drift and is under water-table conditions. A well inventory was made to identify all pumping centers and to locate wells that would be accessible for measurement and water sampling.

Nineteen observation wells were installed in the basin, some near suspected sources of pollution (fig. 2). During the test drilling, samples were collected at 5-foot depth intervals and examined to prepare lithologic well logs. The logs and water-level data were used to prepare geologic sections and potentiometric maps of the sand and gravel aquifer. Three wells were drilled in close proximity to each other to determine the hydraulic characteristics of the aquifer through detailed testing. Well pairs consisting of one shallow well with a screened interval below the water table and one deep well with a screened interval above the base of the aquifer were installed at eight sites to provide information on water-quality changes with depth. Casings of 1 1/4- and 2-inch inside diameter screened opposite the desired intervals were placed in the drill hole. Bentonite was used to prevent mixing of water between the two open intervals and to prevent contamination from the surface. The pairs of wells were sampled the same day, and the water was analyzed for chemical constituents. The data were used to prepare maps showing the distribution of selected chemical constituents in the upper 60 feet of the aquifer. To determine the thickness of the aquifer, four wells were drilled to bedrock and were finished with a screened interval in permeable material above bedrock at depths ranging from 90 to 250 ft. Table 1 gives detailed information on the wells.

A stream-gaging site was installed on Otter Creek at its mouth where it joins the West Branch of Tioughnioga River, and several partial-record sites were established on Otter and Dry Creeks to monitor streamflow. Streamflow measurements were made on a seasonal basis at nine different sites on major streams and tributaries to determine gaining and losing reaches and surface-water discharge from the basin. The measurement sites are shown in figure 2. This information was used to determine the distribution of recharge to the aquifer from streamflow and discharge from the aquifer to streams.

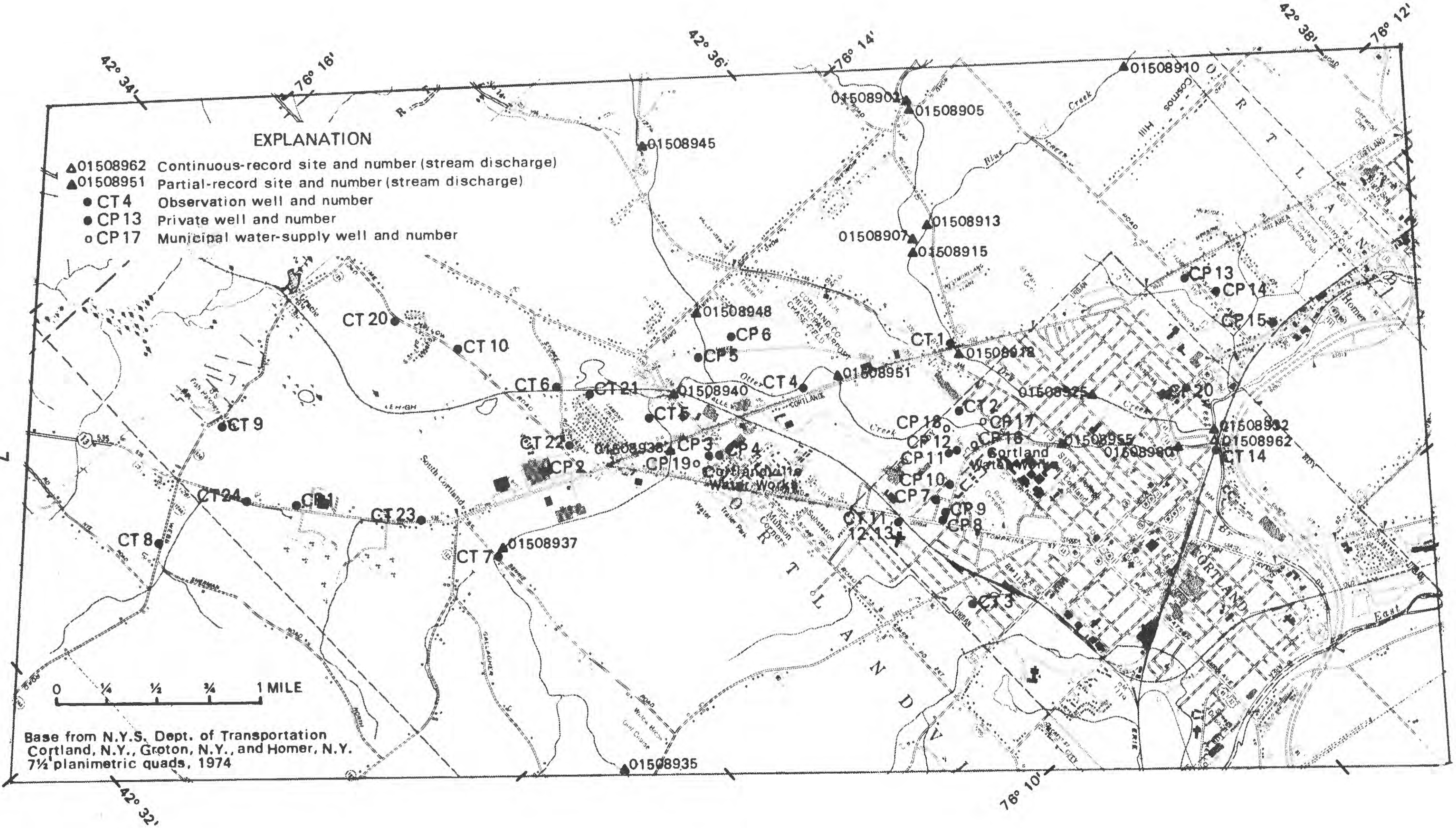


Figure 2.--Data-collection sites, Otter Creek-Dry Creek basin.

Table 1.--Records of wells, Otter Creek - Dry Creek basin

[Depths are in feet below land surface]

Well number	Latitude	Longitude	Owner or name	Driller	Date completed	Land-surface elevation[1]	Type of well[2]	Depth of well (ft)	Casing record Diameter (in)	Casing record Depth (ft) From	Casing record Depth (ft) To	Screened interval Diameter (in)	Screened interval Depth (ft) From	Screened interval Depth (ft) To	Remarks
CT 1	42°35'58"	76°12'15"	Cortland County	Randolph	09-29-75	1156.0	0	44 143	6.0 1.25	0 0	166 138	6.0 1.25	20 138	30 143	Shallow well (multiwells; packer at 44 ft) Deep well
CT 2	42°35'48"	76°11'57"	Do.	do.	10-01-75	1137.6	0	25 49	1.25 2.0	0 0	20 45	1.25 2.0	20 45	25 49	Shallow well (multiwells) Deep well
CT 3	42°35'18"	76°11'04"	Do.	do.	10-03-75	1138.0	0	28 54	1.25 2.0	0 0	23 50	1.25 2.0	23 50	28 54	Shallow well (multiwells) Deep well
CT 4	42°35'22"	76°12'39"	Do.	do.	10-07-75	1149.1	0	23 42	1.25 2.0	0 0	18 38	1.25 2.0	18 38	23 42	Shallow well (multiwells) Deep well
CT 5	42°34'47"	76°13'06"	Do.	do.	10-09-75	1168.7	0	26 59	1.25 2.0	0 0	21 55	1.25 2.0	21 55	26 59	Shallow well (multiwells) Deep well
CT 6	42°34'33"	76°13'33"	Do.	do.	10-22-75	1171.8	0	26 255	1.25 2.0	0 0	21 251	1.25 2.0	21 251	26 255	Shallow well (multiwells; 6-in. casing Deep well remains in ground, 0-267 ft)
CT 7	42°33'53"	76°13-03"	Do.	do.	10-24-75	1223.7	0	24 46	1.25 2.0	0 0	19 42	1.25 2.0	19 42	24 46	Shallow well (multiwells) Deep well
CT 8	42°32'51"	76°14'23"	Do.	do.	10-30-75	1297.4	0	38	2.0	0	34	2.0	34	38	--
CT 9	42°33'23"	76°14'40"	Do.	do.	11-17-75	1241.6	0	304	6.0	0	304	6.0	90	110	--
CT 10	42°34'22"	76°14'07"	Do.	do.	11-28-75	1189.8	0	33 88	1.25 2.0	0 0	28 84	1.25 2.0	28 84	33 88	Shallow well (multiwells; 6-in. casing Deep well remains in ground, 0-106 ft)
CT 11	42°35'18"	76°11'41"	Do.	do.	12-04-75	1154.4	0	81	6.0	0	105	6.0	38	60	--
CT 12	42°35'18"	76°11'41"	Do.	do.	12-18-75	1152.4	0	70 90	6.0 1.25	0 0	112 85	6.0 1.25	40 85	60 90	Shallow well (multiwells; packer at 70 ft; well removed after aquifer test)
CT 13	42°35'18"	76°11'41"	Do.	do.	12-15-75	1152.4	0	63	12.0	0	38	10.0	38	63	Well removed after aquifer test
CT 14	42°36'32"	76°10'51"	Do.	do.	01-27-76	1111.7	0	24	6.0	0	24	6.0	14	23	--
CT 20	42°34'14"	76°14'28"	Do.	do.	09-10-76	1260	0	160	6.0	0	124	6.0	114	124	Well is open hole in bedrock from 124 to 160 ft
CT 21	42°34'40"	76°13'25"	Do.	do.	09-13-76	1170	0	32	6.0	0	32	6.0	20	30	--
CT 22	42°34'29"	76°13'17"	Do.	do.	09-15-76	1190	0	45	6.0	0	45	6.0	35	45	--
CT 23	42°33'46"	76°13'32"	Do.	do.	09-20-76	1230	0	85	6.0	0	85	6.0	75	85	--
CT 24	42°33'14"	76°14'15"	Do.	do.	09-28-76	1270	0	105	--	--	--	--	--	--	Well did not yield water, abandoned

Table 1.--Records of wells, Otter Creek - Dry Creek basin (Continued)

[Depths are in feet below land surface]

Well number	Latitude	Longitude	Owner or name	Driller	Date completed	Land-surface elevation[1]	Type of well[2]	Depth of well (ft)	Casing record Diameter (in)	Casing record Depth (ft) From	Casing record Depth (ft) To	Screened interval Diameter (in)	Screened interval Depth (ft) From	Screened interval Depth (ft) To	Remarks
CP 1	42°33'23"	76°14'03"	Monarch Tool Company	Randolph	--	1257.0	0	--	6.0	--	--	--	--	--	--
CP 2	42°34'16"	76°13'14"	Smith-Corona	Stewart Bros.	1960	1198.4	0	--	2.0	--	--	--	--	--	--
CP 3	42°34'51"	76°12'44"	Town of Cortlandville	Hall & Co.	09-1975	1174.4	0	58	2.0	0	58	--	--	--	--
CP 4	42°34'54"	76°12'42"	Do.	do.	--	1173.4	0	63	1.5	0	63	--	--	--	--
CP 5	42°35'01"	76°13'09"	Do.	Randolph	--	1169.4	0	36	5.0	--	--	--	--	--	Abandoned well on Luker Road
CP 6	42°35'15"	76°13'08"	Cortland County	do.	--	1188.7	0	--	6.0	--	--	--	--	--	Abandoned well near Airport
CP 7	42°35'28"	76°11'38"	Leonard Barker	do.	--	1147.0	0	20	2.0	--	--	--	--	--	Observation well, underground gasoline-leakage study
CP 8	42°35'26"	76°11'31"	Do.	do.	--	1146.2	0	24	2.0	--	--	--	--	--	Do.
CP 9	42°35'27"	76°11'32"	Do.	do.	--	1146.2	0	24	2.0	--	--	--	--	--	Do.
CP 10	42°35'35"	76°11'40"	Curtis	do.	--	1148.6	0	23	2.0	--	--	--	--	--	Do.
CP 11	42°35'40"	76°11'48"	Cortland Water Works	do.	--	1142.4	0	12	6.0	0	13	--	--	--	Destroyed
CP 12	42°35'41"	76°11'47"	Do.	do.	--	1143.8	0	--	1.25	--	--	--	--	--	--
CP 13	42°36'56"	76°11'40"	Cortland County	do.	11-1973	1115.6	0	25	1.25	0	22	1.25	22	25	Drilled by Cortland County
CP 14	42°37'00"	76°11'30"	Do.	do.	11-1973	1119.8	0	25	1.25	0	22	1.25	22	25	Do.
CP 15	42°37'04"	76°11'08"	Do.	do.	--	1114.3	0	--	2.0	--	--	--	--	--	Abandoned well near Fisher Avenue
CP 16	42°35'47"	76°11'44"	Cortland Water Works	do.	--	--	W	--	--	--	--	--	--	--	Water-supply well used for water-quality samples
CP 17	42°35'51"	76°11'49"	Do.	Kelly Well Co.	--	--	W	77	32.0	0	36	32.0	36	68	Do
CP 18	42°35'45"	76°11'52"	Do.	do.	--	--	W	77	32.0	0	16	32.0	16	52	Do.
CP 19	42°34'50"	76°12'43"	Town of Cortlandville	do.	--	--	W	--	--	--	--	--	--	--	Do.
CP 20	42°36'30"	76°11'16"	Cortland Memorial Hospital	Randolph	--	--	0	35	4.0	0	35	--	--	--	Installed to measure dewatering effects

Note.--For multiwell systems with packers, the intervals indicated for the 6-inch screen are perforations through the 6-inch drill casing. Perforations were also made at the lower zone opposite the small-diameter screen, and in all other wells where small-diameter screens were placed inside drill casing left in the ground.

[1] feet above mean sea level

[2] 0, observation; W, water supply

Hydraulic characteristics of the aquifer were determined from data collected during three aquifer tests. (Values of hydraulic characteristics are given in table 7.) The values determined by the aquifer tests provided estimates of aquifer characteristics and were used in developing the hydrologic model.

Water-level measurements at the test wells and accessible private wells were made bimonthly from November 1975 to June 1976 and monthly from July to December 1976. Well-water levels measured in March and September 1976 were used to define the potentiometric surfaces at the beginning of the model calibration. Discharge measurements at gaging stations and other sites along streams were used to define natural discharge from and recharge to the aquifer as well as to calibrate the model.

The model was designed to simulate in two dimensions the response of an aquifer to an imposed stress (pumping). The computed steady-state water levels, presented in map form, generally are in close agreement with potentiometric-surface maps prepared from field measurements for March and September 1976.

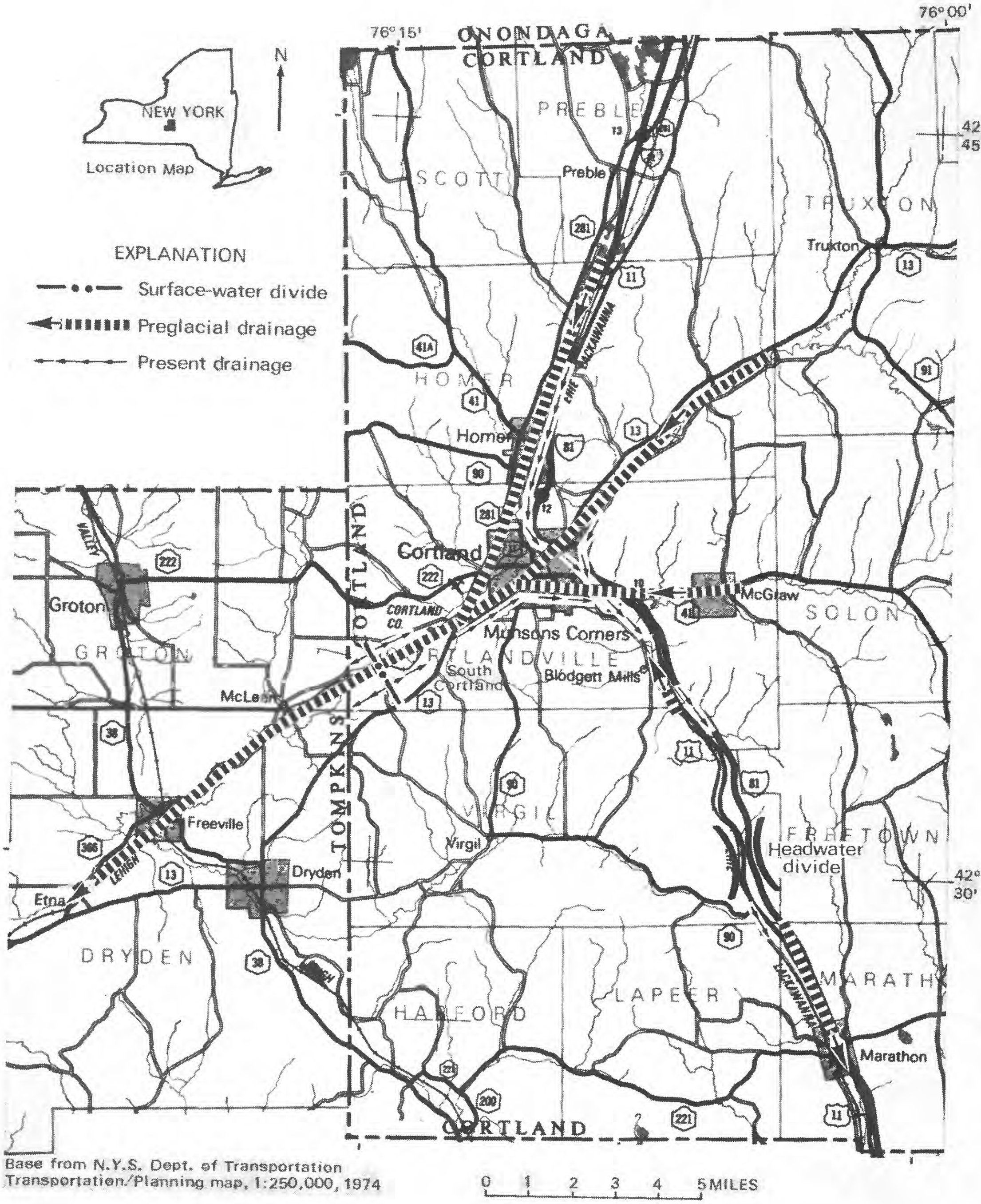
GEOLOGY

The Otter Creek-Dry Creek basin lies within the glaciated Allegheny Plateau province of central New York. Bedrock consists of Upper Devonian siltstone and shale beds that dip gently south-southwest at approximately 40 ft/mi. This dip led to the development of cuesta-type topography in preglacial times. Although the preglacial drainage (fig. 3) on this topography is not known in detail, the authors believe that it played an important role in the development of present landforms.

Physiography and Glacial History

The glacial history of central New York is not completely understood because the area is characterized by landscapes that record glaciation of multicyclic origin. Each ensuing advance of a glacier tends to mask or remove the evidence of the preceding advance. However, interpretation of the drift or deposits of the Otter Creek-Dry Creek basin involves only the last two advances of the continental glacier--the ice sheet during early Wisconsin time, which deposited drift belonging to the Olean Substage (MacClintock and Apfel, 1944), and the last advance of the ice sheet during late Wisconsin time, which deposited drift referred to by MacClintock and Apfel (1944) as the Valley Heads Substage.

In preglacial times, the bedrock valley now partly occupied by the Otter Creek-Dry Creek drainage area drained to the southwest (fig. 3); however, it is now partly filled with Valley Heads Drift, and drainage is to the southwest and northeast from a divide southwest of South Cortland.



Base from N.Y.S. Dept. of Transportation Transportation/Planning map, 1:250,000, 1974

Figure 3.--Present and preglacial drainage of the Cortland area.

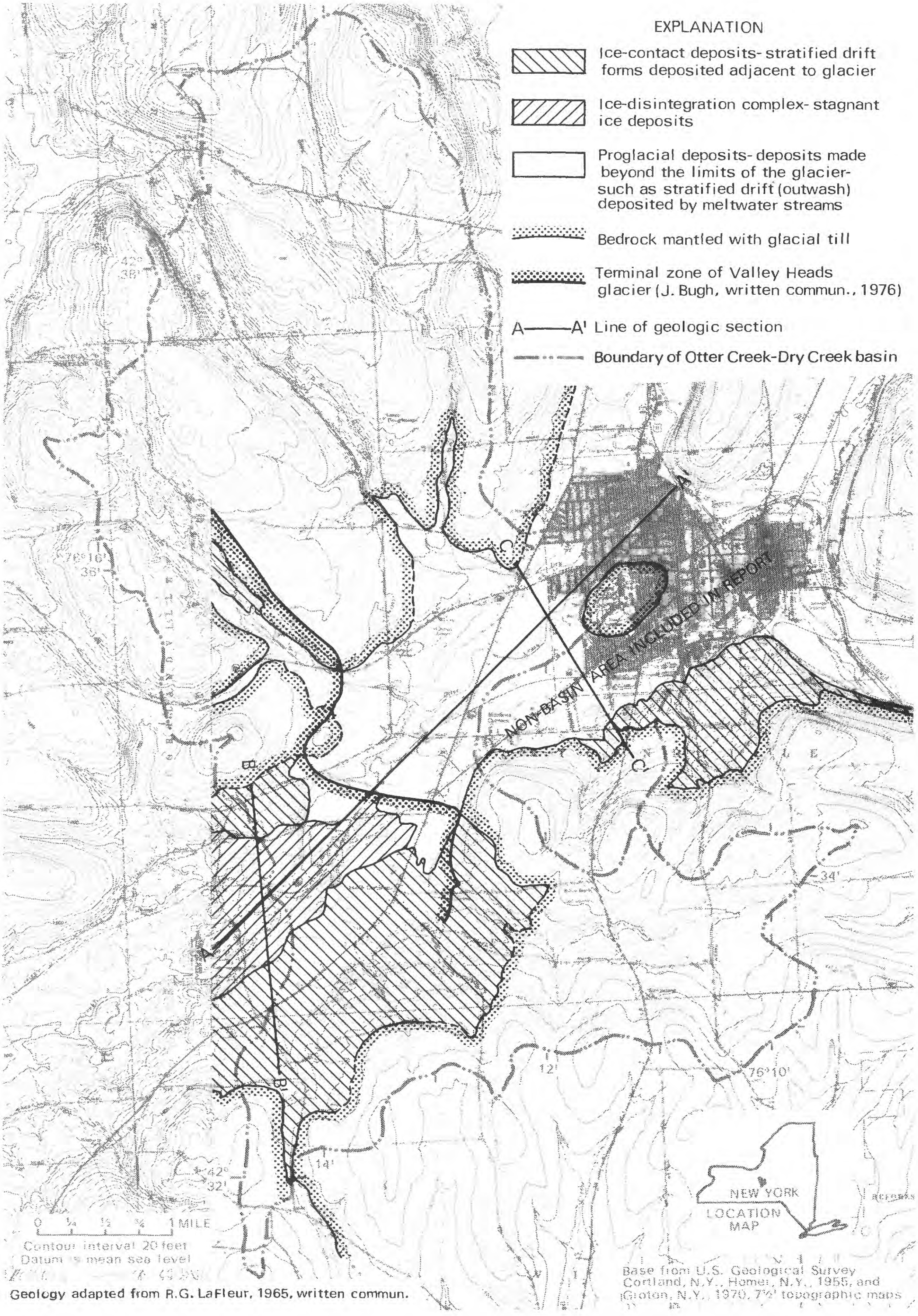
Olean Drift is not identified in the bedrock valley deposits but is represented as the till mantle on the bedrock hills. The glacial deposits have been mapped (R. G. LaFleur, written commun., 1965); LaFleur's unpublished map was adapted for use in figure 4. The contact of the Valley Heads Drift with the Olean Drift has been mapped (Fairchild, 1932), but James Bugh (written commun., 1976) states:

> A lobe of the Valley Heads glacier advanced from the southwest into the area of South Cortland in late Wisconsin time. The end moraine deposited in this area does not correspond to Fairchild's (1932) location of the Valley Heads end moraine, but the topography and deposits at South Cortland justify this revised interception. Fairchild (1932) used the term "Valley Heads" to describe thick plugs of drift in the southern end of the Finger Lake valleys. The valley Heads end moraine occurs in all major valleys but, on the uplands, it is sporadic and in many areas untraceable, which may account for the absence of the morainal deposits near South Cortland on Fairchild's map.
>
> The Valley Heads glacial advance formed an ice dam in the area southwest of South Cortland. The valley fill underlying State Highway 13 near Cortland is composed of an upper gravel unit representing deposition of coarse outwash aggrading east-northeastward from the Valley Heads end moraine just west of South Cortland (Muller, 1966). The glacier may have completely blocked the preglacial southwest-flowing river and created a lake in the valley. A lake fronting the glacier would allow water to back up in the valley until it spilled over the preglacial headwater divide southeast of Cortland. Drainage continued through this new spillway while the glacier served as a dam. When the glacier finally melted from the scene, the drainage was well established through the spillway and continued to flow southeastward.

Geologic sections A-A' and B-B' (figs. 5 and 6, respectively), based on sampling of test holes drilled for this project, show that the divide at the southwest part of Otter Creek-Dry Creek basin is underlain by deposits that are interpreted as being an ice-disintegration complex. This deposit is the end moraine of the glacier that occupied the former valley postulated by Bugh (written commun., 1976) and is shown on figure 4. Note that at section A-A', the ice-disintegration complex grades into deposits that are interpreted as being proglacial and running southwest to northeast.

Glacial Deposits

Glacial deposits cover the bedrock nearly everywhere within the basin (fig. 4). In the headwater areas above the valley floor, the bedrock is covered by till of the Olean Substage and in the valley by deposits of the Valley Heads Substage. The till is composed of unsorted silty clay



Geology adapted from R.G. LaFleur, 1965, written commun.

Base from U.S. Geological Survey Cortland, N.Y., Homer, N.Y., 1955, and Groton, N.Y., 1970, 7½' topographic maps

Figure 4.--Geology of Otter Creek-Dry Creek basin.

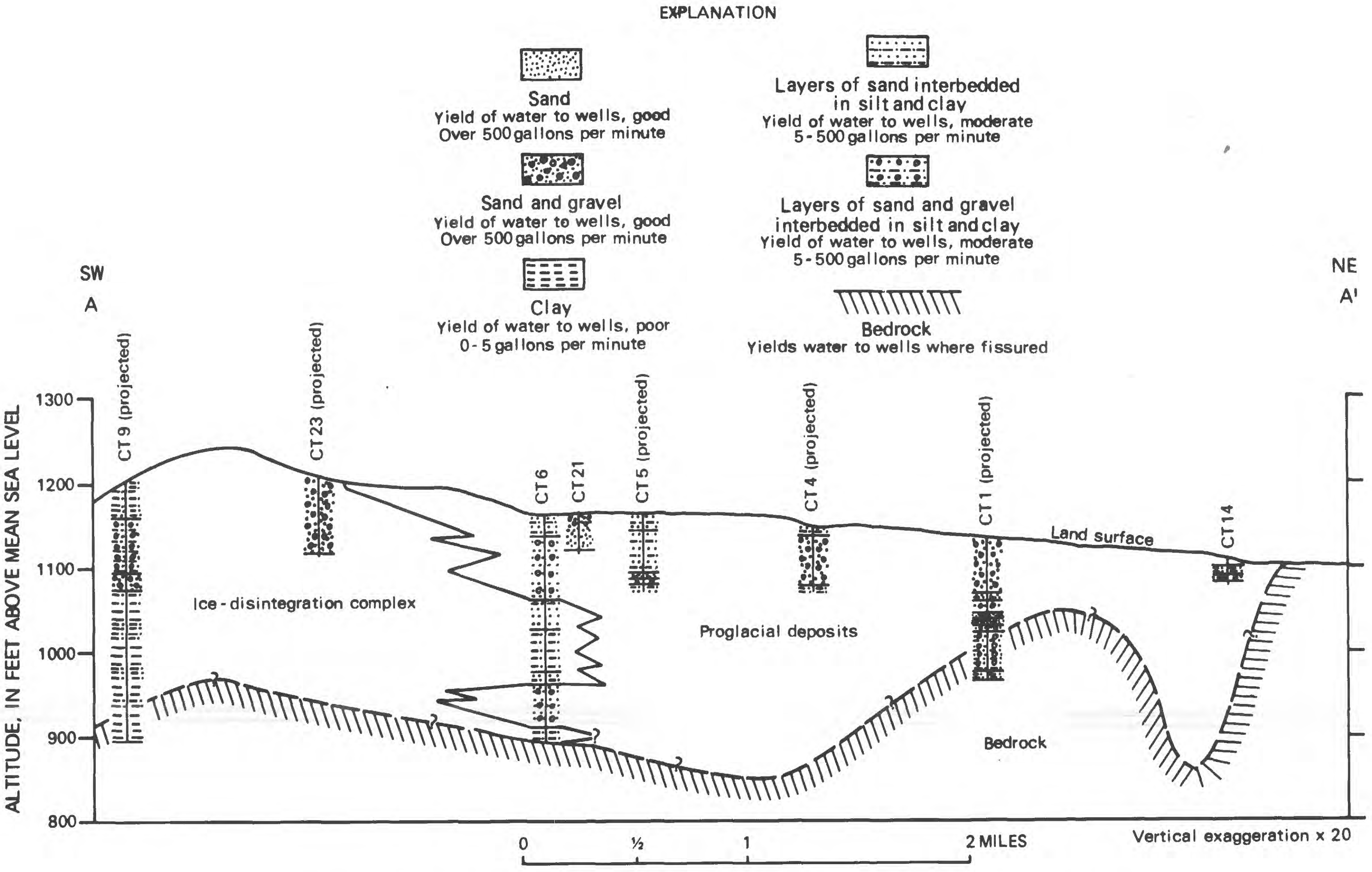


Figure 5.--Geologic section along length of Otter Creek-Dry Creek basin.

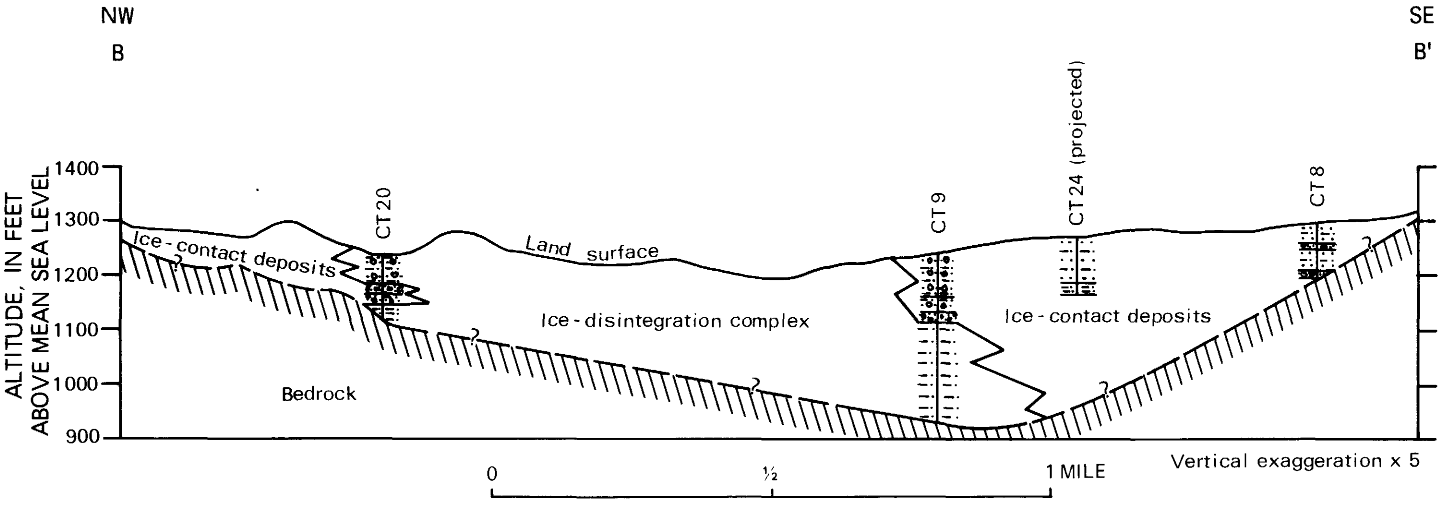


Figure 6.--Geologic section across western part of Otter Creek-Dry Creek basin.

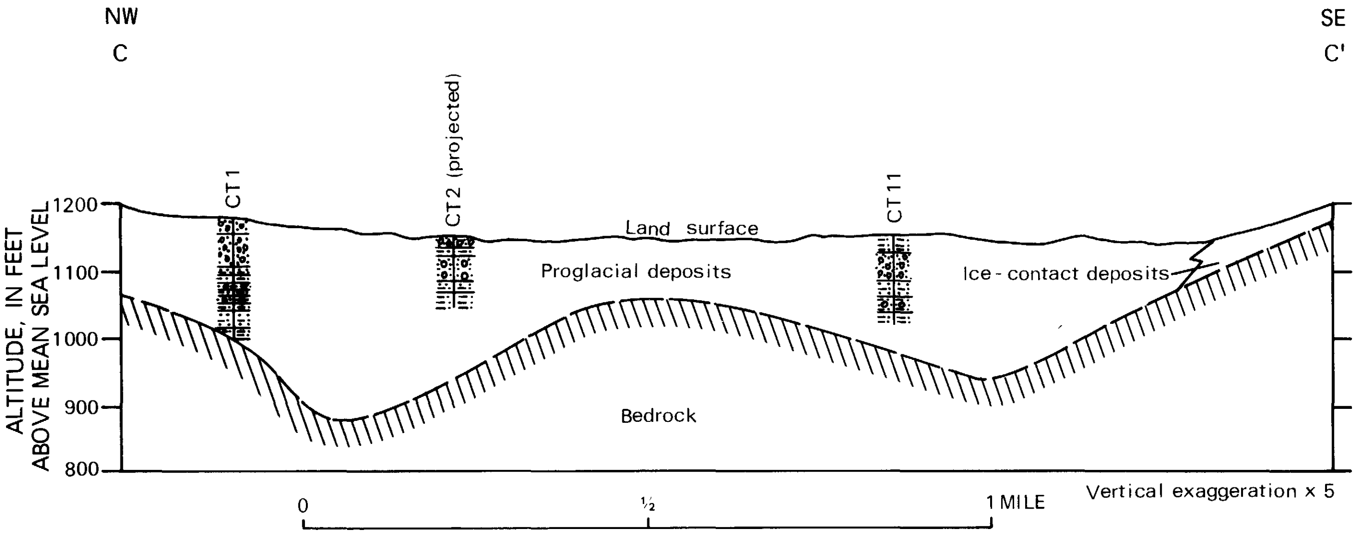


Figure 7.--Geologic section across eastern part of Otter Creek-Dry Creek basin.

having varying amounts of sand, gravel, and boulders and ranges from 2 to 20 feet in thickness. Such till generally has low hydraulic conductivity. Thus, the upland glacial deposits yield only small quantities of water to farm and domestic wells. The till areas affect runoff and provide water storage to supply the base flow of streams that drain the upland area.

Ice-disintegration and ice-contact deposits are distributed irregularly along the valley sides and floor of Otter and Dry Creeks. Figure 4 shows the distribution of these deposits. Ice-contact deposits are least extensive along the east margin of the valley. In ice-disintegration deposits, water-yielding properties vary from those of clay (very low) to those of very coarse gravel (high) (Davis and DeWiest, 1966, p. 164). The ice-disintegration deposits contain a high percentage of silt and clay and are for the most part poorly sorted. Large-capacity wells for commercial and industrial needs may be difficult to develop in the ice-disintegration deposits; however, several farm and industrial wells pump water from these deposits. Geologic section C-C' (fig. 7) shows a sectional view across deposits that are interpreted as being proglacial deposits perpendicular to section A-A'. The proglacial deposits are generally well-sorted outwash sand and gravel with a few lenses of silt and clay. The principal source of water for industrial and municipal needs is the outwash aquifer. The hydrogeologic characteristics of outwash are similar to valley alluvial deposits (Davis and DeWiest, 1966, p. 375).

Upper Devonian Bedrock

The Upper Devonian shale (bedrock) is exposed in a few roadcuts and locally along the steep valley walls. Where exposed, the shale is well weathered and cut by many joints. Jointing and weathering decrease with depth. Weathering at first tends to open the joints, but later the shale becomes soft, and the joints tend to close. Joints and bedding-plane openings form a minor part of the total rock volume but provide the only significant space in which water can be stored and transmitted. Yields of bedrock wells are low and sufficient only for farm and domestic supplies.

The quantity and quality of water from bedrock wells is often unpredictable. The risk of local pollution has been demonstrated by sampling by the Cortland County Health Department (James Feuss, oral commun., 1977). It is difficult to locate the sources of pollutants entering the joints and bedding-plane openings and to determine rates and direction in which polluted ground water is likely to move.

The bedrock surface configuration is not well known. Drilling data from six deep wells prior to this project provided some information on the depth to bedrock in the Otter Creek-Dry Creek basin, and test drilling during the present study established four new bedrock altitudes. Geologic sections A-A', B-B', and C-C' (figs. 5, 6, and 7, respectively) show the position of bedrock in relation to land surface along the lines of sections as interpolated from the bedrock-contour map.

GEOHYDROLOGY

Surface Water

Surface water is closely related to the ground-water system. The lowest order tributaries to Otter and Dry Creeks originate in the till-covered shale hills surrounding the valley floor. Stream reaches within the till areas are gaining reaches except during sustained dry weather, when they may go dry. In contrast, the higher order tributaries on the valley floor are almost entirely losing reaches that create long reaches of ground-water recharge. Thus, streamflow is a major source of recharge and is discussed in this context in the section "Recharge."

The study area is drained by Otter Creek and Dry Creek, both of which are tributary to the West Branch of the Tioughnioga River (fig. 2). A continuous-recording stream gage was installed on Otter Creek at its mouth in December 1975 to determine surface-water discharge; measurements of streamflow for the period of record are given in table 2. Average flow during this period was 18 ft^3/s. Periods of no flow in 1976 were September 5-9, 13-15, and 19-25. A hydrograph for the period of record is given in figure 8. Streamflow measurements were made on a seasonal basis at other sites on Otter Creek to determine gaining and losing reaches.

In addition, the gage height at two sites on Dry Creek and one site on Otter Creek was read daily from March 1 to December 31, 1976 (see fig. 2 for location). Measurements of streamflow at these sites are given in tables 3-5; hydrographs are given in figures 9-11. Streamflow measurements from the two staff-gage sites show that Dry Creek is a losing stream from station 01508918 to station 01508932 at the mouth (table 6). Streamflow measurements from the continuous-recording gage at the mouth of Otter Creek (station 01508962) and from the staff gage at station 01508951 indicate that Otter Creek has also been a losing reach during the period of record (table 6).

Miscellaneous low-flow measurements at several partial-record sites in the Otter Creek-Dry Creek basin provided surface-water-inflow data used in developing the model; these measurements are given in table 6. Sites of seepage measurements and values of discharge at these sites are plotted in figures 12 and 13, respectively.

Ground Water

Ground water in the study area occurs in the pores or openings between rock particles in the glacial deposits and bedrock. The size and orientation of the openings determine how much water is stored and the ease with which water moves. In general, at depths greater than 25 feet, the glacial deposits and shales of Otter Creek-Dry Creek basin are saturated with water. Exceptions to this are in the headwater areas and on the high ridges that form the topographic divides between the study area and the adjoining basins; in these areas, depth to water may be as much as 100 ft.

Table 2.--Discharge at station 01508962, Otter Creek at mouth, January 5 to September 30, 1976

[Discharges in cubic feet per second; dashes indicate no measurement taken]

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	--	9.1	51	26	20	32	38	19	0.37
2	--	8.4	48	23	21	26	26	14	.26
3	--	12	82	21	24	21	26	11	.04
4	--	8.4	74	20	17	18	22	10	.03
5	5.6	8.4	57	13	15	16	24	9.1	0
6	5.0	9.1	56	15	15	20	20	8.6	0
7	1.5	7.8	45	14	14	22	17	10	0
8	1.1	7.8	42	14	13	18	16	13	0
9	2.3	7.2	39	13	13	17	18	18	0
10	1.3	6.2	36	12	12	18	14	10	.80
11	1.2	6.5	33	12	17	14	15	9.6	.06
12	2.3	6.5	30	11	22	13	54	86	.03
13	2.5	6.5	30	10	20	13	51	9.1	0
14	2.3	7.2	28	9.1	26	13	42	8.6	0
15	1.5	7.8	26	10	28	11	33	8.6	0
16	1.5	16	24	24	29	10	30	8.2	.03
17	1.5	53	22	18	30	13	28	6.3	.21
18	2.1	57	22	12	31	10	26	5.2	.03
19	2.1	117	21	11	36	10	22	4.6	0
20	2.5	63	22	13	63	18	21	3.5	0
21	3.1	53	25	13	43	18	22	2.9	0
22	2.5	140	24	15	35	16	21	2.6	0
23	.64	75	20	15	34	17	20	2.1	0
24	.90	62	18	15	32	16	19	1.3	0
25	.65	56	18	40	31	16	19	1.0	0
26	3.6	46	16	43	29	15	18	.58	.04
27	24	46	16	24	27	17	18	.37	.05
28	24	40	18	26	26	18	14	.06	.04
29	16	39	16	24	25	19	15	.94	.03
30	12	--	14	21	26	26	15	.53	.03
31	9.8	--	15	--	28	--	13	.16	--

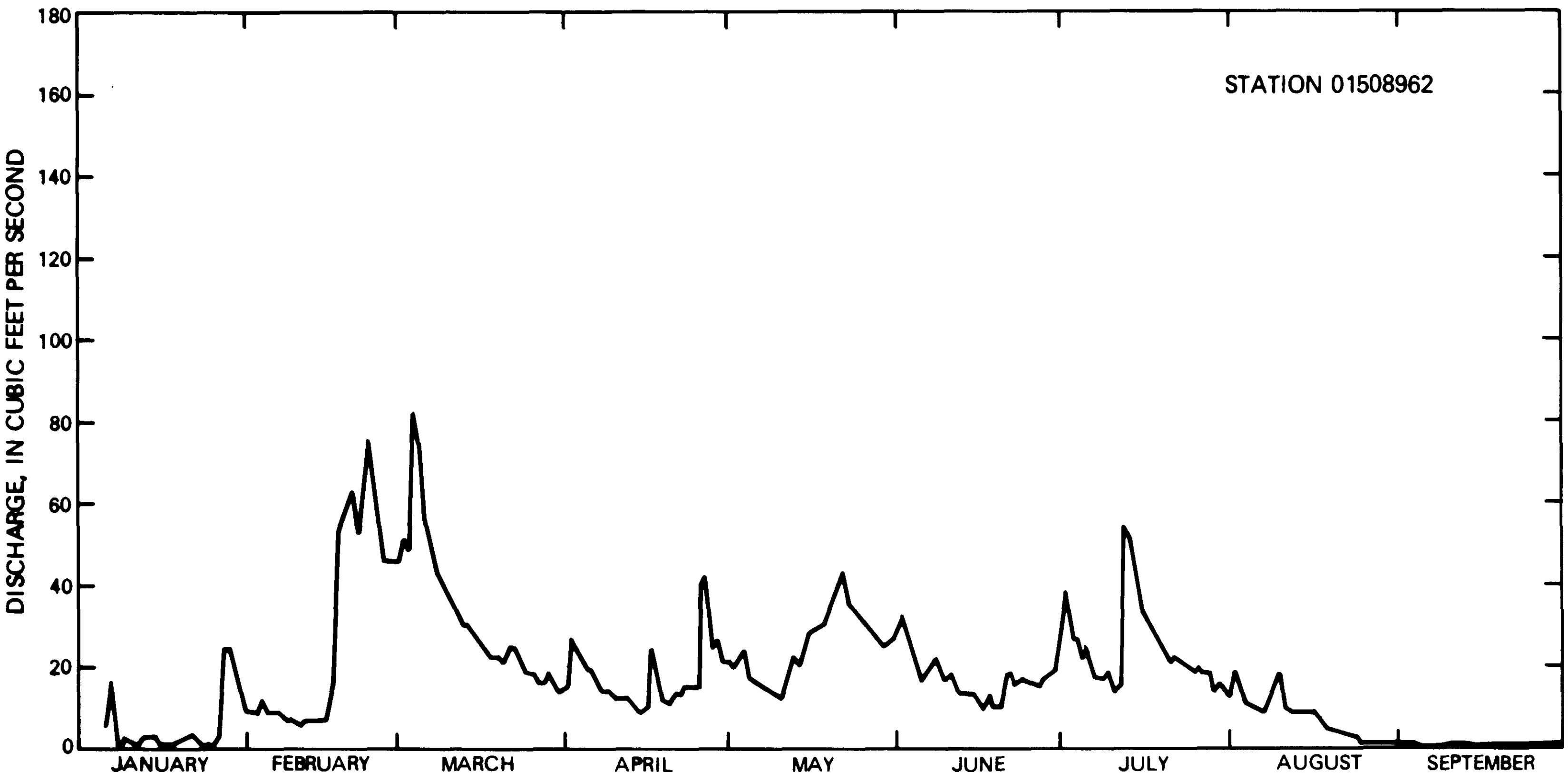


Figure 8.--Hydrograph for Otter Creek at mouth, 1976 (station 01508962)

Table 3.--Discharge at station 01508962, Otter Creek at McLean Road, March 1 to September 30, 1976

[Discharges in cubic feet per second; dashes indicate no measurement taken]

Day	Mar.	Apr.	May	June	July	Aug.	Sept.
1	6.7	19	--	3.1	3.4	1.3	0.8
2	7.1	17	--	2.5	4.0	1.8	.8
3	40	--	3.0	2.0	2.8	1.8	.8
4	9.4	--	2.4	--	2.7	1.7	.8
5	8.8	--	2.3	1.8	2.6	1.6	.8
6	6.0	2.6	2.6	1.9	2.1	1.6	.7
7	4.7	2.0	2.3	2.1	2.2	2.2	.7
8	4.3	1.2	2.2	1.8	2.0	12	.8
9	2.8	2.3	2.2	1.8	2.0	1.8	.7
10	4.1	--	2.1	1.9	2.0	1.8	2.2
11	3.9	--	--	1.9	1.4	1.3	.7
12	3.4	--	--	1.8	8.0	1.8	.7
13	3.2	--	--	1.8	6.0	1.4	.7
14	1.4	--	--	1.7	3.6	1.6	.7
15	--	2.0	--	1.8	2.9	1.4	.7
16	3.5	2.4	--	1.8	3.0	1.4	.7
17	3.0	2.3	--	1.8	2.8	1.4	.7
18	2.8	1.9	--	1.8	2.4	1.0	.6
19	3.4	1.8	--	1.6	1.8	1.4	.7
20	3.4	2.0	38	2.4	2.0	1.2	.6
21	4.4	1.8	--	2.6	2.4	1.2	.6
22	--	1.8	--	2.3	2.2	1.0	.5
23	--	1.9	--	2.0	2.0	1.0	.4
24	--	2.8	--	2.4	2.0	1.0	.5
25	--	6.4	--	2.5	2.0	.9	.5
26	--	4.0	--	--	2.2	.9	.5
27	--	3.0	--	2.0	2.2	.9	.4
28	--	--	2.2	2.2	2.0	.9	.3
29	14	--	2.2	5.1	2.0	.9	0
30	13	--	1.6	6.4	1.8	.8	0
31	13	--	2.2	--	2.2	.8	--

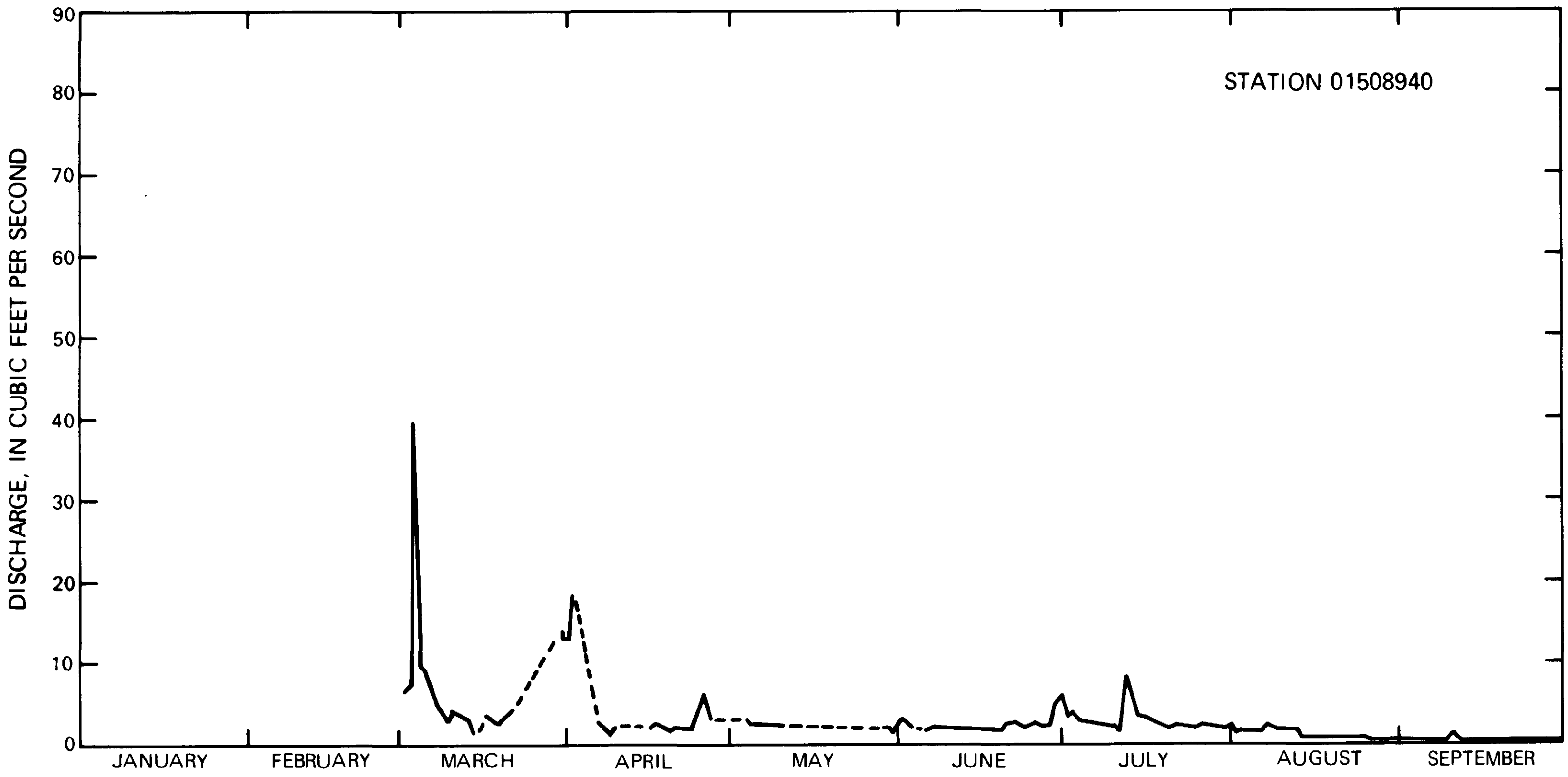


Figure 9.--Hydrograph for Otter Creek at McLean Road, 1976 (station 01508940)

Table 4.--Discharge at station 01508918, Dry Creek at State Highway 281, March 1 to September 30, 1976

[Discharges in cubic feet per second; dashes indicate no measurement taken]

Day	Mar.	Apr.	May	June	July	Aug.	Sept.
1	55	17	--	8	14	19	1.8
2	67	9.0	--	5.6	14	5.2	1.7
3	190	--	19	4.9	10	3.8	1.6
4	62	--	11	--	8.0	3.5	1.6
5	53	--	9.1	4.4	8.0	3.6	1.7
6	28	6.0	8.5	4.3	7.4	3.7	1.6
7	21	5.5	7.7	4.4	7.5	6.0	1.6
8	18	4.8	6.6	4.5	7.3	7.0	1.6
9	18	6.6	6.1	3.8	7.4	6.0	1.5
10	16	--	5.5	4.0	7.5	5.0	6.2
11	17	--	--	7.5	10.5	3.9	5.8
12	12	--	--	8.0	22	3.9	2.8
13	11	--	--	8.0	68	3.7	2.7
14	9.5	--	--	7.0	25	3.9	2.7
15	--	4.5	--	7.0	19	4.5	2.7
16	7.3	18	--	8.0	27	4.3	2.6
17	6.0	10	--	7.5	19	4.5	7.0
18	6.8	6.8	--	3.7	13	3.6	--
19	10.9	6.0	--	3.8	11	3.6	3.8
20	20	5.9	33	21	10	2.8	2.7
21	22	5.1	--	19	8.8	2.8	2.8
22	--	14	--	18	6.0	2.7	2.7
23	--	10	--	14	6.7	2.7	2.7
24	--	28	--	14	6.9	2.7	2.7
25	--	83	--	13	6.4	2.7	2.8
26	--	35	--	--	9.9	2.7	2.9
27	--	23	--	7.5	12	2.7	9.5
28	--	--	5.6	7.5	4.5	2.7	6.0
29	3.8	--	5.6	8.0	7.5	1.8	2.9
30	3.8	--	5.5	41	6.8	1.7	2.9
31	7.0	--	5.3	--	5.3	1.6	--

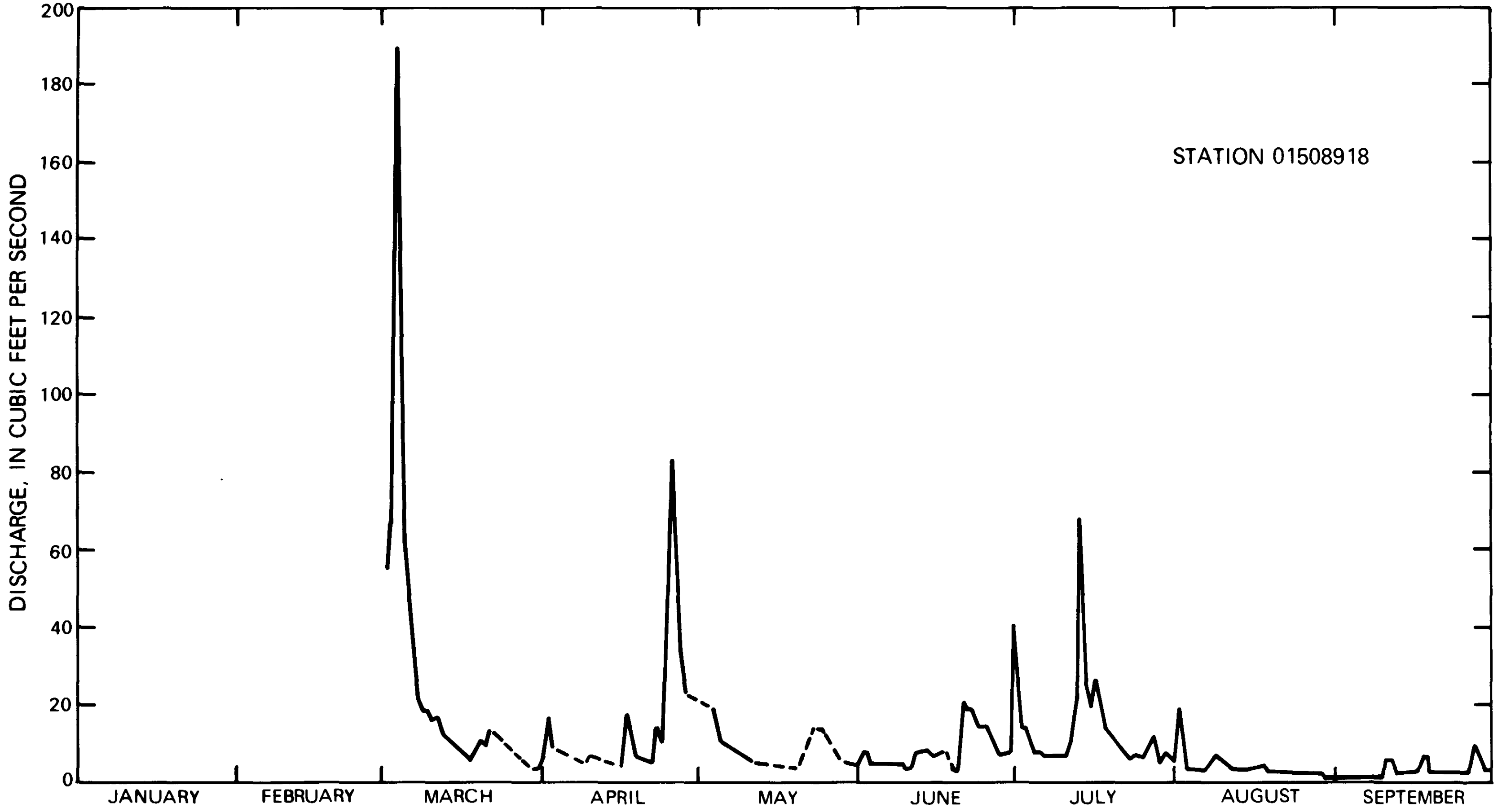


Figure 10.--Hydrograph for Dry Creek at State Highway 281, 1976 (station 01508918)

Table 5.--Discharge from station 01508932, Dry Creek at mouth, March 1 to September 30, 1976

[Discharges in cubic feet per second; dashes indicate no measurement taken]

Day	Mar.	Apr.	May	June	July	Aug.	Sept.
1	48	14	--	5.5	12	15	1.2
2	63	8.2	--	3.3	10	4.0	.9
3	180	--	14	2.4	8.3	3.1	.7
4	56	--	8.7	--	6.8	2.4	.4
5	48	--	7.1	1.4	6.2	2.4	.8
6	24	3.9	7.8	2.0	5.0	2.2	.4
7	16	3.5	6.8	3.5	5.0	5.0	.1
8	14	3.0	4.2	3.5	5.6	5.6	.1
9	14	2.9	4.0	3.5	6.2	4.6	.1
10	14	--	4.0	3.1	5.0	4.2	5.0
11	14	--	--	6.2	5.0	2.7	--
12	8.2	--	--	6.8	17	2.4	1.6
13	9.0	--	--	5.6	62	2.6	1.1
14	7.1	--	--	4.5	22	2.6	.8
15	--	1.4	--	6.2	15	3.5	.4
16	5.0	14	--	5.6	22	3.1	.4
17	3.5	7.1	--	5.6	14	2.3	5.6
18	5.0	5.0	--	2.8	9.0	2.3	3.3
19	8.2	3.7	--	2.4	7.6	1.8	1.6
20	14	4.0	25	16	6.2	1.6	1.2
21	18	4.2	--	15	6.8	1.4	.2
22	--	10.0	--	13	5.0	1.2	1.2
23	--	7.8	--	12	5.6	1.2	1.1
24	--	22	--	10	5.6	1.2	1.2
25	--	75	--	11	3.5	.9	1.4
26	--	30	--	--	8.3	.9	2.5
27	--	19	--	5.6	9.0	.8	8.3
28	--	--	2.9	5.6	3.5	.8	4.5
29	--	--	2.9	6.2	6.2	1.2	2.4
30	--	--	3.0	35	5.0	.9	2.3
31	5.10	--	3.5	--	4.5	.6	--

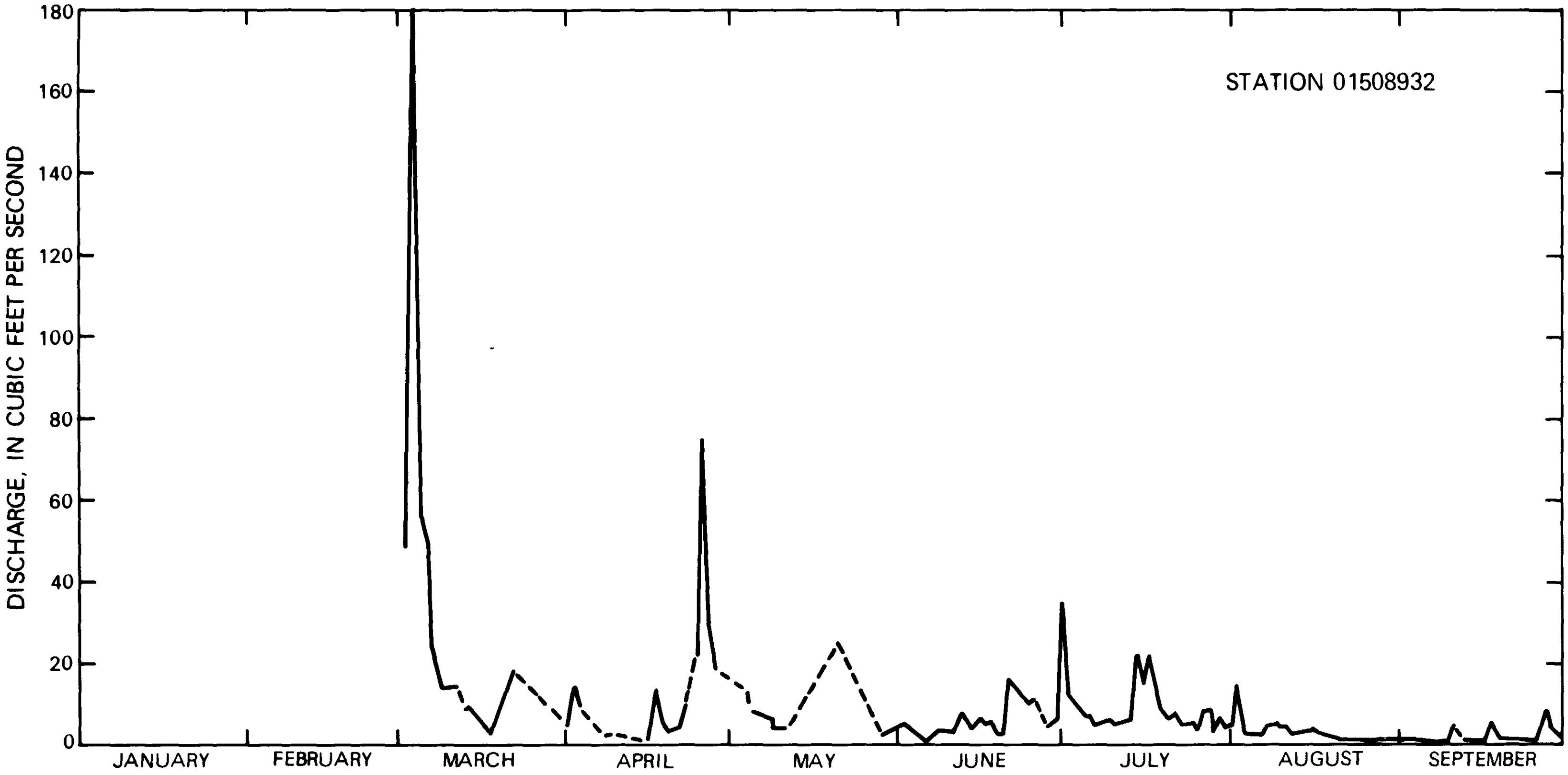


Figure 11.--Hydrograph for Dry Creek at mouth, 1976 (station 01508932)

Table 6.--Dry Creek and Otter Creek seepage investigations

[Discharges in cubic feet per second]

Station no.	Distance upstream from mouth (miles)	Measurement site	Measured discharge	Gain or loss	Measured discharge	Gain or loss	Measured discharge	Gain or loss	Measured discharge	Gain or loss
A. DRY CREEK BASIN (drainage area 8.78 mi^2)			12-2-75		8-15-75		9-9-76		9-30-76	
01508918	1.3	Dry Creek State Highway 281	10.5	--	--	--	0.874	--	--	--
01508932	.0	Dry Creek at Mouth	8.18	-2.3	--	--	.015	-0.859	--	--
B. OTTER CREEK BASIN (drainage area 14.28 mi^2)			12-1-75		8-15-75		9-9-76		9-30-76	
01508935	--	Otter Creek State Highway 90	2.24	--	0.096	--	--	--	0.62	--
01508937	--	Otter Creek at Bennie Road	2.38	+.14	0	-0.096	--	--	0	--
01508938	--	Otter Creek State Highway 281	0	-2.4	0	--	--	--	0	--
01508940	3.1	Otter Creek at McLean Road	4.08	+4.1	0	--	--	--	0	-0.62
01508945	4.1	Otter Creek Tributary at Sears Road	.84	--	--	--	.770	--	0	0
01508948	3.2	Otter Creek Tributary at Fairview Drive	.11	-.7	--	--	--	--	--	--
01508951	2.1	Otter Creek at State Highway 281 Water Works	3.78	-.3	0	--	--	--	0	--
01508955	.3	Otter Creek at Groton Ave. 1/	5.93	+2.2	.12	--	.076	-.694	.026	--
01508962	.0	Otter Creek at mouth	5.16	-.8	0	-.12 1/	0	-.076	0	-.026

1/ Includes intermittent flow from storm sewer

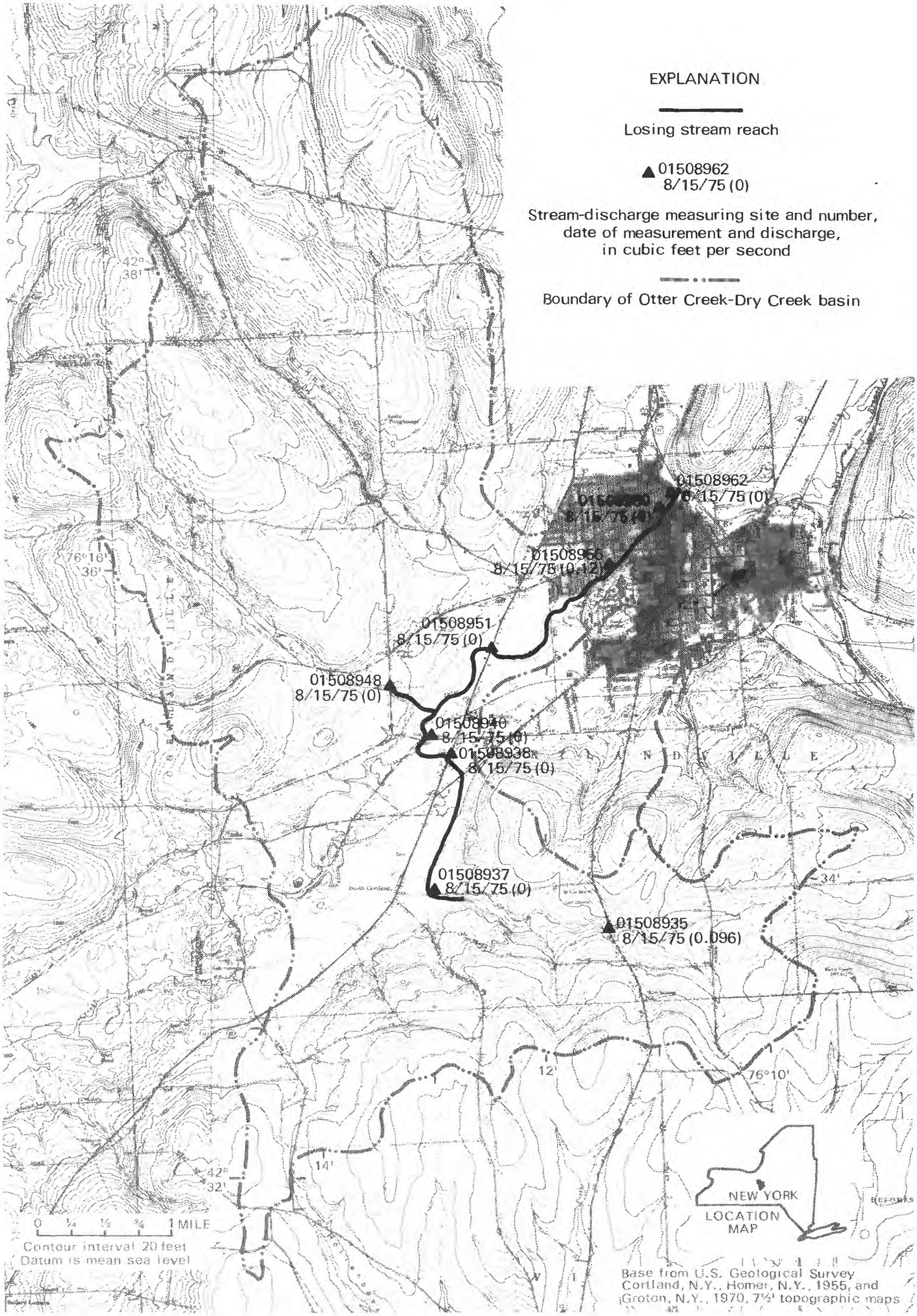


Figure 12.--Seepage-measurement sites in Otter Creek-Dry Creek basin, August 15, 1975.

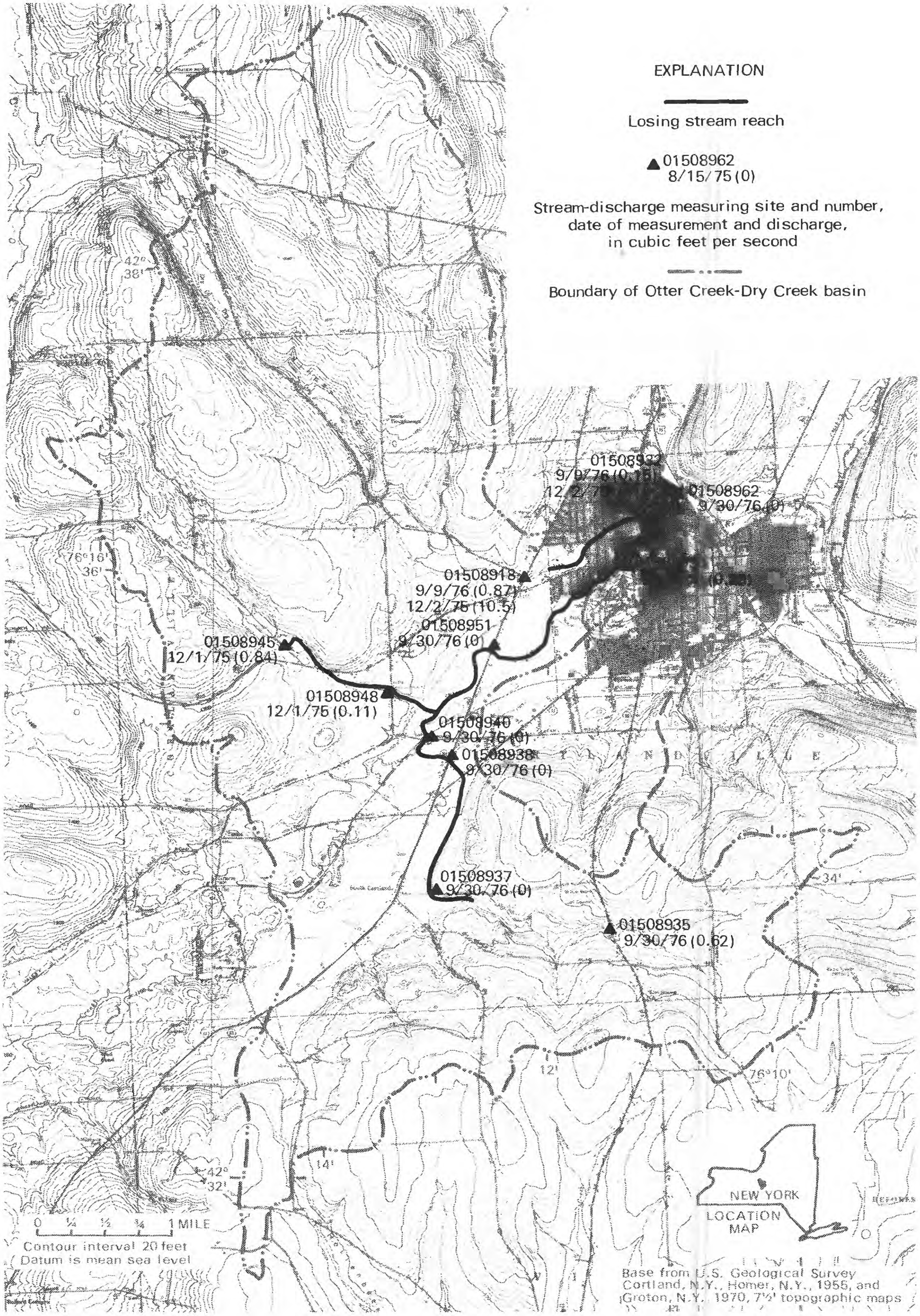


Figure 13.--Seepage-measurement sites in Otter Creek-Dry Creek basin, December 1 and 2, 1975, and September 9 and 30, 1976.

During this investigation, water-level measurements were made in the valley at regular intervals to aid in determining the hydrology of the basin. These data were used to prepare potentiometric maps (figs. 14 and 15), and hydrographs were prepared to show the seasonal variation in water levels in the aquifer and to define the periods of high and low recharge. The map for March 5 shows the highest water levels of 1976 (fig. 14), and the map for September 29, the lowest (fig. 15). Both sets of data were used as bases of comparison for calibrating the ground-water flow model. Figure 16 presents a hydrograph of well CT 2 and a graph of monthly precipitation measured at State University College of New York at Cortland to show the relationship between water-level fluctuation and precipitation for the period of record. The hydrograph of well CT 2 is representative of most wells in the valley floor.

Recharge

Recharge to the aquifer occurs in several ways and at many different areas within the basin. The major sources of recharge are rainfall and losing-stream reaches. Some water enters the aquifer from the shale bedrock but only in insignificant quantities because the upper 2 feet of shale at the base of the glacial deposits has been observed in drilling to be tight and unproductive. Although it is possible that the shale may yield significant amounts of water locally along joints or bedding planes widened by weathering, drilling data do not indicate the presence of such openings.

Recharge from precipitation probably occurs at varying rates throughout the basin. These rates can only be estimated because they cannot be measured directly; however, relative rates of direct recharge can be deduced from the nature of the surficial materials and the slope of land surface. Till has a high percentage of clay and is therefore less permeable than the glacial materials of the valley floor; therefore, the rate of direct recharge is assumed to be greater on the valley floor than on the till-covered shale slopes.

Recharge from streams occurs along stream channels on the valley floor from the point where the streams leave the till-capped shale slopes to their mouth at the West Branch of Tioughnioga River. Recharge does not take place continually along the entire reach but wherever the ground-water level is below stream level. During most of the year, ground-water levels are below stream level throughout the length of the valley.

Movement and Discharge

The water table roughly parallels the land surface beneath the till-capped shale slopes of the basin; therefore, ground water moves in much the same directions as surface runoff--toward and into the streams. As a result, the streams in the uplands gain in flow.

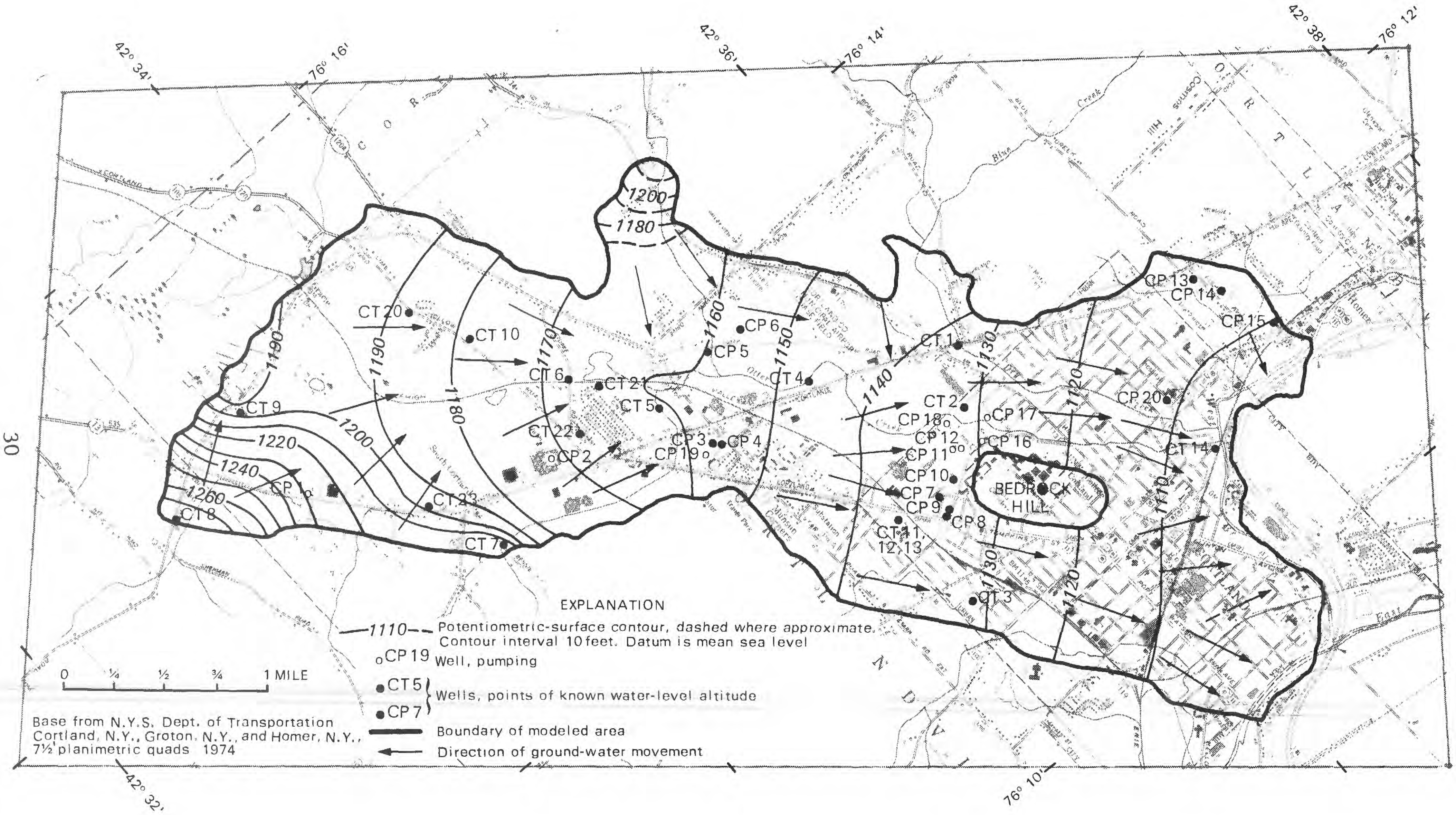


Figure 14.--Potentiometric surface of Otter Creek-Dry Creek aquifer on March 5, 1976, and direction of ground-water movement.

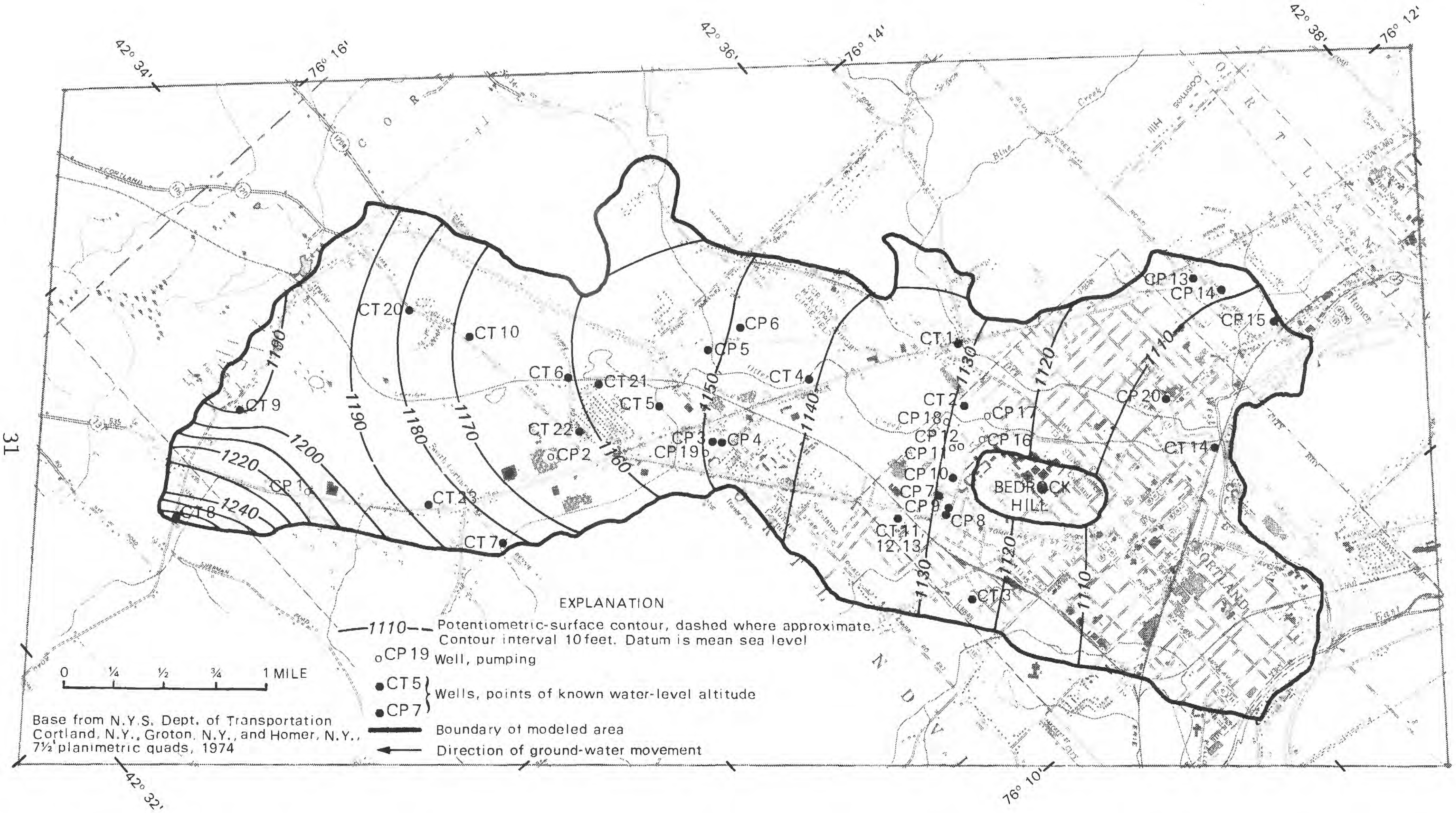


Figure 15.--Potentiometric surface of Otter Creek-Dry Creek aquifer, September 29, 1976.

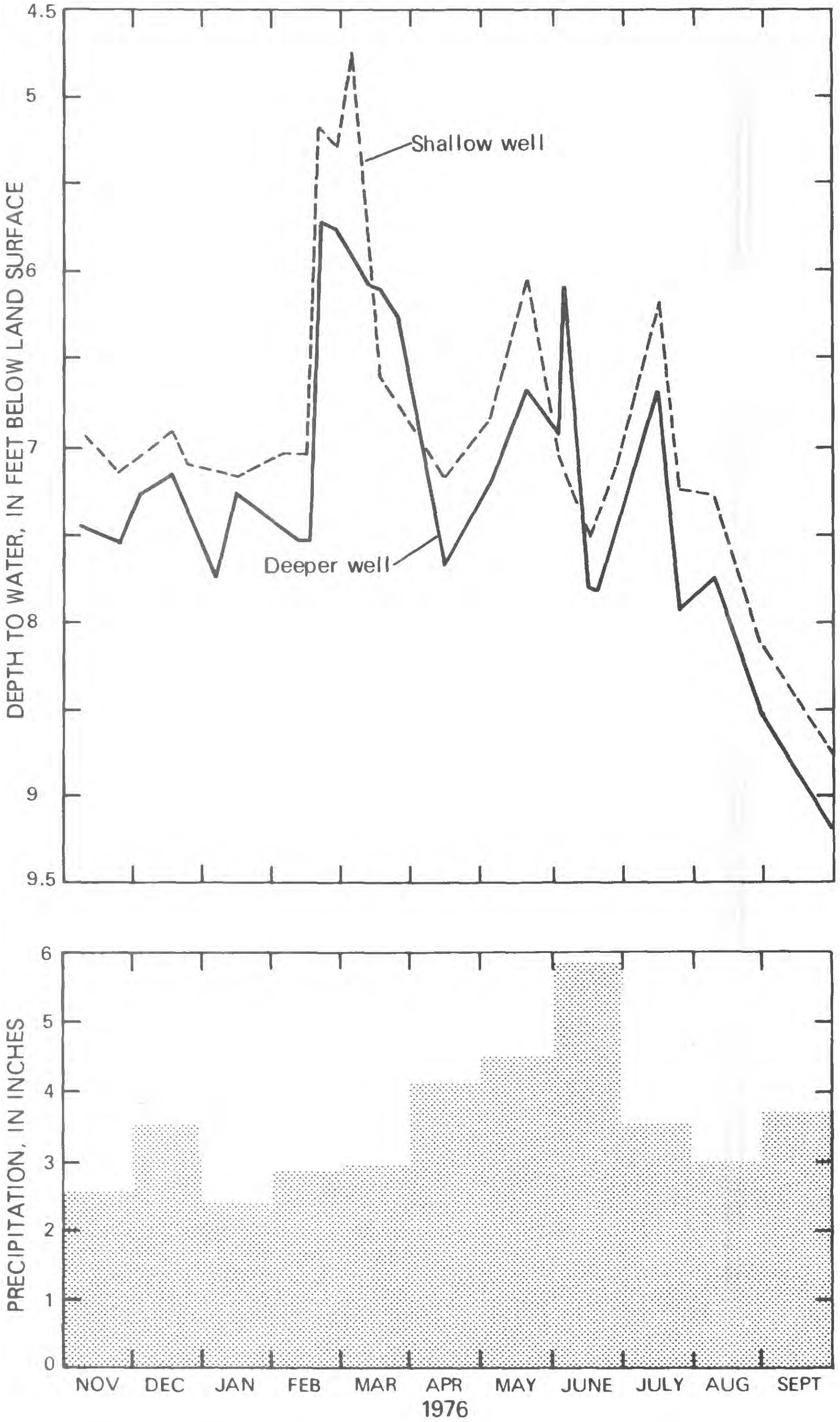


Figure 16.--Water levels in well CT 2 in relation to precipitation at State University College of New York at Cortland, water year 1976.

On the valley floor, ground water moves downstream perpendicular to the water-table contours, as shown by the arrows in figure 14. Beneath the losing reaches, ground-water mounds tend to form and cause ground water to move away from the streams for short distances. (Figures 14 and 15 are not of sufficient detail to show this phenomenon.) Eventually the ground water is intercepted by the cone of influence of a pumping well and is either discharged from the well or continues downgradient toward the main rivers of the area--the West Branch of the Tioughnioga River and the Tioughnioga River.

Water leaves the basin not only through wells and rivers, but through evapotranspiration, or evaporation from surface- and near-surface water and by plant transpiration, especially along the stream channels. Part of the water transpired by vegetation comes from the streams, and an unknown quantity is drawn from the unsaturated zone and from the water table. Transpiration virtually ceases from the end of the growing season to the following spring. Although evapotranspiration draws water mainly from the unsaturated zone, it has a transient effect of reducing recharge to the water table. In summer, evapotranspiration takes up all excess water that would become recharge, whereas in winter, rain and snowmelt are able to infiltrate to the water table after the soil-moisture deficiency is made up. This pattern is largely responsible for the seasonal fluctuations in the water level of well CT 2, indicated in figure 10.

Aquifer Characteristics

The principal hydraulic characteristics of an aquifer are hydraulic conductivity, saturated thickness, and storage coefficient. Hydraulic conductivity is the ratio of flow velocity to driving force (hydraulic gradient) for viscous flow under saturated conditions of a specified liquid in a porous medium (Cooley and others, 1972). Saturated thickness and hydraulic conductivity combined are commonly referred to as transmissivity (conductivity multiplied by saturated thickness), and storage coefficient in unconfined (water-table) aquifers is essentially equal to specific yield. Specific yield is the change in the amount of water in storage per unit area of unconfined aquifer per unit change in head (Lohman and others, 1972).

Hydraulic characteristics of the outwash aquifer were estimated initially from data collected during three aquifer tests and analyzed by the type-curve solutions for water-table conditions according to Prickett (1965) and Jacob (1945). Results from analyses of the test data are summarized in table 7. The predominant aquifer material at the three test sites is sand and gravel.

Values determined by the aquifer tests are representative for the immediate testing area only, but transmissivity values at other locations were estimated on the basis of test results, examination of aquifer-material samples collected during test drilling, and published transmissivity data on similar aquifer materials. Values of specific yield were not obtained from the test data; but 0.15 was selected as representative for the outwash aquifer.

Table 7.--Results of aquifer tests in Otter Creek-Dry Creek basin

[Well locations given in figure 2]

Well No.	Date	Length of test (hours)	Average pumping rate (gal/min)	Average hydraulic conductivity (ft/d)	Transmissivity (ft^2/d)
CP 17	9-12-75	2.2	3,000	1,144	80,000
CT 11	4-26-76	48	1,200	1,050	47,000
CP 19	3-15-76	26	630	950	37,000

Ground-Water Model

One of the objectives of the overall study was to develop a digital ground-water flow model of the Otter Creek-Dry Creek aquifer system to evaluate the effects that proposed ground-water development and land-use schemes would have on quantity and movement of ground water. A detailed description of this model is given in Cosner and Harsh (in press). After the data had been collected, flow in the sand and gravel deposits was simulated on the model.

For a model to determine effects of ground-water development, it must first be capable of simulating flow in the aquifer to an acceptable degree of accuracy. The model was calibrated for steady-state conditions (wherein the components of flow velocity do not vary with time) by comparing well-water levels measured in the outwash aquifer on March 5 (fig. 14) with corresponding computed water levels. When appropriate adjustments had been made, a run simulating transient conditions (wherein the components of flow velocity vary with time) was made to obtain measured water levels for September 29 (fig. 15).

Figures 17 and 18 show the best model-generated approximation of water levels in the aquifer in March and September 1976, respectively. The simulated and measured water levels were contoured directly from the plot of water levels generated by the model and those measured in wells, respectively. Wells at which water-level measurements were obtained and where direct comparison of measured and modeled water levels can be made are also shown in figures 17 and 18. The simulated water-level surfaces are generally in close agreement with the potentiometric-contour maps compiled for March and September 1976 (figs. 14 and 15). In the simulated water-level surface for September 29, recharge from precipitation was programmed into the model at a constant rate of 3.10×10^{-8} ft/s, equivalent to 12 inches over the modeled area, whereas in the model run for March 5, the selected recharge rate was 28 inches.

The hydraulic relationship between the outwash aquifer and Tioughnioga River is a major factor in the river's ability to sustain streamflow adequate for dispersion of sewage outfall. The Tioughnioga River is the principal discharge area for water flowing through the aquifer. Thus, large-scale pumping from the aquifer or a decrease in recharge from precipitation may reduce the rate at which ground water is discharged to the river, and this would result in a decreased amount of streamflow in the modeled area.

In the steady-state simulation that represented ground-water flow in the aquifer in March 1976, the rate of ground-water seepage into the Tioughnioga River was calculated to be 14.7 ft^3/s at a constant areal recharge rate of 28 in/yr. In the transient run, which simulated ground-water flow in September 1976, the seepage rate was 11.1 ft^3/s at a constant areal recharge rate of 12 in/yr. Thus, a decrease in the rate of recharge produced a decrease of 3.6 ft^3/s in ground-water seepage into the Tioughnioga River.

In summary, the digital model can be used to determine how the local hydrologic system functions and to predict aquifer response to many types of water development. Given the data for specific hydrologic changes, the model can calculate, for example, specific recharge/discharge relationships between the Tioughnioga River and the outwash aquifer and the rate at which the Tioughnioga River gains ground water.

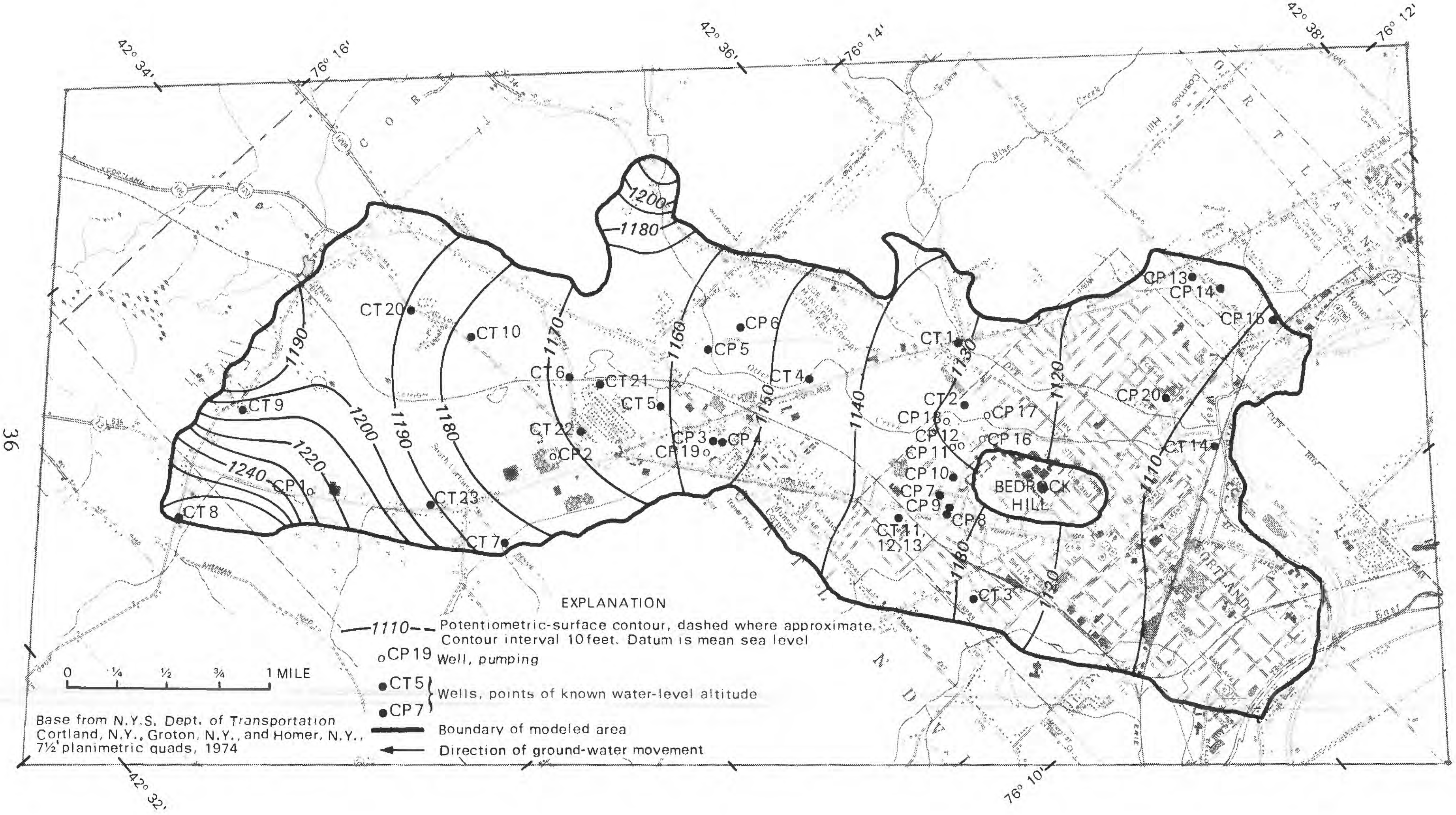


Figure 17.--Simulated water-level contours of Otter Creek-Dry Creek aquifer, March 5, 1976

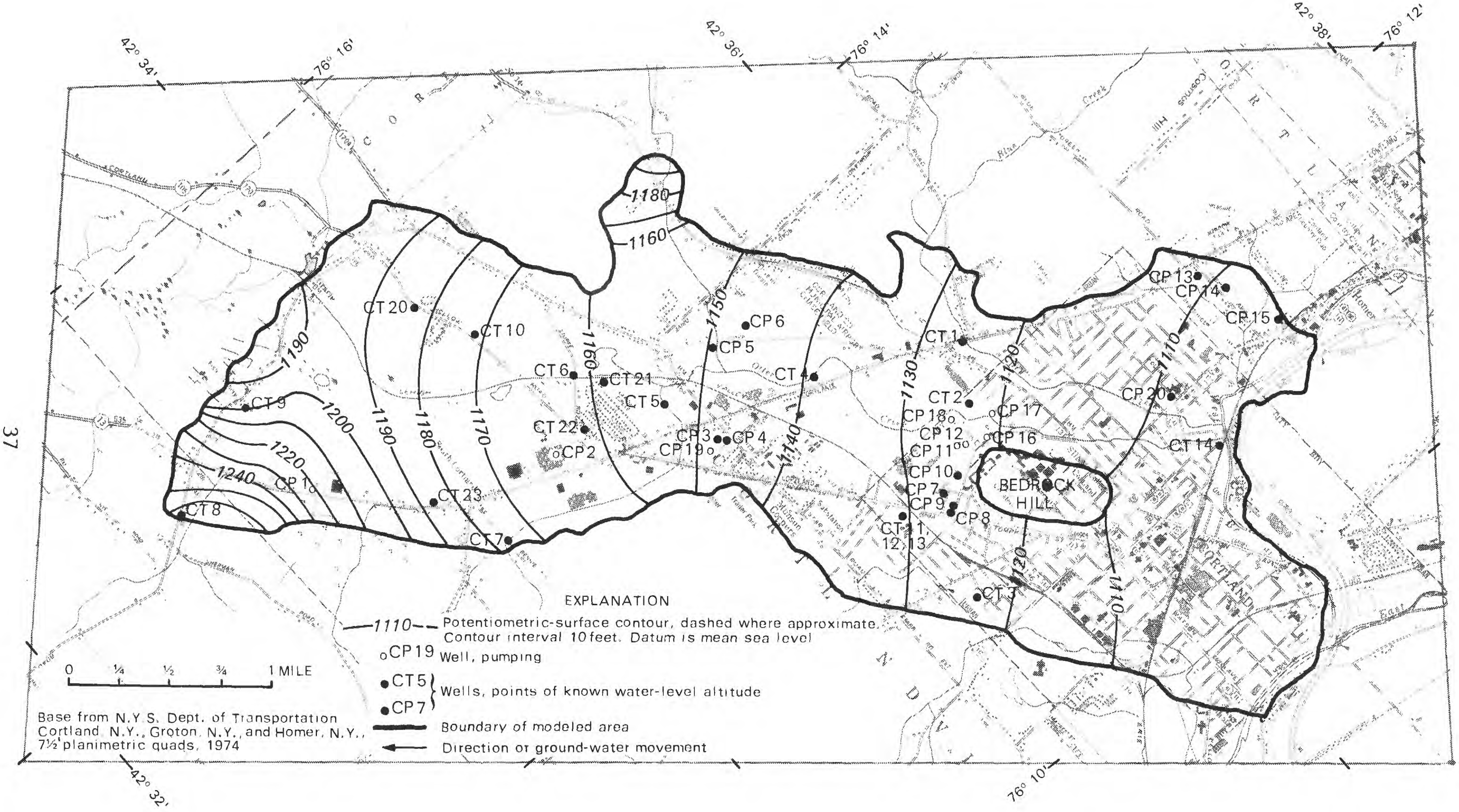


Figure 18.--Simulated water-level contours of Otter Creek-Dry Creek aquifer, September 29, 1976.

WATER QUALITY

General Water Quality

Samples were collected periodically from selected wells and surface-water sites for chemical analysis to provide a basis for evaluation of water quality in the Otter Creek-Dry Creek basin. Ground-water samples from upper and lower zones of the aquifer were collected on the same day to provide comparative data for the two levels. The major objective was to provide chloride and nitrate analyses, but samples were also analyzed for major chemical constituents, trace metals, total phosphorus, insecticides, total organic carbon, and detergents. These data are stored in the computerized water-quality files of the U.S. Geological Survey.

Results of the analyses indicate that in the study area, the chemical quality of surface water is similar to that of ground water and that ground-water quality is fairly uniform within the saturated thickness of the aquifer. Concentrations of the major chemical constituents of selected ground-water and surface-water samples are given in table 8. The predominant mineral constituent of the water is calcium-magnesium carbonate, which causes water hardness; sodium, chloride, and nitrate also add appreciably to the mineralization of the water. Figure 19 illustrates the composition of the surface- and ground-water samples. Chemical constituents are paired as cations (positively charged) and anions (negatively charged) and are plotted as percent milliequivalents of total milliequivalents of cations and anions. Point A on figure 19, for example, indicates that calcium + magnesium constitutes 20 percent of the total cations (calcium + magnesium + sodium + potassium) and that sulfate + chloride constitutes 80 percent of the total anions (sulfate + chloride + bicarbonate + carbonate). Total dissolved solids in surface water and ground water ranged from 70 to 300 mg/L. Most ground-water samples contained total dissolved-solids concentrations near 250 mg/L, which is well below the recommended limit of 500 mg/L for source waters used for drinking (New York State Department of Health, 1971). The pH (degree of acidity or alkalinity) of most surface waters and ground waters was close to neutral (6.5 to 7.5).

Industrial processes and urbanization may add certain trace metals to the hydrologic system. Although these generally occur in very small concentrations, the high toxicity of certain of them may seriously degrade water quality. Water samples for trace-metal analysis were collected from several wells open in the upper 60 feet of the aquifer. These analyses (table 9) showed trace-metal concentrations to be near zero or below recommended limits for source waters used for drinking (New York State Department of Health, 1971). Limits are not given for aluminum, nickel, strontium, or vanadium, but concentrations were well below maximum concentrations found in other public water supplies (New York State Department of Health, 1974).

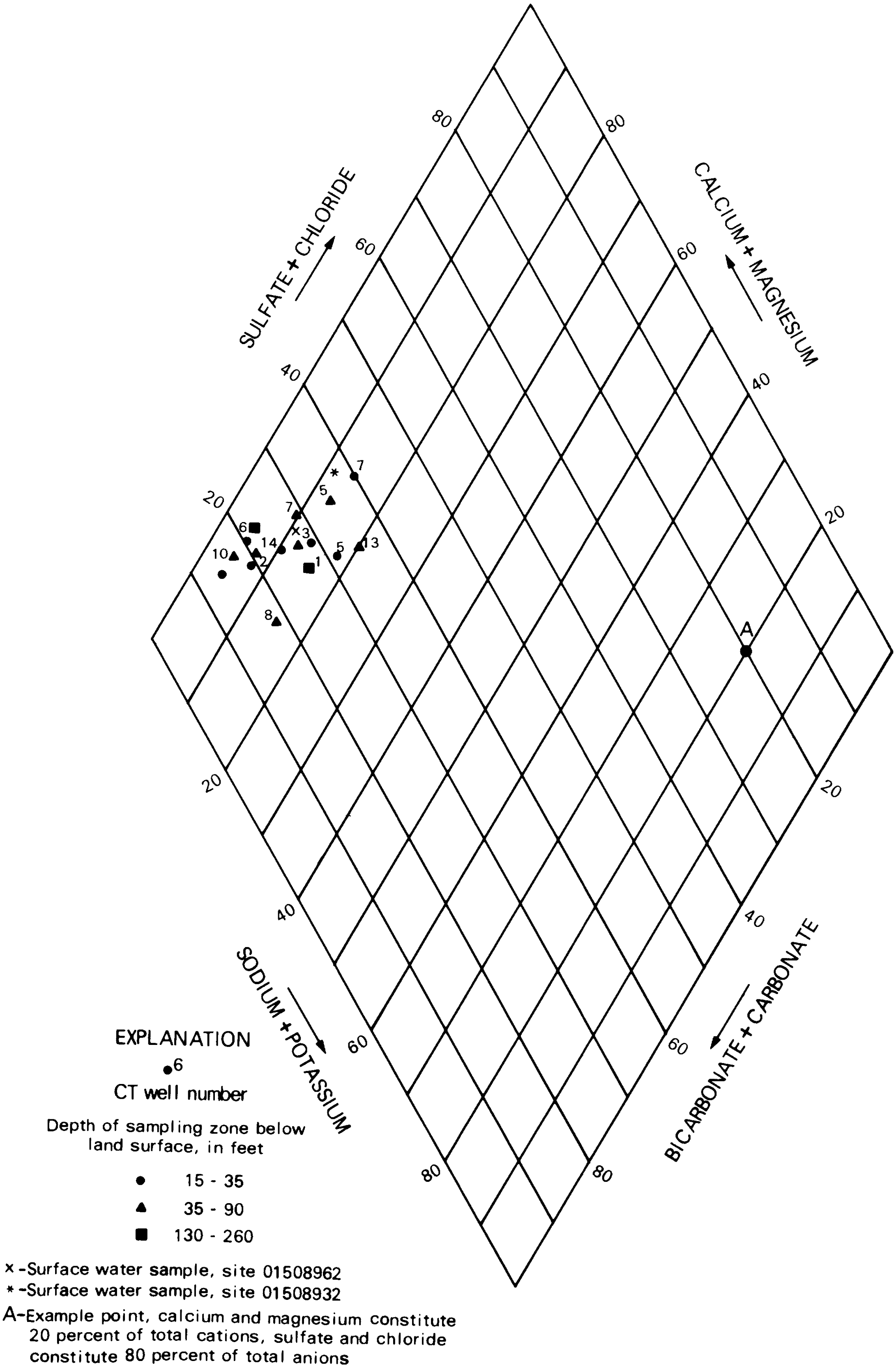


Figure 19.--Diagram showing water analyses for major cations and anions.

Table 8.--Concentrations of major chemical constituents in samples from selected ground-water and surface-water sites.

[Analyses by U.S. Geological Survey; all values in milligrams per liter unless otherwise noted]

Sampling site	Sampling depth (ft)	Date of Collection	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride	Nitrate + nitrate (as N)	Total phosphorous (P)	Dissolved solids, calculated from determined constituents	Hardness (Ca, Mg)	Noncarbonate hardness	Specific conductance (µmho/cm at 25°C)	pH	Temperature (°C)
WELLS																				
CT 2	20-25	2-9-76	0.050	0.010	66	12	6.3	0.6	222	0	19	13	4.0	0.02	230	210	32	520	7.3	--
	45-49	2-9-76	.030	.010	59	12	4.4	.4	196	0	20	14	5.2	.04	212	200	36	405	7.4	--
CT 6	21-26	2-11-76	.020	.060	59	15	3.4	.5	200	0	21	13	3.9	.02	215	210	45	410	7.2	10.0
	251-255	2-11-76	.080	.150	51	15	3.3	.5	196	0	32	8.0	.20	.11	207	190	28	375	7.4	10.0
CT 8	34-38	2-10-76	--	--	79	15	21	1.0	273	0	21	20	5.6	.02	298	260	35	580	7.3	10.0
STATIONS																				
01508932	--	2-27-76	--	--	22	3.7	4.0	1.2	57	0	13	11	2.0	--	85	70	23	170	6.4	--
01508940	--	2-27-76	--	--	47	8.8	6.2	1.5	144	0	18	18	3.3	--	174	150	35	325	6.3	--
01508962	--	2-27-76	--	--	56	10	9.0	1.3	176	0	19	24	3.6	--	210	180	37	400	6.7	7.5

Table 9.--Trace metal concentrations in ground water, Otter Creek-Dry Creek basin

[Analyses by U.S. Geological Survey; concentrations in micrograms per liter unless otherwise noted]

Sampling site	Sampling depth (ft)	Date of collection	Aluminum (Al)	Arsenic (As)	Barium (Ba)	Boron (B)	Cadmium (Cd)	Chromium (Cr)	Cobalt (Co)	Copper (Cu)	Lead (Pb)	Lithium (Li)	Mercury (Hg)	Molybdenum (Mo)	Nickel (Ni)	Selenium (Se)	Silver (Ag)	Strontium (Sr)	Vanadium (V)	Zinc (Zn)
Wells																				
CT 2	20-25	2-9-76	20	0	0	30	0	<10	0	0	2	0	<.5	0	1	0	0	100	0	60
	45-49	2-9-76	20	0	0	30	0	<10	0	0	1	0	<.5	0	1	0	4	90	.9	40
CT 5	21-26	2-10-76	10	1	0	10	1	<10	0	0	3	0	<.5	0	2	0	0	110	.6	20
	55-59	2-10-76	20	0	0	20	1	<10	0	0	4	0	<.5	0	1	0	0	100	1.5	20
CT 14	14-23	2-12-76	80	0	--	--	0	<10	0	0	3	--	<.5	0	1	1	--	--	--	20

Insecticides such as DDT and DDE, which are used for domestic and agricultural purposes, may also enter the ground water. Samples from several wells open in the upper 60 feet of the aquifer were analyzed for insecticides and polychlorinated biphenyl compounds (PCB's), but the concentrations were zero.

Although phosphorus compounds are quite common in nature, they are largely removed from ground waters through chemical reactions with earth materials. However, wide use of phosphorous compounds in fertilizers and detergents may cause elevated phosphorous concentrations in water supplies. Samples for phosphorus analyses were collected from most wells; concentrations ranged from 0.02 to 0.61 mg/L total phosphorus. The higher concentrations were in the deeper zones of wells CT 1 (138-143 ft), CT 5 (55-59 ft), and CT 6 (251-255 ft). Analyses for methylene blue active substance (MBAS), a measure of apparent detergents, were made on samples from wells CT 2, CT 5, and CT 14; results indicated very little detergent (less than 0.2 mg/L). Total organic carbon concentrations ranged from 0.8 to 3.7 mg/L at wells CT 2, CT 5, and CT 8 and do not indicate significant pollution because this concentration range is similar to or below concentrations in surface waters of less developed areas (U.S. Geological Survey, 1975).

Ground-water samples were also analyzed for fecal coliform bacteria--an indicator of pollution from human and animal wastes. Results were mostly negative; only well CT 8, a shallow well (screened at 34-38 ft) in a farming area, produced bacteria counts (75 colonies per 100 mL). Thus, animal wastes are the likely source of coliform colonies. Because most earth materials prevent bacteria from moving very far from the source (Bouwer and others, 1972), widespread bacterial contamination of the ground water in the Otter Creek-Dry Creek aquifer is not expected.

The data in tables 8 and 9 indicate that except for high hardness and rather high total dissolved-solids concentration, ground water in the Otter Creek-Dry Creek aquifer is of good quality and without serious or widespread contamination. The constituents most likely to degrade the quality of ground water in the area are chloride and nitrate. Although concentrations of these constituents are at present (1976) well below limits for drinking-water standards, previous analyses of the Cortland municipal-well system have indicated a rising trend that could eventually exceed recommended limits. Hardness is also indicated to be increasing (Stearns and Wheler, 1970) so that water softening may become desirable for home owners in the future. The effects and possible sources of chloride and nitrate ions in the ground water are discussed in sections that follow.

Chloride

A graph showing change in chloride concentrations with time at well 5 of the Cortland Municipal Water Works (well CP 17 and others) shows a fluctuating but generally increasing trend of chloride levels since about 1948 (fig. 20). Chloride concentrations before this period were about 2 mg/L, which suggests that chloride from natural sources in the area is almost nil. Chloride concentrations in samples from the Cortland Water Works ranged from 15 to 18 mg/L, which is well below the 250-mg/L limit for drinking water (New York State Department of Health, 1971). Figure 20 suggests that even if the present trend continues, the safety limit for chloride concentrations will not be exceeded for several hundred years.

Most chloride compounds are highly soluble in water and, when introduced to the environment, readily enter the natural water supplies. Chloride ions have little tendency to adhere to earth materials and therefore are good for tracing water movement.

Chloride Distribution in Otter Creek-Dry Creek Basin

Data in table 10 show that chloride concentrations in ground water varied only slightly (generally less than 30 percent) at most wells from December 1975 through October 1976. Concentrations in samples from the upper 60 feet of the aquifer were generally similar, which suggests that vertical diffusion has occurred throughout most of the aquifer. Samples from deeper zones were obtained only from wells CT 1, CT 6, and CT 10; results indicate that chloride has reached as deep as 250 feet. However, concentrations at this depth were about 50 percent of those near the surface. Figure 21, based on data collected in September and October 1976, shows the chloride distribution in the upper 60 feet of the aquifer; chloride distribution during other sampling periods is similar (table 10). The lines of equal concentration (fig. 21) show the highest chloride concentrations to be in the central part of the valley; this indicates that water entering the aquifer from the periphery of the valley gains chloride as it moves toward the center. Surface waters in the basin show a similar trend--chloride concentrations generally increase downstream. The association of high chloride concentrations with the more developed areas supports the premise that urbanization is causing the change in ground-water quality. Figure 21 shows two widely separated areas of high chloride levels in the central part of the aquifer--the area near the Lamont Circle housing development and the area near the bedrock hill.

Municipal sewage systems, septic-tank and cesspool systems, agricultural practices, road salting, and industrial wastes are cited in literature as sources that may yield chloride compounds to the environment. Almost all industrial sites in the Cortland area are serviced by the municipal sewer system, which discharges outside the Otter Creek basin; therefore, industry and municipal sewage are unlikely to be major contributors of chloride to the basin. However, septic systems, dairy farming, and road salting are extensive in the Cortland area and are therefore the probable major sources of chloride.

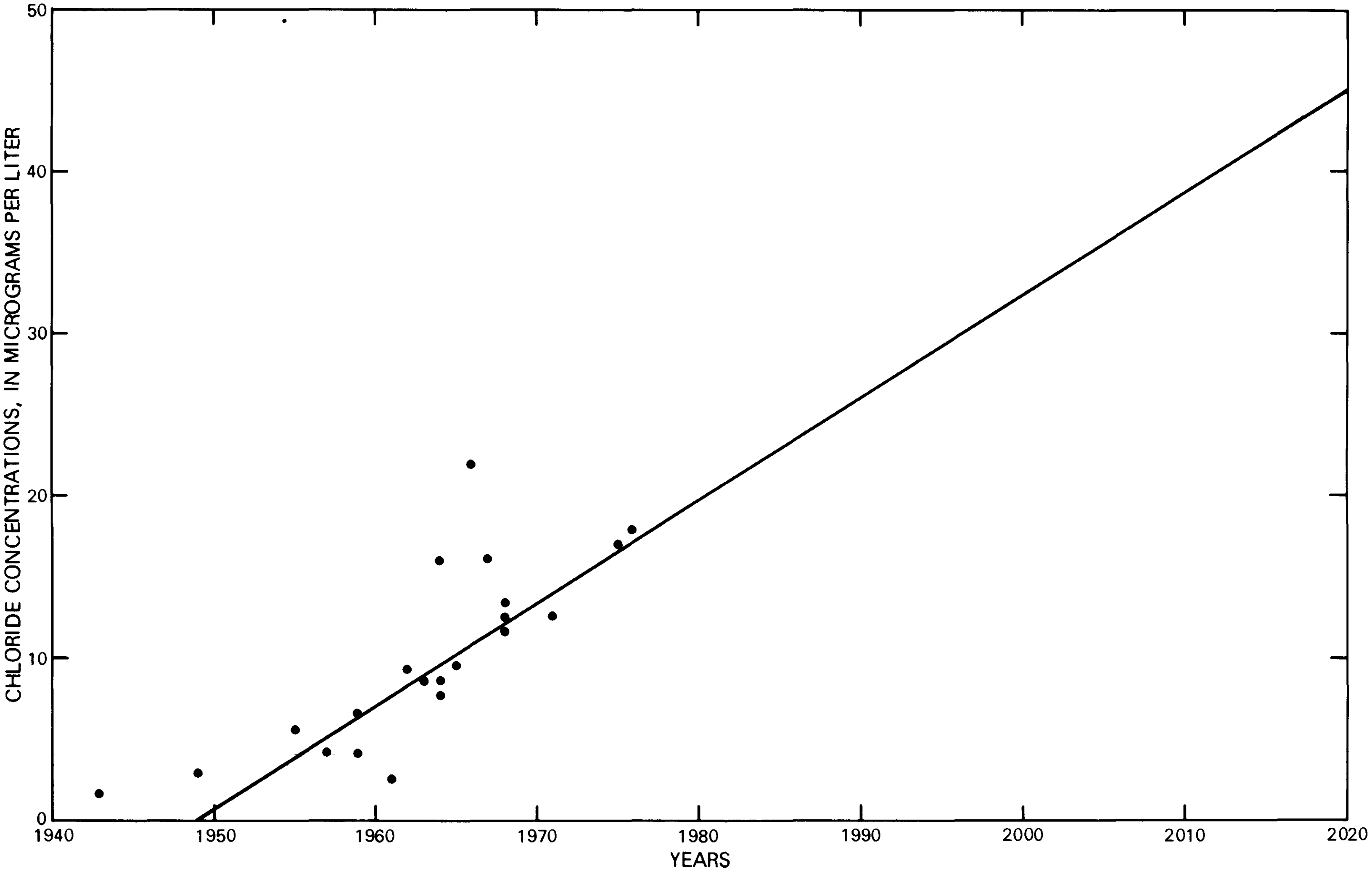


Figure 20.--Chloride concentrations in water from wells at Cortland Water Works, 1943-76.

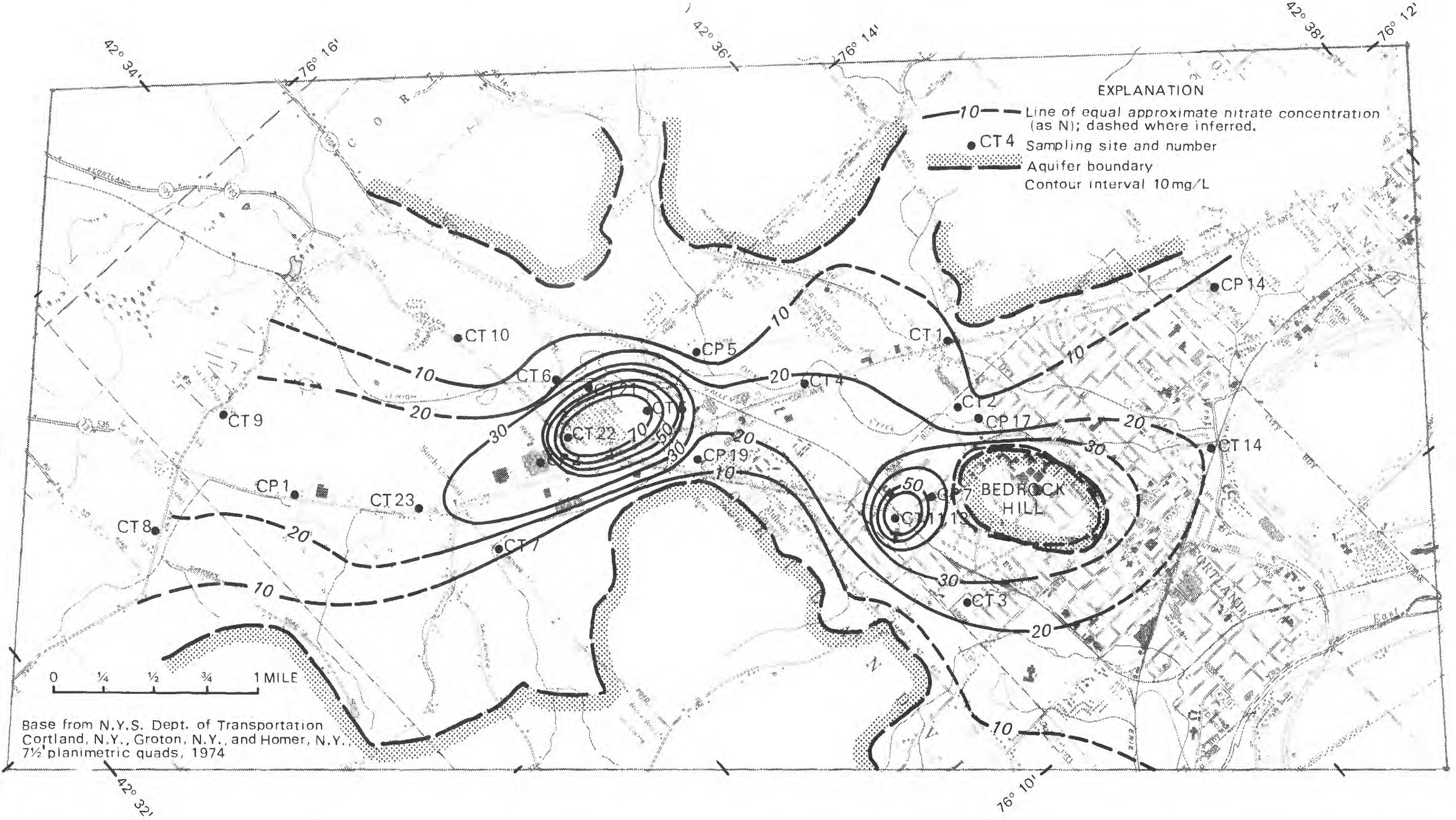


Figure 21.--Chloride concentrations in upper 60 feet of Otter Creek-Dry Creek aquifer, September-October 1976.

Table 10.--Chloride and nitrate concentrations in ground water and surface water, Otter Creek-Dry Creek basin

[Analyses by U.S. Geological Survey; concentrations in milligrams per liter]

A. WELLS

Sampling site (wells)	Sampling depth (ft)	Date of collection	Chloride (Cl)	Nitrite plus nitrate (as N)
CT 1	20-30	12-12-75	30	1.5
		3-09-76	18	2.6
		6-15-76	18	--
		7-26-76	10	1.5
		10-06-76	12	.84
	138-143	12-12-75	23	.05
		2-11-76	19	.02
		3-09-76	--	.04
		6-15-76	14	.02
		7-26-76	14	.01
CT 2	20-25	12-18-75	11	4.1
		2-09-76	13	4.0
		6-18-76	13	3.8
		7-26-76	12	3.8
		10-06-76	11	3.8
	45-49	12-18-75	11	4.0
		2-09-76	14	5.2
		6-18-76	11	4.5
		7-26-76	11	4.5
CT 3	23-28	12-04-75	25	3.4
		2-12-76	27	3.9
		6-18-76	30	4.4
		7-23-76	28	4.4
		10-04-76	27	3.8
	50-54	12-04-75	22	3.1
		2-12-76	25	3.7
		6-18-76	29	4.3
		7-23-76	27	4.2
		10-04-76	25	3.6
CT 4	18-23	12-18-75	16	2.7
		4-14-76	17	3.8
		6-15-76	18	3.1
		7-27-76	18	2.8
		10-04-76	22	2.4
	38-42	12-18-75	16	3.0
		4-14-76	20	3.1
		6-15-76	19	3.1
		7-27-76	20	3.1
		10-04-76	22	2.8
CT 5	21-26	12-04-75	65	4.0
		2-10-76	56	3.6
		4-14-76	50	4.4
		6-18-76	59	3.9
		7-23-76	65	4.0
		10-05-76	78	3.6
	55-59	12-04-75	35	3.4
		2-10-76	33	4.9
		3-09-76	37	3.3
		4-14-76	34	3.1
		6-18-76	36	2.8
		7-23-76	39	2.7
		10-05-76	42	2.6
CT 6	21-26	12-29-75	12	3.7
		2-11-76	13	3.9
		6-15-76	15	3.7
		7-27-76	14	3.9
		10-05-76	14	3.2
	251-255	12-29-75	6.3	.17
		2-11-76	8.0	.20
		3-09-76	7.4	.29
		6-15-76	10	.03
		7-27-76	6.6	.22
		10-05-76	7.8	.16

Table 10.--Chloride and nitrate concentrations in ground water and surface water, Otter Creek-Dry Creek basin (Continued)

[Analyses by U.S. Geological Survey; concentrations in milligrams per liter]

A. WELLS

Sampling site (wells)	Sampling depth (ft)	Date of collection	Chloride (Cl)	Nitrite plus nitrate (as N)
CT 7	19-24	12-18-75	10	2.9
		2-10-76	13	3.5
		7-26-76	11	2.8
	42-46	12-18-75	11	2.1
		2-10-76	12	2.5
		6-15-76	12	2.3
		7-26-76	10	2.3
CT 8	34-38	12-04-75	26	4.0
		2-10-76	20	5.6
		5-28-76	17	4.0
		6-15-76	18	4.3
		7-26-76	18	4.3
		10-04-76	22	4.2
CT 9	90-110	7-30-76	24	7.0
		11-16-76	22	.01
CT 10	28-32	12-29-75	3.5	1.1
		2-10-76	3.0	.78
		6-15-76	4.7	.55
		7-27-76	3.5	.82
	84-88	12-29-75	7.0	1.7
		2-10-76	8.2	1.8
		3-09-76	8.4	1.8
		6-15-76	9.8	2.1
		7-27-76	9.6	2.1
CT 11	38-60	9-28-76	62	3.7
CT 13	38-63	4-26-76	69	5.2
CT 14	14-23	2-12-76	19	4.2
		6-18-76	25	3.7
		7-08-76	23	--
		7-26-78	22	3.5
		10-06-76	18	2.9
CT 21	20-30	9-29-76	48	3.2
		10-05-76	45	3.2
CT 22	35-45	9-27-76	77	3.0
CT 23	75-85	9-27-76	28	2.4
CP 1	--	10-05-76	21	2.4
CP 2	--	10-06-76	20	3.9
CP 5	--	4-15-76	8.2	5.1
		11-15-76	7.6	3.0
CP 14	--	4-15-76	20	1.2
		10-06-76	16	.87
CP 17	36-38	2-13-76	17	4.4
		4-14-76	19	5.6
		5-28-76	17	3.7
		7-08-76	18	3.6
		7-26-76	15	3.7
		8-14-76	--	3.8
		8-30-76	16	3.7
CP 19	55-73	4-15-76	49	2.5
		7-08-76	20	1.8
		7-26-76	18	1.8
		10-06-76	15	1.7
		11-15-76	13	1.6

Table 10.--Chloride and nitrate concentrations in ground water and surface water, Otter Creek-Dry Creek basin (Continued)

[Analyses by U.S. Geological Survey; concentrations in milligrams per liter]

B. SURFACE-WATER SITES

Sampling site (wells)	Date of collection	Chloride (Cl)	Nitrite plus nitrate (as N)
01508905	5-20-75	6.2	1.7
	7-29-76	7.5	1.6
01508910	5-20-75	7.0	.44
	3-19-76	--	1.1
01508913	5-20-75	6.4	.62
	7-29-76	7.0	.93
01508915	5-20-75	6.9	1.3
	12-02-75	6.9	1.3
01508918	5-20-75	7.7	1.3
	2-27-76	9.5	1.9
	7-08-76	7.9	1.3
	7-29-76	7.7	1.5
01508925	5-20-75	5.1	1.4
01508932	12-02-75	8.1	3.3
	2-27-76	11	2.0
	3-03-76	6.0	--
	6-18-76	13	1.3
	7-08-76	14	1.9
	7-27-76	--	1.7
	7-29-76	9.3	1.7
	8-05-76	--	1.9
	8-11-76	--	1.0
	8-15-76	--	1.1
	8-20-76	--	2.1
	8-26-76	--	1.8
	9-01-76	--	1.7
	9-03-76	--	1.7
	9-10-76	--	.80
01508937	2-27-76	17	2.2
	7-08-76	10	1.3
	7-27-76	9.3	1.8
01508940	5-20-75	17	3.2
	2-27-76	18	3.3
	3-19-76	21	3.7
	7-08-76	10	3.0
	7-27-76	18	2.9
01508945	5-20-75	4.4	2.7
01508948	5-20-75	5.6	2.5
01508951	5-20-75	16	3.2
	12-02-75	15	3.5
01508955	5-20-75	21	3.3
	7-08-76	25	2.9
	7-27-76	23	2.8
01508960	5-20-76	19	3.3
01508962	12-02-75	26	1.5
	1-26-76	780	--
	2-27-76	24	3.6
	3-04-76	18	--
	3-19-76	28	3.8
	3-30-76	26	--
	4-06-76	29	--
	4-10-76	21	--
	4-15-76	27	--
	4-20-76	28	--
	4-25-76	22	--
	4-28-76	29	--
	5-03-76	19	--
	6-18-76	29	2.8
	7-08-76	25	2.9
	7-14-76	16	2.4
	7-27-76	24	2.8
	7-29-76	--	2.0
	8-05-76	--	2.5
	8-11-76	--	2.6
	8-15-76	--	2.1
	8-20-76	--	2.4
	8-26-76	--	2.2
	9-01-76	--	1.4
	9-10-76	--	.87
Smith-Corona effluent pond (near well CP 2).	4-15-76	30	--

Septic Systems

Septic systems are used by private homes and other establishments not connected to public sewer systems. Septic systems usually include a septic tank, which serves as a storage basin in which waste material is biologically decomposed, and a leach field containing perforated pipe a few feet below land surface that discharges the septic-tank effluent into the ground. Septic effluent contains numerous chemical constituents in varying amounts, depending upon type of use. According to Metcalf and Eddy, Inc. (1972), domestic septic effluent may have chloride concentrations ranging from 30 to 100 mg/L; 50 mg/L is considered average. Septic effluent may enter the ground in the unsaturated zone or it may enter the ground water directly during periods of high water-table levels.

Effluent entering the unsaturated zone is subject to the effects of rainfall and evapotranspiration and may be diluted or concentrated as a result. In the latter case, chemical concentrations in the ground water may build up to exceed those of the original effluent.

To compare input loads to the basin, one may use the ratio of input load (tons per year) to total affected area (square miles). The input load is best calculated as an annual rate because of seasonal variation of input loads. Although this approach ignores many variables, it provides a useful basis from which to make comparisons. Although certain input loads may affect the entire Otter Creek-Dry Creek drainage basin, water movement carries the dissolved constituents to the aquifer underlying the central valley in a relatively short time; therefore, the aquifer area, rather than the entire basin, is considered the affected area in this study.

The total septic effluent discharge from residential sites in the basin is estimated to be 200,000 gallons per day. This estimate is based on 750 residential sites with 3.5 people per site (Cortland County Planning Department, 1976) and 75 gallons of effluent per day per capita (Feth, 1973). An additional 50,000 gallons of effluent per day from commercial establishments make a total of 250,000 gallons of effluent added to the basin per day. With an average chloride concentration of 50 mg/L, this amounts to 20 tons of chloride added to the basin each year. Although the majority of septic systems are in the southwestern half of the valley, water movement would disperse the chloride throughout the aquifer. Twenty tons of chloride applied over the 9.4-mi^2 aquifer area yields an input rate of 2 tons per year per mi^2. The Lamont Circle housing development and surrounding septic systems (fig. 21) generate about 30,000 gallons of effluent per day, or about 2 tons of chloride per year. The 0.4-mi^2 area enclosed by the lines of high concentration in figure 21 may be considered the most severely affected area; the 2-ton annual input to this area gives a total annual input rate of 5 tons per mi^2.

Agricultural Practices and Residential Fertilizers

The predominant type of farming in the basin is dairy farming, which generally includes cultivation of corn, alfalfa, hay, and grains. Dairy cattle population is 2,770 head of cattle and 1,840 head of young stock (Cortland County Cooperative Extension, 1977). Chloride output from cattle averages about 0.1 pound per day for mature cattle and 0.05 pound per day for young stock (John Peters, oral commun., 1976). From these figures, total chloride input to the basin from cattle would total 70 tons per year. In addition, 90 tons of chloride in the form of commercial fertilizer was applied to croplands in the basin in 1976 (Cortland County Cooperative Extension, 1977). This would give a total chloride input of 150 tons per year, (15 tons per mi^2 per year) from farming. Chloride input from lawn and garden fertilizer could be as high as 5 tons per year (0.5 tons per mi^2 per year); this estimate is based on an average application rate of 40 pounds of fertilizer per year (with an average chloride content of 4 percent from 4,000 residential sites).

Chloride distribution in the basin does not indicate farming to be a major contributor of chlorides to ground water. Test well CT 8, (opened from 34- to 38-foot depth) is near an animal farm and also adjacent to a road; chloride concentrations in this well ranged from 17 to 26 mg/L (table 1). Though not very high, these concentrations are somewhat greater than might be expected near the periphery of the valley. The chloride input from residential fertilizer, which is less than 5 tons a year, does not seem significant.

Road Salting

Road salting is extensive in the Cortland area because of heavy snowfall. Although road salting provides a valuable service to the community, contamination of ground water by deicing salts is well documented.

Toler and Pollock (1974) found in their studies of deicing-salt retention in the unsaturated zone that chloride concentration in ground water is responsive to annual salt applications and that 45 to 85 percent of the chloride applied each winter reaches the water table by the following midsummer. According to Toler and Pollock (1974), the amount of chloride retained in the unsaturated zone depends on the grain size of the earth materials, the depth to water table, and the amount and seasonal distribution of precipitation. Their study site was in northeast Massachusetts, and the deposits consisted of about 60 feet of fine to coarse sand and silt overlying glacial till. The time needed for salts to reach the water table in the outwash deposits of Otter Creek valley may be less because of the deposits' greater permeability.

Road salt applied in the Cortland area consists of sodium chloride and a small amount of calcium chloride and is applied with a sand mix.

The salt is stored in open piles at several sites in the basin, and these are usually depleted by springtime. Five different highway departments (one State, one County, and three towns) that maintain roads in the Otter Creek-Dry Creek basin apply road-deicing salts.

The total amount of salt applied annually to roads in the basin varies with weather conditions, but salt applications average 15 tons per mile on a total of 60 miles of roads in the basin excluding the City of Cortland. This amounts to an annual load of 900 tons. The City of Cortland applies 1,500 tons of salt annually to roads in the city. Although 80 percent of this is estimated to be removed from the basin directly by storm sewers, the remaining 300 tons brings the total annual salt load to the basin to 1,200 tons. Because road salt contains 60 percent chloride by weight, the total annual chloride input to the basin is 700 tons, which amounts to an input rate of 70 tons per year per mi^2, which is more than 30 times the input rate from septic systems and about 5 times the input rate from farming practices.

Well samples taken at different times of year did not show much fluctuation in chloride concentrations, and in test wells near secondary roads, chloride concentrations were all below 15 mg/L. Chloride concentrations at two test wells installed near Highway 13 in September 1976 (wells CT 22 and CT 23) were between 20 and 30 mg/L in September but may be higher in winter because Highway 13 is more heavily salted than county roads. Toler and Pollack (1974) reported chloride concentrations as high as 400 mg/L in wells near major highways in Massachusetts.

Because road salt is applied at ground surface, where surface runoff can readily transport it, it is likely to be removed from the basin more rapidly than salts that enter the basin through septic systems. Salt applied to roadways is washed into ditches and drains, from which a large part of it flows to the main channels of Otter and Dry Creeks and thus leaves the basin without entering the ground water.

To obtain an estimate of the amount of road salt leaving the basin as surface flow, the authors monitored chloride concentrations at the surface-water gaging site at the mouth of Otter Creek from February through December 1976 by recording the electrical conductivity of the stream water. Normal chloride concentrations at the site ranged from 20 to 30 mg/L; concentrations greater than this amount may be attributed to the addition of road salt by surface runoff.

Random stream sampling before the monitoring period indicated that during periods of snowmelt, significant amounts of road salt may be carried out of the basin in a relatively short time. For example, a stream sample collected January 26, 1976 had a chloride concentration of 780 mg/L; at this concentration, a mean daily stream discharge of 4 ft^3/s would carry nearly 9 tons of chloride out of the basin within 24 hours. However, data collected during the monitoring period revealed only a few short periods of elevated chloride concentrations and indicate that no significant amounts of chloride directly attributable to road-salting were transported during this period. This may have been because temperatures during the winter months of the monitoring period were generally below freezing so that little runoff occurred; had the project not been terminated in January 1977, chloride loads during the spring snowmelt would probably have been found to be elevated.

Areas of High Chloride Concentrations

Road salting and septic effluent seem to be the major chloride sources at Lamont Circle (fig. 21). The location of Lamont Circle suggests that farming is not a major source of chloride at this site. Residential fertilizer is only a minor source in this area because annual input, at the rate of 2 pounds per residence per year with 100 residences, is not likely to exceed 0.1 ton.

Chloride from deicing applications on 1 mile of roads at Lamont Circle would total 10 tons per year; this applied to a 0.4-mi^2 area yields an input rate of 20 tons per year per mi^2. The input rate from septic effluent for the same area is 5 tons per year per mi^2. Thus, the input rate of chloride from road salting at Lamont Circle is about one-third (20:70) the input rate from road salting in the entire basin, and the septic-effluent input rate at Lamont Circle is more than twice (5:2) that for the entire basin. This comparatively high input rate from septic systems and the close correlation between high chloride concentrations and high-density septic systems suggest that septic systems are a major source of chloride at this site.

Water from test-well CT 22 (fig. 21), although upgradient from Lamont Circle, has a high chloride concentration; it may be that heavy pumping at a nearby industrial site has changed the direction of gradient so that the high-chloride water moves toward the well. Analyses indicate that the discharge of industrial effluent near Lamont Circle does not contribute to the high chloride concentrations (table 10).

The high chloride concentrations near the bedrock hill (fig. 21) may be attributed to several sources. Although the area is serviced by public sewer systems, contamination from leaky sewers is possible, and in addition, several septic systems are upgradient from well CT 11. Still another significant source of chloride may be the washout of road salt from the bedrock hill.

The future trend of water quality in the high-chloride areas, and the directions in which the high-chloride ground water will move, will be important considerations in the future. The Lamont Circle housing development was completed in the early 1960's; thus, the high chloride concentration at Lamont Circle has developed in 15 years or less. It is not known at this time whether the chloride concentrations there will increase and cause the area of high chloride to expand. The Cortlandville Water Works is close to the Lamont Circle area and other septic systems, and data indicate that pumping from Cortlandville wells may already be drawing some water from the Lamont area (chloride concentration at well CP 19 was 49 mg/L on April 15, 1976). The high-chloride area near the bedrock hill could also affect the Cortland water supply; however, data (table 10, well CP 17) do not indicate that pumping at the Cortland Water Works is drawing water from this area. Because the drinking-water standard for chloride is 250 mg/L (New York State Department of Health, 1971), and the highest concentration to date in the aquifer is about 70 mg/L, no immediate threat to municipal water supplies is indicated.

Future Trends of Chloride Concentrations

A comparison of total chloride input and output loads during the 1976 water year (October 1, 1975 to September 30, 1976) should give some indication as to whether the chloride content in the basin decreased or increased during that time. Total chloride output is the sum of the chloride loads moved out of the basin by discharges of ground water and surface water. The average rate of ground-water discharge is estimated from the digital model to be 15 ft^3/s plus an additional 7 ft^3/s that is pumped directly out of the basin by the Cortland Water Works. Thus, the total ground-water outflow of 22 ft^3/s, with an average chloride concentration of 20 mg/L, carried 450 tons of chloride out of the basin in 1976. For Otter Creek, a mean yearly flow of 18 ft^3/s and an estimated average chloride concentration of 25 mg/L would give a load in the range of 400 to 500 tons in 1976. For Dry Creek, a mean yearly flow of 11 ft^3/s and an average chloride concentration of 10 mg/L would give a total chloride load of 100 tons. Thus, total chloride output during 1976 from ground-water and surface-water discharge is about 1,000 tons as compared to a total input of 900 tons from road salting, septic-tank effluent, and farming. Although these calculations suggest that output chloride loads may have exceeded input loads of the basin during the 1976 water year, historical streamflow data of nearby gaging stations show that runoff in the area may have been as much as 200 percent above normal. A normal runoff would probably result in a closer balance of input and output loads. However, the margin of error in load estimates, combined with variables in the system, precludes any reliable prediction of future trends.

Total chloride in the upper 60 feet of saturated thickness of the aquifer is estimated to be about 1,800 tons, with an average concentration of 20 mg/L. Total chloride outflow from the aquifer is estimated to be between 500 and 600 tons per year. This estimate is based on a normal runoff year and includes only chloride loads discharged from the basin by pumping, ground-water outflow into the Tioughnioga River, and base flow (streamflow derived from ground-water seepage from stream banks) by Otter and Dry Creeks. Chloride load in surface runoff is not included in this estimate. This figure suggests that if chloride input were stopped and outflow remained the same, chloride concentrations in the aquifer would be reduced to original concentrations in about 3 or 4 years. However, the process would actually take longer because, as flushing of chloride continued, concentrations in the aquifer would decrease and the rate of chloride outflow would also decrease as a result.

Estimates of input loads indicate that except in the Lamont Circle area, road salting and farming are the major sources of chloride input to the basin and are the primary cause of the increase in chloride concentration in the aquifer.

Nitrates

Chemical analyses of well-water samples collected at the Cortland Municipal Water Works show that recent nitrate1/ concentrations are three to four times as high as during the 1930's, when they were near 1 mg/L (James Feuss, oral commun., 1977), as compared to recent concentrations of 3 to 5 mg/L. Extensive development in the basin may further elevate nitrate concentrations.

High nitrate concentrations in drinking water have been correlated with the disease methemoglobinemia (nitrate cyanosis), which affects mostly infants. Bacterial action within the intestinal tract causes the conversion of nitrate to nitrite, which eventually reduces oxygen in the bloodstream. Infants are especially susceptible to the disease because their digestive system is favorable for this conversion (National Research Council, 1972). In that report, The National Academy of Sciences reported that from 1945 to 1950, 278 cases of cyanosis in the United States, 39 of which were fatal, were attributed to nitrate in well water. As a result of careful regulation of water supplies by public health departments, only 40 cases were known from 1952 to 1966, and only 10 from 1960 to 1969. No fatalities occurred during either period. The U.S. Public Health Service (1972) recommends a limit of 10 mg/L of nitrate (as N) for drinking water and further recommends that the public be warned of the health hazard when water with that concentration is used for infant feeding.

Nitrate Properties

Nitrogen, which forms about 79 percent of the atmosphere, is abundant in nature in chemical combination with other elements and plays a vital role in the life processes of plants and animals. Nitrogen in its gaseous, elemental form is relatively inert but plays a role in nature through the fixation process, whereby it is converted into combined forms that can be used by plants and animals. Nitrification is a series of reactions in which microorganisms oxidize the ammonium ion (NH_4^+)

1/ Nitrate (as N) concentrations are expressed as elemental nitrogen (N). To convert N values to NO_3 (nitrate) values, multiply the N value by 4.43. All nitrate values in this report are reported as N.

to nitrite (NO_2^-), or nitrite to nitrate (NO_3^-). The ammonium ion is the result of the ammonification process, in which complex nitrogen compounds are broken down to yield ammonium and other products. The reverse of nitrification is denitrification, wherein certain species of microorganisms convert nitrite or nitrate to gaseous compounds such as elemental nitrogen and nitrous oxide. These processes are a major part of the nitrogen cycle, in which nitrogen moves from the atmosphere to the cells of microorganisms, then to the soil, where it becomes available to plants and ultimately to animals. When the plants and animals die, the nitrogen is either recycled through a new generation of plants and animals or it is returned to the atmosphere through denitrification (Delwiche, 1970).

Because nitrogen compounds are widely dispersed in the air and soils, they are commonly present in natural water supplies also. Under aerobic (abundant air) conditions, nitrification takes place, with nitrate as the stable end product. Nitrate is negatively charged and moves through groundwater reservoirs with little tendency to be adsorbed onto clay particles. Bouwer and others (1972), who studied the effects of sewage discharges into infiltration basins, suggest that nitrogen can be removed from water by several processes. For example, the positively charged ammonium ion may be adsorbed by earth materials, nitrogen may be incorporated into the tissues of soil microorganisms, or nitrogen may be taken up by plants, and, under anaerobic conditions, denitrification may occur. However, only through denitrification and plant uptake followed by harvesting is nitrogen actually removed from the soil. Bouwer and others (1972) state that soil particles may become saturated with ammonium, which causes them to lose their ability to absorb the ammonium ion. Data in U.S. Geological Survey (1975) indicate that nitrate is the most common nitrogen species in surface water and ground water, whereas nitrite, usually with concentrations of less than 0.1 mg/L, is unstable and generally undergoes nitrification or denitrification (Behnke, 1974).

Nitrate Sources and Distribution

Data in table 10 show that nitrate concentrations in ground water did not change greatly (generally less than 30 percent) during the sampling period. Data from the well pairs (open to two different zones) show that vertical distribution of nitrate was quite uniform throughout the upper 60 feet of the aquifer, with concentrations ranging from 2 to 5 mg/L, whereas below 150 feet, they were less than 0.5 mg/L. Thus, nitrate has diffused through at least the upper 60 feet of the aquifer but apparently no deeper. Data show that nitrate is the most abundant form of nitrogen species in the aquifer except in the deeper zones, where organic nitrogen and ammonia (kjeldahl nitrogen)1/ predominate. Organic nitrogen and ammonia are nitrogen compounds that have not undergone the complete processes of ammonification and nitrification.

1/ The kjeldahl nitrogen analysis includes organic nitrogen and ammonia nitrogen.

Figures 22, 23, and 24 show nitrate concentrations, which varied seasonally during December 1975-February 1976, June-July 1976, and September-October 1976. The lines of equal concentration show that nitrate concentrations are generally higher in the central valley and that nitrate loading is therefore higher there than in peripheral areas. Agricultural and residential fertilizers, domestic sewage, and farm animals are most commonly cited as the causes of elevated nitrate concentrations in ground water.

Input rates for these sources of nitrogen can be estimated in the same way as for chloride. The total septic effluent of 250,000 gallons per day with a total nitrogen concentration of 40 mg/L (Metcalf and Eddy, Inc., 1972) would yield about 15 tons of nitrogen per year. The nitrogen input from dairy cattle is estimated to be about 40 tons per year. This estimate is based on (a) a cattle population of 2,800 dairy cattle and 1,800 young stock, and (b) a nitrogen-production rate of 90 pounds per dairy cow per year and 40 pounds per young cow per year (Cortland County Cooperative Extension, written commun., 1977). The nitrogen-production rate for cattle allows for a 50-percent nitrogen loss due to volatilization of ammonia and a 75-percent loss through nitrogen assimilation by crops because most of the animal wastes are used for fertilizing crops. It is estimated that 55 percent of the nitrogen is available to the crop the first year, 13 percent in the second year, 5 percent in the third year, and in decreasing amounts in succeeding years (Cortland County Cooperative Extension, written commun., 1977). Cortland County Cooperative Extension also reported that 80 tons of nitrogen from commercial fertilizer was applied to croplands in the basin in 1976 but only 25 percent (20 tons) would be released to ground water (D. R. Bouldin, written commun., 1977).

Studies of undisturbed forest lands in Fall Creek basin, which is adjacent to Otter Creek basin, indicate that the net nitrogen input from precipitation after natural biogeochemical processes is about 1 pound per acre per year (Johnson and others, 1977). At this rate, annual nitrogen input to the basin from precipitation would be between 5 and 10 tons. Legume crops may fix nitrogen as needed but are mainly used for cattle feed, and this nitrogen input would be accounted for in the cattle-input estimates (D. R. Bouldin, written commun., 1977).

The nitrogen input from lawn and garden fertilizer could be as high as 15 tons per year. This estimate is based on an average application rate of 40 pounds of fertilizer per residence per year for approximately 4,000 residences. The average nitrogen concentration in lawn and garden fertilizer is about 20 percent.

These nitrogen loads are presented to provide a general basis for comparison. Nitrogen from these sources may be affected throughout the nitrogen cycle, which involves assimilation by plants, nitrification, and denitrification processes; therefore, these figures should be considered as maximum values that represent a potential input load.

The distribution of nitrate in the basin does not indicate any one major source. Figures 22-24 show high nitrate concentrations (4-7 mg/L) near farming areas at the upper southwest end of the valley. In this area, earth materials have low permeability so that ground-water movement is comparatively slow; thus, the dilution of nitrate here would also be slow. Consequently, nitrate concentrations in this area may indicate a greater input from agricultural practices than is actually the case. Well CT 4, which is downgradient from a dairy farm, had considerably lower concentrations (2.7 to 3.8 mg/L). High nitrate concentrations were also found near urbanized areas distant from agricultural sources of nitrate (figs. 22-24).

Nitrate concentrations at Lamont Circle show a less distinct dispersion pattern than chloride, although a similar pattern might be expected because septic effluent usually contains similar amounts of chloride and nitrogen (Metcalf and Eddy, Inc., 1972). The additional input of chloride from road salt and the effects of denitrification could account for this. Leakage from municipal sewer lines and residential fertilizer may be the major nitrogen source at well CT 11. The high nitrate concentration (5.4 mg/L) at this well probably cannot be attributed to septic systems alone because concentrations at Lamont Circle are lower (3.6 to 4.0 mg/L). It is apparent that the combined nitrogen sources from agriculture practices, sewer systems, and lawn and garden fertilizer are causing the elevated nitrate concentrations in the basin, but no particular source is clearly indicated to be predominant.

Future Trends of Nitrate Concentrations

Nitrogen that was carried out of the basin in 1976 by ground-water and surface-water flow is estimated to be 110 tons, and nitrogen input from farm animals, septic effluent, and fertilizers amounted to 100 tons. Thus, the output load seemed to exceed the input load during this year of high runoff. The output-load estimate is based on average nitrate concentrations of 3.0 mg/L for ground water and 2.5 mg/L and 1.5 mg/L for Otter and Dry Creeks, respectively. The nitrogen cycle is a complex system, and input and output loads of nitrogen provide only a rough approximation of budget conditions and cannot serve as a basis for predicting future trends. If input loads remain constant, it is probable that nitrate concentrations will remain fairly constant, and an increase in input loads will result in an increase in nitrate concentrations.

Comparison of nitrate concentrations in Otter Creek-Dry Creek basin with those in Gridley Creek basin, which is also in Cortland County, reveals a significant difference. Nitrate concentrations in the Gridley Creek aquifer are lower (generally less than 1.5 mg/L) than in the Otter Creek aquifer (3-5 mg/L). Population in Gridley Creek basin is about 40 people and 30 cattle per mile^2, as compared to more than 1,000 people and about 200 cattle per mile^2 in the Otter Creek basin. Thus, the greater development in the Otter Creek-Dry Creek basin is reflected by the elevated nitrate concentrations in ground water.

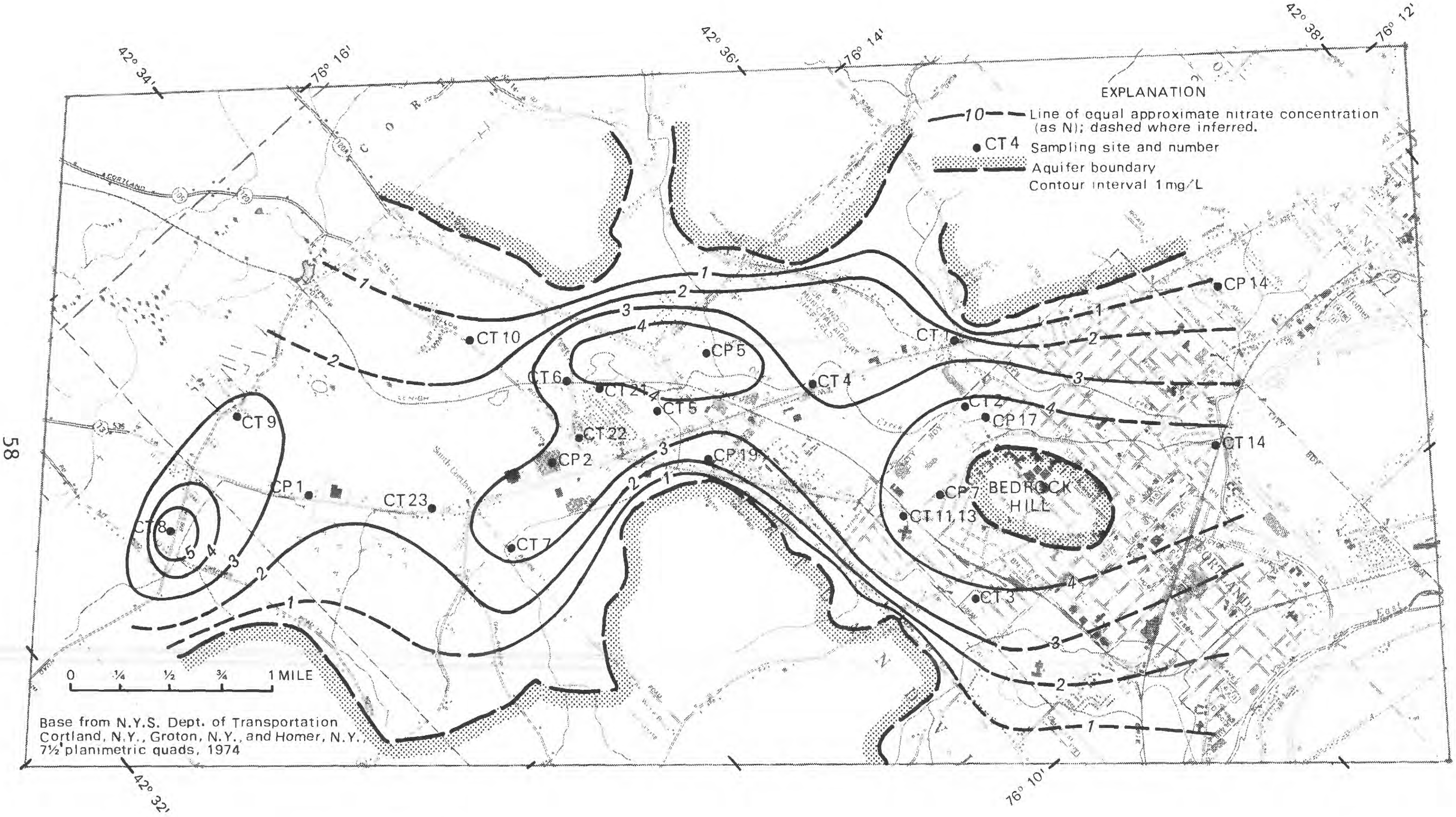


Figure 22.--Nitrate concentrations in upper 60 feet of Otter Creek-Dry Creek aquifer, December 1975-February 1976.

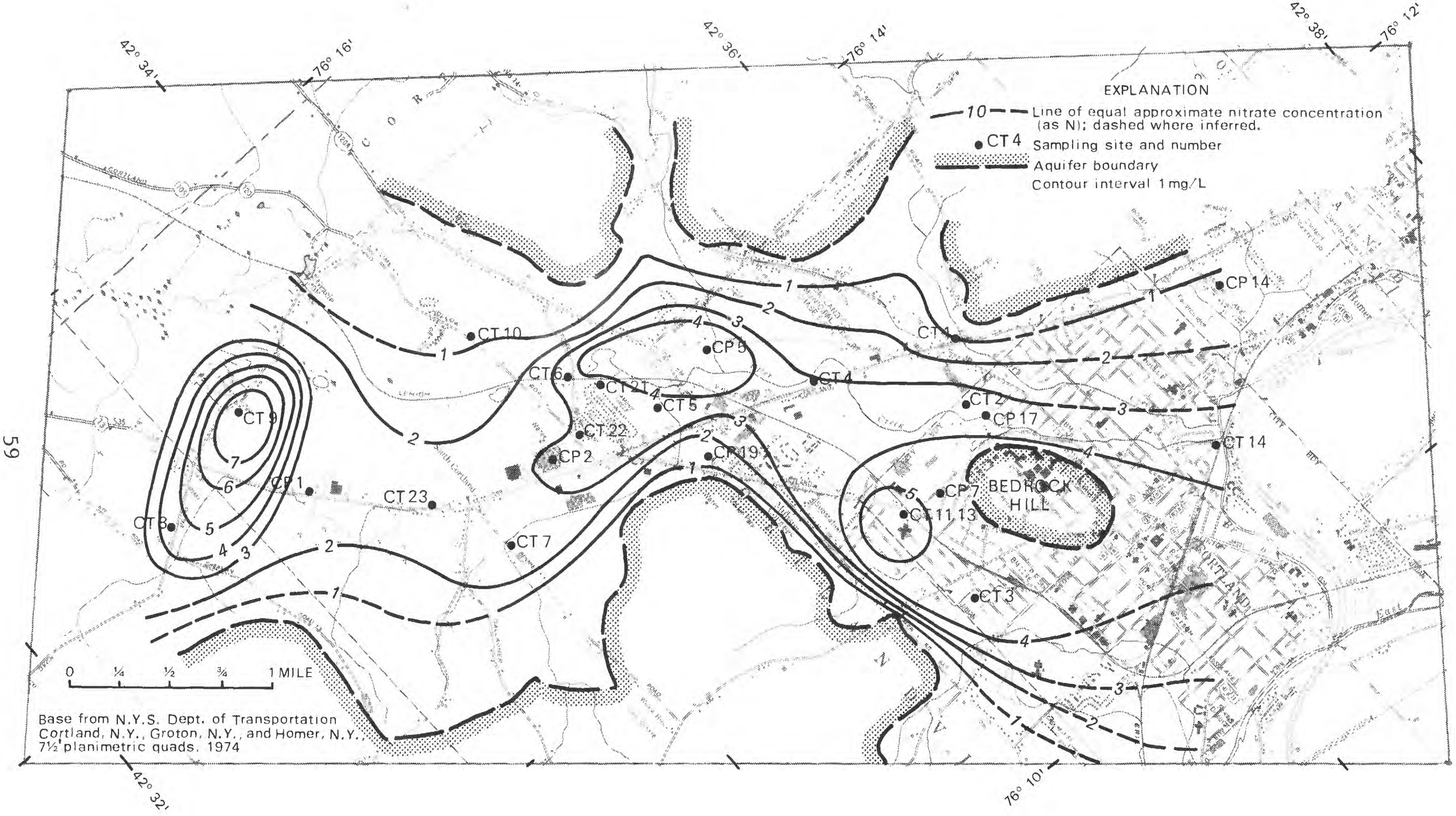
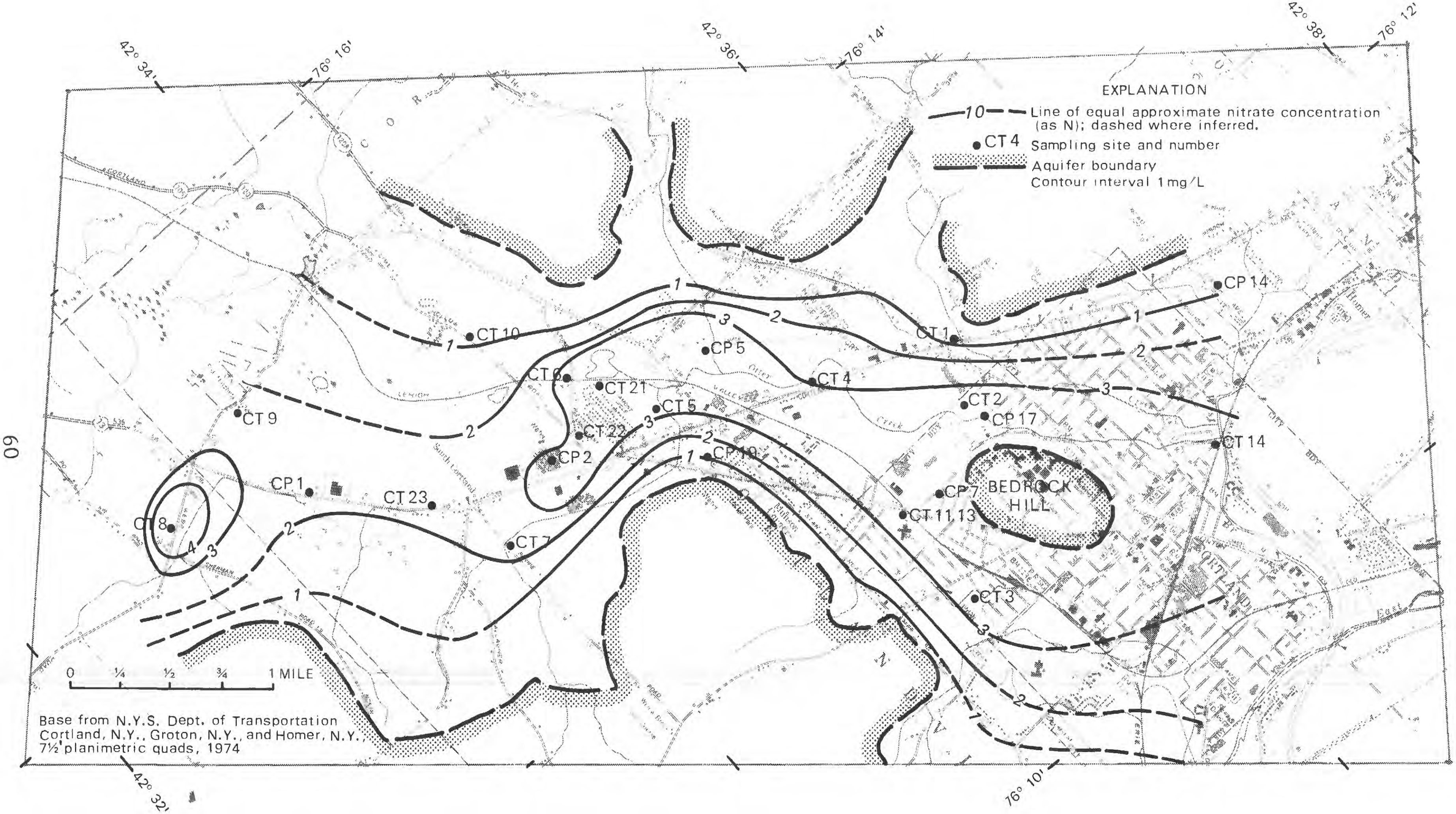


Figure 23.--Nitrate concentrations in upper 60 feet of Otter Creek-Dry Creek aquifer, June-July 1976.



Base from N.Y.S. Dept. of Transportation Cortland, N.Y., Groton, N.Y., and Homer, N.Y., 7½' planimetric quads, 1974

Figure 24.--Nitrate concentrations in upper 60 feet of Otter Creek-Dry Creek aquifer, September-October 1976.

SUGGESTIONS FOR FURTHER INVESTIGATIONS

This study provided an inventory of the hydrologic regime of the Otter Creek-Dry Creek basin and revealed the areas of major ground-water pollution. It was not of sufficient duration or scope to determine movement of pollution or to predict future patterns and trends.

The hydrologic model developed during the study provides a sound starting point for future hydrologic studies in the Otter Creek-Dry Creek basin at Cortland. Continued updating of the model with new data will produce more accurate results. New data of particular value would be additional measurements of ground-water levels in the basin at regular intervals for potentiometric maps and refinement of the model.

Additional monitoring of chemical quality of ground water and surface water could determine more accurately the rate and direction of movement of nonpoint and point sources of chlorides and nitrates in the part of the aquifer delineated by this study. This would also be a major step toward the development of a coupled flow and solute-transport model to analyze the widespread input of chemical constituents over a large part of the aquifer area.

SUMMARY

A highly productive glacial-outwash aquifer in the Cortland area was studied for a 17-month period to determine the quality of surface water and ground water in the basin. As part of the study, a digital model of the aquifer was developed to simulate ground-water movement in the system. Ground-water movement in the upland area is directly toward the streams and results in gaining reaches in the streams. On the valley floor, the ground water moves in a general downvalley direction and ultimately discharges into the West Branch Tioughnioga River and Tioughnioga River. The completed model was calibrated by comparing simulated water levels with a map of measured water levels. The model can be used in the future to evaluate ground-water seepage between stream channels and the aquifer.

Chemical quality of ground water and surface water in the Otter Creek-Dry Creek basin is within the recommended limitations set for source waters used for drinking by the New York State Department of Health. The most likely threat to the quality of ground water is the continued increase in nitrate and chloride concentrations. Input-output budgets indicate that in wet years, the output of these constituents may exceed the input. Continued monitoring of water quality is needed to reveal (1) the concentration trends of these constituents, and (2) the direction and rate of movement of polluted water from its sources. Road salting and farming practices are indicated to be the primary cause of chloride increase in streams and ground water, although septic systems are probably a major source for localized areas of high chloride concentrations in the aquifer. Farm-animal waste, septic systems, and fertilizers are the major contributors of nitrate to ground water, although none of these is clearly predominant.

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