

DIGITAL-MODEL SIMULATION OF THE GLACIAL-OUTWASH AQUIFER,
OTTER CREEK-DRY CREEK BASIN, CORTLAND COUNTY, NEW YORK

by Oliver J. Cosner and John F. Harsh

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CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

H. William Menard, Director

For additional information write to:

U.S. Geological Survey
343 U.S. Post Office and Courthouse
P.O. Box 1350
Albany, New York 12201

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FACTORS FOR CONVERTING U.S. CUSTOMARY UNITS TO INTERNATIONAL
SYSTEM (SI) UNITS, AND ABBREVIATIONS OF UNITS

<u>Multiply U.S. Customary units</u>	<u>by</u>	<u>To obtain SI units</u>
<u>Length</u>		
inch (in)	25.4	millimeters (mm)
foot (ft)	.3048	meter (m)
mile (mi)	1.609	kilometer (km)
<u>Area</u>		
acre	.405	hectare (ha)
square mile (mi ²)	2.590	square kilometer (km ²)
<u>Flow</u>		
cubic feet per second (ft ³ /s)	28.32	cubic meters per second (m ³ /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 meter [(L/s)/m]
<u>Hydraulic Units</u>		
feet squared per day (ft ² /d)	.0929	meters squared per day (m ² /d)
feet per day (ft/d)	.3048	meters per day (m/d)
feet per mile (ft/mi)	.1894	meters per kilometer (m/km)

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ABSTRACT

The city of Cortland, New York, and surrounding areas obtain water from the highly productive glacial-outwash aquifer underlying the Otter Creek-Dry Creek basin. Pumpage from the aquifer in 1976 was approximately 6.3 million gallons per day and is expected to increase as a result of population growth and urbanization.

A digital ground-water model that uses a finite-difference approximation technique to solve partial differential equations of flow through a porous medium was used to simulate the movement of water within the aquifer. The model was calibrated to equilibrium conditions by comparing water levels measured in the aquifer in March 1976 with those computed by the model. Then, from the simulated water-level surface for March, a transient-condition run was made to simulate the surface as measured in September 1976. Computed water levels presented as contours are generally in close agreement with potentiometric-surface maps prepared from field measurements of March and September 1976.

1000

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INTRODUCTION

Population growth and urban development in the Otter Creek-Dry Creek basin are likely to cause a substantial increase in ground-water demand in the near future. The result will be a lowering of water levels, particularly in areas of concentrated pumping, and an overall reduction in base flow of the Tioughnioga and West Branch Tioughnioga Rivers at Cortland.

In the summer of 1975, the County of Cortland asked the U.S. Geological Survey to develop a hydrologic model of the aquifer system in the Cortland area to evaluate the present ground-water situation and predict the effect of future water development. The model was to be developed from data obtained from a correlative study of the quality and movement of ground water in the Otter Creek-Dry Creek basin (Buller, Nichols, and Harsh, 1978). The project was undertaken as part of the Areawide Waste Treatment Management Plan, Section 208, of the Federal Water Quality Pollution Act.

Purpose and Scope

The purpose of the study was to gain detailed knowledge of the integrated surface-water and ground-water systems in the Otter Creek-Dry Creek drainage basin and to determine how these systems would respond to hydrologic stresses such as drought or increased pumpage. A major objective was to construct an aquifer model that could be used to evaluate the effects of proposed ground-water development and land-use schemes on quantity and movement of ground water. The model is intended for use in designing data-collection programs and to help in formulating local programs for ground-water management and land use.

Cooperation and Acknowledgments

The study was made by the U.S. Geological Survey in cooperation with the County of Cortland. Cooperation and assistance were provided by James Feuss of the Cortland County Department of Health, and Walker Banning of the Central New York Regional Planning and Development Board. Thanks are given to William Buller and William J. Nichols of the U.S. Geological Survey for their assistance in collecting and compiling field data, to the staff of the Cornell University Computer Center for their generous assistance, and to Peter Trescott and Steven Larsen of the U.S. Geological Survey, Reston, Va., for assistance in several program modifications.

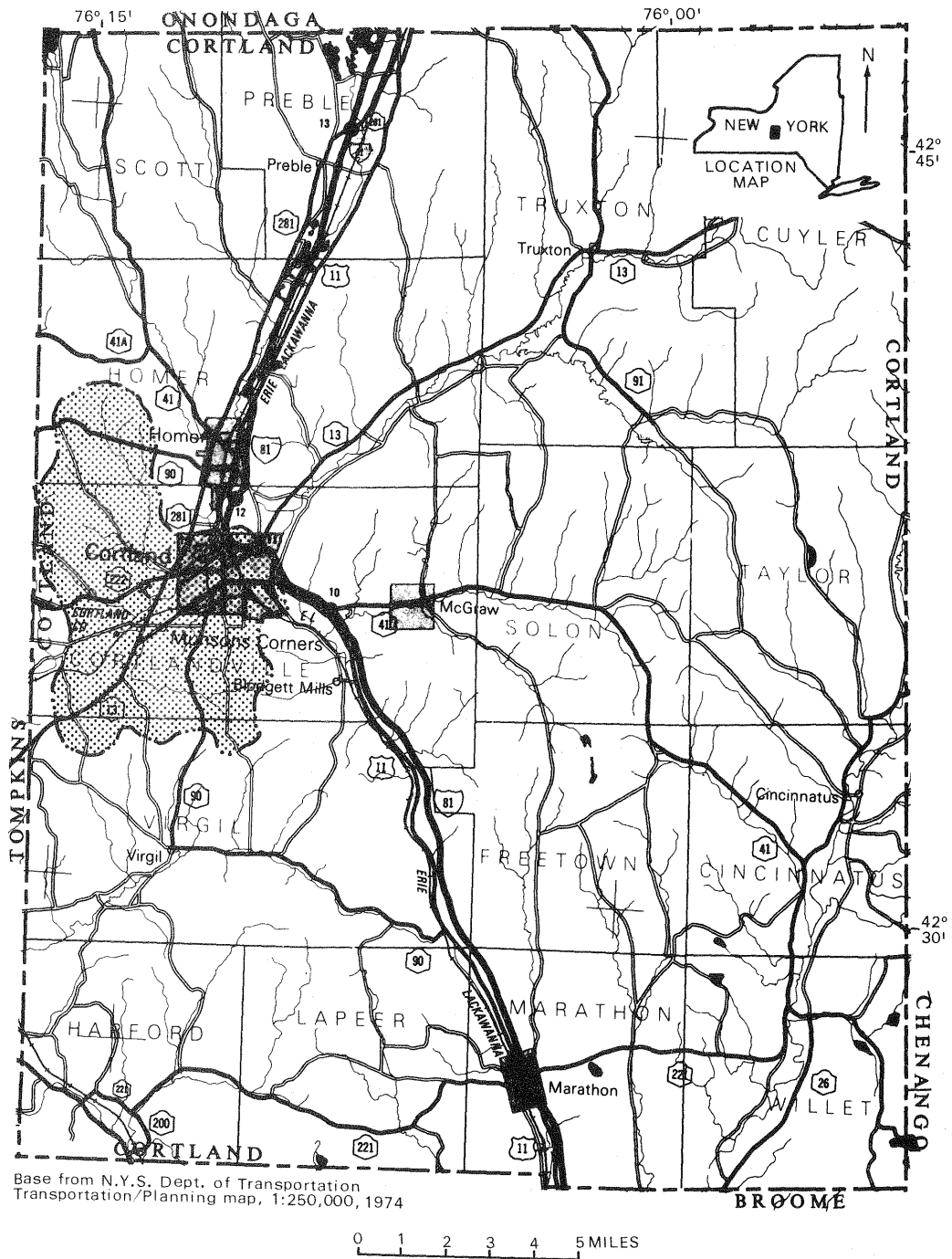


Figure 1.--Location and major geographic features of Otter Creek-Dry Creek basin.

Location and Description of Study Area

The 9.4-mi² study area, hereafter called the Otter Creek--Dry Creek modeled area, encompasses the valley floor areas of Otter and Dry Creeks and includes the city of Cortland and the surrounding Town of Cortlandville. Cortland is a fairly industrialized, growing community; the surrounding areas of South Cortland and Cortlandville are agricultural and residential. 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 location and geographic features of the study area are shown in figure 1. The area consists of a broad, flat valley surrounded by hills that rise to nearly 700 ft above the valley floor except in the western part of the valley, which is lower than the surrounding hills and moderately undulating. Lowland depressions are common in the western part of the valley.

Average annual precipitation is 41 inches, of which 70 percent occurs from March through November. Winters in this area are severe; 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 of central New York are Fairchild (1932), MacClintock and Apfel (1944), von Engel (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. Stearns and Wheler (1970) made a comprehensive water-supply study of Cortland County that describes a 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 study area. Pertinent data from the two latter reports have been incorporated into a more recent study of the chemical quality and movement of ground water in the Cortland area (Buller, Nichols, and Harsh, 1978). Most of the data used to develop the model were taken from that report. The model was developed according to techniques described in Trescott, Pinder, and Larson (1976).

Methods of Investigation

The hydrogeology was evaluated by determining or estimating aquifer geometry (thickness and areal extent), aquifer characteristics (hydraulic conductivity and storage coefficient), and other factors affecting the hydrologic system (streamflow and gradient, aquifer discharge, and area recharge rate).

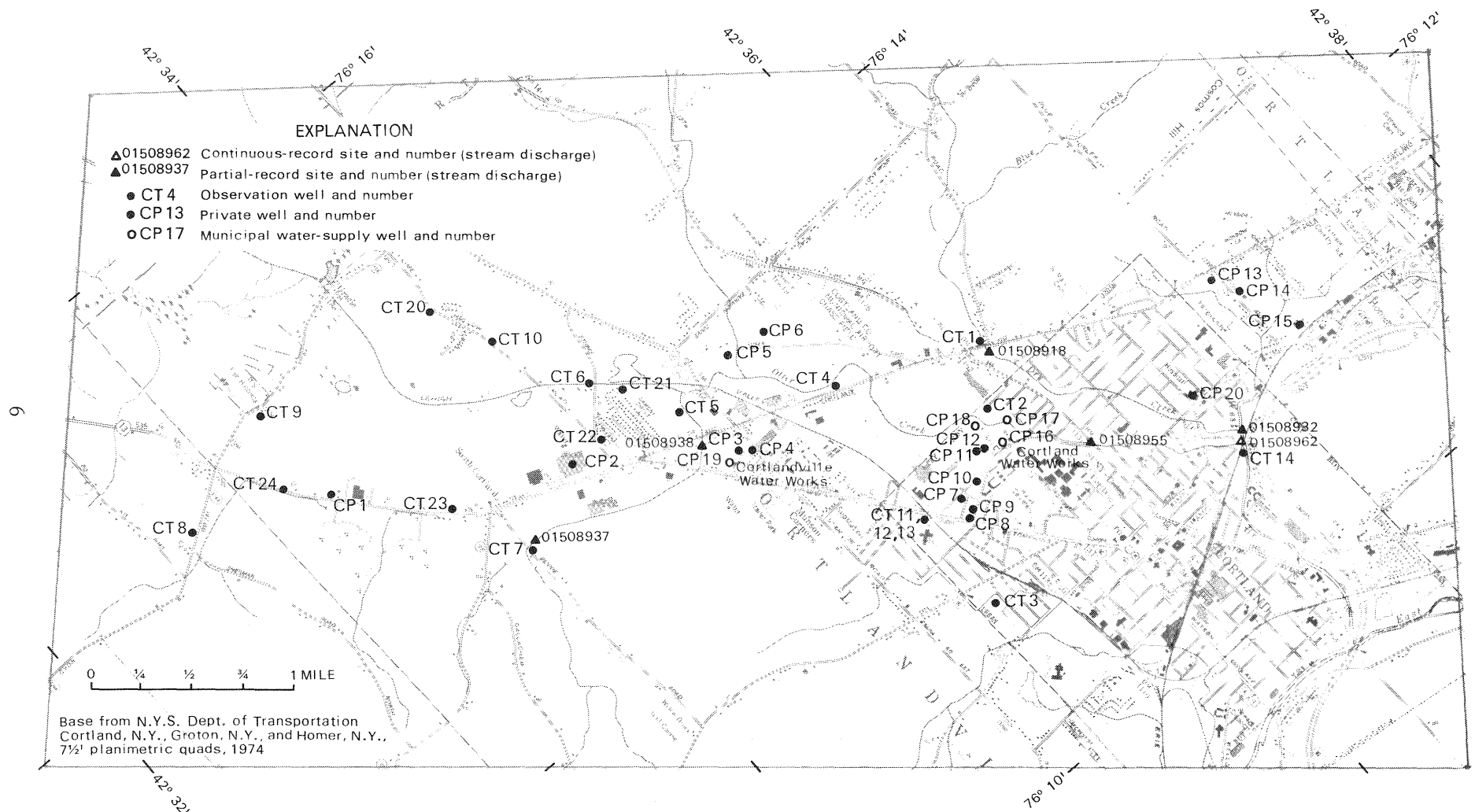


Figure 2.--Data-collection sites, Otter Creek-Dry Creek basin.

In the companion study by Buller and others (1978) to acquire hydrologic data, observation wells were installed at 19 sites; these and accessible private wells were monitored periodically for water-level fluctuations. A continuous recording surface-water gage, a staff gage at one site on Otter Creek, and staff gages at two sites on Dry Creek were monitored concurrently with the observation wells. Hydraulic measurements were collected from three aquifer tests. The location of test holes, observation wells, stream-gaging sites, and aquifer tests are shown in figure 2.

An areal two-dimensional hydrologic model of the valley-floor area of the basin was developed and verified after analysis and interpretation of the basic data. The model is to be used to evaluate the effects that ground-water-development schemes have on the quantity and movement of ground water.

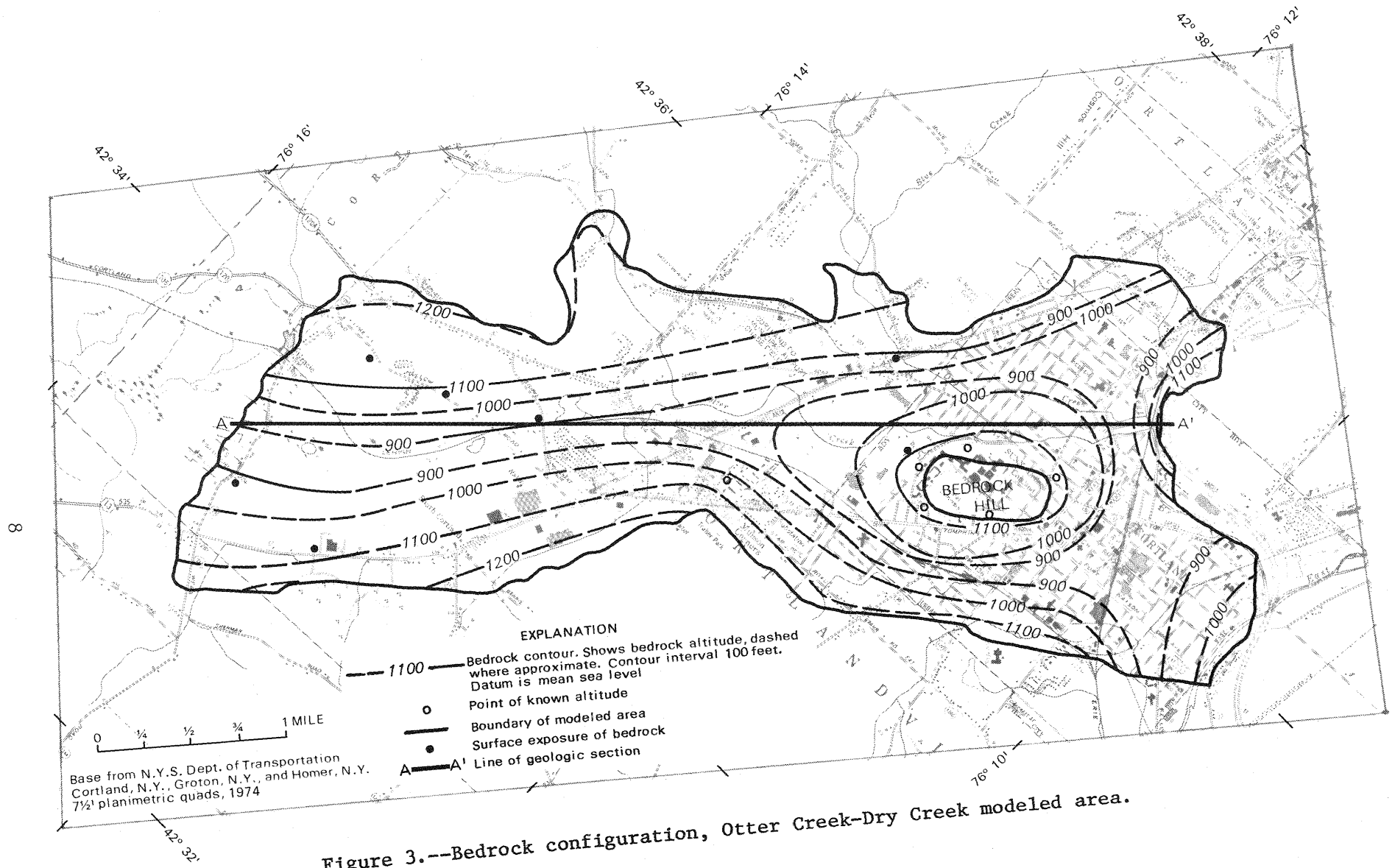
GEOLOGY

Geologic Setting

The Otter Creek-Dry Creek modeled area is within the glaciated part of the Allegheny Plateau physiographic province of central New York. A refinement of earlier concepts of the glacial geology and of the hydrologic system functioning within this geologic framework is presented by Buller and others (1978). The study area is covered by glacial deposits ranging in thickness from 10 to 300 ft. Underlying the glacial deposits are consolidated rocks consisting predominantly of shale with thin interbeds of flaggy siltstone and sandstone of Late Devonian age. The bedrock units dip south at about 40 ft/mi. Low folds with east-west axes are superposed on the regional dip. Two sets of vertical fractures cut the bedrock; one set is parallel, the other orthogonal, to the fold axes.

Upper Devonian Bedrock

The Upper Devonian shales of the area are exposed in very few places within the basin, principally at roadcuts and locally along the steep valley walls. Where the shale is exposed, it is well weathered and cut by many joints. The jointing and weathering are greatest near land surface and decrease with depth. Weathering tends first to open the joints but, as the shale becomes soft, the joints tend to close. Joints and bedding-plane openings form a small part of the total bedrock volume and are the only significant void space in which water can be stored and transmitted. Therefore, shale bedrock in the area is a low-yield source of water and is used only for farm and domestic supplies.



The bedrock configuration is not well known. Drilling data obtained from six deep wells drilled before 1975 provided some information on the depth to bedrock in the Otter Creek-Dry Creek basin, and test drilling during the study by Buller and others (1978) revealed bedrock altitudes at four additional sites. A bedrock-contour map was made from these data points and is shown in figure 3. Formations encountered in test holes, and the position of bedrock in relation to land surface along the length of Otter Creek-Dry Creek basin, are shown in figure 4, geologic section A-A'.

Glacial Deposits

Glacial deposits cover the bedrock nearly everywhere within the basin. In the headwater areas above the valley floor, the bedrock is covered by till, a silty clay with varying amounts of sand, gravel, and boulders, and generally ranging from 2 to 20 ft in thickness. Because till has low hydraulic conductivity, it yields only small quantities of water. Most wells tapping till are used for farm and domestic supplies only. However, the till areas absorb precipitation and provide water storage to supply the base flow of streams that drain the upland area.

Stratified drift covers the valley sides and floor of Otter Creek-Dry Creek basin; it includes ice-disintegration, ice-contact, and proglacial deposits. Figure 5 shows the distribution of these deposits in the study area. The ice-disintegration and ice-contact deposits are distributed irregularly. The most extensive ice-contact deposits are along the west, north, and south margins of the valley. The ice-disintegration deposits contain a high percentage of silt and clay and are for the most part poorly bedded. Their water-yielding properties range from very low (clay) to high (very coarse gravel) (Davis and DeWiest, 1966, p. 164). Large-capacity wells for commercial and industrial needs may be difficult to develop in the ice-disintegration deposits, but several farm and industrial wells obtain water from them. Geologic section A-A' in figure 4 shows that the ice-disintegration complex grades eastward into deposits that are interpreted as proglacial.

Proglacial deposits, as shown in figure 4, are the principal source of ground water for industrial and municipal needs in the Cortland area. The deposits consist predominantly of outwash sand and gravel with discontinuous interbedded lenses of fine-grained silt and clay. Proglacial deposits occur nearly everywhere on the valley floor; northeast of South Cortland they form the entire unconsolidated section. The hydrogeologic characteristics of proglacial deposits are similar to those of valley alluvial deposits (Davis and DeWiest, 1966). Along Otter and Dry Creeks, stratified sand and gravel deposits are overlain by thin Holocene alluvial deposits of gravel, sand, silt, and clay.

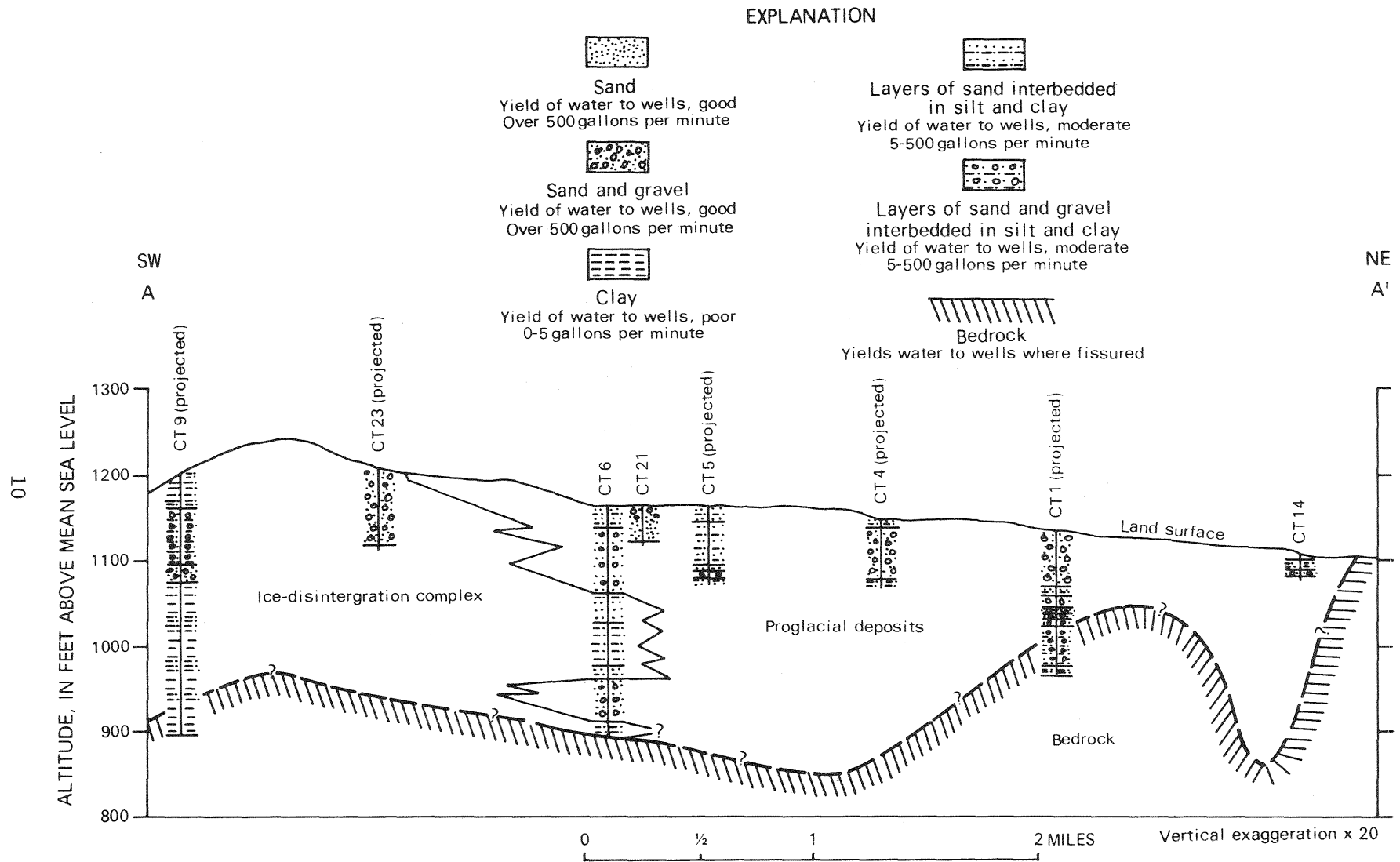


Figure 4.--Geologic section along length of Otter Creek-Dry Creek modeled area.

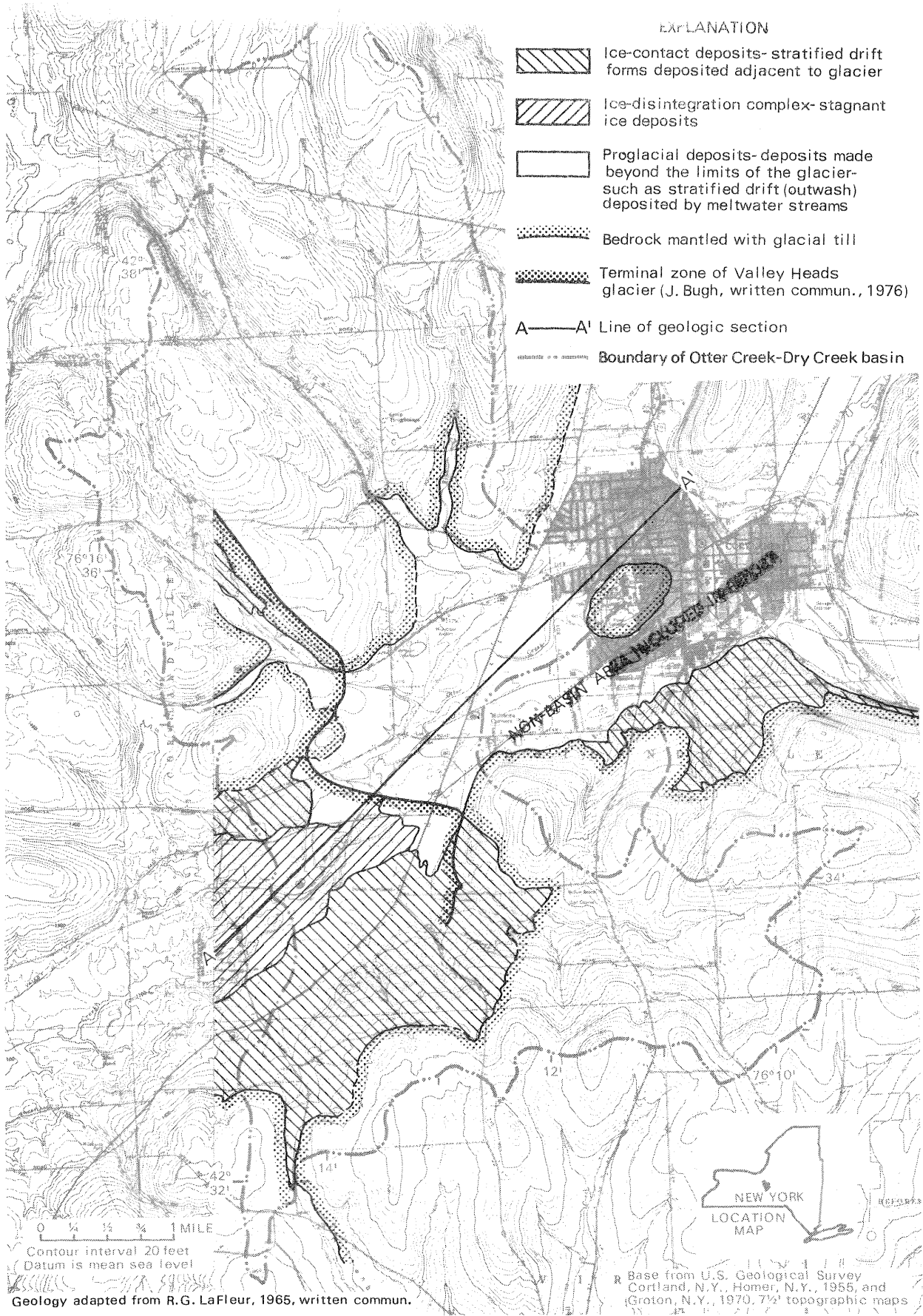


Figure 5.--Geology of Otter Creek-Dry Creek basin.

GROUND-WATER HYDROLOGY

Occurrence of Ground Water

Ground water in the study area moves through the pores or openings between rock particles in the glacial deposits and bedrock. The size and orientation of openings determine how much water is stored and the ease with which it moves. In general, at depths below 10 to 25 ft, the glacial deposits and shales of Otter Creek-Dry Creek basin are saturated. Exceptions to this are in the headwater areas and on the high ridges that form topographic divides between the study area and the adjoining basins; in these areas, depth to water may be as much as 100 ft.

During this investigation, water-level measurements were made periodically in observation wells in the valley. The water-level data were used to prepare potentiometric maps shown in figures 6 and 7. In addition, hydrographs were prepared to show the seasonal variation in water levels in the aquifer and to indicate the periods of high and low recharge. During the year of record (1976), March 5 had the highest water levels (fig. 6), and September 29 the lowest (fig. 7). These two sets of water-level data were used as bases of comparison for calibration of the ground-water-flow model.

Recharge

The aquifer is recharged in several ways. The major sources of recharge are rainfall on the entire drainage basin and water from losing reaches of streams within the basin. Although some water enters the aquifer from the shale bedrock, it is assumed to be in insignificant quantities because the top 1 or 2 ft of shale at the base of the glacial deposits has been observed in drilling to be tight and unproductive.

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

Recent studies in Connecticut (Randall and others, 1966) show that average annual recharge to stratified drift may reach 1 (Mgal/d)/mi². With similar climatic conditions on the Otter Creek-Dry Creek modeled area, average recharge to a 9.4-mi² area of stratified drift was computed by the digital model to be 28 in/yr (9.89 Mgal/d). Although about 30 percent of the average annual precipitation (41 inches) falls during the growing season (Sealy and others, 1961), nearly all of it

is evaporated and transpired by vegetation during this period so that only a small amount recharges the aquifer (MacNish and others, 1969). Also during the growing season, the water table normally falls below streambed altitude so that the streams contribute recharge to the aquifer until they become dry.

Recharge from streams occurs along the stream channels throughout the valley floor from the point where they leave the till-capped shale slopes to their confluence with the Tioughnioga River and its West Branch. Recharge occurs along the flowing streams wherever the water table falls below streambed altitude. Because the proglacial deposits are highly permeable, they can assimilate large quantities of water; thus, head buildup in the aquifer beneath flowing streams is not large, and conditions are generally conducive to recharge.

During the course of model calibration, $4.9 \text{ ft}^3/\text{s}$ of underflow was computed to enter the aquifer from the southern boundary of the modeled area, and $1 \text{ ft}^3/\text{s}$ was computed to enter along the northern boundary. The ice-contact deposits on either side of the valley are the source of this ground water.

Movement and Discharge

In the till-capped shale slopes of the basin, water-level contours roughly parallel the surface topography; therefore, ground water moves in much the same directions as surface runoff--toward and into the streams. As a result, streams in the upland areas gain flow from ground-water discharge.

On the valley floor, ground water moves in a general downstream direction along the valley axis as shown by the arrows in figure 6. Beneath the losing reaches of the streams, water in the stream infiltrates through the streambed toward the water table. (Figures 6 and 7 are not of sufficient detail to show this feature.) The ground water moves downgradient until it is intercepted by the cone of depression of a pumping well, to which it is discharged, or it moves toward and discharges into the main rivers--the West Branch of Tioughnioga River and the Tioughnioga River.

During most of the year, water is discharged from the aquifer along the Tioughnioga River and is computed by the model to average 7.8 Mgal/d . This figure is based on the assumption that natural discharge and pumpage approximately equal inflow to the system and that storage remains virtually constant.

For the model simulations, it is assumed that the rates of ground-water discharge and recharge within the basin have remained constant and stabilized. Although the ground-water levels show a seasonal variation, long-term well-water-level records indicate that the current rates of withdrawal have reached equilibrium condition.

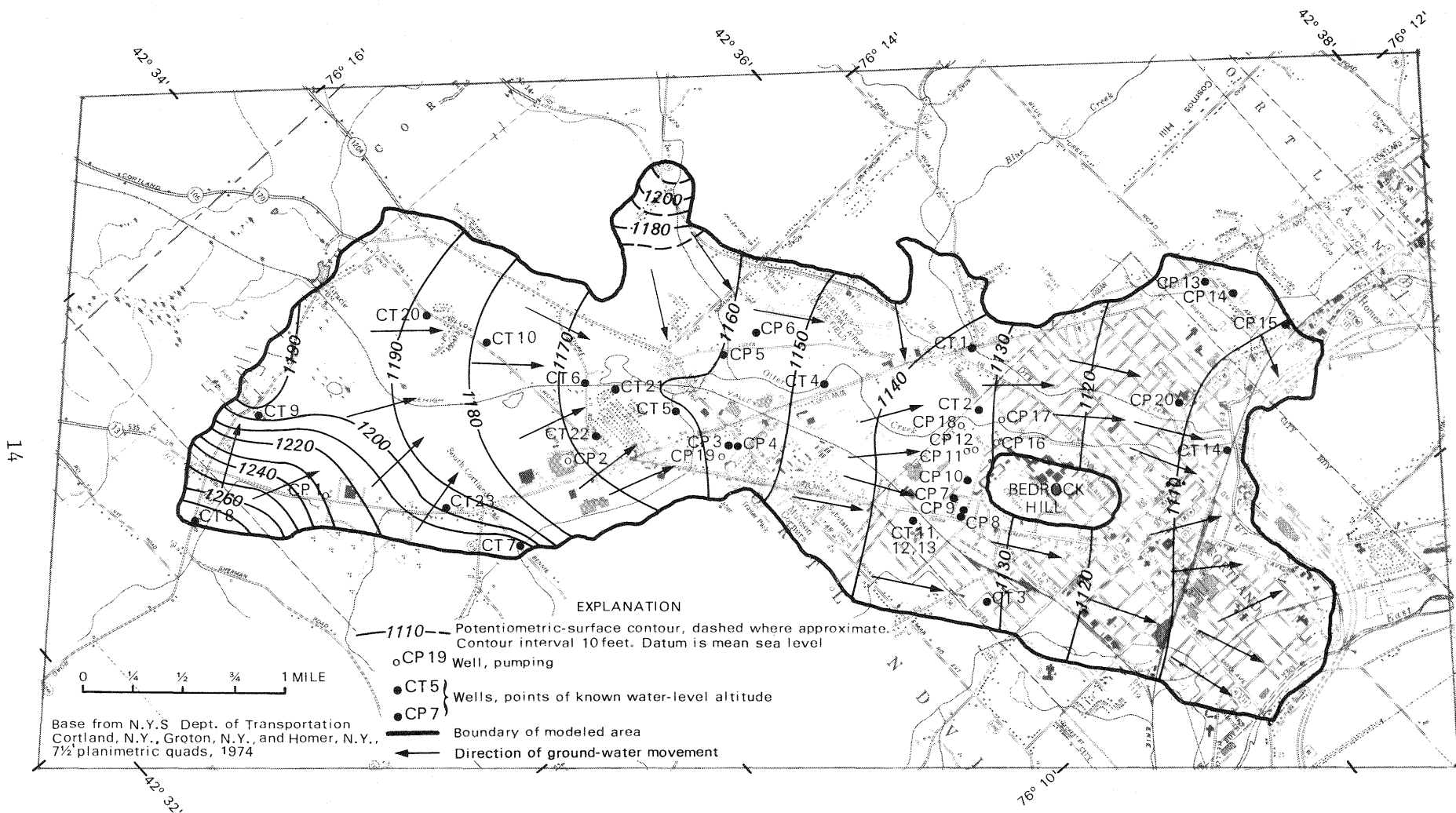


Figure 6.--Potentiometric surface of outwash aquifer on March 5, 1976,
and direction of ground-water movement.

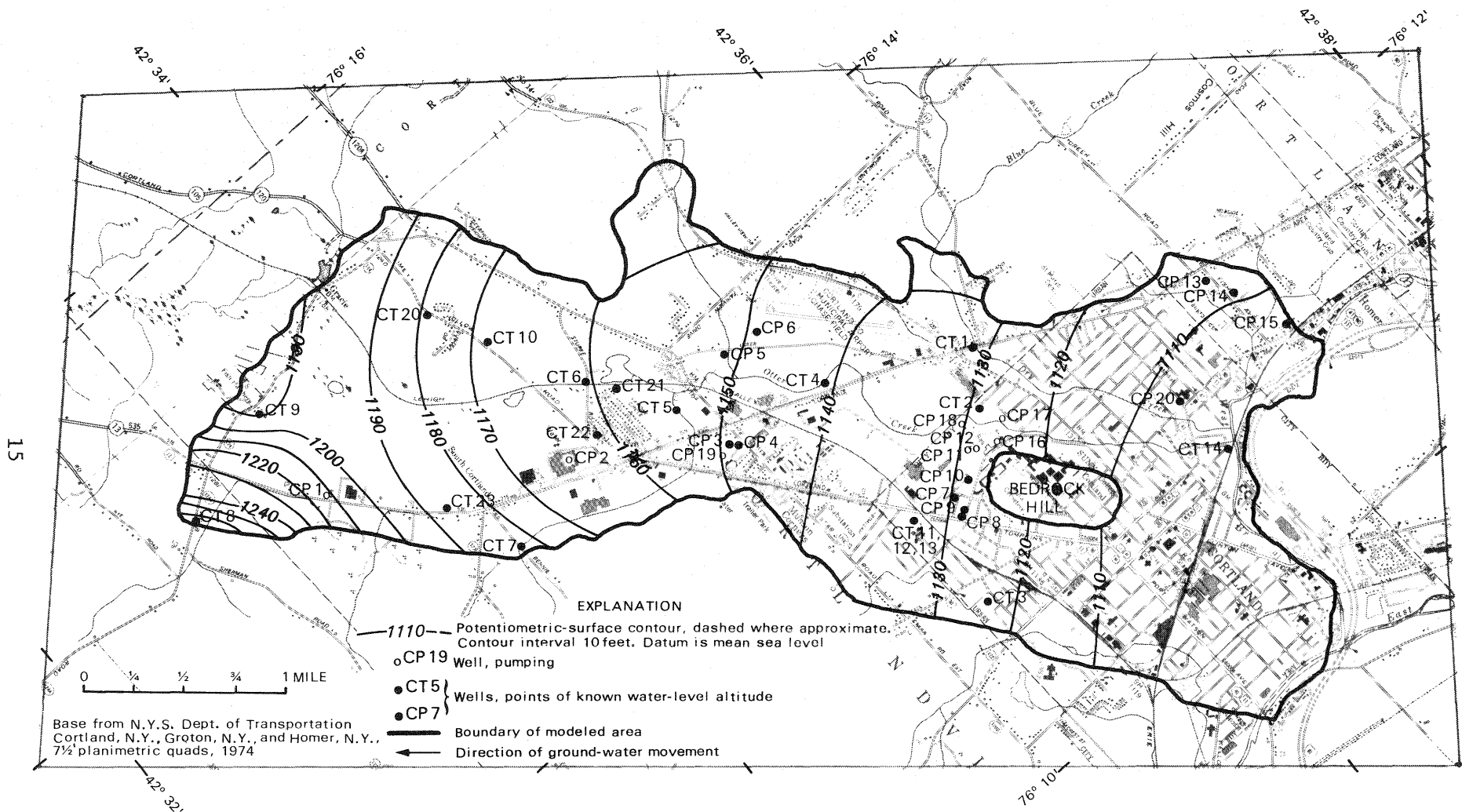


Figure 7.--Potentiometric surface of outwash aquifer on September 29, 1976.

Ground-Water Withdrawal

Data on withdrawal from the outwash aquifer by municipal and industrial users were obtained from pumpage records. Total current pumpage (1976) is estimated to be 6.3 Mgal/d. This estimate does not include the presumably negligible pumpage from private wells in the valley. Locations of pumping centers are indicated on figures 6 and 7; they are the Cortland well field (well CP 16), Town of Cortlandville well field (well CP 19), and industrial well fields (wells CP 2 and CP 1). Pumping rates in 1976 at these four sites, in Mgal/d, were 4.5, 0.75, 1, and 0.035, respectively.

Evapotranspiration

Ground water leaves the basin not only through wells and streams, but through evaporation and through transpiration by vegetation, especially along stream channels. Part of the water transpired by vegetation comes from streams, but an unknown additional amount is drawn from the unsaturated zone and from the water table. Transpiration virtually ceases between the end of the growing season and the following spring.

Although evapotranspiration draws water predominantly from the unsaturated zone, it has a transient lowering effect on the water table by intercepting recharge from precipitation. In summer, evapotranspiration of water in the unsaturated zone leaves little excess water for recharge, whereas in winter the minimal evapotranspiration permits rain and snowmelt to infiltrate to the water table as soon as the soil-moisture deficiency is replenished.

Evapotranspiration rates are probably highest near ponds and streams, where the water table is near land surface. The maximum potential rate is at fully vegetated land surfaces where transpiration is not limited by soil-moisture deficiency. Evapotranspiration rates are lower where depth to water is greater (Tovey, 1969). The calculated maximum potential rate of evapotranspiration in the modeled area is 24.27 in/yr (Weist and Giese, 1969).

Aquifer Characteristics

The primary hydraulic characteristics of an aquifer are its hydraulic conductivity, saturated thickness, and storage coefficient. Hydraulic conductivity and saturated thickness are commonly combined as transmissivity (conductivity multiplied by saturated thickness), and storage coefficient is essentially equal to specific yield in unconfined (water-table) aquifers. These factors can be evaluated to determine the rate and magnitude of water-table declines resulting from pumping of water from an aquifer.

Hydraulic characteristics of the outwash aquifer were estimated initially from data collected during three aquifer tests. Results of analyses of the test data are summarized in table 1. The predominant aquifer material at the three test sites was sand and gravel.

Values determined by aquifer tests are representative of the immediate testing area only, but transmissivity values at other locations were estimated on the basis of test results, examination of samples collected during test drilling, and published data on similar geologic materials. The hydraulic conductivity values used in the model simulations were calculated by dividing the estimated values of transmissivity by the saturated thickness. Values of specific yield were not obtained from analysis of the test data, so an estimated value of 0.15 was selected as representative of the entire outwash aquifer.

Surface-Water/Ground-Water Relationships

Surface water is closely interrelated with the ground-water system in the study area. The lowest order (smaller, unbranched) tributaries to Otter Creek and Dry Creek originate in the till-covered shale hills surrounding the valley floor and, within the till areas, are gaining streams except during sustained dry weather, when they may go dry. In contrast, the higher order (larger, branched) tributaries on the valley floor are almost entirely losing streams and thus create long reaches of ground-water recharge. Streamflow is a major source of recharge to ground-water bodies in the basin and is discussed in this context in the section "Recharge" (p. 12).

Streamflow measurements from a continuous recording gage at the mouth of Otter Creek (station 01508962) and from a staff-gage site (station 01508955) indicate that Otter Creek has been a losing stream below station 01508955 during the period of record (table 2). Other streamflow measurements at two staff-gage sites show that Otter Creek is a losing stream between stations 01508937 and 01508938. Streamflow measurements at two staff-gage sites on Dry Creek show that Dry Creek is a losing stream from station 01508918 to the mouth. The orientation of water-level contours indicates that ground water discharges into the Tioughnioga River all along a 2-mile reach in the area (figs. 6 and 7) rather than at the mouths of the two creeks. Increased large-scale pumping from wells or a decrease in recharge from precipitation would reduce the rate at which the Tioughnioga River gains ground water, and this would result in a net reduction in streamflow in this reach.

Table 1.--Results of aquifer tests in Otter Creek-Dry Creek basin

[Well locations are 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	2.16	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

Table 2.--Results of Dry Creek and Otter Creek seepage investigations, 1975-76

[all measurements are in cubic feet per second]

Station Number	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
Dry Creek Basin (drainage area 8.78 mi ²)										
			Dec. 2, 1975		Aug. 8, 1975		Sept. 9, 1976		Sept. 30, 1976	
01508918	1.3	Dry Creek at State Highway 281	10.50	--	--	--	0.87	--	--	--
01508932	--	Dry Creek at mouth	8.18	-2.32	--	--	.02	-0.86	--	--
Otter Creek Basin (drainage area 14.28 mi ²)										
			Dec. 1, 1975		Aug. 15, 1975		Sept. 9, 1976		Sept. 30, 1976	
01508937	4.5	Otter Creek at Bennie Rd.	2.38		--	--	--	--	--	--
01508938	3.4	Otter Creek at State Highway 281	--	-2.38	--	--	--	--	--	--
01508955	.3*	Otter Creek at Groton Ave. (no flow from reservoir)	5.93	--	0.12	--	.08	--	0.03	--
01508962	--	Otter Creek at mouth	5.16	-.77	--	-0.12	--	-.08	--	-0.03

AQUIFER SIMULATION AND ANALYSIS BY DIGITAL MODEL

Finite-Difference Model

The finite-difference model of Trescott and others (1976) was used to simulate the movement of water within the outwash aquifer. The model program is an areal two-dimensional flow model designed to simulate aquifer flow in response to an imposed stress such as pumping. Given specific values for aquifer characteristics, such as transmissivity and specific yield, the model can be used to calculate water levels that would result under both steady-state and transient hydrologic conditions and to calculate changes in water levels that would result from pumping at specific sites. The effects of physical hydrologic boundaries, streams, and evapotranspiration can also be incorporated into the model.

Because the model represents the aquifer system by a finite number of nodes (or grid points) and is, therefore, an approximation, it can be used in water management to indicate how the local hydrologic system functions and to forecast aquifer response to many anticipated water-development plans. Given specific water-use plans for the study area, the model can calculate, for example, the resulting change in recharge-discharge relationships between the Tioughnioga River and the outwash aquifer. From this information, the rate at which the Tioughnioga River would gain ground water from the modeled area or lose water into the aquifer can be estimated.

Development of the Model

Ground water in the basin occurs mainly under unconfined water-table conditions. The model was formulated to produce an approximate solution to a ground-water flow equation given by Bredehoeft and Pinder (1970). Finite-difference techniques are used to approximate this equation, and the strongly implicit procedure (SIP) is used to produce a numerical solution. Details on the mathematics of the model are given in Trescott and others (1976).

Description of the Model

Only part of the study area was selected for modeling. In general, areas beyond the physical boundaries of the outwash aquifer were excluded (fig. 8), and hydrologic boundaries of the ground-water system governed selection of model boundaries. The total modeled area contains 9.4 mi². The following description of the model format is paraphrased from Gillies' discussion (1976, p. 16) of a similar model.

To place the data in a form compatible with the model, the modeled aquifer was divided into small squares in map view with a finite-difference grid. Each square has the volume $b\Delta x\Delta y$, where b is the saturated

thickness, and Δx and Δy are the grid spacings in the x and y directions on coordinate axes. The center of each square is called a node. At these nodes, data representing the average specific aquifer characteristics at that square are used in the model. Water levels at these nodes are then calculated by the model and printed out for interpretation. The modeled aquifer was divided into a grid containing 1,049 nodes. Each node represents a 500-ft by 500-ft ground area. The model grid contains 24 nodes running north-south and 62 nodes running east-west; its shape approximates the boundaries of the outwash aquifer, as shown in figure 8.








The model grid was positioned over the following maps: aquifer-base altitude (bedrock map, fig. 3), water-level altitude (fig. 6), saturated thickness map (fig. 9), and transmissivity map (fig. 10). An appropriate average value for each factor was then assigned to each square in the grid. In simulation of a water-table aquifer, transmissivity at each node is recalculated whenever the water level changes to adjust for dewatering of the aquifer. The model calculates transmissivity as the product of saturated thickness and hydraulic conductivity; thus, values for these factors must be entered into the model initially. Values of hydraulic conductivity were obtained by dividing the estimated values of transmissivity (fig. 10) by the saturated thickness (fig. 9). The values of transmissivity were recalculated by the model for each time increment according to the new saturated thickness. The initial saturated thickness of the outwash aquifer was determined by subtracting the altitude of bedrock surface (fig. 3) from the altitude of the water table, as determined on March 5, 1976, at the nodal points. The hydraulic conductivity of silt and clay is low compared with that of other lithologies. Although the glacial material is assumed to be fully saturated, silt and clay were ignored in development of figure 9, and only the more permeable zones that readily yield water were considered part of the aquifer in estimating transmissivity.

In the model run for March 5, 1976, the hydraulic connection of Otter Creek and Dry Creek and their respective tributaries with the aquifer was simulated with a streambed altitude as the hydraulic head above a leaky confining layer. Values of thickness and hydraulic conductivity were assigned to the confining bed to reflect the degree of hydraulic connection with the aquifer. Thus, a difference between streambed altitude and hydraulic head in the aquifer would result in recharge to (or discharge from) the aquifer. In the model simulation, a constant vertical hydraulic conductivity of 3.8×10^{-2} ft/d and a uniform streambed thickness of 30 ft were assigned to the confining bed. These values were selected to facilitate model simulation of stream leakage during a wet period and to accommodate the ratio of stream area to node area because node area determines the quantity of water leaking through the streambed. In the model, the smallest areal unit in which leakage can be treated is the nodal block. Therefore, it is convenient to use an exaggerated thickness for the confining bed to accommodate the actual streambed width, which is about 5 percent

of the block width. A 30-ft thick confining bed in the model is computed to give an actual streambed thickness of 1.5 ft, a reasonable value for streams in the valley floor of the basin. These values of streambed thickness, conductivity, and altitude yielded a leakage rate of $5.4 \text{ ft}^3/\text{s}$ from streams, which was a reasonable rate of leakage into the aquifer in the model run for March 5, 1976. It was also assumed that streams were hydraulically connected to the water table during this period.

Figure 8

EXPLANATION

-  Constant-head boundary
 -  Constant-flux boundary
 -  Simulated aquifer boundary
 -  Ground-water pumpage
 -  Stream block with confining bed
 -  Constant-flux stream block
 -  Transmissivity=0
 - CT7 Test well site and number
 - CP9 Private well site and number
- Surface-water sites
- ▲CO55 Miscellaneous site on Otter Creek drainage
 - ▲CD18 Miscellaneous site on Dry Creek drainage
 - ▲CCR Continuous-recording site

NOTE: Finite-difference grid system is used.

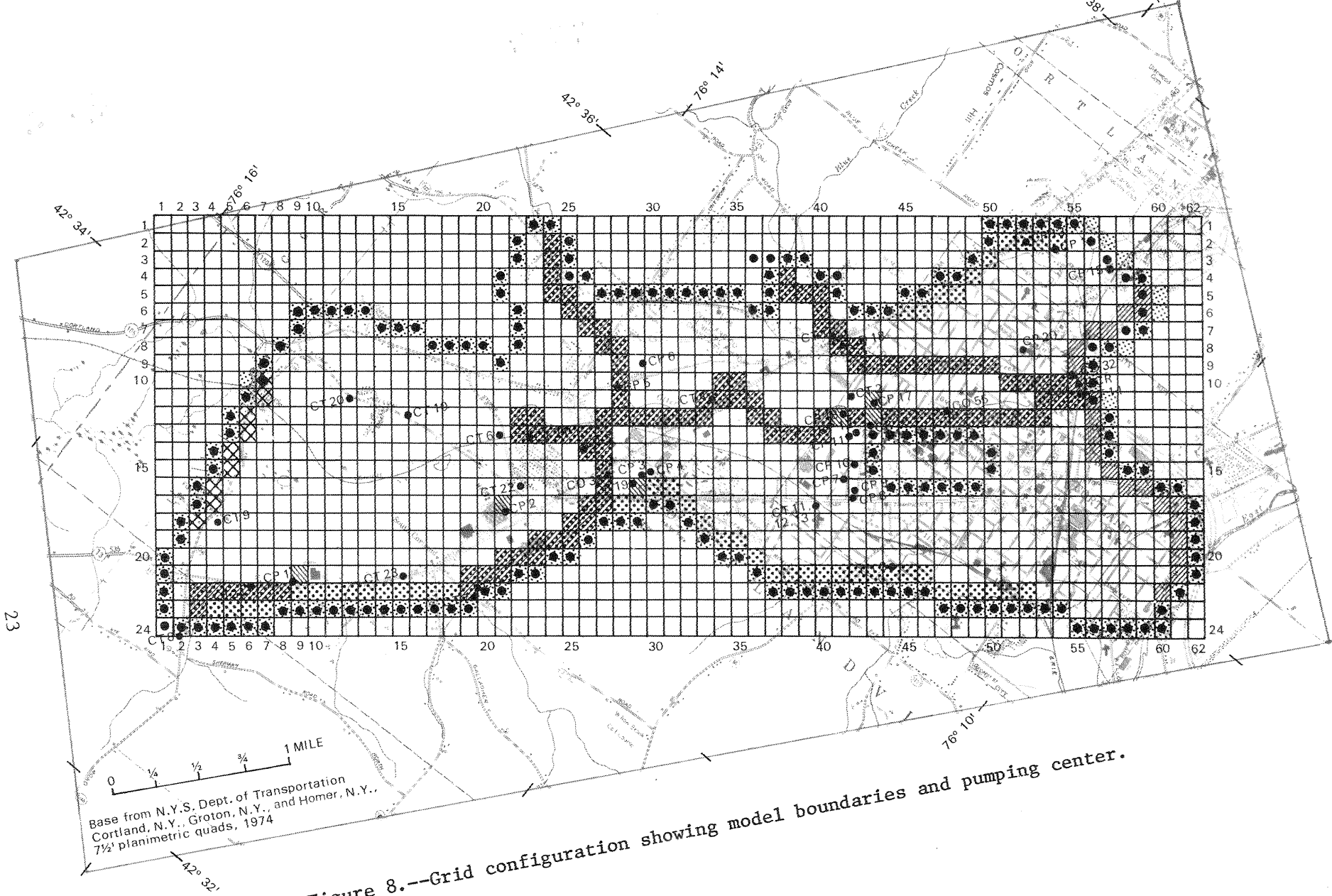


Figure 8.--Grid configuration showing model boundaries and pumping center.

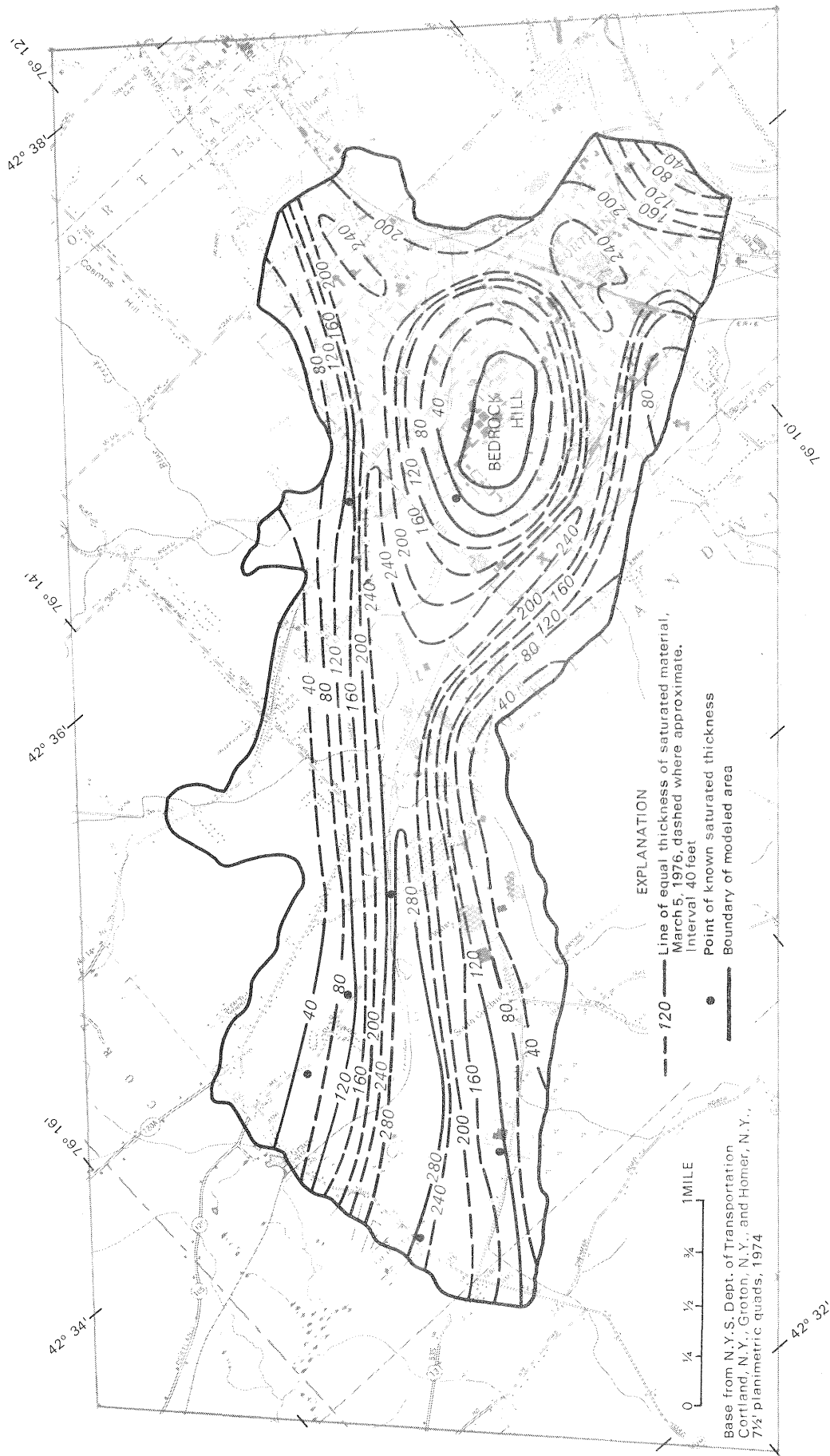


Figure 9.--Saturated thickness of outwash aquifer.

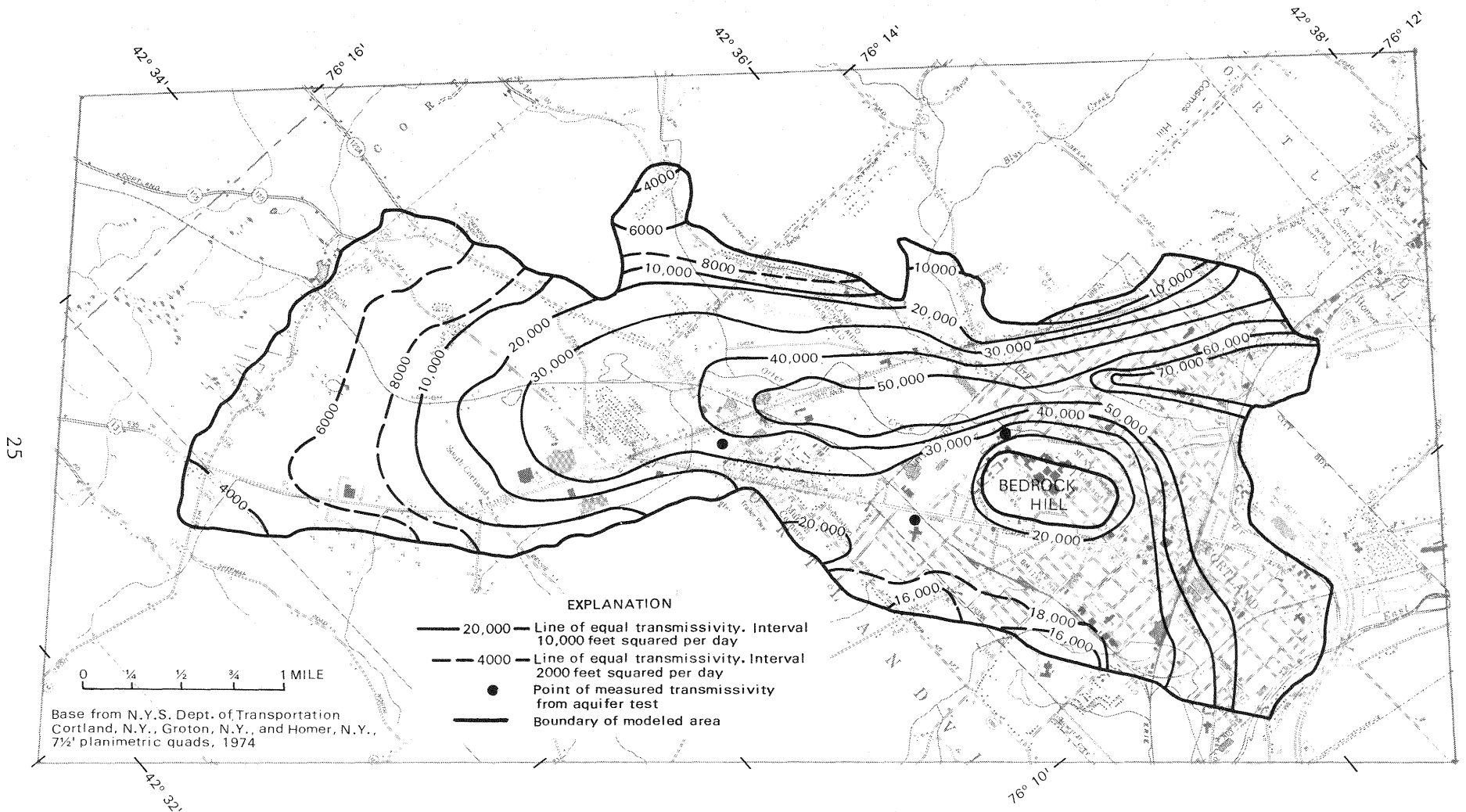


Figure 10.--Transmissivity values used in outwash-aquifer model.

Boundary Conditions

In any aquifer flow model, boundaries must be accurately represented or be far enough away from any imposed stresses that water levels near the boundary will not be significantly affected by those stresses. In this study, the eastern and western boundaries of the model were treated in a manner different from that of the northern and southern boundaries. The potentiometric map (fig. 6) suggests a ground-water divide along the western boundary. To simulate this divide in the model, the western boundary was treated as a constant-head boundary during both the steady-state and the transient-state analyses (fig. 8). A constant-head boundary at this location causes ground water to flow in two directions--into the modeled area and away from it--and thus acts as a ground-water divide.

With this constant-head boundary, the location of the ground-water divide can shift in response to recharge. When head within the aquifer is high compared with the head at the boundary, as during wet periods, the divide is shifted inward, to the east. When head in the aquifer is lower, as during dry periods, it will shift back to the west. Because the glacial deposits in this area have low permeability, wells here cannot be high yielding. However, if an attempt is made to model high-yield wells in this area, the western boundary should be changed to a no-flow boundary because the constant-head nodes would simulate an unreasonably large amount of ground water for this area under stress of heavy withdrawal.

The Tioughnioga River, which forms the eastern boundary of the modeled area, was simulated in the model at grid nodes most representative of the course of the river with appropriate values of streambed altitude and thickness at selected points along the reach. Streambed thickness ranged from 0.5 to 2.0 ft, and vertical hydraulic conductivity was held constant at 3.8×10^{-2} ft/d at all streambed nodes. These values of altitude, streambed thickness, and conductivity yielded an acceptable approximation of the March 5 and September 29 water levels in the aquifer and an acceptable average rate of ground-water discharge ($12.91 \text{ ft}^3/\text{s}$) into the river. This discharge represents about 3 percent of the average discharge determined from a continuous recording gage at Cortland. In none of the model runs was a ground-water decline in the aquifer sufficient to induce recharge from the river.

Further examination of the water-level map (fig. 6) indicated that the selected nodes along the northern and southern boundaries of the aquifer model could be assigned constant-flow values to simulate recharge from the ice-contact deposits bounding the outwash aquifer (figs. 5 and 8). These constant-flux values were computed by model calibration. The remainder of the northern and southern boundaries was treated as impermeable because the outwash bedrock contact is assumed to allow little or no ground-water flow across it.

To allow for the situation where losing reaches of streams become hydraulically disconnected from the water table and cease to provide sustained recharge, constant-flow values representing the average sustained rate of recharge to the aquifer from these streams were assigned to the appropriate stream nodes. These values furnished the model with a simulated rate of ground-water recharge along the stream courses.

The final model boundary condition to be determined was the hydraulic relationship between the outwash aquifer and the bedrock shale beneath it. Because the bedrock has low permeability and contributes only a minor fraction of total inflow to the aquifer system, it was represented in the model analysis as the impermeable base of the unconfined outwash aquifer.

Model Calibration

Before a model can be used to predict the effects of ground-water development, it must be capable of simulating flow in the aquifer to an acceptable degree of accuracy. The model was tested for accuracy by comparing its computed water levels with those actually measured (fig. 6). In the course of model calibration, several adjustments were then made to the model transmissivity values, stream-leakage rates, areal-recharge rates, and flow across the constant-flow boundaries until water levels were accurately simulated. Lack of field data on the latter two factors necessitated trial-and-error estimates of their values by matching the observed March 5 and September 29 water levels. The final transmissivity values used in the model were within the range obtained from the aquifer tests (table 1).

Water levels are constantly changing in the outwash aquifer; they rise in the spring and decline in late summer and early fall. These changes can be simulated, but in the first stages of model development it is desirable to make steady-state (or equilibrium) runs.

The steady-state solution for March 5, 1976 (fig. 11) represents normal wet conditions in the modeled area. Spring rains and snowmelt are major sources of recharge to the outwash aquifer. During this time, stream-flow is high and recharge of stream water to the aquifer occurs in losing reaches of the valley. Evapotranspiration from the aquifer is considered negligible. Twenty-two percent of the recharge to the outwash aquifer in the steady-state solution for March 5 was represented by constant flow across the ice-contact boundaries. This flow was computed to be $5.9 \text{ ft}^3/\text{s}$ by model calibration and can be considered the recharge from precipitation on the ice-contact deposits along the south and north boundaries of the modeled area. The remaining 78 percent of recharge to the aquifer represented direct recharge over the modeled area from precipitation and leakage from losing reaches of streams. Areal recharge over the modeled area was computed to be $15.3 \text{ ft}^3/\text{s}$ by model calibration, and simulated leakage from streams was computed to be $5.4 \text{ ft}^3/\text{s}$. These simulated recharge rates acceptably approximated the March 5 water levels.

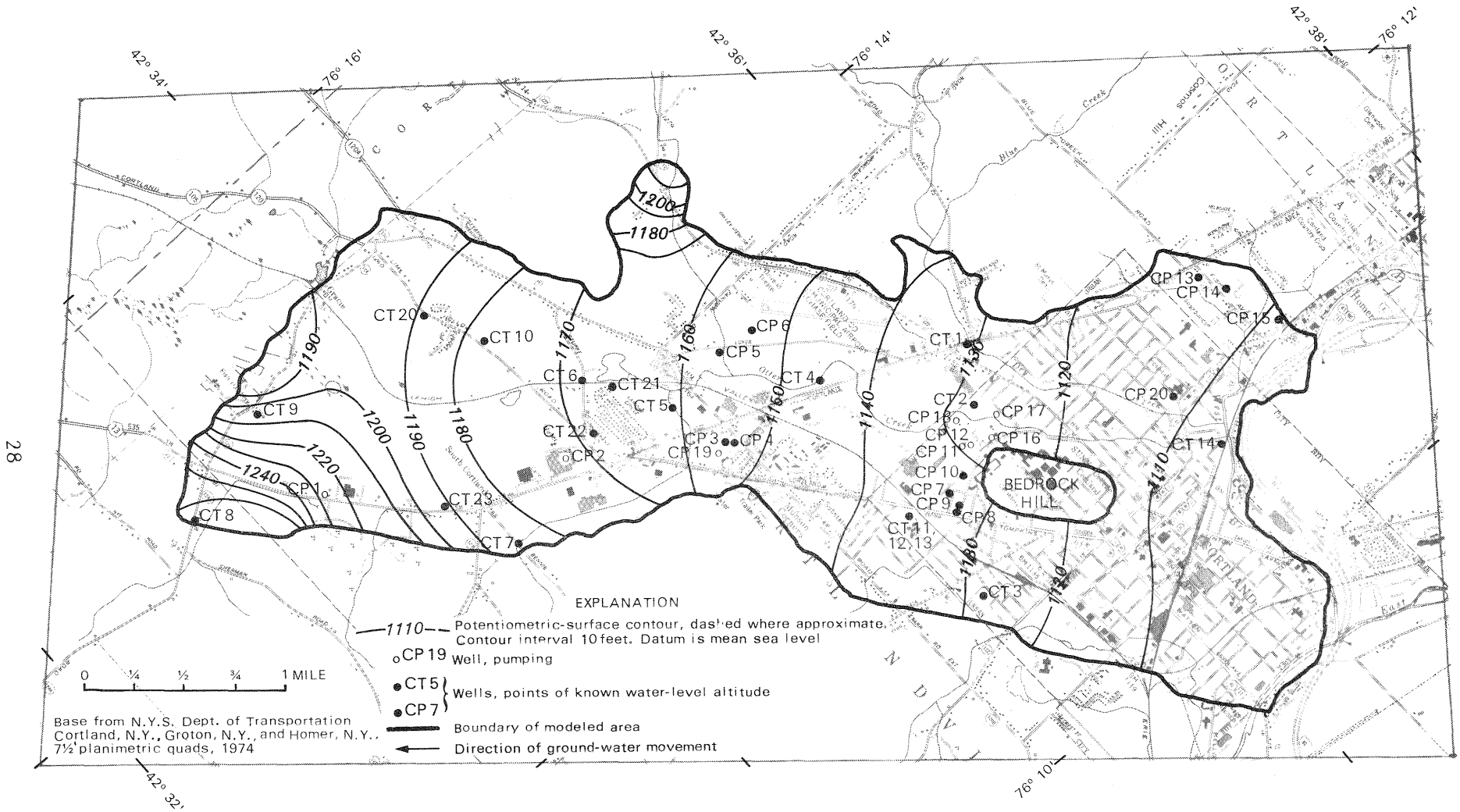


Figure 11.--Simulated water-level contours of outwash aquifer,
March 5, 1976.

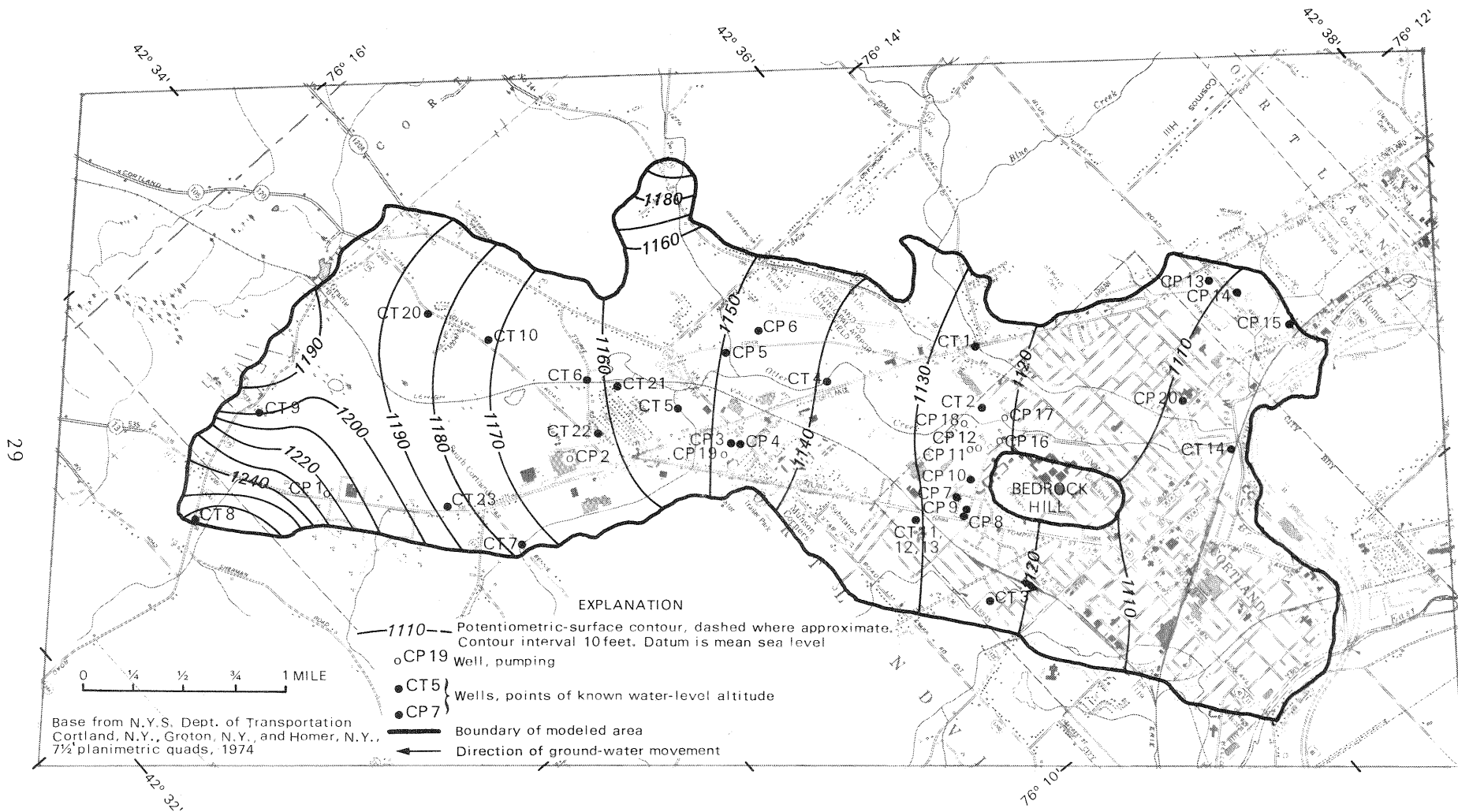


Figure 12.--Simulated water-level contours of outwash aquifer on September 29, 1976.

Figure 11 shows the model steady-state solution for water levels in the aquifer on March 5, 1976. This map was contoured directly from the plot of water levels generated by the model. Locations of wells at which water levels were actually measured are shown in figure 6; direct comparison of observed and computed water levels can be made at these sites on the two maps. In general, the computed water-level surface of March 5, 1976 is in close agreement with the potentiometric-contour map compiled for that date.

Figure 12 shows the computed transient-state water-level contours, which are generally in close agreement with the potentiometric contours derived from measurements on September 29, 1976. This map was contoured directly from the plot of water levels generated by the model. The transient-state solution for September 29 represents normal dry conditions in the modeled area. In that simulation, the steady-state water-level contour of March 5 was used as the starting water level, and recharge rate from precipitation of 3.1×10^{-8} ft/s--equivalent to 12 in/yr over the modeled area--was computed by model calibration. Precipitation is the only major source of recharge to the outwash aquifer. During the growing season, evapotranspiration uses most of the available precipitation, and recharge of stream water to the aquifer is negligible. Therefore, simulated leakage to the aquifer from streams was not included because the losing reaches of streams in the valley are generally intermittent during the summer.

Tables 3 and 4 summarize the sources and discharges used in the steady-state and transient-state solutions described in the preceding paragraphs. These tabulations indicate the magnitude of the various flow components in the water budgets for the steady-state and transient-state conditions simulated in the model. Note that steady-state conditions do not prevail because seasonal changes in recharge as well as long-term cycles of wet and dry years continuously modify these budgets. The significance and utility of the model simulation for March 5 is that it documents a period of relatively high water levels in which water availability was greater than average. In contrast, the model simulation for September 29 represents a period of relatively low water levels with less than average water availability. The seasonal variation in water levels in the modeled area is assumed to reflect typical periods of high and low recharge.

Application of the Model

The hydrologic model can be used to study the effects of ground-water withdrawals associated with various management schemes. In the model, as in the real hydrologic system, withdrawal of water from the aquifer changes the recharge-discharge relationships. Water-level declines (drawdown) from the initial positions will be produced so that a new potentiometric surface is developed. Water moves toward places of withdrawal and, in

Table 3.--March 5, 1976 ground-water budget computed for outwash aquifer under steady-state hydrologic conditions

Factor	Yield	
<u>Sources to aquifer</u>	<u>(Mgal/d)</u>	<u>(ft³/s)</u>
Direct areal recharge (28 in/model area)	9.89	15.32
Constant-flux boundaries	3.82	5.92
Constant-head boundary (underflow)	0.10	0.16
Leakage from streams to aquifer	3.49	5.40
Total	<u>17.30</u>	<u>26.80</u>
 <u>Discharge from aquifer</u>		
Pumping wells	6.29	9.73
Leakage from aquifer to Tioughnioga River	9.46	14.65
Leakage from aquifer to small streams	0.27	0.42
Constant-head boundary (underflow)	1.28	2.00
Total	<u>17.30</u>	<u>26.80</u>

Table 4.--September 29, 1976 ground-water budget computed for outwash aquifer under transient-state hydrologic conditions

Factor	Yield	
<u>Sources to aquifer</u>	<u>(Mgal/d)</u>	<u>(ft³/s)</u>
Direct areal recharge (12 in/model area)	4.17	6.46
Storage (water taken into storage)	6.43	9.95
Constant-flux boundaries	3.82	5.92
Constant-head boundary (underflow)	0.18	0.27
Total	<u>14.60</u>	<u>22.60</u>
 <u>Discharges from aquifer</u>		
Pumping wells	6.29	9.73
Leakage from aquifer to Tioughnioga River	7.20	11.16
Constant-head boundary (underflow)	1.10	1.71
Total	<u>14.60</u>	<u>22.60</u>

response to these declines, water is released from storage within the aquifer or is diverted out of streams to become induced recharge from those streams. If withdrawal is continued long enough at rates that do not exceed total inflow to the system, a state of balance will eventually be reached. When properly calibrated, the model can be used to calculate water-level and discharge values that would prevail at given times and in specific areas as a result of the pumping schemes used. Data for the model should be updated to incorporate long-term cycles of wet and dry years and seasonal fluctuations in recharge, streamflow, and withdrawal rates--all of which would have an effect on the aquifer system. The present model is stored on disk in the Cornell Computer Center, Ithaca, N.Y., and is available to water managers for use in estimating future effects of ground-water development.

SUMMARY

The most productive source of ground water in the Cortland area is the glacial-outwash aquifer, which underlies most of the valley floor of the Otter Creek-Dry Creek drainage basin. The aquifer is composed of stratified beds of sand and gravel and is interbedded with less permeable layers of silt and clay. The aquifer is normally unconfined, and water levels are generally within 25 ft of land surface. Current (1976) pumpage is approximately 6.3 Mgal/d.

An areal two-dimensional ground-water flow model was developed to simulate ground-water movement in the stream/aquifer system. For hydrologic conditions of March 5, 1976 (a wet period), leakage from streams was modeled using the streambed level as the hydraulic head above a leaky confining layer (streambed). The model was calibrated by comparing the computed water levels with measured water levels in the aquifer. In the model run to simulate the water-level contours measured on September 29, 1976, the computed water levels during March were used as the initial water levels. Recharge from stream leakage was not added because the losing reaches of streams in the valley floor normally cease to be a sustained source of recharge during the summer. Computed water-level contours are presented in map form and are generally in close agreement with potentiometric-surface maps prepared from field measurements for March 5 and September 29, 1976.

Ground-water budgets were established for conditions modeled for March and September 1976. These budgets indicate the magnitude of the various recharges and discharges used in the solutions.

The present hydrologic model can be used by managers to show how the local hydrologic system functions and to predict aquifer response to many anticipated water-development plans. The model should be adapted to incorporate long-term cycles of wet and dry years and seasonal fluctuations in recharge, streamflow, and pumpage rates.

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Cortland County, New York"

U.S. Geological Survey
Water Resources Investigations 78-3

E R R A T A

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"

