Hydrogeology and Simulation of Ground-Water Flow in a Deltaic Sand-and-Gravel Aquifer, Cattaraugus Indian Reservation, Southwestern New York

By TODD S. MILLER

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CONVERSION FACTORS AND VERTICAL DATUM

CONVERSION FACTORS

Multiply	By	To Obtain
	Length	
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
inch per year (in/yr)	25.4	millimeter per year
gallons per minute (gal/min)	0.06309	liter per second
million gallons per day (Mgal/d)	3.785	cubic meters per day
	Temperature	
degrees Fahrenheit (°F)	°C = 5/9 (°F-32)	degrees Celsius
	Specific Conductance	
	microsiemens per centimeter at 25° Celsius (µS/cm)	
	Equivalent Concentration Terms	
	milligrams per liter (mg/L) ≈ parts per million = micrograms per gram (µg/g)	
	micrograms per liter (µg/L) ≈ parts per billion = micrograms per kilogram (µg/kg)	

VERTICAL DATUM

Sea Level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929) - a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Hydrogeology and Simulation of Ground-Water Flow in a Deltaic Sand-and-Gravel Aquifer, Cattaraugus Indian Reservation, Southwestern New York

By Todd S. Miller

Abstract

The Seneca Nation of Indians at the Cattaraugus Indian Reservation needs to develop a public water supply because water from many domestic wells that tap bedrock and parts of an overlying confined sand-and-gravel aquifer contains dissolved barium in concentrations that exceed the New York State drinking-water standard of 1.0 milligram per liter. Large amounts of ground water are potentially available, mainly from a deltaic deposit in the eastern part of the reservation. This deposit forms a 4.4-square-mile sand-and-gravel unconfined aquifer that has the potential for meeting the water needs of the Reservation. Barium concentrations in this aquifer are below the New York State drinking-water standard, and several large-diameter wells have pumped as much as 400 gallons per minute from the aquifer.

A quasi-three-dimensional, numerical ground-water-flow model was constructed to compute hydraulic head and direction of ground-water flow in the deltaic aquifer. The unconfined aquifer was represented in the model by two layers—the top layer represents surficial sand and gravel, and the underlying layer represents fine to coarse sand that overlies a lacustrine confining unit.

A water budget calculated for steady-state, nonpumping conditions in the deltaic aquifer indicates that 93 percent of total recharge is from precipitation that falls directly on the aquifer; the rest consists of unchanneled runoff and ground-water inflow from the uplands. All ground water discharges to springs that are represented by drains along the edges of the aquifer.

A flowpath analysis indicates that the area contributing ground water to a hypothetical well that was simulated as 50 feet deep and pumped at a rate of 180 gallons per minute, and screened in the underlying aquifer, would be 0.32 mile wide and 1.33 mile long and would cover an area of 0.42 square miles. The longest ground-water flowpath would extend 1.3 miles from the well to the eastern boundary of the aquifer. Estimated traveltimes of ground water flowing from the eastern boundary to the simulated well would range from 3.5 to 4.5 years.

INTRODUCTION

The Seneca Nation of Indians at the Cattaraugus Indian Reservation (hereafter referred to as the Reservation), in parts of Erie, Cattaraugus, and Chautauqua Counties in western New York (fig. 1), needs to locate an appropriate site for a public-water supply because the water from many domestic wells that tap bedrock, and parts of an overlying confined sand-and-gravel aquifer that lies on top of bedrock, has concentrations of dissolved barium that exceed the New York State drinking-water standard (New York State Department of Health, 1977) of 1.0 mg/L. Barium concentrations in 1982 in wells that tap bedrock were as high as 23.0 mg/L, the highest barium concentration reported from any natural ground-water system in the world (Moore and Staubitz, 1984). Ingestion of barium in high concentrations is a health hazard that may result in vomiting, diarrhea, spasms, and paralysis and, at concentrations exceeding 550 mg/L, may be fatal (U.S. Environmental Protection Agency, 1976).

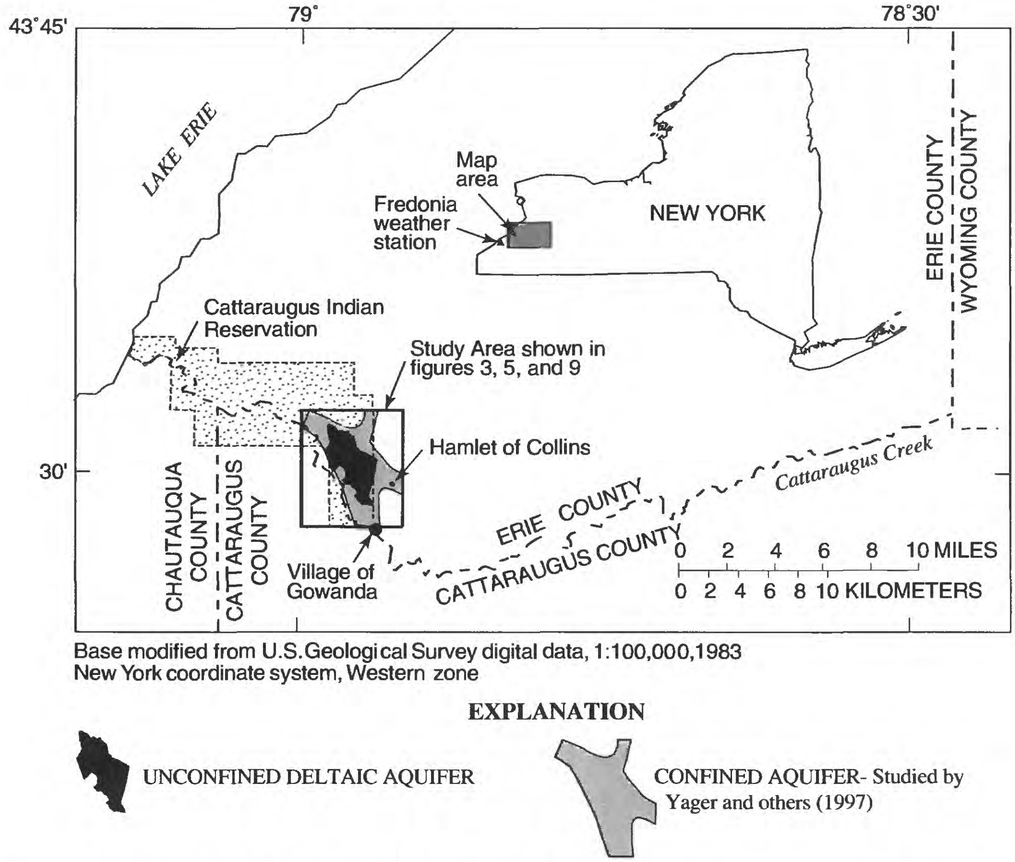


Figure 1. Location of Cattaraugus Indian Reservation study area in southwestern New York.

Ground water in shallow unconsolidated deposits at the Reservation contains little or no barium (Moore and Staubitz, 1984; Edwards and Moncreiff, 1987). The most promising ground-water resource that could supply enough potable water to meet the needs of the Reservation is a 4.4-square-mile surficial deltaic sand-and-gravel aquifer in the eastern part of the Reservation (fig. 1); four abandoned wells that once tapped this aquifer each pumped from 150 to 400 gal/min. Much of the land over the deltaic aquifer is agricultural, however; thus, herbicides and pesticides that are applied seasonally could contaminate the aquifer.

During 1994-95, the U.S. Geological Survey (USGS), in cooperation with the Seneca Nation of Indians, conducted an investigation of the unconfined deltaic aquifer to determine whether it could yield sufficient amounts of potable ground water to meet the needs of the Reservation. This report describes (1) the hydrogeologic setting of the Reservation and of the unconfined deltaic aquifer in the eastern part of the Reservation, and (2) the development of a ground-water flow model and simulation of flow in the aquifer. The report includes (1) maps showing the distribution of hydraulic head in the unconfined aquifer and the area contributing recharge to a simulated, hypothetical pumped well, (2) tables summarizing the inflows and outflows to the aquifer computed for average, steady-state conditions, and (3) results of water-quality analyses of the deltaic aquifer.

Previous Investigations

Moore and Staubitz (1984) studied the high barium concentrations in ground water at the Reservation, and Edwards and Moncreiff (1987) described the ground-water supplies and measured barium concentrations in water from many wells on the Reservation. Yager and others (1996) constructed a ground-water model that simulated flow in the confined aquifer in the Cattaraugus Creek and Clear Creek Valleys in the southern part of Erie County, including part of the Reservation. The model by Yager and others (1997) was used to delineate the area that contributes recharge to the nearby Town of Collins public-supply well, which taps the confined aquifer.

Study Methods

The study entailed a literature search, compilation of available hydrogeologic data, test drilling, synoptic water-level measurements, water sampling, and development of a numerical-ground-water-flow model to simulate the ground-water-flow system in the deltaic aquifer and vicinity, hereafter called the study area.

Fifteen test borings were augered, in which 14 observation wells were installed to locate the areas most favorable for development of ground water for public supply. After the wells were installed (during the summer of 1994), a synoptic-water-level measuring round was conducted on August 9, 1994 to (1) obtain data for construction of a potentiometric surface map, (2) determine the direction of ground-water flow, and (3) provide data for calibration of the ground-water-flow model. Levels were run to obtain elevations of measuring points, which allowed conversion of water level measurements to a common datum plane—mean sea level.

Ground-water samples were collected August 2-3, 1994 from the 14 new wells and several domestic wells. At least three well-casing volumes of water were pumped or bailed from monitoring wells prior to sample collection. Sampling at domestic wells entailed running the pump for 10 to 15 minutes (the estimated time for evacuation of three volumes of standing water in the casing) before collecting samples. All sampling and purging equipment was thoroughly cleaned with deionized water between samples. Samples were analyzed by the USGS laboratory (Arvada, Colo.) for specific conductance, pH, common ions, nutrients, and trace metals, by methods described by Fishman and Friedman (1989), and for volatile organic compounds, insecticides, and herbicides. Results of chemical analyses are given in table 3 (at end of report).

A quasi-three-dimensional, numerical-ground-water flow model, MODFLOW (McDonald and Harbaugh, 1988), was developed to simulate steady-state conditions in the deltaic aquifer and to compute ground-water levels and water budgets. A particle-tracking program, MODPATH (Pollock, 1994), was used to estimate the area that contributes recharge to the proposed municipal well site.

Acknowledgments

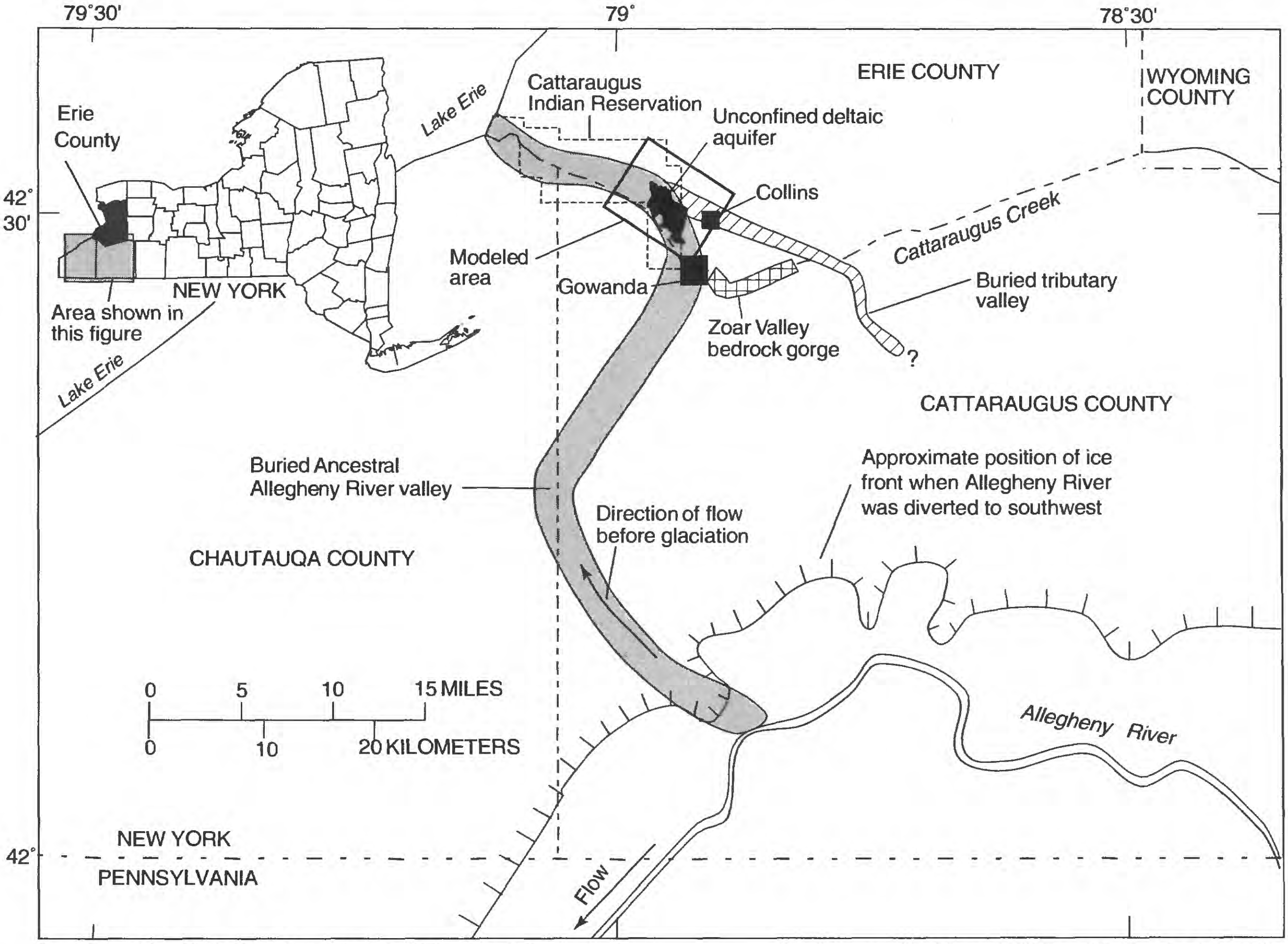
Thanks are extended to Armand Maybee of the Seneca Nation of Indians Waterline Project and to Thomas Plummer of the U.S. Public Health Services for their assistance in providing data, access to drilling sites, and drilling supplies.

HYDROGEOLOGY

The study area is characterized by buried bedrock valleys that are partly filled with glacial drift deposited mostly during the last deglaciation of western New York during Wisconsinan time, 13,000 to 14,000 years ago (Muller and Calkin, 1993). Most of the Reservation lies over the buried ancestral Allegheny River Valley, now occupied by Cattaraugus Creek (fig. 2).

During early glaciation of southwestern New York, the advancing ice sheet blocked the course of the ancestral Allegheny River, which had flowed northwestward in a roughly 1-mile-wide valley that extended from the southwestern part of New York toward Gowanda (fig. 2) and eventually to the Lake Erie basin (Muller and Calkin, 1993). The ice blocked the preglacial northwestern course of the Allegheny River and diverted the flow to the southwest, such that the river now flows to the Ohio River.

The bedrock that underlies the study area consists of Devonian-age shales, which are relatively undeformed and dip gently to the south-southwest (Buehler and Tesmer, 1963). The bedrock surface in the Cattaraugus Creek Valley represents the ancestral buried valley of the Allegheny River. The shales are relatively impermeable and generally yield only small amounts of water to wells (LaSala, 1968); they also form the bottom of the confined aquifer.



Base from New York State Department of Transportation, 1980, 1:250,000 scale, New York State Map

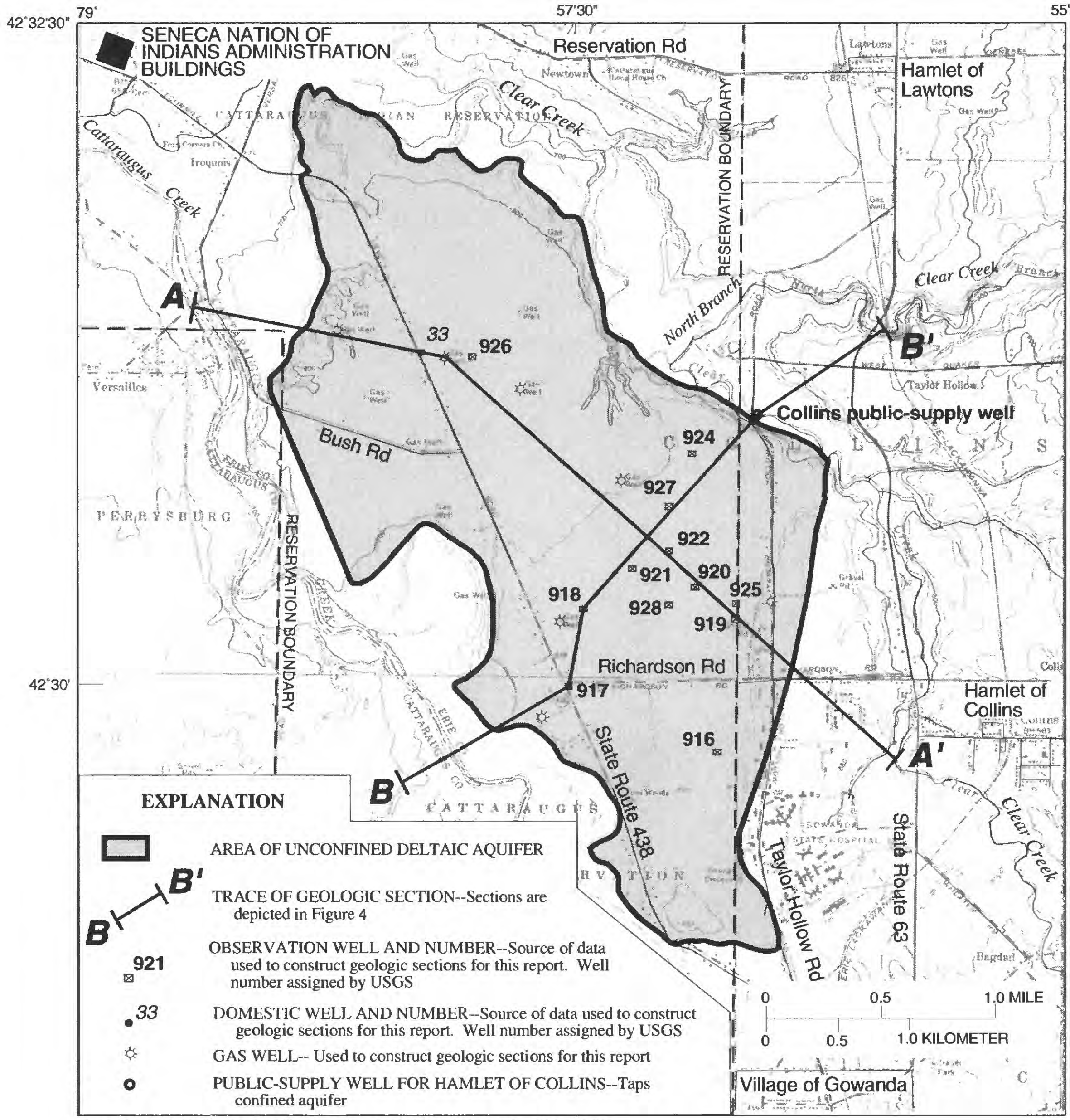
Geology modified from Muller and Fahnestock (1974)

Figure 2. Pertinent geologic features of the study area and vicinity in southwestern New York.

Unconsolidated Deposits

Multiple surges and retreats of the ice in valleys of the study area resulted in deposition of a complex mix of till, glaciofluvial sediment, and glaciolacustrine sediment. Little information is available on the stratigraphy of glacial deposits in the deep zones of the valleys, but records of gas wells (in files on the Reservation) indicate that as much as 550 ft of glacial sediment was deposited in the buried ancestral Allegheny River Valley.

A sand-and-gravel delta was deposited in the study area (fig. 3) during the last phases of deglaciation where Cattaraugus Creek entered proglacial Lakes Wittlesey and Warren (Calkin and others, 1982). The source of this material was a bedrock gorge that Cattaraugus Creek was incising in Zoar Valley, several miles southeast of the study area (fig. 2). The extent of the delta, which now forms the unconfined aquifer, is easily discerned by its geomorphology—a plateau whose surface descends gently to the west and ends as bluffs that surround its southern, western, and northern perimeter. The bluffs formed as Cattaraugus Creek and Clear Creek eroded the edges of the plateau and incised channels into the underlying fine-grained deposits (fig. 4). The incisions by the creeks have isolated most of the plateau from the adjacent uplands, except along its southeastern border.



Base from U.S. Geological Survey, North Collins, N.Y., 1:24,000, 1960, and Gowanda, N.Y., 1:24,000, 1963

Figure 3. Extent of deltaic aquifer, locations of wells, and lines of geologic sections in Cattaraugus Indian Reservation study area, southwestern New York. (Location is shown in fig. 1.)

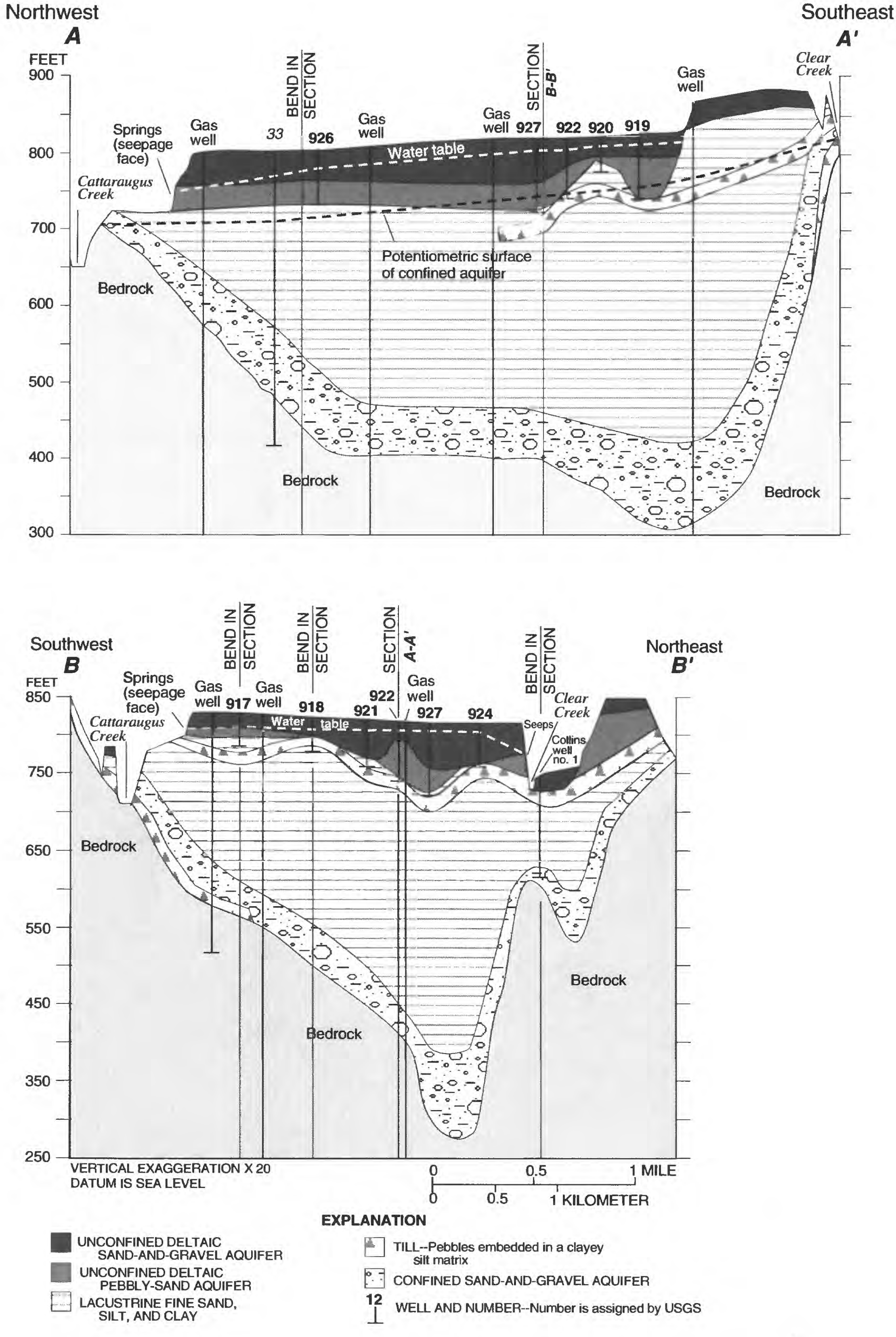


Figure 4. Hydrogeologic sections *A-A´* and *B-B´* showing stratigraphy of Cattaraugus Creek Valley, southwestern New York. (Lines of sections are shown in fig. 3.)

The deltaic deposit is typically 25 to 90 ft thick; the upper part consists of sand and gravel, and the lower parts of pebbly, fine to coarse sand. Underlying the deltaic deposit is a 50- to 350-foot-thick sequence of mostly fine-grained sediments (till and lacustrine fine sand, silt, and clay) that, in turn, are underlain by a basal sand-and-gravel deposit whose thickness typically ranges from 10 to 80 ft but exceeds 100 ft in places. The basal sand-and-gravel aquifer probably consists of subglacial glaciofluvial deposits, such as eskers and esker fans deposited by meltwaters. Seismic-reflection studies in the Finger Lakes valleys of central New York by Mullins and others (1991) indicate that meltwaters flowing beneath the glacier provided coarse-grained sediment to the moraines that formed at the ice front.

Within the Reservation, large amounts of water are potentially available only from sand-and-gravel aquifers. Water-well records indicate that sand-and-gravel deposits typically yield water to 6-in.-diameter, open-ended domestic wells at rates of several tens of gallons per minute and to large-diameter screened municipal and industrial wells at a rate of 150 to 400 gal/min (wells that tap shale typically yield only 0.25 to 5 gal/min [LaSala, 1968]). Two large sand-and-gravel aquifers underlie the Reservation: (1) the surficial deltaic deposit described previously, which forms an unconfined aquifer in the eastern part of the Reservation; and (2) a basal sand-and-gravel deposit that forms a confined aquifer at the bottom of the buried ancestral Allegheny River Valley. The unconfined aquifer was selected during this study as the primary aquifer that could potentially supply water to the Reservation because (1) the barium concentrations in shallow unconsolidated aquifers are typically below the New York State drinking-water standard (Moore and Staubitz, 1984), and (2) several large-diameter wells on the Reservation have pumped as much as 400 gal/min from this aquifer.

Confined aquifers that overlie bedrock are common in many valleys in western and central New York (Miller, 1988; Mullins and others, 1991). The confined aquifer in the Cattaraugus Creek Valley was not selected as the primary potential source of drinking water for the Reservation because (1) barium concentrations in some of the wells that tap it exceed the New York State drinking-water standard; (2) few well records are available that quantify the potential yield of this aquifer; and (3) the cost of drilling and testing needed to define the aquifer properties would be prohibitive. The confined aquifer might provide an alternative water supply, however, should the unconfined aquifer yield insufficient amounts of water or become contaminated. The hydrogeology of the confined aquifer, including aquifer geometry and simulated ground-water flow, is described by Yager and others (1997).

Unconfined Deltaic Aquifer

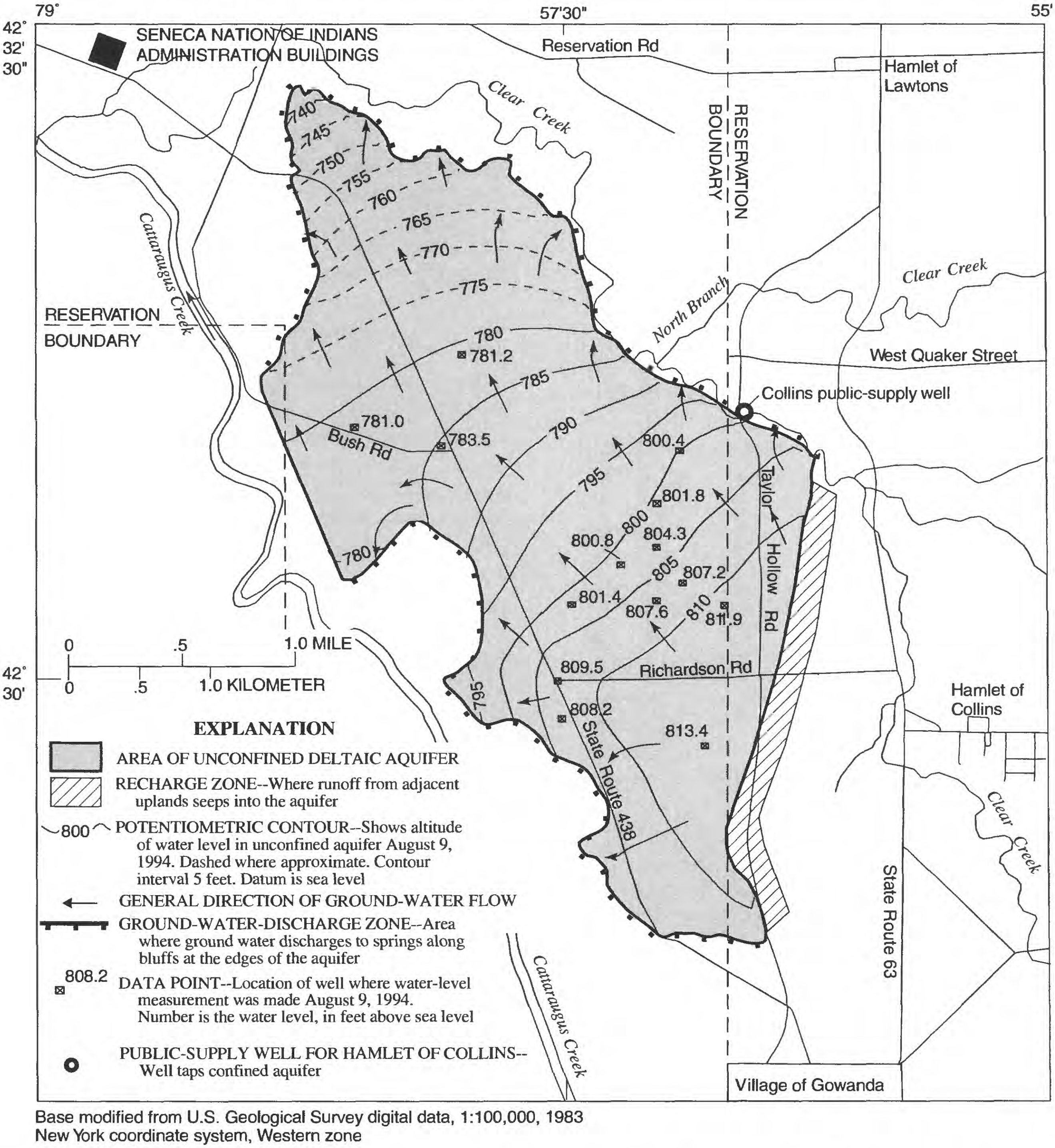
The unconfined deltaic aquifer forms a lens whose top and bottom surfaces slope downward to the northwest. The top of the aquifer is the water table, and the bottom is the top of the underlying lacustrine confining unit. The saturated thickness (the depth from the water table to the top of the lacustrine confining unit) is as much as 75 ft thick locally, but typically averages about 40 ft. The lateral boundaries of the aquifer are the bluffs that surround most of the delta, except along the southeastern edge, where it abuts the uplands.

Water Levels and Direction of Ground-Water Flow

Ground-water levels were measured in 13 wells on August 9, 1994 to (1) determine the configuration of the potentiometric surface and the lateral direction of ground-water flow, and (2) calibrate the ground-water model (discussed further on). Ground water flows roughly perpendicular to the potentiometric contours (lines of equal head), as shown in figure 5. Water in the southeastern part of the unconfined aquifer generally moves northwestward, and water in the central parts moves toward the bluffs along the southern, western, and northern edges of the aquifer, where it discharges as springs.

Sources of Recharge

The unconfined deltaic aquifer receives recharge from two sources: (1) precipitation that falls directly on the aquifer, and (2) upland sources along the southeastern border of the aquifer, such as runoff from unchanneled hillsides and seepage from adjacent till deposits and bedrock. Part of the precipitation that falls on the aquifer is returned to the atmosphere by evapotranspiration; the remainder infiltrates to the water table.



Base modified from U.S. Geological Survey digital data, 1:100,000, 1983
New York coordinate system, Western zone

Figure 5. Potentiometric-surface altitude in the unconfined deltaic aquifer in the Cattaraugus Indian Reservation study area, southwestern New York, August 9, 1994. (Location is shown in fig. 1.)

Rates of recharge from precipitation vary seasonally. Most of the precipitation that falls during the dormant period of vegetation (typically from mid-October through the end of April) infiltrates into the ground and recharges the aquifer, whereas most of the precipitation that falls during the growing season (May through September) is lost through evapotranspiration. The average annual recharge to surficial sand-and-gravel aquifers in the northeastern United States is about equal to the long-term average annual stream runoff (Randall and Johnson, 1987), which, for 30 years (1951-80) in southwestern New York, ranged from 22 to 25 in. (Randall and Johnson, 1987) and averaged 23.5 in. Therefore, the amount of recharge that the unconfined deltaic aquifer receives from precipitation that falls on the aquifer is calculated to be 666,000 ft^3/d, from an average annual recharge rate of 23.5 in. (0.00536 ft/d) multiplied by the area of the delta (4.46 mi^2 or 124,253,700 ft^2).

Recharge to valley-fill aquifers from adjacent unchanneled hillsides includes surface runoff and lateral flow of ground water from the till, sand and gravel, and bedrock; this water flows toward the valley and seeps into the aquifer along its edges. All precipitation that is not lost through evapotranspiration in the uplands adjacent to the aquifer is assumed to become either runoff or ground water that eventually flows to the valley and seeps into the unconfined deltaic aquifer.

The amount of recharge from runoff from adjacent unchanneled hillsides can be calculated by the following equation

$$R = \frac{(P - ET) \times DA}{t}, \qquad (1)$$

where

R = recharge from runoff from unchanneled hillsides, in cubic feet per day;

P = annual precipitation, in feet;

ET = annual evapotranspiration, in feet;

DA = drainage area of hillside, in square feet; and

t = time (365 days).

The estimated recharge from runoff from unchanneled hillsides along the southeastern border of the deltaic aquifer is 50,400 ft^3/d.

Ground-Water Discharge

Most water in the unconfined deltaic aquifer discharges to springs along the middle and lower parts of bluffs on its southern, western, and northern edges. Some water may also move downward into the underlying confining unit.

Area Favorable for Development of Ground-Water Resources

The two hydrogeologic criteria that are most critical to development of ground-water resources in the Reservation are that (1) the chemical quality of the water meet New York State and Federal drinking-water standards, and (2) the aquifer yield at least 200 gal/min to a screened well. Test-well site 921 (fig. 3) was judged favorable for development because it (1) is in area with relatively thick saturated sand and gravel (30 ft); (2) is in the central part of the aquifer, far from aquifer boundaries that could limit the amount of water that could be pumped; (3) is near two abandoned municipal wells and an industrial well that each had previously been pumped at 150 to 400 gal/min; and (4) the water quality meets New York State drinking-water standards.

Water Quality

Water samples from 14 wells completed in the unconfined deltaic aquifer were analyzed for specific conductance, pH, and concentrations of common ions, nutrients, trace metals, volatile organic compounds (VOC's), insecticides, and herbicides. All samples met New York State drinking-water standards except one, from well 917, where the nitrate concentration was 12.0 mg/L. (The New York State drinking-water standard for dissolved nitrate is 10 mg/L.) No significant concentrations of organic chemicals (pesticides, insecticides, or VOC's) were found in the sampled wells. Barium concentrations in all samples were below the New York State drinking-water standard of 1,000 µg/L and ranged from 58 to 400 µg/L. Results of the chemical analyses are given in table 3 (at end of report).

SIMULATION OF GROUND-WATER FLOW

A three-dimensional numerical ground-water flow model was adapted from a previously developed regional model (Yager and others, 1997) and was used to (1) compute hydraulic heads (hereafter referred to as head) in the deltaic aquifer under steady-state conditions, (2) develop a water budget, and (3) delineate the area contributing recharge to a hypothetical pumped well (observation well site 921, fig. 3). The previously constructed model (Yager and others, 1997) simulated ground-water flow in the confined aquifer in the part of the buried ancestral Allegheny River Valley that is tapped by a municipal well for the Town of Collins was modified to include the unconfined aquifer in the Reservation. In this study, two additional layers were added to the regional model to represent the unconfined aquifer in the Reservation.

Description and Design

The model was developed through the computer program MODFLOW, described by McDonald and Harbaugh (1988), and was based on block-centered, finite-difference equations that describe the physics of water flowing through a porous medium.

Simplifying Assumptions

Use of the MODFLOW program to model the unconfined deltaic aquifer at the Reservation required five simplifying assumptions to simulate the ground-water flow system; these assumptions were that:

1. Ground-water flow is horizontal within the model layers and vertical between layers. (The assumption that ground water moves only horizontally within layers applies reasonably well throughout the modeled area except near pumped wells and directly beneath recharge and discharge areas, where vertical flow within layers may be appreciable. The effect of this simplification is that modeled heads might not match observed heads in areas where ground-water discharge is appreciable, such as near the springs along the bluffs and near pumping wells.)
2. Recharge to the aquifer is areally uniform.
3. The modeled aquifer can be divided into a finite number of square blocks or cells, each of which has uniform properties. The center of each block is called a "node," and the water level calculated for the node is assumed to be representative of water levels over that entire block.
4. A simulated pumping well in a model cell is considered to be screened through full saturated thickness of the cell.
5. The large thickness and low vertical hydraulic conductivity of the underlying confining unit impedes vertical flow between the unconfined deltaic aquifer and the basal confined aquifer, such that vertical flow is negligible compared to the amount of horizontal flow in the aquifers. Assuming that the anisotropy (ratio of vertical to horizontal hydraulic conductivity, explained further on) ranges from 1:10 to 1:100, and horizontal hydraulic conductivity of till and lacustrine fine sand, silt, and clay is 1×10^{-2} ft/d (Heath, 1983, p. 3), the vertical hydraulic conductivity would range from 1×10^{-3} to 1×10^{-4} ft/d. Applying Darcy's law,

$$Q = KIA,$$

where

Q = discharge from the deltaic aquifer to the confined aquifer, in cubic feet per day;
K = vertical hydraulic conductivity, estimated to range from 1×10^{-3} to 1×10^{-4} ft/d;
I = hydraulic gradient, estimated to be 0.33 (dimensionless); and
A = area of the bottom of layer 2, estimated to be 1.24×10^{8} ft^2,

indicated that ground-water discharge from the deltaic aquifer to the confined aquifer ranges from 4,090 ft^3/d to 40,900 ft^3/d. This amount equals a relatively small part (0.6 to 6 percent) of the total discharge from the aquifer (716,750 ft^3/d) calculated by the model.

The steady-state simulations were calibrated to the ground-water levels measured in 14 wells on August 9, 1994, a period judged to represent average annual flow conditions. Although the average flow conditions typically occur in June, the average flow conditions for 1994 probably occurred later in the summer because precipitation was above average during the first half of the year—4.52 in. above normal at Fredonia, 28 mi. west of the study area (see location map in fig. 1), for the first 6 months of 1994 (U.S. National Oceanic and Atmospheric Administration, 1994). Therefore, the water-level measurements that were made on August 9, 1994 are assumed to represent average, steady-state flow conditions.

Model Grid

The unconfined deltaic aquifer is represented in the model as two layers—layer 1 (top layer) represents the upper sand and gravel, and layer 2 represents the underlying pebbly, fine to coarse sand that overlies the lacustrine confining unit (fig. 6).

The rectangular, finite-difference grid used by Yager and others (1997) was used for this model. The grid has 125 rows and 175 columns and was superimposed on a map of the study area (fig. 7) to discretize the hydrogeologic properties of the unconfined deltaic aquifer. A uniform cell size of 200 × 200 ft was used. The modeled area encompasses 4.46 mi^2 and contains a total of 6,606 active cells in the two model layers.

Hydraulic Values and Boundary Conditions

The saturated thickness of aquifer layers 1 and 2 were calculated from results of the test-drilling program and was estimated for areas with no data. The test hole at most drilling sites penetrated both layers and terminated several feet into the underlying fine-grained deposits. The thickness of layer 1 typically ranged from 10 to 30 ft and averaged about 20 ft; that of layer 2 typically ranged from 5 to 25 ft and averaged about 15 ft. The horizontal hydraulic conductivity of layer 1 was estimated to be 300 ft/d, from an average transmissivity obtained from specific capacity (*Q/s*) values of 15.0 and 15.8 (ft^3/d)/ft of two former public-supply wells that tapped the unconfined aquifer.

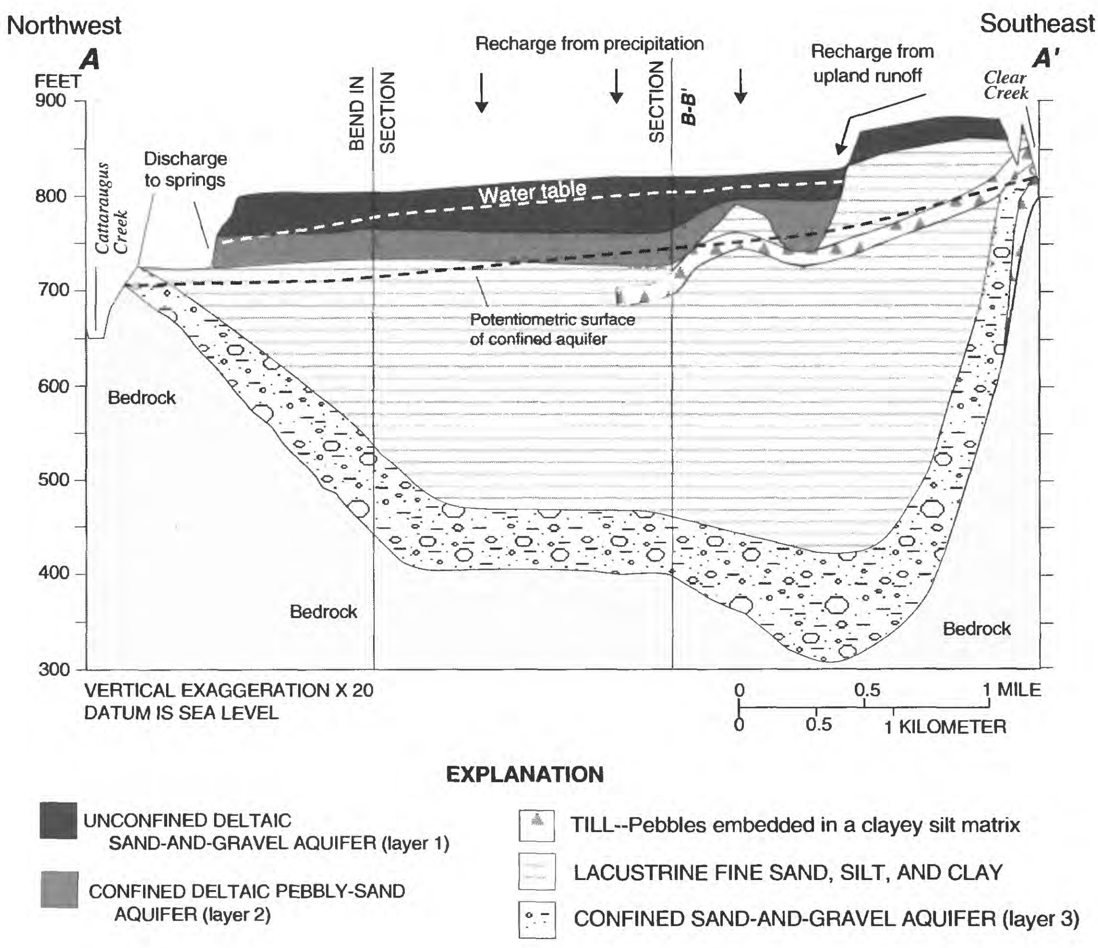


Figure 6. Conceptual model of ground-water flow system in the unconfined deltaic aquifer in the Cattaraugus Indian Reservation study area, southwestern New York. (Line of section is shown in fig. 3.)

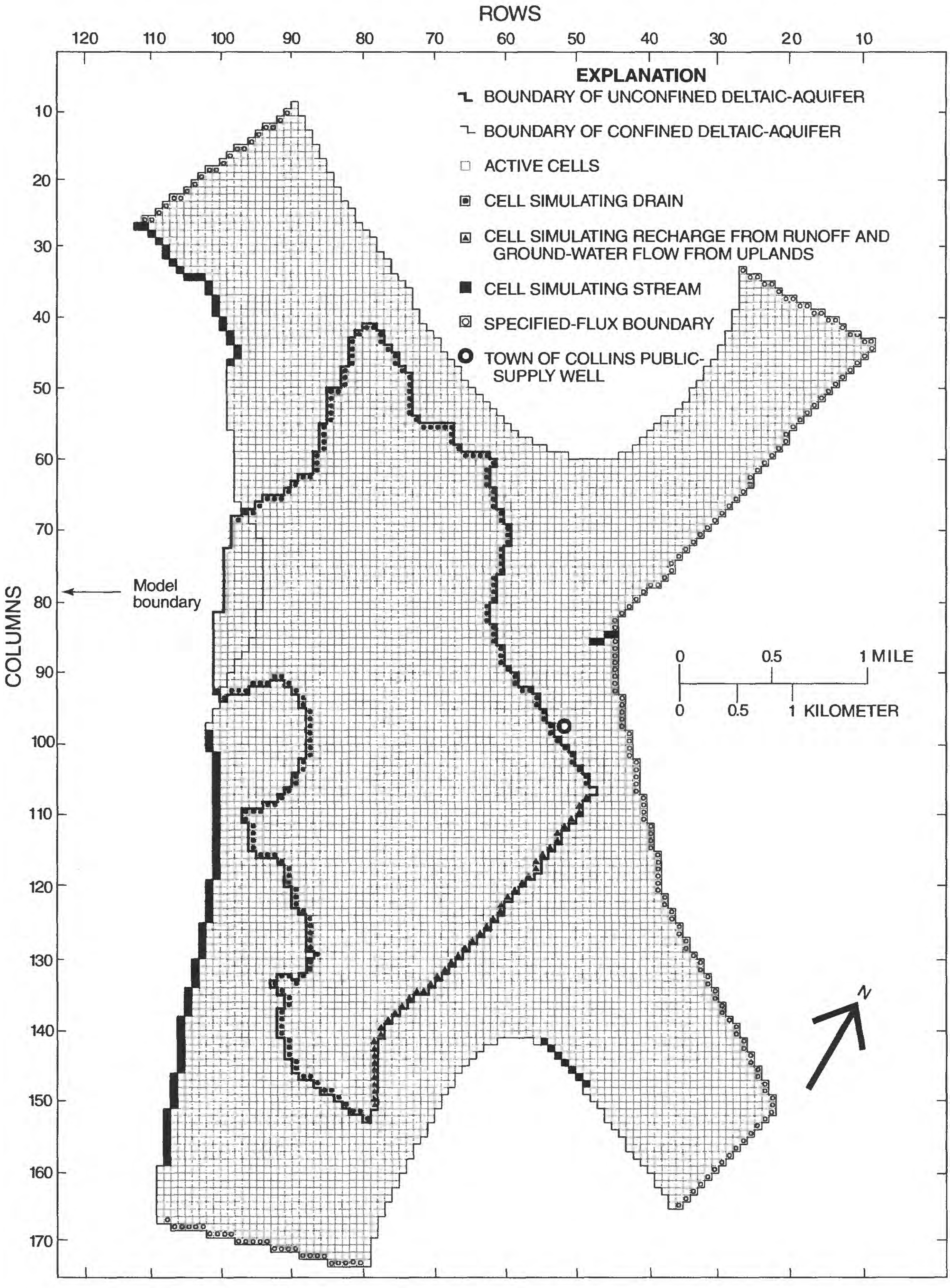


Figure 7. Active cells and grid boundaries in model of unconfined and confined deltaic aquifers in Cattaraugus Creek Valley, southwestern New York. (Grid location is shown in fig. 1.)

Storativity was estimated to be 0.0001, and the well's radius was 0.75 ft. Transmissivity was calculated from the following equation (Todd, 1980, eq. 4.70):

$$T = \left[\frac{2.3Q}{4\pi\, s}\log 2.25\frac{Tt}{r_w^2 S}\right]^{-1}, \qquad (2)$$

where

Q = well discharge, in cubic feet per day;
s = drawdown, in feet;
T = transmissivity, in square feet per day;
t = time of pumping, in days;
r_w = well radius, in feet; and
S = storativity, dimensionless.

The bottom of the deltaic aquifer (bottom of layer 2) slopes uniformly from an altitude of 795 ft in the southeastern part of the aquifer to 720 ft in the northwestern part. A horizontal hydraulic conductivity value of 25 ft/d, which is a typical for grain sizes ranging from fine to coarse sand (Heath, 1983), was used for layer 2.

Vertical hydraulic conductivity values for layers 1 and 2 were estimated to be 30 and 2.5 ft/d, respectively; these were calculated as the previously explained horizontal hydraulic conductivity values of 300 and 25 ft/d multiplied by 0.1 to represent an assumed anisotropy of 1:10. Vertical hydraulic conductivity in stratified drift tends to be less than horizontal hydraulic conductivity because, at a small scale, the stratified drift contains many layers of sediment, some of which consist of plate-shaped particles that tend to settle horizontally and, thus, impede the vertical flow of ground water. Vertical leakance between cells representing layers 1 and 2 was computed as 0.3 ft^2/d, from equation 51 of McDonald and Harbaugh (1988) for two vertically adjacent geohydrologic units, each unit with its own value of hydraulic conductivity, and an average thicknesses of 20 ft for layer 1 and 15 ft for layer 2.

Several types of boundary conditions were specified in the model to represent the unconfined aquifer (fig. 7). A specified-flux boundary, represented by recharge wells, was used along the southeastern border of the unconfined aquifer to simulate recharge from surface runoff and ground water flowing from bordering unchanneled uplands into the unconfined aquifer (layer 1). The drainage area of the unchanneled uplands was delineated on a map, and its size was measured by a digitizer. Then, the total recharge from this upland area (see eq. 1, p. 9) was divided by the number of bordering active model cells to obtain the recharge rate for each of these wells.

Ground-water discharge from seepage faces along the southern, western, and northern bluffs was simulated in the model by drains. The drains were placed along the bluffs at the bottom of the aquifer (bottom of layer 2), the elevation of which was obtained by test drilling. The altitude of the drains used in the model ranged from 810 ft in the southeastern parts of the model to 721 ft in the northwestern parts of the model. Each drain receives seepage from a grid cell at a rate proportional to the difference in elevation between the water table and the drain. The model calculates the rate of seepage between the drain and the aquifer through the equation:

$$Q = C(h-d), \qquad (3)$$

where

Q = seepage rate, cubic feet per day;
C = hydraulic conductance of the interface between the aquifer and the drain, in feet squared per day;
h = hydraulic head in the model cell, in feet; and
d = elevation of the drain, in feet above sea level.

Drain conductance as used in this study is defined as:

$$C = \frac{AK}{l}, \qquad (4)$$

where

A = average cross-sectional flow area, in square feet;
K = hydraulic conductivity of the interface, in feet per day; and
l = flowpath length, in feet.

An initial value of 100 ft^2/d for drain conductance was calculated from the above equation, from (1) a seepage-face area of 4,000 ft^2 (seepage-face height of 20 ft multiplied by a cell width of 200 ft), (2) a vertical hydraulic conductivity of 2.5 ft^2/d for the interface, and (3) a flowpath length of 100 ft. The final value used for the model was 145 ft^2/d, which was obtained through trial-and-error adjustments during model calibration.

Model Calibration

The model was calibrated by trial and error, which entails running the model with initial estimates of input values, then identifying where significant differences between measured and simulated values indicate a need for changes in selected input data. After appropriate changes to one or more input values, the model is run again, and the process is repeated until simulated values are acceptably close to measured values. Calibration was considered complete when the root mean squared error of differences between simulated and measured water levels was less than 2 ft (table 1).

Model Sensitivity

Sensitivity analyses were conducted to identify which model parameters, when varied, resulted in large changes in simulated heads. Future data-collection efforts can be directed to those aquifer properties to which the simulated heads were most sensitive.

Recharge, horizontal hydraulic conductivity of layers 1 and 2, vertical conductance between layers 1 and 2, and the vertical conductances between the aquifer and the drains were increased or decreased, one at a time, by a multiplication factor, and the effect on calculated heads at 12 observation wells was noted and is shown in figure 8. The vertical axis in figure 8 shows the root mean squared error between the computed and observed heads. The smallest root mean square of the difference between calculated and measured heads was 1.70 (table 1) for the final, calibrated model (multiplication factor equal to 1 in fig. 8). All other multiplication factors resulted in root mean squared errors greater than 1.70.

Results of the sensitivity analyses indicate that recharge, conductance between the aquifer and the drains, and the horizontal hydraulic conductivity of layer 1 had a relatively large effect on simulated heads (fig. 8), whereas vertical conductance between layers 1 and 2, and the horizontal hydraulic conductivity of layer 2, did not (fig. 8).

Table 1. Difference, and root mean square of the difference, between measured and simulated heads at 12 selected wells screened in the unconfined deltaic aquifer in the Cattaraugus Indian Reservation study area, southwestern New York

[Values are observed head minus simulated head in layer 1, in feet. Well locations shown in fig. 3]

Well No.	Location: Model row	Location: Model column	Difference between heads (X)	X^2
28	92	76	1.2	1.44
916	74	128	-.3	.09
917	86	113	-3.9	15.21
918	80	106	.8	.64
919	64	114	-.4	.16
920	67	110	.2	.04
921	77	105	.8	.64
922	68	105	-1.3	1.69
924	60	97	-2.8	7.84
926	77	75	1.6	2.56
928	71	110	-.9	.81
929	84	83	1.9	3.61
			TOTAL	34.78
			ROOT MEAN SQUARE	1.70

Model Application

The simulated water budget for long-term average, steady-state nonpumping conditions is given in table 2. The largest source of recharge to the unconfined aquifer (93 percent of total recharge) is from precipitation that directly falls on the aquifer; unchanneled runoff and ground-water inflow from the uplands together constitute the remaining 7 percent. All ground water was simulated as discharging to springs along the edges of the aquifer, although some may discharge to the underlying confining unit.

The calibrated model was then used to compute heads in the unconfined deltaic aquifer that would result from simulated pumping conditions and to estimate the area contributing recharge to a hypothetical pumped well at observation-well site 921 (fig. 9). The area contributing water to a pumped well is defined as the land-surface area within which water that infiltrates to the water table eventually flows to the pumping well.

The simulated pumped well in the central part of the model was 50 ft deep (the depth of the bottom of layer 1) and was "pumped" at a rate of 180 gal/min (34,650 ft^3/d). The flowpath analysis indicates that the well's contributing area is 0.32 mi wide and 1.33 mi long, and covers an area of 0.42 mi^2 (fig. 9). The longest flowpaths extend 1.33 mi from the well to the southeastern aquifer boundary. Maximum traveltimes of ground water flowing from the southeastern boundary to the well, based on an assumed porosity of 0.3 for the deltaic aquifer, ranged from 3.5 to 4.5 years.

Agricultural activity and a sand-and-gravel-washing operation 3,000 ft southeast of the simulated well (fig. 9) could adversely affect the water quality within the area contributing recharge to the well. Controlling land use in areas contributing recharge to public-supply wells is one effective approach to protecting the chemical quality of drinking water.

Table 2. Steady-state water budgets for the unconfined deltaic aquifer in the Cattaraugus Indian Reservation study area, southwestern New York

[Values are in cubic feet per day]

Budget component	Amount	Percent of total
A. Recharge to aquifer		
Precipitation on aquifer	666,350	93
Unchanneled runoff and ground-water inflow from uplands	50,400	7
TOTAL	716,750	100
B. Discharge from aquifer		
Seepage as springs along edges of aquifer	716,750	100
TOTAL	716,750	100

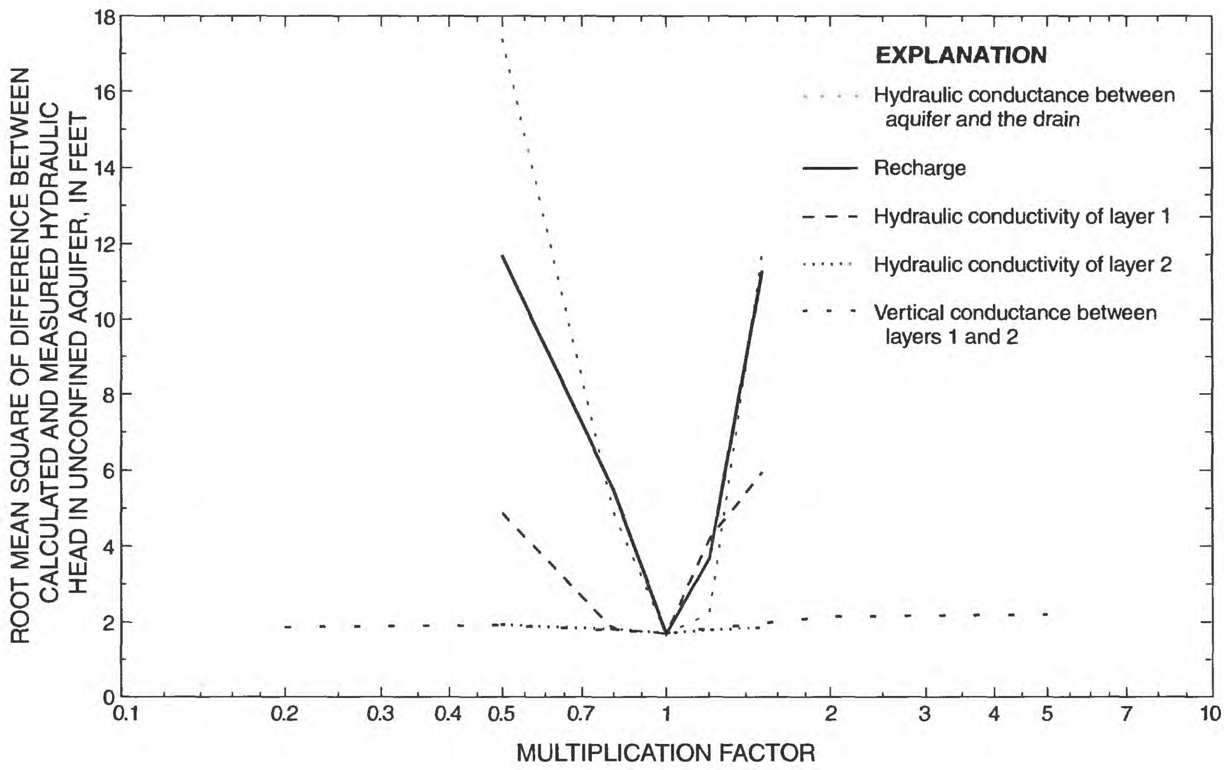
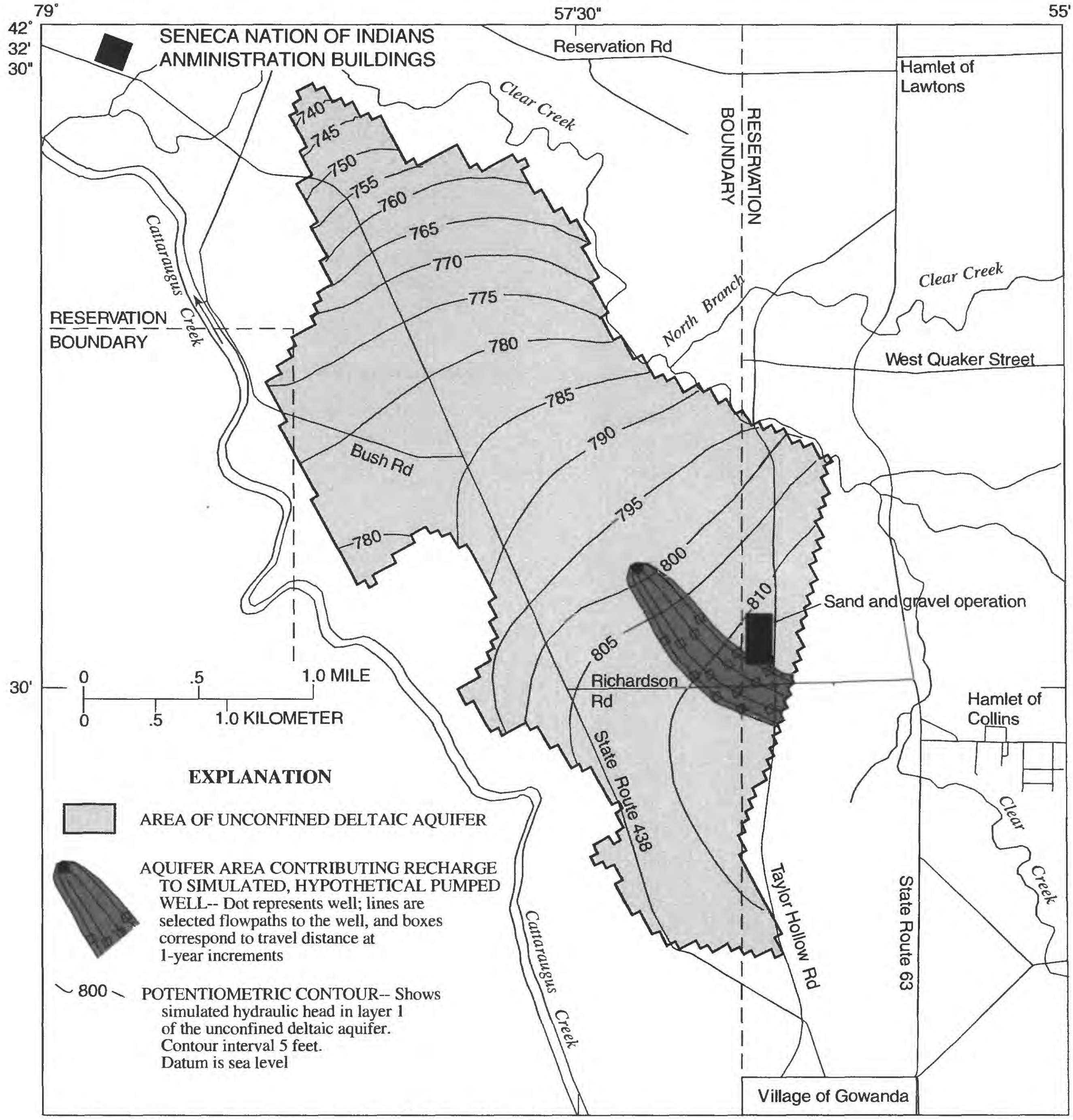


Figure 8. Results of sensitivity analyses for simulated hydraulic head in layer 1 of the unconfined deltaic aquifer in the Cattaraugus Indian Reservation study area, southwestern New York.



Base modified from U.S. Geological Survey digital data, 1:100,000, 1983
New York coordinate system, Western zone

Figure 9. Simulated heads in unconfined deltaic aquifer in Cattaraugus Indian Reservation study area, southwestern New York, during steady-state conditions, and area contributing recharge to a hypothetical well that withdraws ground water at a rate of 34,650 cubic feet per day (180 gallons per minute). (Location is shown in fig. 1.)

SUMMARY

The Seneca Nation of Indians at the Cattaraugus Indian Reservation needs to identify aquifer areas that are favorable for development of a public water supply because water from many domestic wells that tap bedrock, and parts of an overlying confined sand-and-gravel aquifer that lies on top of bedrock, contains dissolved barium in concentrations that exceed the New York State drinking-water standard of 1.0 mg/L. Most of the Reservation overlies the buried ancestral Allegheny River Valley, which is now occupied by Cattaraugus Creek. The valley contains as much as 550 ft of glacial drift, the upper part of which contains an unconfined deltaic aquifer that is typically 25 to 90 ft thick. The upper part of the deltaic aquifer consists of sand and gravel; the lower part is pebbly, fine to coarse sand. The deltaic aquifer overlies a 50- to 450-foot-thick sequence of mostly fine-grained sediments (till and lacustrine fine sand, silt, and clay) that, in turn, overlies a basal sand-and-gravel deposit whose thickness typically ranges from 10 to 80 ft but exceeds 100 ft in places. Shale that underlies the study area is relatively impermeable and forms the bottom of the confined sand-and-gravel aquifer.

Within the Reservation, large amounts of water are potentially available only from sand-and-gravel aquifers. These aquifers yield several tens of gallons per minute to domestic wells and from 150 to 400 gal/min to large-diameter screened municipal and industrial wells. Wells that tap bedrock typically yield only 0.25 to 5 gal/min. The unconfined aquifer was identified during this study as the unit that could supply the greatest amount of potable water to the Reservation because several large-diameter wells have pumped as much as 400 gal/min from this aquifer and because barium concentrations in wells that tap similar shallow unconsolidated aquifers in western New York typically are below the New York State drinking-water standard.

The unconfined deltaic aquifer receives recharge from two sources— infiltration of precipitation over the aquifer, and upland sources along the southeastern border of the aquifer, such as runoff from unchanneled hillsides and seepage from adjacent till and bedrock. Cattaraugus Creek and Clear Creek have incised through the deltaic aquifer, leaving a plateau with 80- to 100-foot high bluffs along its southern, western, and northern edges. All water in the unconfined aquifer discharges to springs near the base of these bluffs.

Water samples from 14 wells that were completed in the unconfined deltaic aquifer during this study were analyzed for specific conductance, pH, and concentrations of common ions, nutrients, trace metals, volatile organic compounds, insecticides, and herbicides. All samples met New York State drinking-water standards except those from one well (no. 917), in which the nitrate concentration was 12.0 mg/L.

A three-dimensional numerical ground-water-flow model was developed to compute hydraulic heads and a water budget for the unconfined deltaic aquifer under steady-state, nonpumping conditions. The unconfined aquifer was represented by two layers; layer 1 (top layer) represents the surficial sand-and-gravel deposits, and layer 2 represents the underlying pebbly sand that overlies the lacustrine confining unit in the central parts of the valley.

The model-computed water budget indicated that 93 percent of recharge to the unconfined deltaic aquifer is from precipitation that falls directly falls on the aquifer, and 7 percent is unchanneled runoff and ground-water inflow from the uplands.

A flowpath analysis indicates that the area contributing recharge to a hypothetical pumped well is in a part of the aquifer that is favorable for development of ground-water resources adequate for public supply. Land uses within the contributing area that could adversely affect the quality of water pumped from the well include agricultural activities and a sand-and-gravel-washing operation 3,000 ft southeast of the simulated well.

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Table 3. Results of chemical analyses of water samples from selected wells completed in the unconfined deltaic aquifer in the Cattaraugus Indian Reservation study area, southwestern New York, August 2-3, 1994

[ft, feet; µS/cm, microsiemens per centimeter at 25°C; <, less than. Well locations are shown in fig. 3. Analysis by U.S. Geological Survey laboratory, Arvada, Colo.]

A. PHYSICAL PROPERTIES AND NUTRIENTS, in milligrams per liter unless otherwise noted

USGS site identification No.	Local identifier	Date (m-d-y)	Land-surface elevation (ft above mean sea level)	Depth of well (ft)	Specific conductance (µS/cm)	Alkalinity as $CaCO_3$	pH, lab (standard units)	Nitrogen, ammonia dissolved	Nitrogen, nitrite dissolved	Nitrogen, ammonia + organic dissolved	Nitrogen, ammonia + organic total	Nitrogen NO_2+NO_3, dissolved	Phosphorus, total	Phosphorus, dissolved	Phosphorous ortho, dissolved
422945078564501	916	08-03-94	833	41	524	216	7.6	0.160	<0.010	0.50	0.60	4.80	0.020	<0.010	<0.010
422959078573101	917	08-03-94	830	35	781	196	7.3	0.070	<0.010	0.40	4.8	12.0	1.50	<0.010	<0.010
423017078563901	919	08-02-94	825	32	742	245	7.3	0.120	0.020	0.70	1.2	2.90	0.170	0.060	0.070
423017078572601	918	08-03-94	824	25	515	238	7.5	0.050	<0.010	0.30	3.1	1.10	1.30	<0.010	<0.010
423018078570001	928	08-02-94	823	29	583	223	7.2	0.090	<0.010	0.50	1.7	2.00	0.500	0.050	0.060
423022078565201	920	08-02-94	822	24	690	228	7.3	0.060	<0.010	0.40	0.90	1.90	0.080	<0.010	<0.010
423026078571101	921	08-03-94	821	40	542	181	7.5	0.030	<0.010	<0.20	0.20	1.40	0.060	<0.010	<0.010
423030078570001	922	08-02-94	820	56	709	236	7.5	0.050	<0.010	0.30	0.60	4.50	0.050	<0.010	<0.010
423037078574401	923	08-03-94	818	45	536	206	7.5	0.040	<0.010	<0.20	0.20	0.940	0.050	<0.010	<0.010
423040078570001	927	08-03-94	817	40	663	222	7.4	0.050	0.010	<0.20	0.60	9.70	0.150	<0.010	<0.010
423051078580701	929	08-02-94	811	45	842	236	7.4	0.020	<0.010	<0.20	<0.20	2.30	<0.010	<0.010	<0.010
423052078565301	924	08-03-94	817	43	650	235	7.4	0.050	<0.010	0.20	<0.20	9.20	0.020	<0.010	<0.010
423100078580701	930	08-02-94	810	38	641	242	7.5	0.020	<0.010	<0.20	<0.20	4.00	<0.010	<0.010	<0.010
423113078573701	926	08-03-94	804	40	568	234	7.4	0.070	<0.010	0.30	0.20	3.30	<0.010	0.010	<0.010

Table 3. Results of chemical analyses of water samples from selected wells completed in the unconfined deltaic aquifer in the Cattaraugus Indian Reservation study area, southwestern New York, August 2-3, 1994—*Continued*

B. COMMON IONS AND METALS, dissolved, in milligrams per liter

USGS site-identification No.	Local identifier	Date (m-d-y)	Calcium	Mag-nesium	Sodium	Chloride	Fluoride	Silica	Barium	Beryllium	Cadmium	Chro-mium	Cobalt
422945078564501	916	08-03-94	77	17	4.5	10	0.10	12	400	<0.50	<1.0	<5.0	<3.0
422959078573101	917	08-03-94	92	17	39	71	0.10	8.6	110	<0.50	<1.0	<5.0	<3.0
423017078563901	919	08-02-94	100	20	21	43	0.10	8.4	160	<0.50	<1.0	<5.0	<3.0
423017078572601	918	08-03-94	84	13	4.5	3.9	--	9.2	58	<0.50	<1.0	<5.0	<3.0
423018078570001	928	08-02-94	86	17	8.7	20	--	9.6	170	<0.50	<1.0	<5.0	<3.0
423022078565201	920	08-02-94	95	18	17	37	--	8.5	160	<0.50	<1.0	<5.0	<3.0
423026078571101	921	08-03-94	80	17	6.3	17	0.10	9.8	170	<0.50	<1.0	<5.0	<3.0
423030078570001	922	08-02-94	100	18	18	42	--	8.3	190	<0.50	<1.0	<5.0	<3.0
423037078574401	923	08-03-94	84	17	3.2	6.9	--	9.5	140	<0.50	<1.0	<5.0	<3.0
423040078570001	927	08-03-94	93	17	15	30	--	9.1	180	<0.50	<1.0	<5.0	<3.0
423051078580701	929	08-02-94	110	22	37	91	--	10	200	<0.50	<1.0	<5.0	<3.0
423052078565301	924	08-03-94	93	17	15	33	--	11	130	<0.50	<1.0	<5.0	<3.0
423100078580701	930	08-02-94	96	20	7.4	25	<0.10	9.8	220	<0.50	<1.0	<5.0	<3.0
423113078573701	926	08-03-94	85	18	4.7	19	--	9.0	160	<0.50	1.0	<5.0	<3.0

Local identifier	Date	Copper	Iron	Lead	Manganese	Molybdenum	Nickel	Silver	Strontium	Vanadium	Zinc	Aluminum	Lithium
916	08-03-94	<10	7.0	<10	360	<10	<10	<1.0	280	<6	17	20	6
917	08-03-94	<10	<3.0	20	82	<10	<10	<1.0	130	<6	<3.0	<10	10
919	08-02-94	10	<3.0	<10	91	<10	<10	<1.0	150	<6	14	20	5
918	08-03-94	<10	<3.0	20	19	<10	<10	<1.0	110	<6	<3.0	<10	<4
928	08-02-94	<10	<3.0	30	15	<10	<10	<1.0	140	<6	5.0	<10	12
920	08-02-94	<10	<3.0	20	97	<10	<10	<1.0	120	<6	<3.0	<10	8
921	08-03-94	<10	<3.0	20	6.0	<10	<10	<1.0	130	<6	<3.0	<10	11
922	08-02-94	<10	<3.0	20	50	<10	<10	<1.0	140	<6	7.0	<10	13
923	08-03-94	<10	<3.0	10	40	<10	<10	<1.0	110	<6	5.0	<10	9
927	08-03-94	<10	<3.0	<10	57	<10	<10	1.0	120	<6	6.0	<10	9
929	08-02-94	<10	6.0	<10	3.0	<10	<10	2.0	120	<6	14	<10	13
924	08-03-94	<10	<3.0	30	11	<10	<10	1.0	120	<6	12	<10	5
930	08-02-94	<10	<3.0	<10	<1.0	<10	<10	<1.0	110	<6	7.0	<10	9
926	08-03-94	<10	<3.0	10	67	<10	<10	1.0	100	<6	12	<10	13

Table 3. Results of chemical analyses of water samples from selected wells completed in the unconfined deltaic aquifer in the Cattaraugus Indian Reservation study area, southwestern New York, August 2-3, 1994—*Continued*

C. ORGANOCHLORINE INSECTICIDES, total, in micrograms per liter

Local identifier	Date (m-d-y)	*alpha*-Hexachlorocyclohexane	*beta*-Hexachlorocyclohexane	Lindane	*delta*-Hexachlorocyclohexane	Heptachlor	Aldrin	Heptachlor-epoxide	*trans*-Chlordane	Endosulfan I	*cis*-Chlordane	Dieldrin	*p,p'*-DDE	Eldrin	Endosulfan II
916	08-03-94	<0.030	<0.030	<0.030	<0.090	<0.030	<0.040	<0.800	<0.100	<0.100	<0.100	<0.020	<0.040	<0.060	<0.040
917	08-03-94	<0.030	<0.030	<0.030	<0.090	<0.030	<0.040	<0.800	<0.100	<0.100	<0.100	<0.020	<0.040	<0.060	<0.040
919	08-02-94	<0.030	<0.030	<0.030	<0.090	<0.030	<0.040	<0.800	<0.100	<0.100	<0.100	<0.020	<0.040	<0.060	<0.040
918	08-03-94	--	--	--	--	--	--	--	--	--	--	--	--	--	--
928	08-02-94	<0.030	<0.030	<0.030	<0.090	<0.030	<0.040	<0.800	<0.100	<0.100	<0.100	<0.020	<0.040	<0.060	<0.040
920	08-02-94	<0.030	<0.030	<0.030	<0.090	<0.030	<0.040	<0.800	<0.100	<0.100	<0.100	<0.020	<0.040	<0.060	<0.040
921	08-03-94	<0.030	<0.030	<0.030	<0.090	<0.030	<0.040	<0.800	<0.100	<0.100	<0.100	<0.020	<0.040	<0.060	<0.040
922	08-02-94	<0.030	<0.030	<0.030	<0.090	<0.030	<0.040	<0.800	<0.100	<0.100	<0.100	<0.020	<0.040	<0.060	<0.040
923	08-03-94	<0.030	<0.030	<0.030	<0.090	<0.030	<0.040	<0.800	<0.100	<0.100	<0.100	<0.020	<0.040	<0.060	<0.040
927	08-03-94	<0.030	<0.030	<0.030	<0.090	<0.030	<0.040	<0.800	<0.100	<0.100	<0.100	<0.020	<0.040	<0.060	<0.040
929	08-02-94	--	--	--	--	--	--	--	--	--	--	--	--	--	--
924	08-03-94	<0.030	<0.030	<0.030	<0.090	<0.030	<0.040	<0.800	<0.100	<0.100	<0.100	<0.020	<0.040	<0.060	<0.040
930	08-02-94	--	--	--	--	--	--	--	--	--	--	--	--	--	--
926	08-03-94	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Local identifier	Date (m-d-y)	*p,p'*-DDD	Endrin aldehyde	Endosulfan sulfate	*p,p'*-DDT	Chlordane, total	Toxaphene	Aroclor 1221 PCB	Aroclor 1232 PCB	Aroclor 1016 PCB	Aroclor 1242 PCB	Aroclor 1248 PCB	Aroclor 1254 PCB	Aroclor 1260 PCB
916	08-03-94	<0.100	<0.200	<0.600	<0.100	<0.100	<2.00	<1.00	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
917	08-03-94	<0.100	<0.200	<0.600	<0.100	<0.100	<2.00	<1.00	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
919	08-02-94	<0.100	<0.200	<0.600	<0.100	<0.100	<2.00	<1.00	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
918	08-03-94	--	--	--	--	--	--	--	--	--	--	--	--	--
928	08-02-94	<0.100	<0.200	<0.600	<0.100	<0.100	<2.00	<1.00	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
920	08-02-94	<0.100	<0.200	<0.600	<0.100	<0.100	<2.00	<1.00	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
921	08-03-94	<0.100	<0.200	<0.600	<0.100	<0.100	<2.00	<1.00	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
922	08-02-94	<0.100	<0.200	<0.600	<0.100	<0.100	<2.00	<1.00	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
923	08-03-94	<0.100	<0.200	<0.600	<0.100	<0.100	<2.00	<1.00	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
927	08-03-94	<0.100	<0.200	<0.600	<0.100	<0.100	<2.00	<1.00	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
929	08-02-94	--	--	--	--	--	--	--	--	--	--	--	--	--
924	08-03-94	<0.100	<0.200	<0.600	<0.100	<0.100	<2.00	<1.00	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
930	08-02-94	--	--	--	--	--	--	--	--	--	--	--	--	--
926	08-03-94	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 3. Results of chemical analyses of water samples from selected wells completed in the unconfined deltaic aquifer in the Cattaraugus Indian Reservation study area, southwestern New York, August 2-3, 1994—*Continued*

D. TRIAZINE HERBICIDES, total, in micrograms per liter

Local identifier	Date (m-d-y)	Prometryne	Atrazine	Prometone	Simezine	Sime-tryne	Propazine	Cyanazine	Alachlor	Trifluralin	Metribuzin	Metolachlor	Terbacil
916	08-03-94	<0.100	<0.100	<0.200	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.100	<0.200	<0.200
917	08-03-94	<0.100	<0.100	<0.200	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.100	<0.200	<0.200
919	08-02-94	<0.100	<0.100	<0.200	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.100	<0.200	<0.200
918	08-03-94	--	--	--	--	--	--	--	--	--	--	--	--
928	08-02-94	<0.100	<0.100	<0.200	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.100	<0.200	<0.200
920	08-02-94	<0.100	<0.100	<0.200	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.100	<0.200	<0.200
921	08-03-94	<0.100	<0.100	<0.200	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.100	<0.200	<0.200
922	08-02-94	<0.100	<0.100	<0.200	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.100	<0.200	<0.200
923	08-03-94	<0.100	<0.100	<0.200	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.100	<0.200	<0.200
927	08-03-94	<0.100	<0.100	<0.200	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.100	<0.200	<0.200
929	08-02-94	--	--	--	--	--	--	--	--	--	--	--	--
924	08-03-94	<0.100	0.100	<0.200	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.100	<0.200	<0.200
930	08-02-94	--	--	--	--	--	--	--	--	--	--	--	--
926	08-03-94	--	--	--	--	--	--	--	--	--	--	--	--

Local identifier	Date (m-d-y)	Bromacil	Carboxin	Diphenamid	Hexazinone	Vernolate	Butachlor	Cycloate	Butylate	Propachlor	De-ethyl atrazine	De-isopropyl atrazine
916	08-03-94	<0.200	<0.200	<0.100	<0.200	<0.100	<0.100	<0.100	<0.100	<0.100	<0.200	<0.200
917	08-03-94	<0.200	<0.200	<0.100	<0.200	<0.100	<0.100	<0.100	<0.100	<0.100	<0.200	<0.200
919	08-02-94	<0.200	<0.200	<0.100	<0.200	<0.100	<0.100	<0.100	<0.100	<0.100	<0.200	<0.200
918	08-03-94	--	--	--	--	--	--	--	--	--	--	--
928	08-02-94	<0.200	<0.200	<0.100	<0.200	<0.100	<0.100	<0.100	<0.100	<0.100	<0.200	<0.200
920	08-02-94	<0.200	<0.200	<0.100	<0.200	<0.100	<0.100	<0.100	<0.100	<0.100	<0.200	<0.200
921	08-03-94	<0.200	<0.200	<0.100	<0.200	<0.100	<0.100	<0.100	<0.100	<0.100	<0.200	<0.200
922	08-02-94	<0.200	<0.200	<0.100	<0.200	<0.100	<0.100	<0.100	<0.100	<0.100	<0.200	<0.200
923	08-03-94	<0.200	<0.200	<0.100	<0.200	<0.100	<0.100	<0.100	<0.100	<0.100	<0.200	<0.200
927	08-03-94	<0.200	<0.200	<0.100	<0.200	<0.100	<0.100	<0.100	<0.100	<0.100	<0.200	<0.200
929	08-02-94	--	--	--	--	--	--	--	--	--	--	--
924	08-03-94	<0.200	<0.200	<0.100	<0.200	<0.100	<0.100	<0.100	<0.100	<0.100	<0.200	<0.200
930	08-02-94	--	--	--	--	--	--	--	--	--	--	--
926	08-03-94	--	--	--	--	--	--	--	--	--	--	--

Table 3. Results of chemical analyses of water samples from selected wells completed in the unconfined deltaic aquifer in the Cattaraugus Indian Reservation study area, southwestern New York, August 2-3, 1994—*Continued*

E. CARBAMATE INSECTICIDES total, in micrograms per liter

Local identifier	Date (m-d-y)	Carbaryl	Propham	Methomyl	Carbofuran	Aldicarb	1-Naphthol	Propoxur	Methiocarib
916	08-03-94	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500
917	08-03-94	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500
919	08-02-94	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500
918	08-03-94	--	--	--	--	--	--	--	--
928	08-02-94	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500
920	08-02-94	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500
921	08-03-94	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500
922	08-02-94	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500
923	08-03-94	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500
927	08-03-94	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500
929	08-02-94	--	--	--	--	--	--	--	--
924	08-03-94	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500
930	08-02-94	--	--	--	--	--	--	--	--
926	08-03-94	--	--	--	--	--	--	--	--

Table 3. Results of chemical analyses of water samples from selected wells completed in the unconfined deltaic aquifer in the Cattaraugus Indian Reservation study area, southwestern New York, August 2-3, 1994—*Continued*

F. VOLATILE ORGANIC COMPOUNDS total, in micrograms per liter

Local identifier	Date (m-d-y)	Dibromo-methane	Benzene	Bromo-form	Carbon-tetra-chloride	Chloro-benzene	Chloro-dibromo-methane	Chloro-ethane	Chloro-form	Bromo-dichloro-methane	Dichloro-difluoro-methane	1,1-Dichloro-ethane	1,2-Dichloro-ethane	1,1-Dichloro-ethene	*trans*-1,2-Dichloro-ethene
916	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	0.400	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
917	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	0.500	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
919	08-02-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
918	08-03-94	--	--	--	--	--	--	--	--	--	--	--	--	--	--
928	08-02-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
920	08-02-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
921	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
922	08-02-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	0.400	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
923	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	0.400	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
927	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
929	08-02-94	--	--	--	--	--	--	--	--	--	--	--	--	--	--
924	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
930	08-02-94	--	--	--	--	--	--	--	--	--	--	--	--	--	--
926	08-03-94	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Local identifier	Date (m-d-y)	1,2-Dichloro-propane	Ethyl-benzene	Methyl-bromide	Methylene chloride	1,1,2,2-Tetra-chloro-ethane	Tetra-chloro-ethene	Toluene	1,1,1-Trichloro-ethane	1,1,2-Trichloro-ethane	Trichloro-ethene	Trichloro-fluoro-methane	Vinyl chloride	1,3-Dichloro-benzene
916	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
917	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
919	08-02-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
918	08-03-94	--	--	--	--	--	--	--	--	--	--	--	--	--
928	08-02-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
920	08-02-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
921	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
922	08-02-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
923	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
927	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	0.300	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
929	08-02-94	--	--	--	--	--	--	--	--	--	--	--	--	--
924	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
930	08-02-94	--	--	--	--	--	--	--	--	--	--	--	--	--
926	08-03-94	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 3. Results of chemical analyses of water samples from selected wells completed in the unconfined deltaic aquifer in the Cattaraugus Indian Reservation study area, southwestern New York, August 2-3, 1994 —*Continued*

F. VOLATILE ORGANIC COMPOUNDS—*Continued*, total, in micrograms per liter

Local identi-fier	Date (m-d-y)	1,4-Dichloro-benzene	1,2-Dibromo-ethane	Chloro-methane	*o*-Dichloro-benzene	*Cis*-1,3-Dichloro-propene	*Trans*-1,3-Dichloro-propene	Styrene	Xylene	Dibromo-chloro-propane	1,1-Dichloro-propene	2,2-Dichloro-propane	1,3-Dichloro-propane	*o*-Chloro-toluene	Toluene *p*-chlor	1,2,3-Trichloro-propane
916	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<1.00	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
917	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<1.00	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
919	08-02-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<1.00	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
918	08-03-94	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
928	08-02-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<1.00	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
920	08-02-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<1.00	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
921	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<1.00	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
922	08-02-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<1.00	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
923	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<1.00	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
927	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	0.400	<1.00	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
929	08-02-94	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
924	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<1.00	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
930	08-02-94	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
926	08-03-94	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Local identi-fier	Date (m-d-y)	1,1,1,2-Tetra-chloro-ethane	Acrolein	Acryl-olein	Methyl *tert*-butyl ether	Bromo-chloro-methane	*cis*-1,2-Dichloro-ethene	2-Chloro-ethyl vinyl ether	Iso-propyl-benzene	*n*-Propyl-benzene	*t*-Butyl-benzene	1,2,4-Tri-methyl-benzene	*sec*-Butyl-benzene	*p*-Iso-propyl-toluene	*n*-Butyl-benzene	1,2,4-Tri-chloro-benzene
916	08-03-94	<0.200	<20.0	<20.0	<0.200	<0.200	<0.200	<1.00	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
917	08-03-94	<0.200	<20.0	<20.0	<0.200	<0.200	<0.200	<1.00	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
919	08-02-94	<0.200	<20.0	<20.0	<0.200	<0.200	<0.200	<1.00	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
918	08-03-94	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
928	08-02-94	<0.200	<20.0	<20.0	<0.200	<0.200	<0.200	<1.00	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
920	08-02-94	<0.200	<20.0	<20.0	<0.200	<0.200	<0.200	<1.00	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
921	08-03-94	<0.200	<20.0	<20.0	<0.200	<0.200	<0.200	<1.00	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
922	08-02-94	<0.200	<20.0	<20.0	<0.200	<0.200	<0.200	<1.00	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
923	08-03-94	<0.200	<20.0	<20.0	<0.200	<0.200	<0.200	<1.00	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
927	08-03-94	<0.200	<20.0	<20.0	<0.200	<0.200	<0.200	<1.00	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
929	08-02-94	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
924	08-03-94	<0.200	<20.0	<20.0	<0.200	<0.200	<0.200	<1.00	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
930	08-02-94	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
926	08-03-94	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 3. Results of chemical analyses of water samples from selected wells completed in the unconfined deltaic aquifer in the Cattaraugus Indian Reservation study area, southwestern New York, August 2-3, 1994—*Continued*

F. VOLATILE ORGANIC COMPOUNDS—*Continued*, total, in micrograms per liter

Local identifier	Date (m-d-y)	Hexa-chloro-butadiene	Naph-thalene	1,2,3-Trichloro-benzene	Freon-113	1,3,5-Trimethyl-benzene	Bromo-benzene
916	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
917	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
919	08-02-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
918	08-03-94	--	--	--	--	--	--
928	08-02-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
920	08-02-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
921	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
922	08-02-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
923	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
927	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
929	08-02-94	--	--	--	--	--	--
924	08-03-94	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
930	08-02-94	--	--	--	--	--	--
926	08-03-94	--	--	--	--	--	--