# SIMULATION OF GROUND-WATER FLOW PATHS AND TRAVELTIME IN RELATION TO TRITIUM AND ALDICARB CONCENTRATIONS IN THE UPPER GLACIAL AQUIFER ON THE NORTH FORK, LONG ISLAND, NEW YORK

by Debra E. Bohn-Buxton, Herbert T. Buxton, and
Valerie-ann K. Eagen

---

U.S. GEOLOGICAL SURVEY
Open-File Report 95-761

Prepared in cooperation with the
SUFFOLK COUNTY DEPARTMENT OF
HEALTH SERVICES and the
SUFFOLK COUNTY WATER AUTHORITY

Coram, New York
1996

**U.S. DEPARTMENT OF THE INTERIOR**
**BRUCE BABBITT, Secretary**

U.S. Geological Survey
Gordon P. Eaton, Director

For additional information
write to:

U.S. Geological Survey
2045 Route 112, Bldg. 4
Coram, NY 11727

Copies of this report may be
purchased from:

U.S. Geological Survey
Earth Science Information Center
Open-File Reports Section
P.O. Box 25286, MS 517
Denver Federal Center
Denver, CO 80225

# CONTENTS



## FIGURES

FIGURES (continued)



TABLES

## CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

| Multiply | By | To obtain |
|---|---|---|
| | **Length** | |
| inch (in.) | 2.54 | centimeter |
| inch (in.) | 25.40 | millimeter |
| foot (ft) | 0.3048 | meter |
| mile (mi) | 1.609 | kilometer |
| | **Area** | |
| acre | 0.4047 | hectare |
| square foot ($ft^2$) | 0.09294 | square meter |
| | **Hydraulic Conductivity** | |
| foot per day (ft/d) | 0.3048 | meter per day |
| | **Mass** | |
| pound, avoirdupois (lb) | 4.536 | kilogram |
| | **Temperature** | |
| degree Fahrenheit (°F) | 5/9 x (°F-32) | degree Celsius |
| | **Other** | |
| pound (avoirdupois) per acre (lb/acre) | 1.121 | kilogram per hectare |

| Other abbreviations used in this report |
|---|
| micrograms per liter (µg/L) |
| pico curies per liter (pCi/L) |
| tritium units (TU) |
| gram per cubic centimeter ($g/cm^3$) |

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.

# SIMULATION OF GROUND-WATER FLOW PATHS AND TRAVELTIME IN RELATION TO TRITIUM AND ALDICARB CONCENTRATIONS IN THE UPPER GLACIAL AQUIFER ON THE NORTH FORK, LONG ISLAND, NEW YORK

by Debra E. Bohn-Buxton, Herbert T. Buxton, and Valerie-ann K. Eagen

## Abstract

Contamination of ground water by agricultural pesticides is a major concern on the North Fork of eastern Long Island because the shallow ground-water system is the sole source of drinking water. Ground water was contaminated from 1975-79 through use of the oxime-carbamate pesticide aldicarb, which was used to kill the golden nematode and Colorado potato beetle. Aldicarb was believed to have less than a 7-day half-life and was not expected to leach into the ground-water system, but Long Island's humid, temperate climate and sandy, permeable soils allowed this chemical to enter the ground water. By 1979, aldicarb and its toxic degradation products had contaminated the ground water.

Ground-water-flow models of two vertical sections on the North Fork—one in Cutchogue and one in Jamesport—were developed. The models were used to construct numerical flow nets for which ground-water travel times were calculated. Calculations indicate that, under natural (nonpumping) conditions, ground-water flow has large vertical components and ground-water travel time increases with depth.

Aldicarb concentrations along the modeled sections indicate that the movement of aldicarb is characterized by a horizontal front, and that aldicarb dispersed within ground water in a conservative manner, with virtually no decay, during 1975-82. Analysis of water-quality data collected in 1988 shows that aldicarb had persisted throughout the thickness of the aquifer in the northern half of the section at Jamesport, an area in which downward movement is probably accelerated by pumping for irrigation. These data also appear to indicate that aldicarb has dissipated in the section at Cutchogue, but this has not been verified because the area does not have wells screened in the depth zone that is estimated to contain water 9 to 13 years old—the age of water affected by aldicarb.

## INTRODUCTION

The contamination of ground water by agricultural pesticides is a major concern on the North Fork of eastern Long Island (fig. 1), where the shallow, unconfined ground-water system is the sole source of drinking water. Most of the land on the North Fork has been under cultivation for more than 200 years. Recent commercial and residential development has claimed some of the land, but a large amount is still devoted to agriculture (fig. 2).

Potatoes thrive in the local sandy soils and, with the introduction of commercially prepared fertilizers in the mid 1870's (Talmage, 1977), they became the main cash crop. The potato plant attracts several types of insects, the most damaging of which are the golden nematode and Colorado potato beetle. Pesticides have been applied since the early 1950's to combat these pests. During 1975-79, the oxime-carbamate pesticide aldicarb was applied to agricultural land throughout eastern Suffolk County. Although aldicarb was

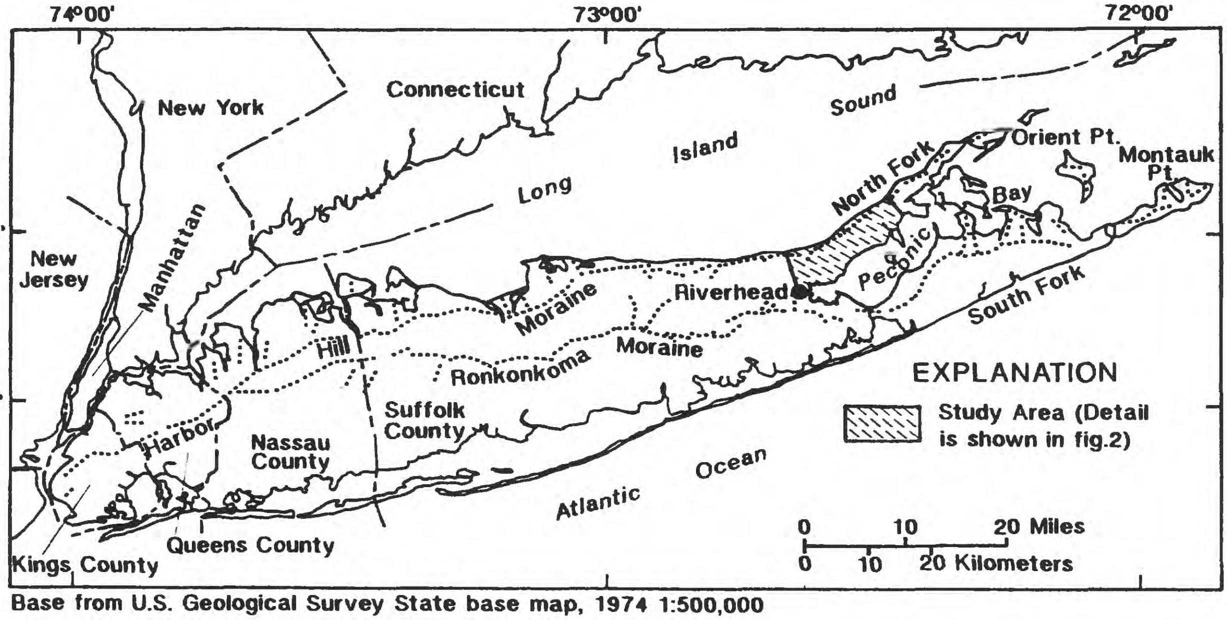



**Figure 1.** Location of study area on North Fork of Suffolk County, N.Y.

believed by the manufacturer to have less than a single 7-day half life and, therefore, was not expected to leach into the ground-water system, Long Island's humid, temperate climate and highly permeable, sandy soils allowed the aldicarb to leach rapidly to the water table. In 1979, the Cornell University Agricultural Research station at Riverhead (fig. 1) found that aldicarb had entered the water-table aquifer, and ground-water sampling in 1980 by the Suffolk County Department of Health Services (SCDHS) delineated an extensive area of contamination (Soren and Stelz, 1984).

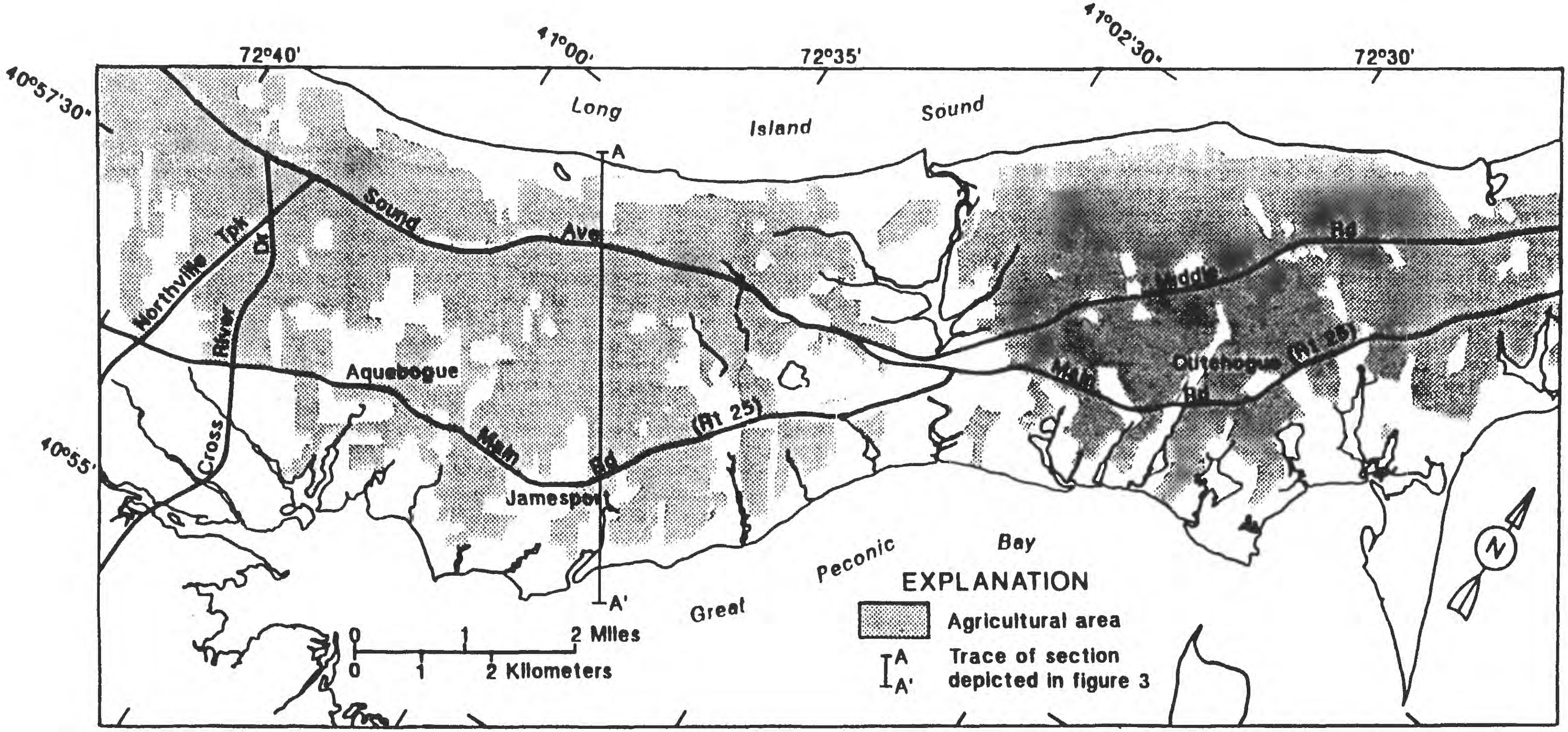
In 1980, at the manufacturer's request, the U.S. Environmental Protection Agency called for a halt to the use of aldicarb on Long Island, and the New York State Department of Health set an interim maximum aldicarb concentration of 7 µg/L in drinking water.

A study conducted during 1982 on a small, representative area of the North Fork by the U.S. Geological Survey (USGS), in cooperation with the SCDHS and Suffolk County Water Authority (SCWA), investigated the extent of the aldicarb contamination. Aldicarb had been used on about 24,000 acres of potato farms during 1975-79. The residence time, calculated from water-table gradients, indicates that aldicarb would remain in the shallow ground-water system until between 1990 and 2030 (Soren and Stelz, 1984). In 1992, the SCDHS was monitoring aldicarb concentrations in private drinking-supply wells and tracking the movement of aldicarb within the ground-water system.

In response to concern over the persistence of aldicarb in this shallow ground-water system, the USGS, in cooperation with SCDHS and SCWA, began a 1-1/2 year investigation in 1988 that used numerical flow-net analysis to identify the directions and rates of ground-water movement on the western half of the North Fork (fig. 1, fig. 3) and to estimate residence time of aldicarb in the system.

## Purpose and Scope

This report describes the ground-water flow paths and distribution of ground-water age in the upper glacial aquifer on the North Fork of Long Island, and the use of these results to help explain the distribution of aldicarb in ground water. The report includes (1) a description of the hydrogeology of the study area, including the geologic framework, the location and configuration of the saltwater/freshwater interface, and




Base from Department of Transportation topographic maps Southampton, Mattituck, Mattituck Hills, Riverhead, and Southold 1:24,000

**Figure 2.** Location of agricultural land within the study area and location of section A-A′ on the North Fork of Long Island, N.Y. (Modified from Long Island Regional Planning Board, 1982. Location is shown in fig. 1.)

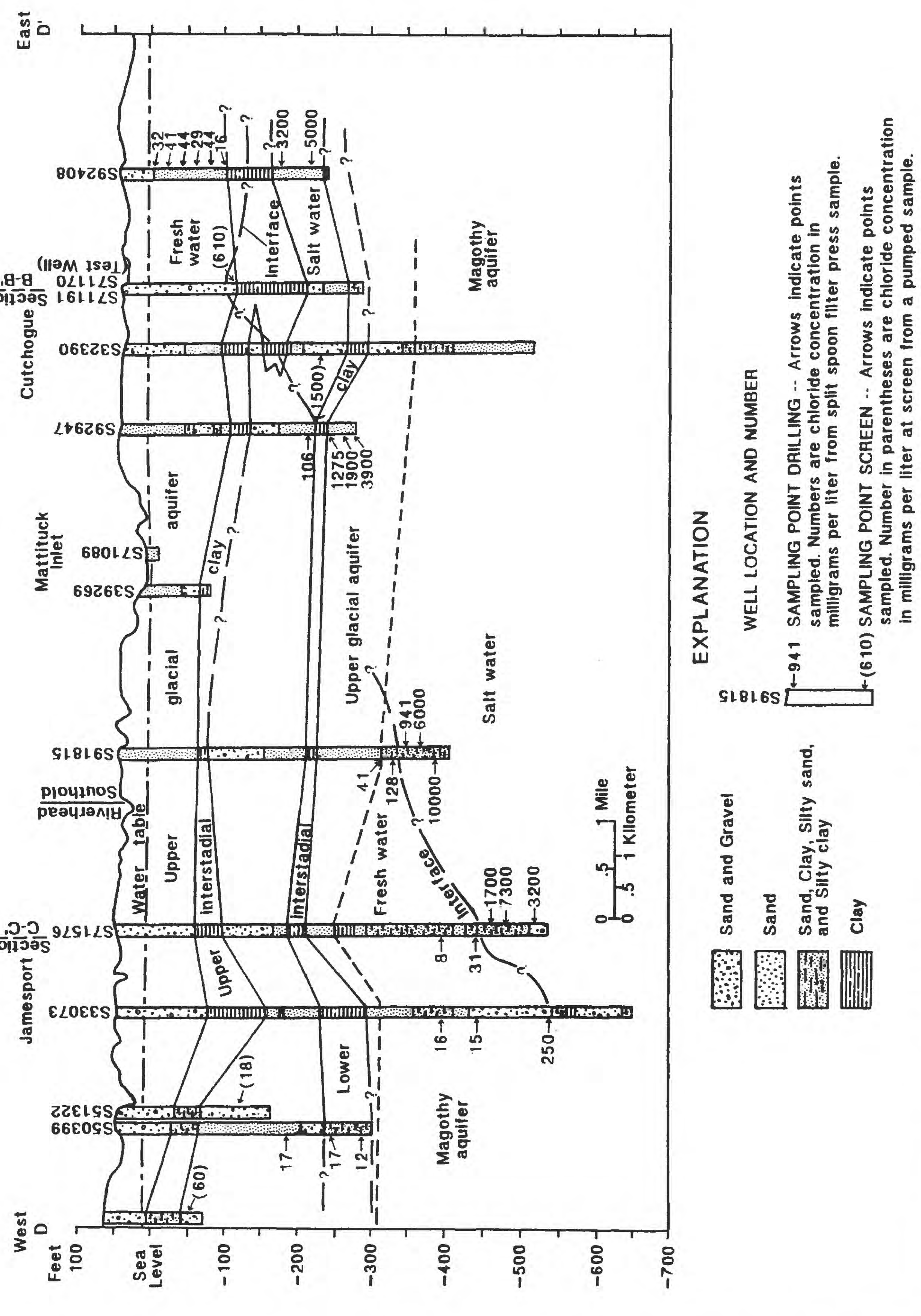



**Figure 3.** Hydrogeologic section D-D′ on North Fork, Long Island, N.Y.

the flow directions within the fresh ground-water system; (2) a depiction of aldicarb and tritium concentrations along two representative vertical sections; (3) an explanation of the development of ground-water-flow models of these sections and presentation of the resulting flow nets and ground-water traveltimes calculated with the models; and (4) a discussion of the application of ground-water traveltimes to aldicarb and tritium concentrations to delineate the migration of aldicarb in the ground-water system. The report also contains several vertical sections; their locations with associated observation wells are shown in figure 4.


### Acknowledgments

The authors express thanks to Philip Bucher, Brian Boogertman, Paul Murphy, and Frank Basile of the SCDHS rotary-drill-rig crew, and to Richard Markel and Edward Olsen of the SCDHS, who provided information and assistance during the data-collection phase of the project.


## HYDROGEOLOGY

Directions and rates of ground-water flow are controlled by the rate and distribution of water entering and leaving the system, the geometry of the system (usually defined as the configuration of the aquifers and confining units), and the distribution of water-transmitting and storage properties of the system. The following section discusses the geologic framework and hydrology of the study area. Some of the information is derived from previous work conducted on the North Fork by Hoffman (1961), Crandell (1963), and Soren and Stelz (1984).

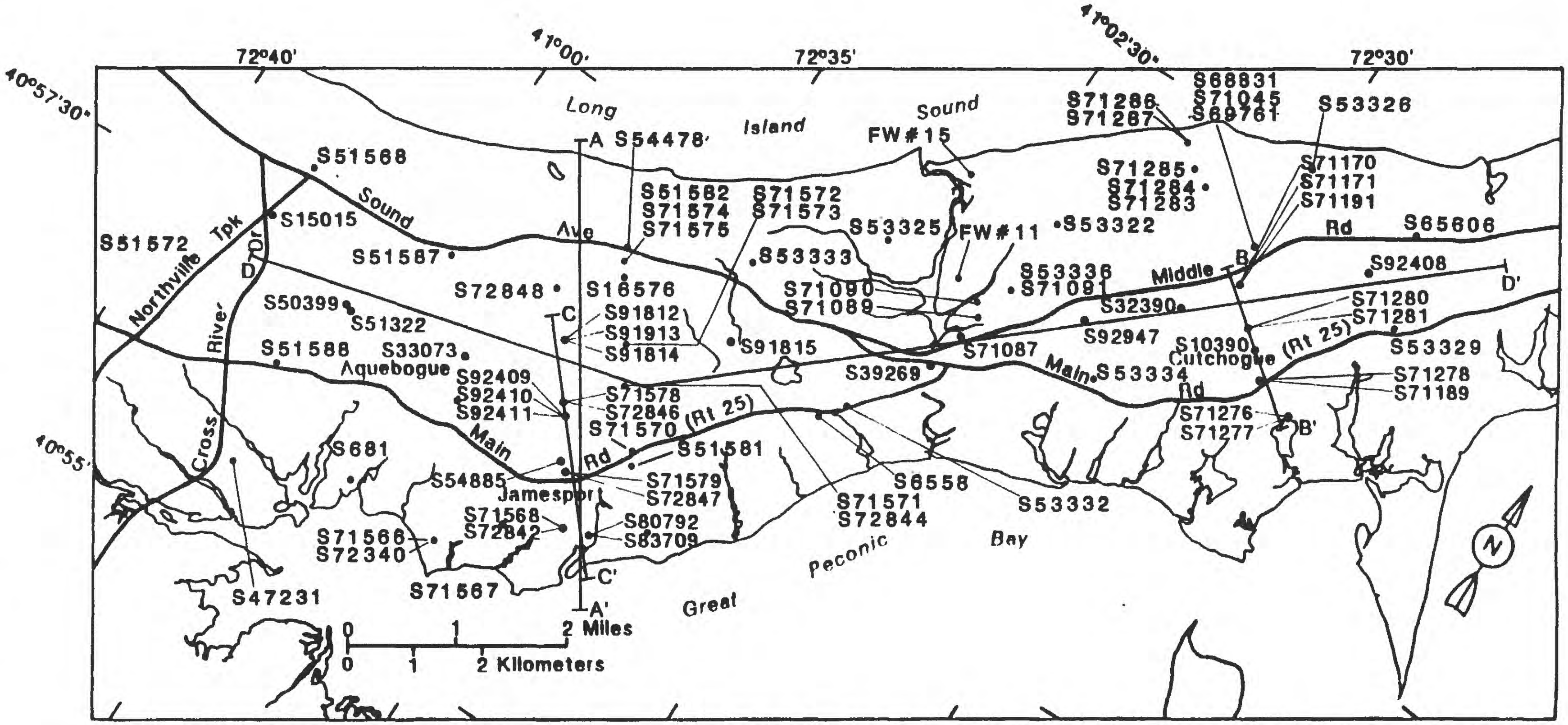
### Geologic Framework

The North Fork contains a sequence of southeastward dipping unconsolidated deposits similar to those that form the main body of Long Island. A generalized geologic section depicting the hydrogeologic units on the North Fork is shown in figure 5. Unconsolidated deposits are underlain by relatively impermeable Precambrian crystalline bedrock that has a highly weathered surface (Jensen and Soren, 1974). Directly overlying the bedrock are the Lloyd aquifer, Raritan confining unit, and Magothy aquifer, all of Cretaceous age. The Raritan confining unit confines the Lloyd aquifer and separates it from the Magothy aquifer. These aquifers are not used for water supply on the North Fork because they contain naturally saline water.

The Cretaceous deposits are overlain by Pleistocene deposits of the Wisconsin glacial stage. These overlying deposits are referred to as the upper glacial aquifer and consist of three distinct units, whose origin and depositional history are discussed by Soren and Stelz (1984) and summarized as follows. The oldest and deepest unit is a sand and gravel layer associated with the Ronkonkoma ice sheet, which deposited the Ronkonkoma terminal moraine that forms much of the South Fork of Long Island (fig. 1). After the recession of the Ronkonkoma ice sheet, sea level rose to near its present level. During this interstadial period, marine and (or) lacustrine sediments were deposited over the Ronkonkoma deposits—a clay bed at the base, separated from an upper clay bed by an 80-ft-thick band of silty, sandy beds. Overlying the clay bed is a terminal moraine and adjacent outwash deposits associated with the Harbor Hill ice sheet. The Harbor Hill terminal moraine is the major topographic feature on the North Fork.

The two interstadial clay beds and intervening silty beds are depicted in vertical section D-D′ in figure 3. Exploratory drilling at three sites (well S91815 at Aldrich Lane, well S92947 at Elijah Lane, and well S92408 at Bridge Land; fig. 3) confirmed the stratigraphic position of the two clay beds east of Jamesport, and the logs corroborate previous test-hole data. Well information is given in table 2 (at end of report).

The upper surface of the upper clay bed (fig. 6A, p. 8) ranges from 5 ft below sea level in the western part of the study area to 114 ft below sea level farther east. In the northern and eastern parts of the study area, the clay surface dips southwestward, then gradually rises to form a trough. Its thickness in the study area (fig. 6B, p. 9) ranges from 13 ft to 186 ft. Historical well records and recent exploratory drilling indicate that the clay bed is continuous throughout the study area.




Base from Department of Transportation topographic maps Southampton, Mattituck, Mattituck Hills, Riverhead, and Southold 1:24,000

EXPLANATION

| | |
|---|---|
| A-A' | Generalized section |
| B-B' | Cutchogue section (corresponds to model section E-E') |
| C-C' | Jamesport section (corresponds to model section F-F') |
| D-D' | East-west section |
| •S83709 | Observation well and number |

**Figure 4.** Locations of sections A-A′, B-B′ (Cutchogue), C-C′ (Jamesport), and D-D′ in study area on North Fork of Long Island, N.Y., and associated wells.

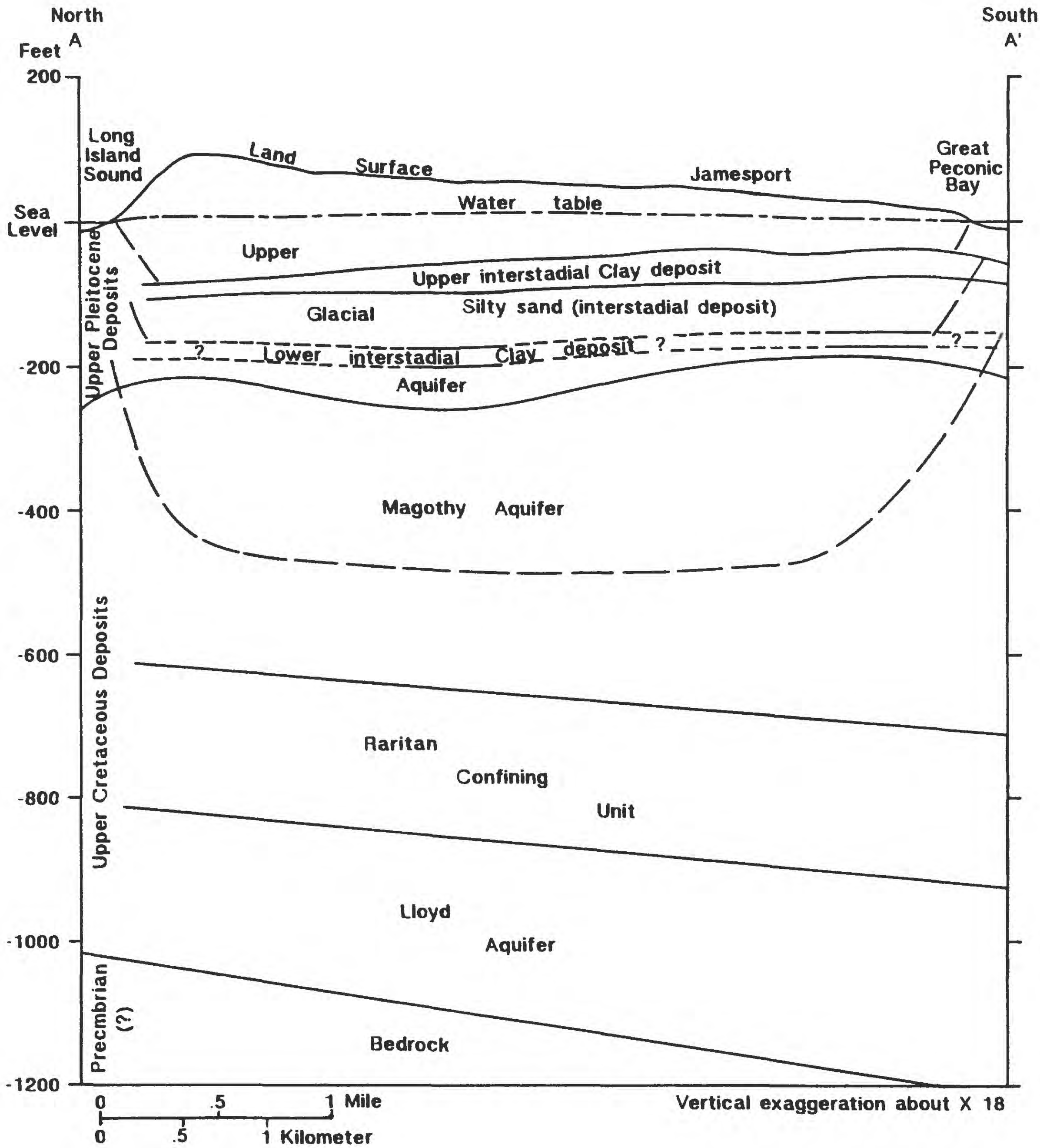
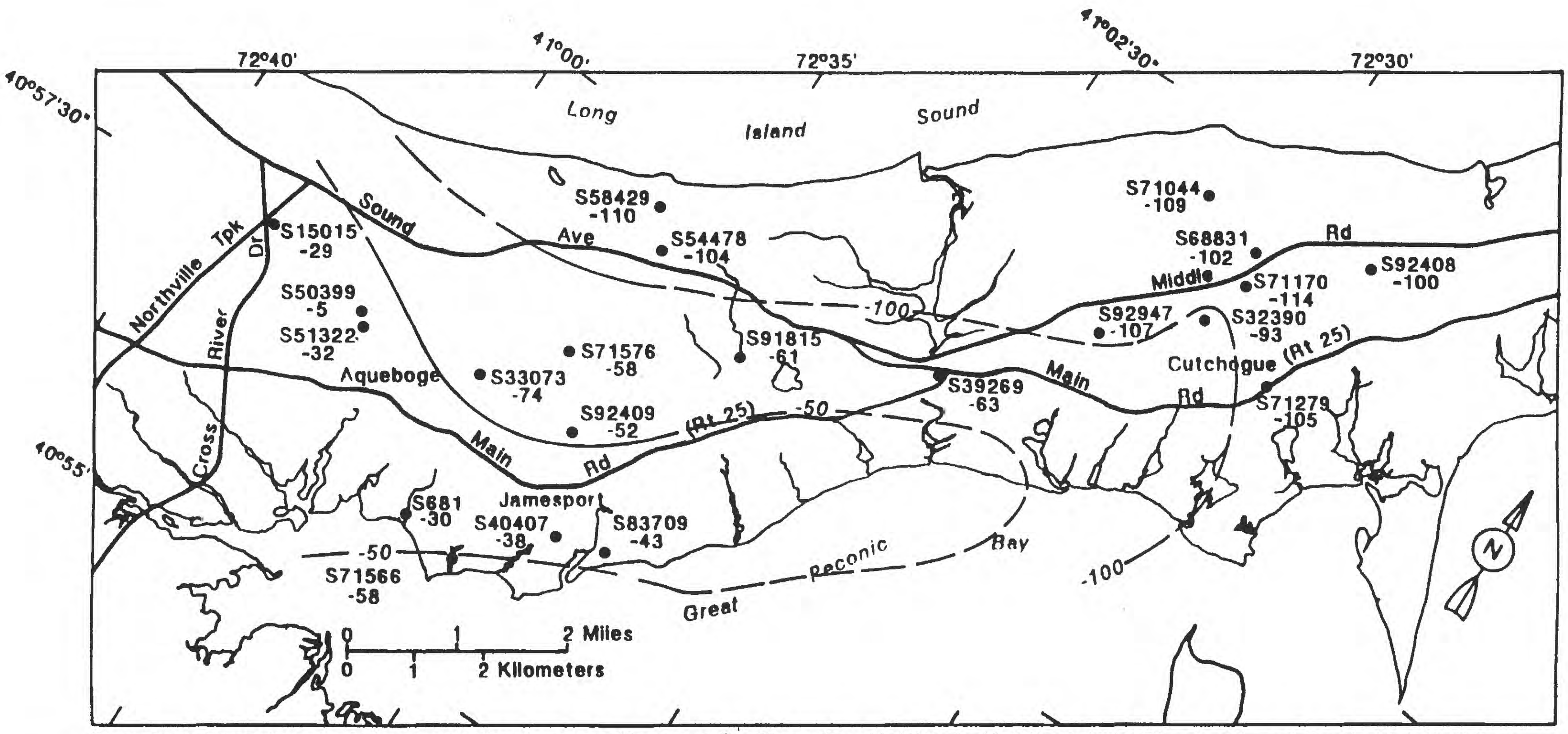



**Figure 5.** Generalized section A-A′ showing stratigraphy, hydrologic units, and position of saltwater interface in the Jamesport area, Long Island, N.Y. (Location is shown in fig. 2. Modified from Soren and Stelz, 1984, fig. 3.)

## Hydrology

All domestic, public-supply, and irrigation wells on the North Fork are screened in the upper glacial aquifer, which ranges in thickness from 300 to 400 ft. This aquifer consists of a series of disconnected, irregularly shaped freshwater lenses bounded by saltwater (fig. 3, section D-D′) (Baier and Robbins, 1982a). Fresh ground water in the Jamesport area is connected to the main Long Island ground-water system, but farther



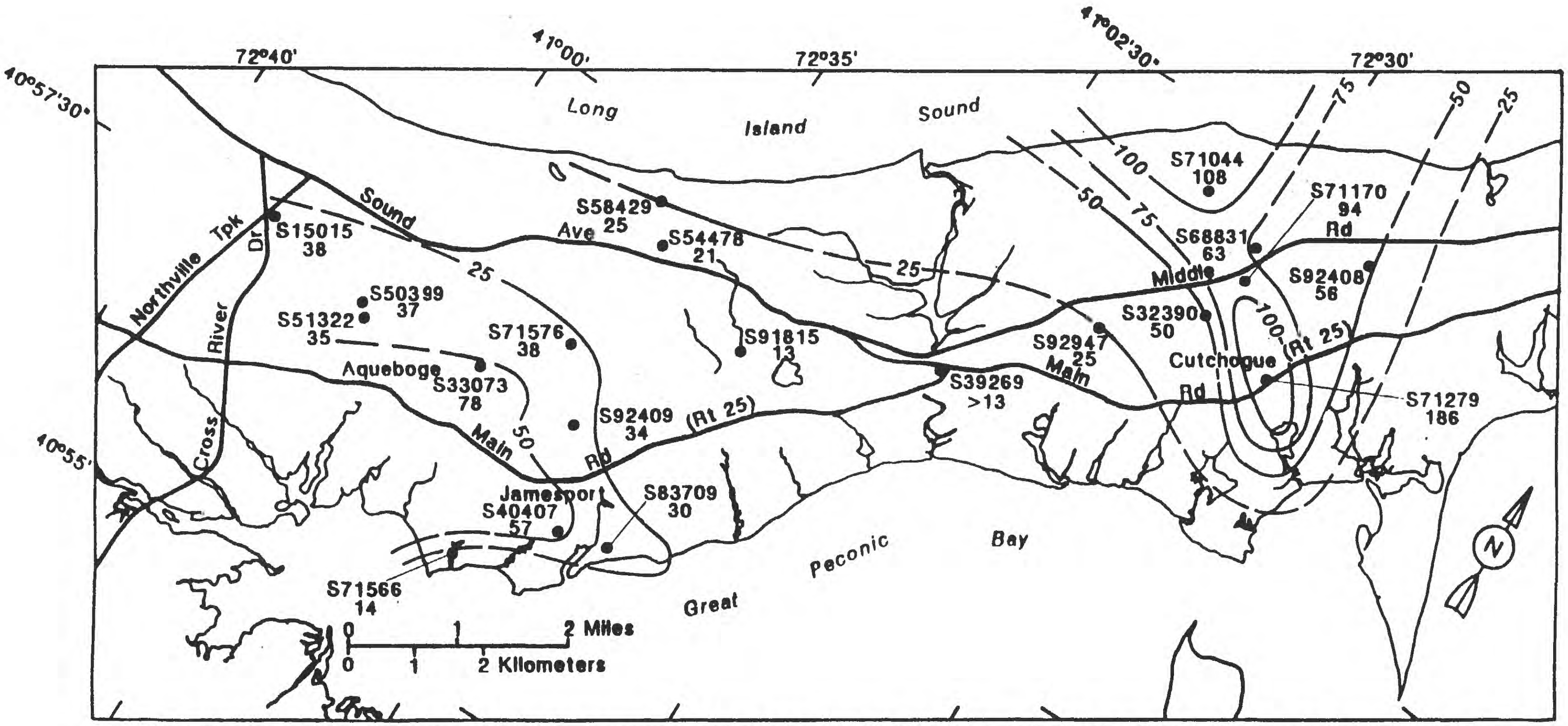

Base from Department of Transportation topographic maps Southampton, Mattituck, Mattituck Hills, Riverhead, and Southold 1:24,000

## EXPLANATION

—— -50 — — SUBSURFACE CONTOUR -- Shows altitude of top of upper interstadial clay unit. Dashed where inferred. Contour interval 50 feet. Datum is sea level

● S681 -30 TEST HOLE -- Upper number is well-identification number; lower number is indicates altitude of top of upper interstadial clay unit, in feet below sea level

**Figure 6A.** Altitude of the top of the upper interstadial clay deposit in study area on North Fork of Long Island, N.Y.




Base from Department of Transportation topographic maps Southampton, Mattituck, Mattituck Hills, Riverhead, and Southold 1:24,000

## EXPLANATION

—— 25 — — LINE OF EQUAL THICKNESS OF UPPER INTERSTADIAL CLAY UNIT -- Dashed where inferred. Contour interval 25 feet.

● S71566 / 14 — TEST HOLE -- Upper number is well-identification number. Lower number indicates thickness of upper interstadial clay unit, in feet

**Figure 6B.** Thickness of upper interstadial clay deposit in study area on North Fork of Long Island, N.Y.

east it consists of a series of isolated freshwater lenses (fig. 3, section D-D′). The westernmost lens (fig. 7, section B-B′) is in the Cutchogue area and extends eastward from Mattituck inlet to just beyond the eastern limit of the study area.

### Precipitation and Recharge

Precipitation is the sole source of natural recharge to this ground-water system. Mean annual precipitation in the study area ranges from 45.5 in. at Aquebogue to 44 in. at Cutchogue (Miller and Frederick, 1969) (fig. 2). Water from precipitation can recharge the ground-water system or be lost as evapotranspiration or direct runoff. Estimates of the percentages of each of these components under predevelopment conditions on Long Island are given by McClymonds and Franke (1972). About 48 percent of precipitation is lost through evapotranspiration and about 2 percent as direct runoff; the remaining 50 percent becomes recharge. Because most of the North Fork is agricultural or undeveloped (fig. 2), these estimates probably still apply today.

### Hydrologic Boundaries

The natural boundaries of the fresh ground-water system on the North Fork are the water table, the saltwater/freshwater interface, and the bordering saltwater bodies (fig. 5). The water table is a recharge boundary, where downward seepage through the unsaturated zone replenishes the upper glacial aquifer. Fresh ground water discharges directly to saltwater bodies at the shore, and, to a lesser degree, where it flows upward through a confining layer offshore to mix with saline ground water. The saltwater/freshwater interface is a zone of diffusion in which freshwater grades into the denser saltwater, and this zone is assumed to approximate an impermeable boundary that can shift in response to changing hydrologic conditions within the aquifer system. The sparse stream channels act as ground-water drains, but ground-water discharge to streams is a negligible component of the local ground-water budget.

### Configuration of Saltwater/Freshwater Interface

The position of the saltwater/freshwater interface was determined from filter-press core samples, samples from a screened auger, multipoint resistivity logs, and water samples from observation wells (figs. 3 and 7, and table 2). The filter-press method used in the field was adapted from Lusczynski (1961). Field measurements of chloride concentration indicated the depth at which ground water changes from fresh to saline. For the purpose of this study, 250 mg/L of chloride was set as the concentration at which the saltwater/freshwater interface begins. In most areas where the chloride concentration reaches 250 mg/L on the North Fork, it abruptly increases by an order of magnitude, generally within the next 50 ft vertically downward.

Chloride concentrations that were measured during drilling operations in 1981-82 (Soren and Stelz, 1984) and in additional drilling for this investigation in 1988 are depicted in sections B-B′, C-C′, and D-D′ in figures 3 and 7. Test hole S71170 (the test hole for well S71171) in section B-B′ shows high chloride concentrations (610 mg/L) just above the upper interstadial clay, and a concentration of 250 mg/L at an altitude of about -195 ft, within the upper interstadial clay. No data were available for altitudes of -135 ft through -190 ft at this well. Section C-C′ (fig. 7) shows high chloride concentrations at wells S71576 and S83709 in the Magothy aquifer at altitudes of -450 ft and -250 ft, respectively. The position of the saltwater/freshwater interface in section D-D′ (fig. 3) is based on chloride and head data that indicate where the ground-water density changes enough that the saltwater and freshwater function differently.

Section D-D′ (fig. 3) shows chloride concentrations measured during drilling and in water samples from the well-screen depth. These data indicate that the saltwater/freshwater interface rises eastward. Also, the freshwater lens beneath Cutchogue is assumed to be separate from that beneath Jamesport and greater Long Island, as stated by Baier and Robbins (1982a). This assumption is verified by the high chloride concentration (130 mg/L) in 1984 at shallow well S71089, near the center of the North Fork between Mattituck Creek on the northern shore and James Creek on the southern shore (section D-D′, fig. 3).

### Aquifer Characteristics

The horizontal hydraulic conductivity of the upper glacial aquifer on the South Fork (fig. 1) has been estimated to range from 200 ft/d to 750 ft/d and to average 350 ft/d (Nemickas and Koszalka, 1982), and that in western Suffolk County (fig. 1) has been estimated to

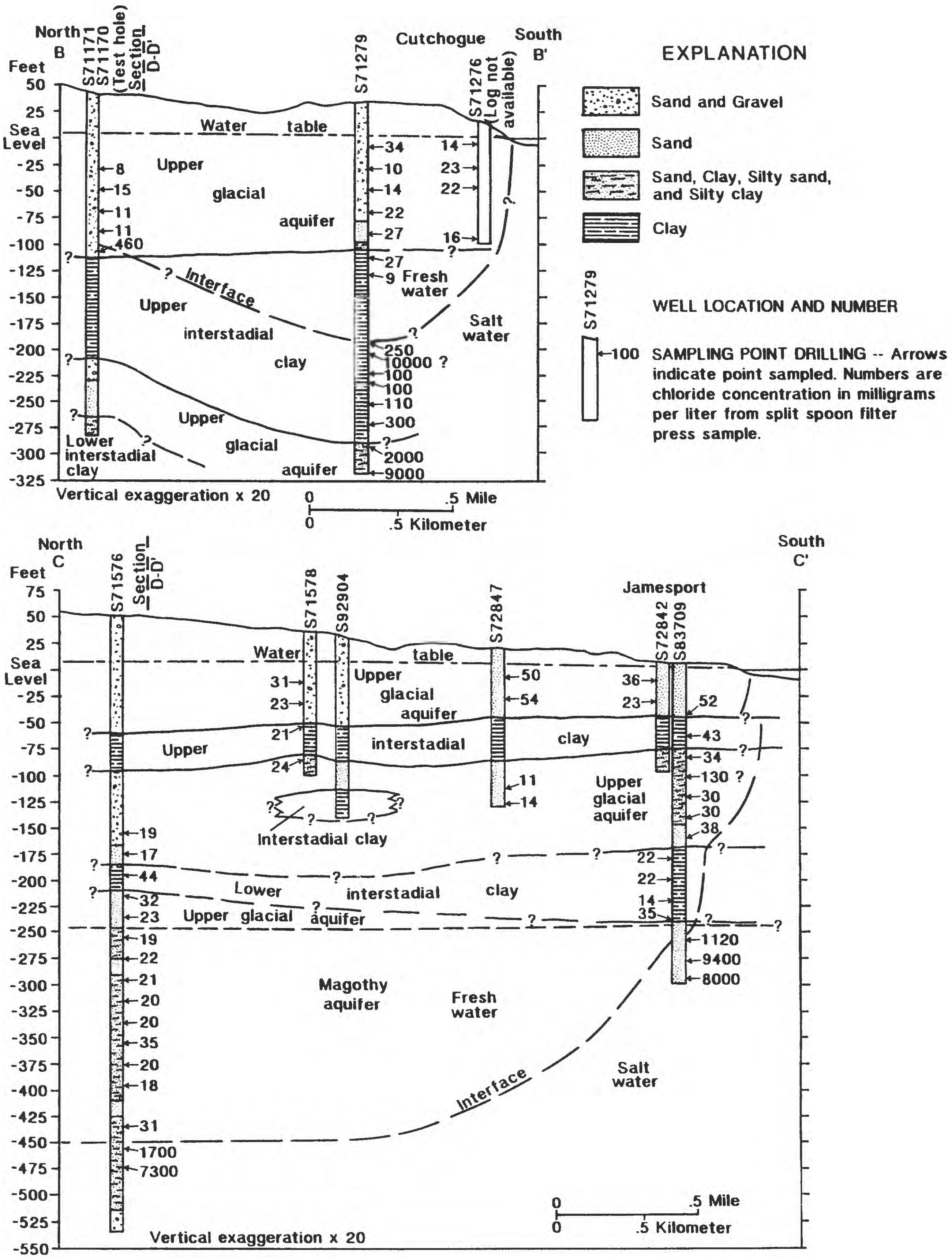



**Figure 7.** Hydrogeologic sections B-B´ and C-C´ on the North Fork, Long Island, N.Y.

range from 187 ft/d to 255 ft/d (from specific-capacity data) and 175 ft/d (from a multiple-well aquifer test) (McClymonds and Franke, 1972). The anisotropy (ratio of horizontal to vertical hydraulic conductivity) in the Jamesport area has been estimated to be 20:1 (Soren and Stelz, 1984), from a horizontal hydraulic conductivity of 200 ft/d estimated by Franke nd Cohen (1972). The horizontal hydraulic conductivity in the Town of Southold, in the eastern part of the study area, has been estimated to range from 130 to 670 ft/d (Hoffman, 1961), on the basis of a 100-hour aquifer test in a shallow irrigation well. The average anisotropy of the upper glacial aquifer within the main part of Long Island has been estimated to be 10:1 (Reilly and others, 1983). a-a´

### *Directions of Ground-Water Flow*

Hydraulic head, or potential, varies spatially within the three-dimensional ground-water system, and its distribution governs the directions of ground-water movement. Synoptic water-level measurements were made at 87 wells on December 7, 1988, about 3 months after localized pumping for agricultural purposes had ceased for the growing season and water levels had recovered from seasonal pumping. The resulting heads were used to construct a detailed water-table map (fig. 8A) and potentiometric-surface map of the upper glacial aquifer below the upper interstadial clay (fig. 8B). The hydraulic gradient, which is perpendicular to the equipotential lines, generally indicates the direction of horizontal flow in these aquifers. Directions of vertical flow are affected by anisotropy and are discussed later in this report.

In Cutchogue, the eastern part of the study area (section B-B´, fig. 7), fresh ground water is limited to a discrete, shallow lens that is detached from the main Long Island ground-water system (fig. 8A). Below the upper interstadial clay in this area, the upper glacial aquifer contains saline ground water (fig. 8B and fig. 7). The observed heads in the water-table aquifer range from a maximum of about 5 ft above sea level along the ground-water divide (fig. 8A) to sea level at the shores. Section B-B´, which trends northwest-southeast (fig. 8A), is approximately perpendicular to the equipotential lines and was selected to represent a typical ground-water flowline from the divide to the shore. Consequently, ground-water flow perpendicular to this section is assumed to be negligible. The head distribution along section B-B´ on December 7, 1988, is shown in figure 9. Here the small downward vertical component of flow is evidenced by small head differences in four pairs of observation wells. Downward vertical gradients are controlled by vertical head differences of only a few hundredths of a foot throughout most of the section; they reverse to upward in areas close to the shore. Water levels were measured to the nearest hundredth of a foot. The measuring points of observation-well clusters (at the same location) were surveyed to within 0.005 ft, and all wetted-tape measurements were made in triplicate. In addition, the difference between measuring points at well clusters was resurveyed to achieve the greatest possible accuracy of observed vertical gradients. Because the minimal distance is <10 ft between the observation wells in each cluster, one line is used to represent all the wells at that location. The screened interval corresponds with depth to the order that the well numbers are listed above the well location.

Jamesport (section C-C´ in figs. 7, 9, and 8A) lies in the western part of the study area, where the observed heads in the water-table aquifer exceed 10 ft near the ground-water divide and decrease to sea level toward the shore. This area differs from the Cutchogue area in that it contains fresh ground water beneath the upper interstadial clay (figs. 9 and 7).

Head data in the upper glacial aquifer beneath this upper clay unit are sparse but sufficient to delineate the potentiometric-surface altitude (fig. 8B). Measured heads below the clay range from 7.90 ft to 3.87 ft, and the equipotential lines are assumed to follow the same general trend as those in the water-table aquifer (fig. 8A).

The distribution of hydraulic head along section C-C´ on December 7, 1988 is shown in figure 9. Hydraulic gradients between observation-well pairs screened above the upper interstadial clay indicate that the direction of vertical flow is downward in the water-table aquifer throughout most of the area. The magnitude of vertical gradients varies considerably near Jamesport and could be as much as an order of magnitude higher locally than at Cutchogue (section B-B´, fig. 8B). This difference probably is caused by a lower vertical hydraulic conductivity of aquifer material at Jamesport, although the geologic logs gave no clear evidence of increased abundance of fine-grained sediments or fine-grained lenses.

The upper interstadial clay is a confining unit that restricts vertical ground-water flow. Hydraulic gradients through the clay reverse from downward near the ground-water divide and in the central area to upward near the shore. The difference in head across the clay at the divide and at the center of the study area is less than 0.5 ft but increases to about 2 ft near the shore, where head in the overlying aquifer decreases abruptly (fig. 9B). The low hydraulic conductivity of the clay layer and the observed horizontal head difference beneath it (fig. 8B) indicates that upward flow through the clay is minimal.

### *Ground-Water Age*

Ground-water samples were collected in November and December 1988 for tritium analysis to indicate the age of ground water in the shallow flow systems in the Cutchogue and Jamesport areas. These analyses provide an additional control for calibration of the numerical models of the ground-water system described later in this report.

Tritium is a radioisotope of hydrogen. It decays by pure beta emission to stable $He^{-3}$ and has a half-life of 12.3 years (Thatcher and others, 1977). In this study, tritium was measured in tritium units (TU), where 1 tritium unit is equal to a gross beta radiation of 3.2 pCi/L (picocuries per liter of water) (Payne and Halevy, 1968). Natural concentrations of tritium in rainfall before 1952 were in the range of just a few TU. Atmospheric nuclear testing, which reached a peak during 1960-64, raised the concentrations of tritium in the northern hemisphere to thousands of TU by the mid-1960's (Bradbury, 1991; Hendry, 1988; Knott and Olimpio, 1986). These elevated concentrations allow use of tritium as a dating tool for precipitation that has entered the ground-water system since the early 1950's. In general, tritium data are limited and permit only a qualitative estimate of ground-water age. Hendry (1988) provides qualitative guidelines for estimating ground-water age from tritium concentration. The concentration ranges used in this study for interpreting ground-water age from tritium concentration (table 1) are modified from Hendry (1988) and based on data from Bradbury (1991) and Knott and Olimpio (1986).

**Table 1.** Estimates of average ground-water age based on tritium concentrations in ground water
[Modified from Hendry (1988). TU, tritium units; >, greater than; <, less than]

| Concentration (TU) | Ground-water age (in years) | Date of entry to aquifer |
|---|---|---|
| >100 | 23-28 | 1960-65 |
| 10-100 | less than 35 | after 1953 |
| <10 | greater than 35 | before 1953 |

Tritium concentrations at wells sampled along sections B-B′ and C-C′ are shown in figures 8A and 8B, respectively. The minimum detection level was 2.6 pCi/L (0.8 TU), and all sample results were above the minimum detection level. The 95-percent confidence interval for the minimum detection level was ± 0.25 TU. Tritium concentrations above the minimum detection level were reported with a standard deviation of 2.0. The tritium data indicate that ground water along most of the two geologic sections is less than 35 years old (table 1). The concentration of 6.3 TU at well S72846 in the Jamesport section (section C-C′, fig. 10B) indicates that, locally, water at or below about -35 ft below sea level is more than 35 years old.

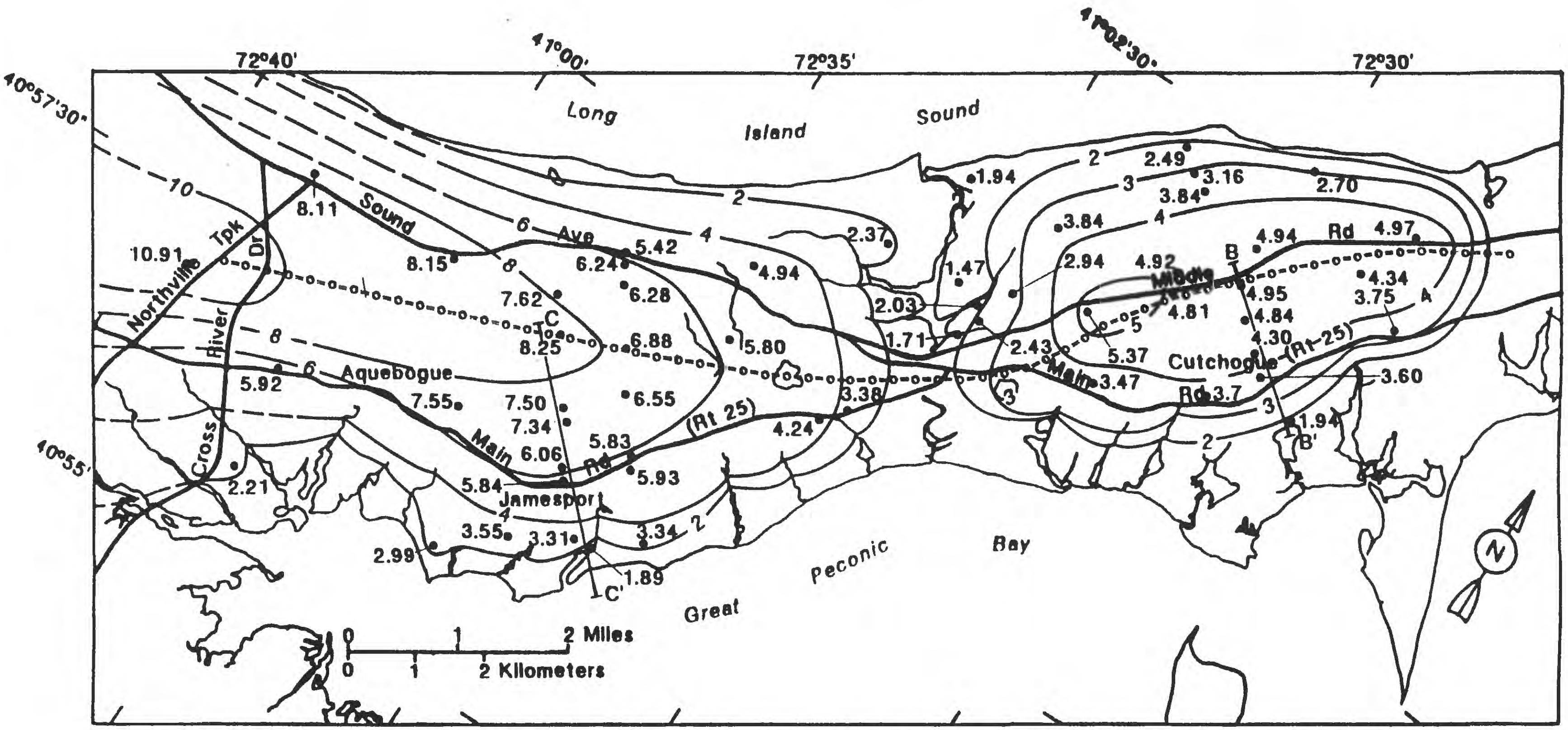
## NUMERICAL FLOW-NET ANALYSIS

A numerical modeling technique was used to evaluate the direction and rate of ground-water movement in the shallow ground-water-flow systems in the Cutchogue and Jamesport vicinities. This technique involves the selection of sections that are representative of the ground-water flow system and satisfy the requirements for cross-sectional symmetry—that is, no flow perpendicular to the line of the section.

### Modeling Technique

Numerical finite-difference models were constructed to simulate steady-state ground-water flow under unstressed conditions along each section. The models were calibrated by comparison of the steady-state simulated hydraulic heads with heads observed in the field, and observed vertical gradients were carefully noted. The numerical models were also used to calculate the stream function over the domain of the model by the method of Christian (1980), Frind and Matanga (1985), Fogg and Senger (1985), and Buxton and Modica (1992). The method is a two-step process that required that (1) $K_x$ is replaced by $1/K_z$, and $K_z$ is replace by $1/K_x$, where $K_x$ and $K_z$ are horizontal and vertical components of hydraulic conductivity, and (2) appropriate stream-function boundary conditions are applied to each modeled section.

The stream function describes the distribution of flow within the flow field and is constant along a




Base from Department of Transportation topographic maps Southampton, Mattituck, Mattituck Hills, Riverhead, and Southold 1:24,000

## EXPLANATION

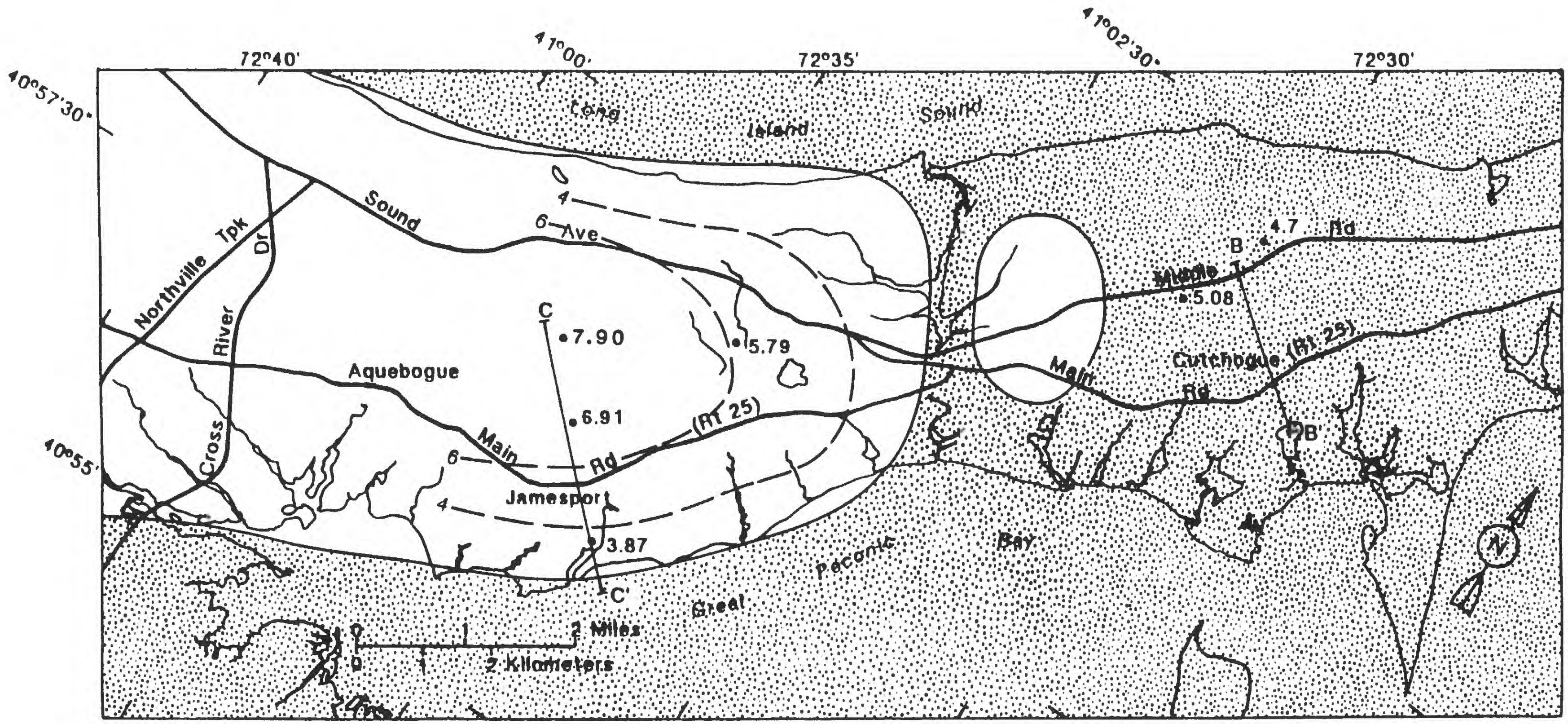
——2—— —— WATER TABLE CONTOUR -- Shows approximate altitude of the water table. Dashed where inferred. Contour interval is variable. Datum is sea level.

• 3.31 OBSERVATION WELL -- Number indicates altitude of water, in feet above sea level.

o-o-o-o-o-o GROUND-WATER DIVIDE

B (C) / B' (C') TRACE OF SECTIONS -- Geologic sections shown in figs 6A,B and Plate 2.

**Figure 8A.** Water-table altitude on December 7, 1988, and locations of geologic sections B-B′ and C-C′ and selected well sites on North Fork, Long Island, N.Y.




## EXPLANATION

SALTY WATER -- Below the clay

—4— POTENTIOMETRIC CONTOUR -- Shows altitude of water level in tightly cased wells that were screened in the upper glacial aquifer below the upper interstadial clay, on December 7, 1988. Dashed where inferred. Contour interval 2 ft. Datum is sea level.

• 3.87 OBSERVATION WELL -- Number shows water level, in feet above sea level.

B (C) — B' (C') TRACE OF SECTIONS -- Geologic sections shown in figs 6A,B and Plate 2.

**Figure 8B**. Potentiometric-surface altitude on December 7, 1988, and extent of freshwater within silty sand unit below the upper interstadial clay, and locations of geologic sections B-B′ and C-C′ and selected well sites on North Fork, Long Island, N.Y.

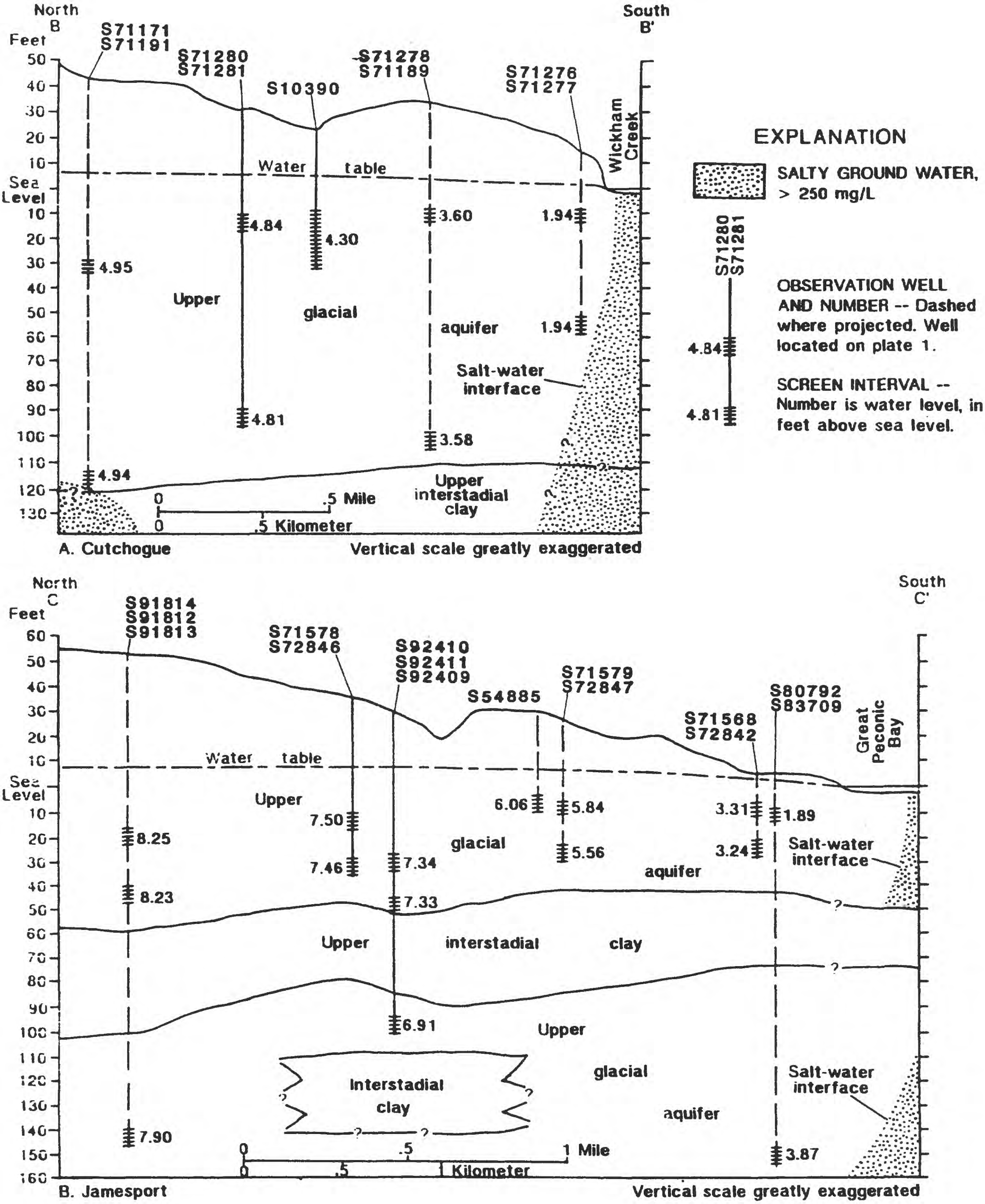



**Figure 9.** Water-table altitude and screened intervals with water-level data along hydrologic sections B-B′ (Cutchogue) and C-C′ (Jamesport) on North Fork of Long Island, N.Y., December 7, 1988. (Trace of sections is shown on fig. 4.)

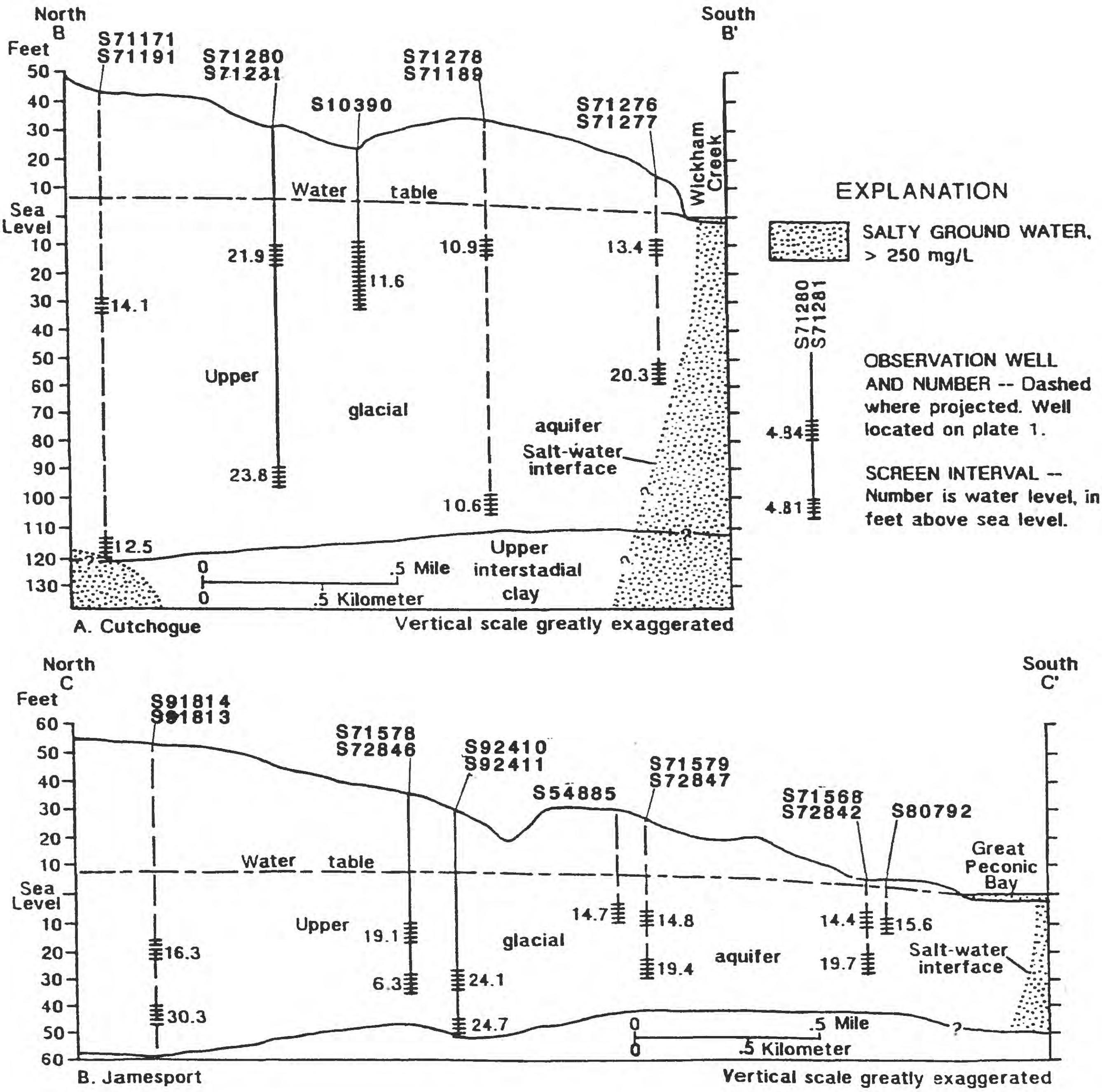



**Figure 10.** Tritium concentrations along hydrologic section B-B′ (Cutchogue) and C-C′ (Jamesport) on North Fork of Long Island, N.Y., in November-December 1988. (Locations of geologic sections is shown on fig. 4.)

streamline (or flowline). Therefore, contours of the stream function yield ground-water flow paths, and contours with equal contour intervals yield "flow tubes" that carry equal quantities of flow. Given the ground-water flowpaths, the distribution of ground-water age or traveltime throughout the modeled section can be readily calculated. A program was developed that permits each flowline to be digitized and calculates traveltimes for discrete segments of each flowline through the equation

$$t = \frac{(s^2)\,n}{K_s \Delta h} \qquad (1)$$

where

- $t$ = traveltime for flowline segment, in days
- $s$ = length of flowline segment, in feet
- $n$ = porosity
- $K_s$ = hydraulic conductivity in the direction of the flowline segment; in feet per day ($K_s$ is calculated from $K_x$ and $K_z$, Wang and Anderson (1982); and
- $\Delta h$ = change in head along the flowline segment as interpolated from model output.

Traveltimes along flowline segments are summed to yield an estimate of traveltimes throughout the model area.

The results of this analysis represent the advective component of solute transport within the section. These results, when compared with the qualitative approximation of the horizontal component of flow paths provided by water-table and potentiometric-surface maps, provide a basis for delineation of the three-dimensional directions and rates of ground-water flow.

## Model Construction

Hydrologic sections B-B′ and C-C′ (fig. 8A) were selected for model simulation because they are representative of their local ground-water flow systems, lie along a ground-water flowline, and best achieve the required symmetry. The sections are represented such that the flow tubes along the section are unit or equal width. The Cutchogue section better satisfies this symmetry because the Jamesport section has a flow tube that widens somewhat toward the shore. Both sections were modeled from the ground-water divide to the southern shore. The Cutchogue hydrologic section B-B′ is represented as model section E-E′, and the Jamesport hydrologic section C-C′ is represented as model section F-F′ (fig. 11).

The numerical model selected for this analysis was the modular finite-difference model developed by McDonald and Harbaugh (1984). The cross-sectional modeling technique requires the solution of a boundary-value problem for the head and stream function solutions, which in turn requires representation of boundary conditions for both solutions along the periphery of the section. Conventional block-centered flow finite-difference algorithms do not suit this boundary configuration; therefore, a general finite-difference formulation developed by Harbaugh (1991) was used. This formulation allows input of water-transmitting properties as values for conductance branches (porous material between two nodes) between nodes and permits use of the face-centered grid configuration (the traditional analog grid, where model nodes are located along the edge of the model domain).

### *Discrete Representation*

An example of a face-centered, finite-difference grid is shown in figure 12. The node-numbering convention for cross-sectional applications is (layer, column) or (z,x). The areas (in cross section) of the flow domain that represent horizontal (x) and vertical (z) conductance branches are shown between nodes (2,2) and (2,3), and (3,3) and (4,3), respectively.

Hydraulic conductance (C) is defined as

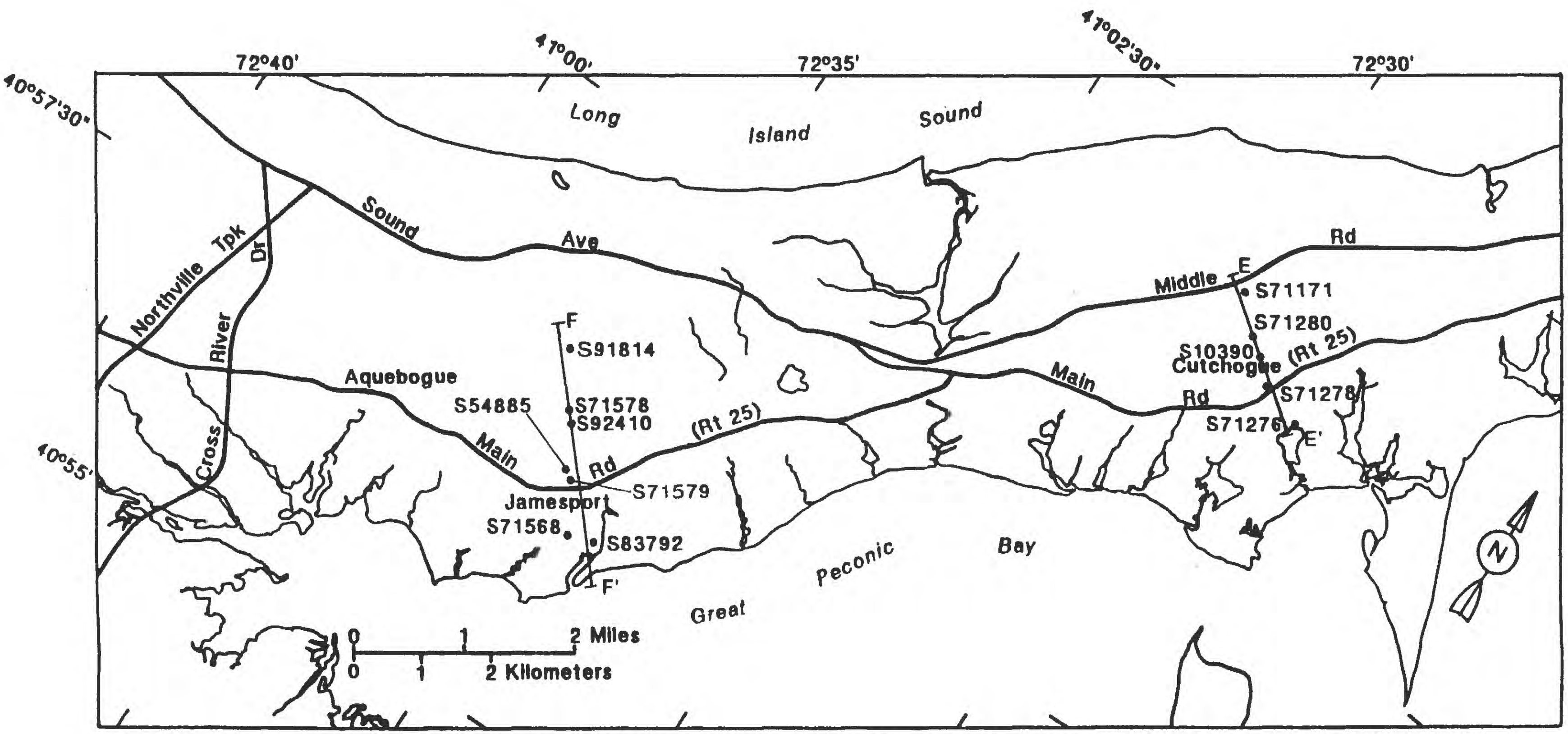
$$C = \frac{KA}{L}, \qquad (2)$$

where

- $K$ is hydraulic conductivity, in feet per day;
- $A$ is the cross-sectional area of flow, in square feet; and
- $L$ is the length of flow, in feet.

Hydraulic conductance is expressed as feet squared per day ($ft^2/d$).

In this analysis, the primary requirements of grid design are (1) accurate representation of the hydrologic boundaries along the periphery of the active model domain, (2) representation of internal permeable boundaries, and (3) adequate resolution of changes in hydraulic gradient. The grid represents irregular boundaries by a saw-toothed approximation that omits from the model those areas of each conduc-



Base from Department of Transportation topographic maps Southampton, Mattituck, Mattituck Hills, Riverhead, and Southold 1:24,000

EXPLANATION

• S83792 OBSERVATION WELL -- Number is identification number of shallowest well at site.

E (F) — E' (F') MODELED SECTIONS

**Figure 11**. Locations of modeled sections E-E′ (Cutchogue) and F-F′ (Jamesport) and of observation wells on North Fork of Long Island, N.Y.

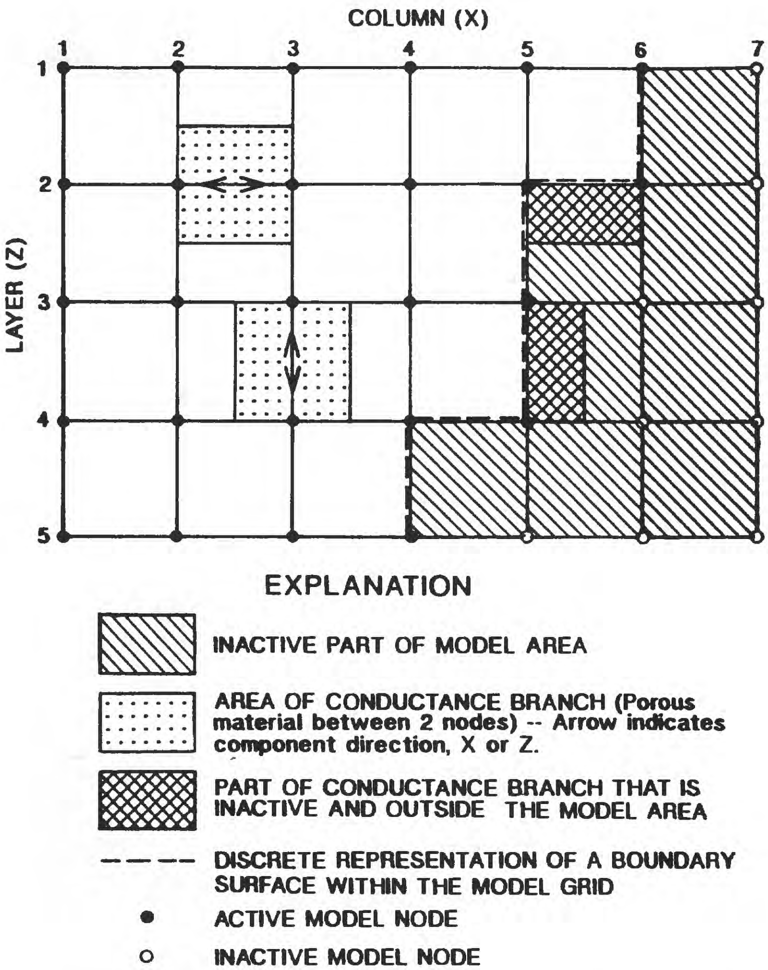



**Figure 12.** Example of a face-centered (analog) finite-difference grid.

tance branch that lie outside the line connecting the nodes (fig. 12).

The grid that was used to represent the hydrogeologic section at Cutchogue (section B-B′, fig. 8) is depicted in figure 13. The grid has 25 layers and 47 columns and represents a length of 8,148 ft. The vertical grid spacing is uniform, with 5 ft between model nodes. The grid is aligned such that each layer is at a constant altitude, with the base of the upper layer at sea level and the base of the lower layer 120 ft below sea level (the lowest altitude of the aquifer in the model section). Although the highest water-table altitude (about 5 ft) is small compared to the total aquifer thickness, both x- and z-component conductance values for the upper layer were adjusted to account for the saturated thickness between sea level and the water table.

The horizontal grid spacing is variable. The maximum spacing between nodes is 257 ft at the ground-water divide, and the smallest is 25 ft near the shore and offshore. This grid design provided fine resolution near the shore, where the spatial variation in hydraulic gradients was expected to be the greatest and where accurate representation of the saltwater interface is most important.

The grid used to represent the hydrologic section at Jamesport (section C-C′, fig. 8A) is depicted in figure 13. The grid has 25 rows and 88 columns and represents a length of 12,830 ft. The vertical spacing is uniform with 2.5 ft between each node, except in the upper layer (as in the Cutchogue section), for which the conductance was calculated to represent the water table. The grid includes the deepest surface elevation of the underlying confining unit, 60 ft below sea level. The horizontal grid spacing is variable, with a maximum of 258 ft between nodes at the ground-water divide and a minimum of 20 ft near the shore.

### Boundary Conditions

The boundary conditions for potential-function and stream-function simulations in the Cutchogue and Jamesport models are illustrated in figure 14. Segment AB is a constant-flux boundary, where the constant flux is the simulated recharge from the infiltration of precipitation. Segment BC is a constant-head boundary that represents the ocean. Simulated discharge to the constant-head boundary is dependent on the head within the flow system. The length of this boundary is determined by the distance from shore to the saltwater interface.

The segments CD, DE, and EA are no-flow boundaries; flow across these boundaries is zero. Segment EA represents the vertical flow line aligned with the major ground-water divide. Although this boundary can move in response to stresses, it is suitable as a fixed no-flow boundary in this steady-state analysis. Segment DE represents the upper surface of the underlying confining unit, and, because the ground water beneath this unit is saline, freshwater is assumed not to cross this boundary. This surface is a limiting flowline in this system. Segment CD represents the saltwater interface, which is represented as a sharp interface and at equilibrium with the fresh ground-water body. The configuration of the interface was solved for during model calibration through a comparison of heads along the interface with the freshwater equivalent head ($h_{fe}$) required to balance stagnant seawater at the depth of each layer, given as

$$h_{fe} = \left(\frac{\rho_s - \rho_f}{\rho_f}\right) z = \frac{z}{40}, \qquad (3)$$

where

$\rho_s$ = density of sea water (1.025 grams per cubic centimeter)

$\rho_f$ = density of freshwater (1.000 grams per centimeter), and

$z$ = depth of the interface below sea level, in feet.

To achieve this configuration, the model grid was adjusted manually, branch conductance values were recalculated, and the model was run. This procedure was repeated until the simulated head distribution along the interface boundary closely matched the freshwater equivalent head (eq. 3).

Both models have the same boundary conditions. The bottom boundary of section F-F′, segment DE, was originally simulated as a head-dependent leakage boundary, but only a minimal amount of water (less than 2 percent of the model budget) flowed upward through the clay from this boundary. Because this amount of flow was assumed to have little effect on flow directions in the system, the boundary condition was changed to no-flow.

The stream-function boundaries for the models are (1) specified-stream-function values where flow is entering or leaving the system, and (2) constant stream-function values. The constant stream function value of 1.0 is the bounding streamline of the system and encloses 100 percent of the flow in the section.

## Model Calibration and Sensitivity Analysis

The hydrologic conditions simulated during calibration represent average unstressed (nonpumping) hydrologic conditions. Pumping for agricultural purposes is intensive at some locations during the summer but is stopped in September. The degree to which agricultural pumping disturbs ground-water flow directions is difficult to estimate because farmers are not required to report pumpage data. Head values in observation wells measured in November-December 1988 were used as an approximation of the average unstressed condition simulated. These head values differ from the average head value represented in the model simulation because the pumping has residual effects, and water levels fluctuate seasonally. Well S6558, east of Mattituck Creek (fig. 3) has a discontinuous record of ground-water levels from 1949 to present. Maximum monthly water level in 1988 was 5.29 ft in April, the minimum water level was 3.71 ft in October, and the annual average water level was 4.48 ft. The water level measured in December was 4.24 ft. A comparison of ground-water levels during the 1988 water year with the period of record indicated that it was representative of the annual average.

The model was calibrated through a process of adjusting horizontal and vertical hydraulic conductivity values and reconfiguring the position of the saltwater interface while comparing simulated heads and

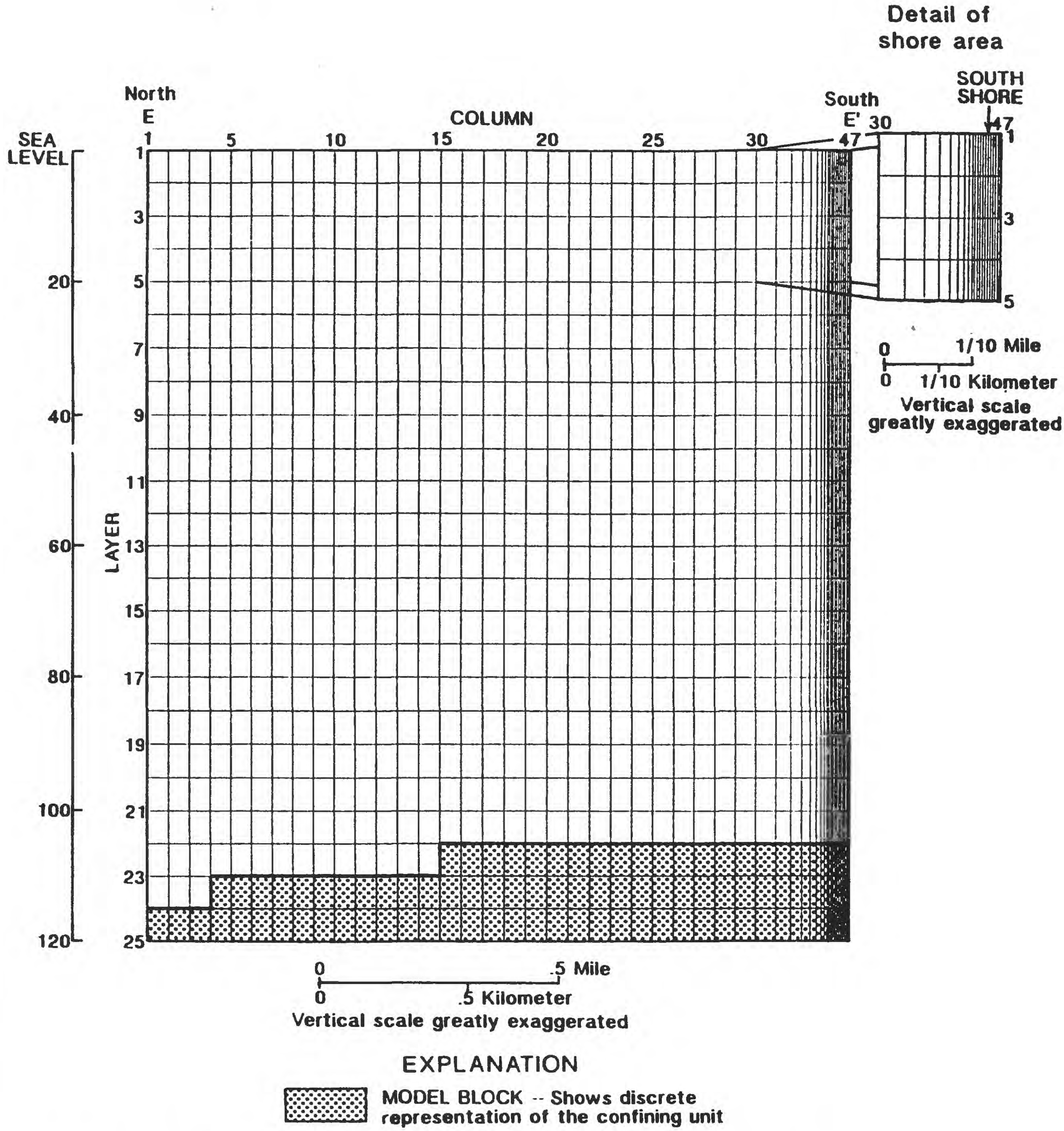



**Figure 13A.** Face-centered finite-difference grid of study-area-model section E-E′ at Cutchogue, Long Island, N.Y., with detail of grid at shore.

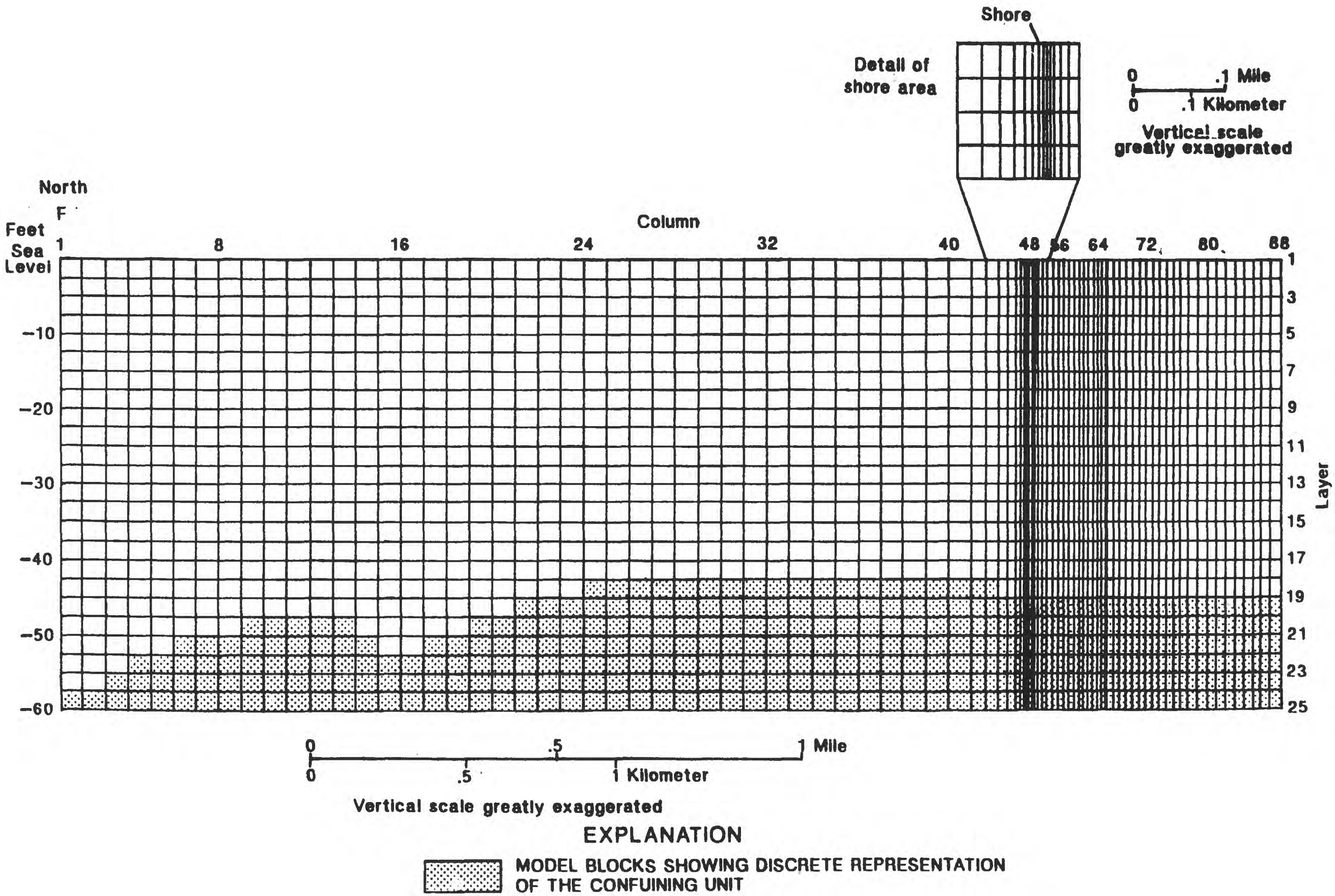
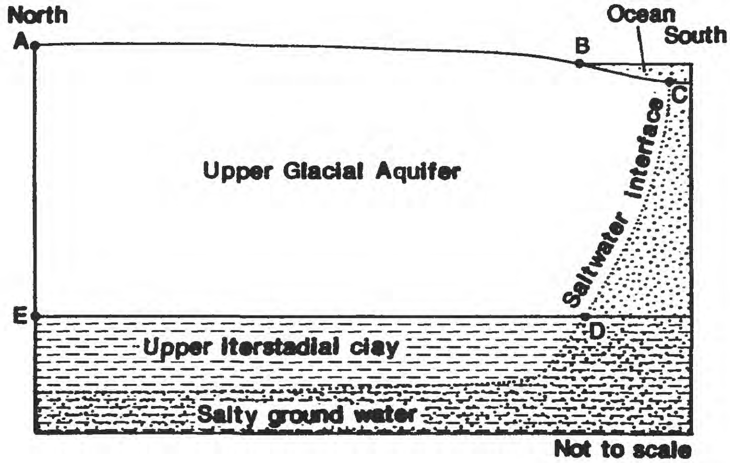



**Figure 13B.** Face-centered finite-difference grid of study-area-model section F-F´ at Jamesport, Long Island, N.Y., with detail of grid at shore.




| SEGMENT | BOUNDARY | CONDITIONS |
|---|---|---|
| | Potential function | Stream function (L3/T) |
| AB | Constant flux | Specified stream (1.0 to 0.0) |
| BC | Constant head | Specified stream (0.0 to 1.0) |
| CD,DE,EA | No flow (stream line) | Constant stream (equal to 1.0) |

**Figure 14.** Boundary conditions for the cross-sectional models of E-E′ (Cutchogue) and F-F′ (Jamesport), Long Island, N.Y.

vertical gradients with measured values and evaluating simulated heads at the saltwater interface. Initial estimates of hydraulic conductivity from published values were revised until simulated heads were representative of measured heads. The final horizontal hydraulic conductivities were within the range of published values, although the final vertical hydraulic conductivity indicated that anisotropy was much greater than the original 10:1 estimate for the upper glacial aquifer. This discrepancy could be attributed to local variations in geologic material. During calibration, different pairs of vertical and horizontal hydraulic conductivity values were found to yield similar water-table profiles but caused significant changes in simulated vertical gradients. Therefore, water-level data collected from multiple depths at given well sites were used to provide direct control on the resultant values of vertical hydraulic conductivity.

The offshore distance of the saltwater/freshwater interface (that is, boundary segment BC in fig. 14) was highly sensitive to anisotropy, but no offshore data on interface location were available for verification. Onshore ground-water flow direction and traveltime distribution were fairly insensitive to changes in anisotropy in this system, however.

The Cutchogue model has a final simulated horizontal hydraulic conductivity of 420 ft/d, a vertical hydraulic conductivity of 8 ft/d, and an anisotropy of about 50:1. The Jamesport model has final simulated horizontal and vertical conductivities of 965 ft/d and 0.25 ft/d, respectively, and an anisotropy of about 4,000:1. The significant difference in vertical hydraulic conductivities is due to the large observed difference in vertical gradients between the two sections (fig. 9). The anisotropy based on the Jamesport model is unexpected. The sensitivity analysis indicated that horizontal and vertical hydraulic conductivities were the only terms that could be adjusted to achieve the observed horizontal and vertical gradients. The above values are presented with some reservation but could be the result of a departure from the required symmetry, residual effects of agricultural pumping, or other transient effects. Although this approach to determining water-transmitting properties has not been tested previously in the area, the results likely provide useful information on the water-transmitting properties of these sediments.

## Results of Model Simulations

Results from the Cutchogue and Jamesport models are presented in the following sections. The results are in the form of flow nets and maps of the distribution of traveltime within the sections and were calculated from flow simulations.

### *Flow-Net Analysis*

The flow net for the Cutchogue model is depicted in figure 15. The streamlines represent flow paths under steady-state conditions; the value of each streamline describes the fraction of flow through the system that passes above that streamline. Two streamlines delineate a stream tube, and the amount of flow through each stream tube is equal to that in the others. For example, 70 percent of the flow in the system is above the 0.7 streamline (between it and the 0.0 line, which is at the shore), and 30 percent of the flow is below the 0.7 line (between it and the bounding stream line [1.0] that runs vertically beneath the ground-water divide, southward along the upper surface of the clay, then upward along the saltwater/freshwater interface). In a homogeneous, isotropic system, equipotential lines cross flow lines at right angles, but in figure 15 the vertical exaggeration of presentation and the anisotropy distort the angle. The flow net shows a large component of flow from the water table downward throughout the section and a large component of upward flow directly beneath the shore, consistent with the interpretation of observed head data. The model indicates that, under steady-state conditions, the saltwater/freshwater interface lies only about 75 ft offshore.

The flownet for the Jamesport model, at the same scale and vertical exaggeration as the Cutchogue flownet (fig. 15A), is shown in figure 15B and includes a detail of the nearshore area. The major hydrogeologic differences between these sections are that: (1) the aquifer at Jamesport is only about half as thick as at Cutchogue, (2) the horizontal hydraulic conductivity at Jamesport is more than twice that at Cutchogue, and (3) the vertical hydraulic conductivity at Cutchogue is more than 30 times that at Jamesport. Also, flow through the Jamesport section is about 36 percent greater than at Cutchogue because the Jamesport system is larger, and the modeled section is longer.

The saltwater/freshwater interface in the Jamesport section was estimated to lie about 2,800 ft offshore, compared to only 75 ft in the Cutchogue section, because the vertical hydraulic conductivity is lower and thus requires a considerably larger discharge area under the bay floor, where flow paths are upward and nearly vertical in both sections.

### *Traveltime Analysis*

Results of traveltime calculations for the Cutchogue and Jamesport sections are shown in figure 16. Simulated traveltimes along the Cutchogue section indicate that, throughout most of this system, ground water is younger than 50 years and attains a maximum age of about 87 years along the bounding flowline before discharging at the shore. Most of the water along the Jamesport section is younger than 25 years and attains a maximum age of about 65 years along its bounding flowline.

The simulated ground-water traveltime in both sections generally increases with depth below land surface; at the shore it increases with distance offshore. The downward deflection of the traveltime lines near the ground-water divide is probably not an actual feature but could be caused by inadequate grid size where flowpaths deviate from vertical.

The porosity of the sediments was assumed to be 0.25. The porosity is directly related to traveltime; thus, a 10-percent increase in porosity would result in a corresponding 10-percent increase in traveltime.

Simulated traveltime of ground water along the Cutchogue and Jamesport sections is plotted in figure 17 along with tritium concentrations at 21 wells sampled in November-December 1988. Tritium concentrations in water from nine wells in the Cutchogue section range from 10.6 to 23.8 TU and indicate that

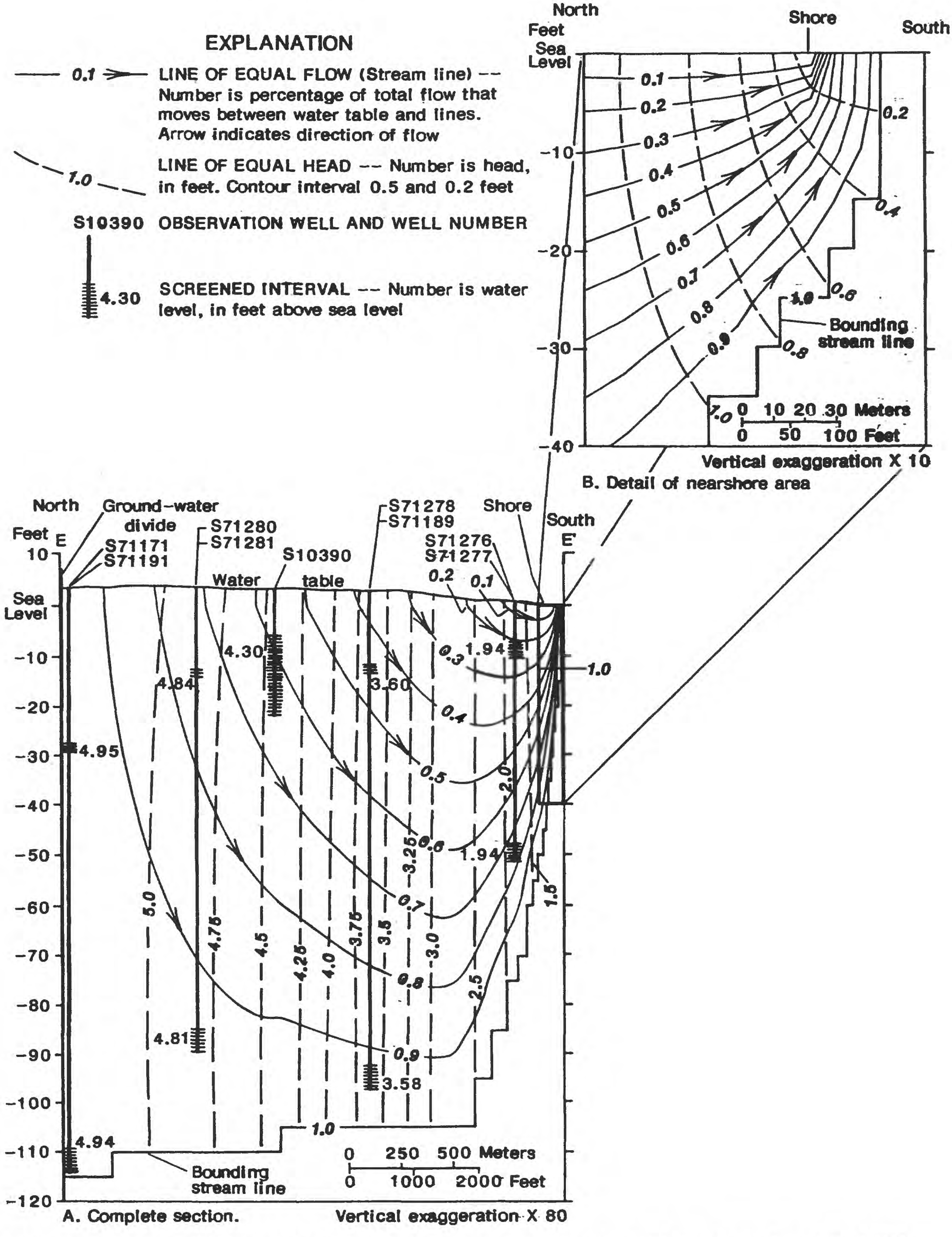



Figure 15A. Lines of equal simulated flow and equal head along model section E-E′, Cutchogue, Long Island, N.Y. Bottom, complete section. Top, detail of nearshore area outlines at bottom. (Location is shown in fig. 11.)

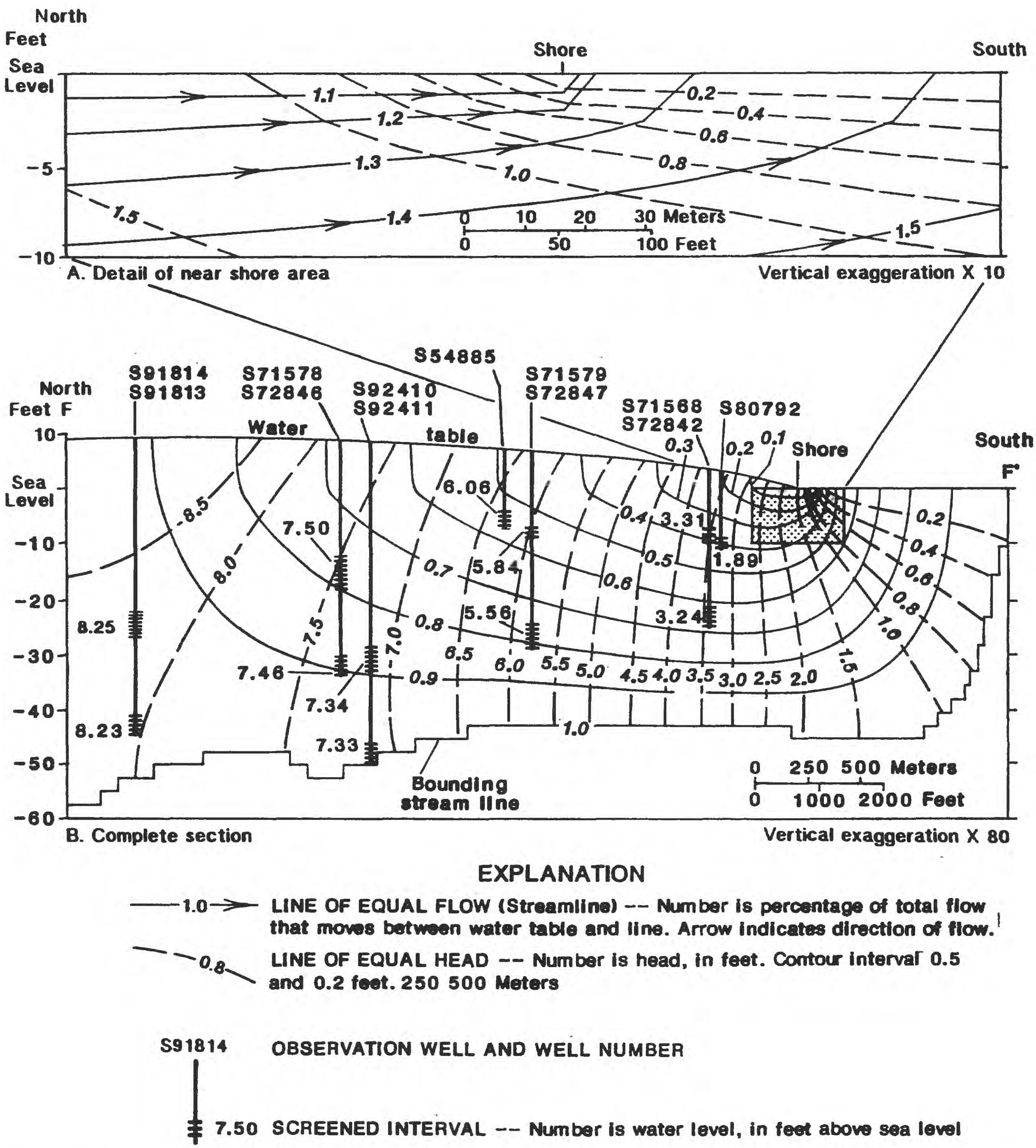



**Figure 15B.** Lines of equal simulated flow and equal head along model section F-F′, Jamesport, Long Island, N.Y. Bottom, complete section. Top, detail of nearshore area outlined at top. (Location is shown in fig. 11.)

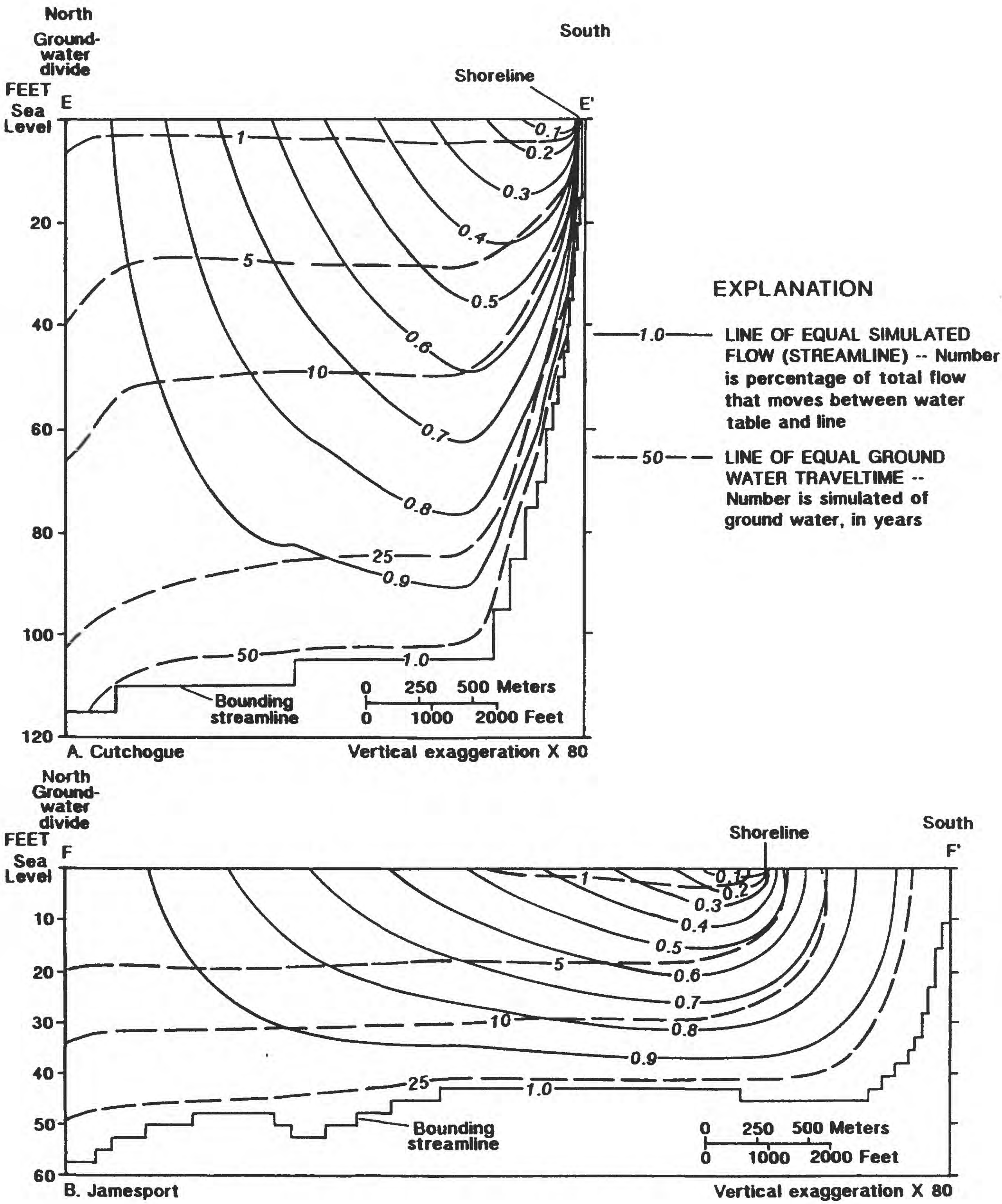



**Figure 16.** Simulated flow lines and traveltimes of ground water along hydrologic sections E-E′ and F-F′ (Jamesport), Long Island, N.Y. (Locations are shown in fig. 11.)

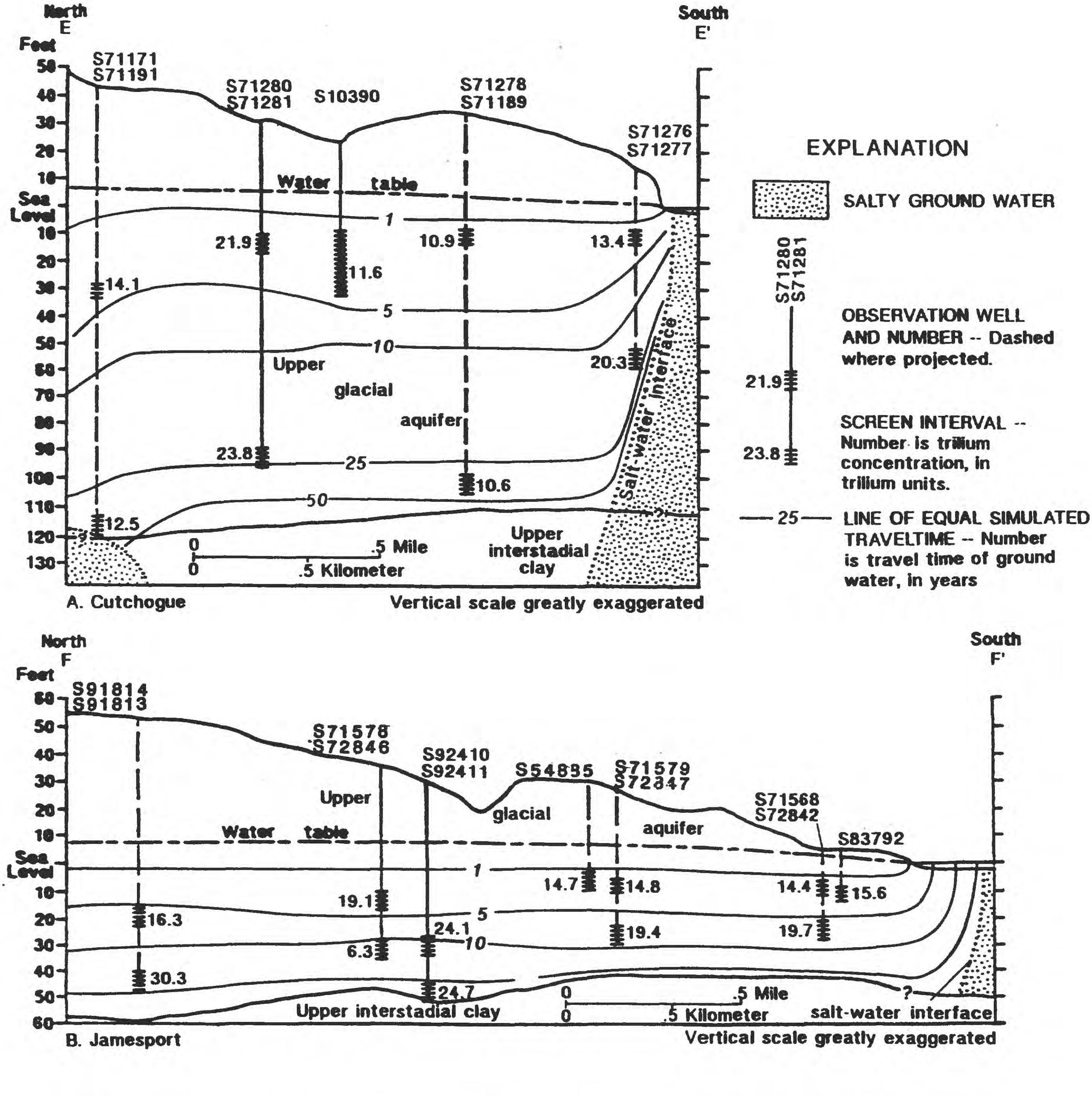



**Figure 17.** Concentrations of tritium in ground water during November-December 1988 and traveltime of ground water along sections E-E′ (Cutchogue) and F-F′ (Jamesport), Long Island, N.Y. (Locations of sections are shown in fig. 11.)

the average ground water is less than 35 years old (table 1), which agrees with the estimates obtained by the traveltime calculations. Tritium data from 12 wells along the Jamesport section also correlate with simulated traveltime estimates. Tritium data from 11 of the 12 wells in the Jamesport section indicate that the average ground water is less than 35 years old. Well S72846 yielded water with 6.3 TU, indicating an age of more than 35 years (table 1), which is greater than the estimated traveltime of 10 years.

These model results can be used to explain the observed distribution of ground-water contamination from land surface, even if the contaminant is assumed to be conservative. This application has several limitations, however, that result from factors not accounted for in the model simulations, such as dispersion, which would expand the area expected to be affected by the contaminant; seasonal variations in hydrologic conditions and the associated changes in ground-water flow direction through the year have a similar effect. Pumping of domestic and irrigation wells creates cones of depression within the ground-water flow system that alter the directions of flow locally, and small local variations in water-transmitting properties of the upper glacial aquifer also can affect flow paths and rates. Despite these uncertainties, the flow-path and traveltime analysis provides a reasonably sound basis from which to evaluate the movement of aldicarb within the system.

## DISTRIBUTION OF ALDICARB

Aldicarb is a highly toxic oxime-carbamate pesticide (a derivative of carbamic acid) used in the past to control the Colorado potato beetle and golden nematode in potato crops on Long Island. Aldicarb degrades by two main processes—hydrolysis and oxidation. The byproducts of hydrolysis are believed to be inert, but oxidation leads to the by-products aldicarb sulfoxide and sulfone. The toxicity of sulfoxide is similar to that of unweathered aldicarb, and sulfone is much less toxic (Union Carbide Corp., 1975). All byproducts are highly soluble in water at 25°C.

During 1975-79, aldicarb was used on about 24,000 acres of potato fields in eastern Suffolk County (fig. 2). The total amount of aldicarb used is unknown, but sales records indicate an average application of 5 lb/acre, or 120,000 lb (Soren and Stelz, 1984).

The belief that aldicarb would not contaminate the ground water was based on manufacturer's evidence that suggested it would not infiltrate more than 3 ft into the soil, would have a half-life of less than 7 days, and would degrade to undetectable levels within 21 days after application (Soren and Stelz, 1984). After detection of substantial concentrations of aldicarb's toxic breakdown products (aldicarb sulfoxide and aldicarb sulfone) in the upper glacial aquifer in 1979, public concern developed over the potential for long-term residence of aldicarb in the ground-water reservoir.

Because Long Island's climate is humid and temperate, aldicarb did not react as it had under controlled laboratory conditions. The sandy deposits on the North Fork contain little organic matter and are highly permeable; thus the compound was only weakly adsorbed, and the mild acidity of water in the upper glacial aquifer retarded its degradation. These factors, along with precipitation during the application season, intensified the leaching of aldicarb's decay products into the ground-water system.

Historical aldicarb concentrations throughout eastern Long Island are illustrated and discussed in detail by Baier and Moran (1981), Baier and Robbins (1982a and 1982b), and Soren and Stelz (1984). Direct use of these historic data in this analysis was difficult, however, because (1) screened zones of domestic wells are not verified, (2) only a few of the wells sampled in 1988 existed or had been sampled in previous investigations, and (3) many of the historical samples were collected from temporary screen settings during test-hole installation. Therefore, these historical data are used only qualitatively in the following discussion.

Baier and Robbins (1982) present concentrations of aldicarb (including daughter products) observed along a section from Long Island Sound to Cutchogue Harbor that is aligned closely with the section selected for flow-simulation analysis (fig. 16A). These data include analyses from 33 domestic wells, 8 observation wells, and 31 temporary screens set during drilling that were sampled from mid-1981 through early 1982. Baier and Robbins (1982a) estimate that aldicarb use in this area started in 1976, which indicates that aldicarb had dispersed in ground water for a maximum of 6 years before detection. Figure 16A indicates that, under unstressed conditions, ground water throughout most of the Cutchogue section would reach a depth of about 30 ft below sea level 6 years after entering the system. Analyses of water samples from the 72 wells indicate that aldicarb concentrations at 14 of 31 wells screened less than 30 ft below sea level were above the detection limit (1 µg/L), and that aldicarb was detected at only 4 of 41 wells screened deeper than 30 ft below sea level. These data are generally consistent with the hypothesis that aldicarb transport in ground water was relatively conservative, with virtually no decay, during 1976-82.

Soren and Stelz (1984) describe aldicarb concentrations observed along the Jamesport section (fig. 16B) in 1982. Although their interpretation indicates that aldicarb dispersal within the ground-water system takes place along a generally horizontal front (Soren and Stelz, 1984; fig. 8A), aldicarb had, by 1982, advanced to as deep as 50 ft below sea level. Model estimates of traveltime at this section (fig. 16B) indicate that aldicarb would not be expected to exceed a depth of about 20 ft under unstressed flow conditions. This discrepancy can be explained by two factors: (1) aquifer properties in the Jamesport area might not be represented accurately in the model (the extreme value of anisotropy is questionable), and (2) ground-water withdrawals for irrigation could have affected ground-water flow and increased the downward movement of aldicarb or affected the observed vertical gradients that were used to calibrate the model.

Ground-water samples were collected in November and December 1988 along the Jamesport and Cutchogue sections and analyzed for total aldicarb (unweathered fraction plus the by-products sulfoxide and sulfone) by the SCDHS Public Health Laboratory; results are shown in figure 18. The shaded areas at the top of each section represent land that was designated as agricultural in 1982 by the Long Island Regional Planning Board.

The distribution of aldicarb as indicated by 1988 sampling along the Cutchogue section (fig. 18A) shows that concentrations at all wells but one were below the 1-µg/L detection limit. The 1988 concentration of aldicarb in well S71280 was 6 µg/L; the decrease from 18 µg/L in 1981 indicates that aldicarb has dissipated along the Cutchogue section. Ground-water traveltime in the area depicted in this section indicates, however, that aldicarb that entered the ground-water system in 1975-79 would have reached depths of 50 to 60 ft below sea level by 1988, corresponding to a traveltime of 9 to 13 years. This cannot be verified, though, because the only well screened at this depth is out of range for the 9- to 13-year traveltime zone.

Water from 4 of 12 wells sampled along the Jamesport section in 1988 (fig. 18B) contained aldicarb; the concentrations indicate that the aldicarb dispersed widely at depths of 10 to 50 ft below sea level in the northern half of the section. The estimated traveltimes of about 4 to 25 years at these depths further support the hypothesis made on the basis of 1981-82 data that ground-water-flow patterns in this section are inaccurately represented in the model.

Water from wells S91814 and S91812 (previously numbered S72845 and S22855, respectively) had aldicarb concentrations of 25 and 14 µg/L in 1982 (Soren and Stelz, 1984) and continued to have elevated concentrations in 1988. The aldicarb concentration in water from well S71578 sharply increases from 1.4 µg/L in 1982 to 59 µg/L in 1988. Conversely, water at wells S71568 and S72842, which had concentrations of 27 and 69 µg/L, respectively, in 1982, no longer had aldicarb detectable concentrations (greater than 1 µg/L) in 1988.

## SUMMARY AND CONCLUSIONS

Ground water in agricultural areas of the North Fork of eastern Long Island has been contaminated by the agricultural pesticide, aldicarb. Aldicarb, a highly toxic oxime-carbamate pesticide, was applied to potato fields in large quantities during 1975-79 and was subsequently detected in shallow ground water. The shallow ground-water system is the sole source for the residents' drinking-water supply.

Aldicarb degrades by two processes—hydrolysis and oxidation. Products produced by hydrolysis are considered inert, but the products produced by oxidation—aldicarb sulfoxide and sulfone—are toxic. Aldicarb's normal half-life is less than 7 days, but it has persisted much longer in the humid, temperate, sandy and slightly acidic environment of Long Island.

In previous studies conducted by the SCDHS and the USGS on the North Fork, aldicarb was found in the shallow ground-water system 2 to 3 years after the cessation of its use in 1979. Sampling after 1982 by the SCDHS continued to detect high concentrations of aldicarb in the local ground water, but in 1988, only 5 of 21 wells sampled (1 of 9 wells in Cutchogue and 4 of 12 wells in Jamesport) had detectable (greater than 1 µg/L) concentrations of aldicarb.

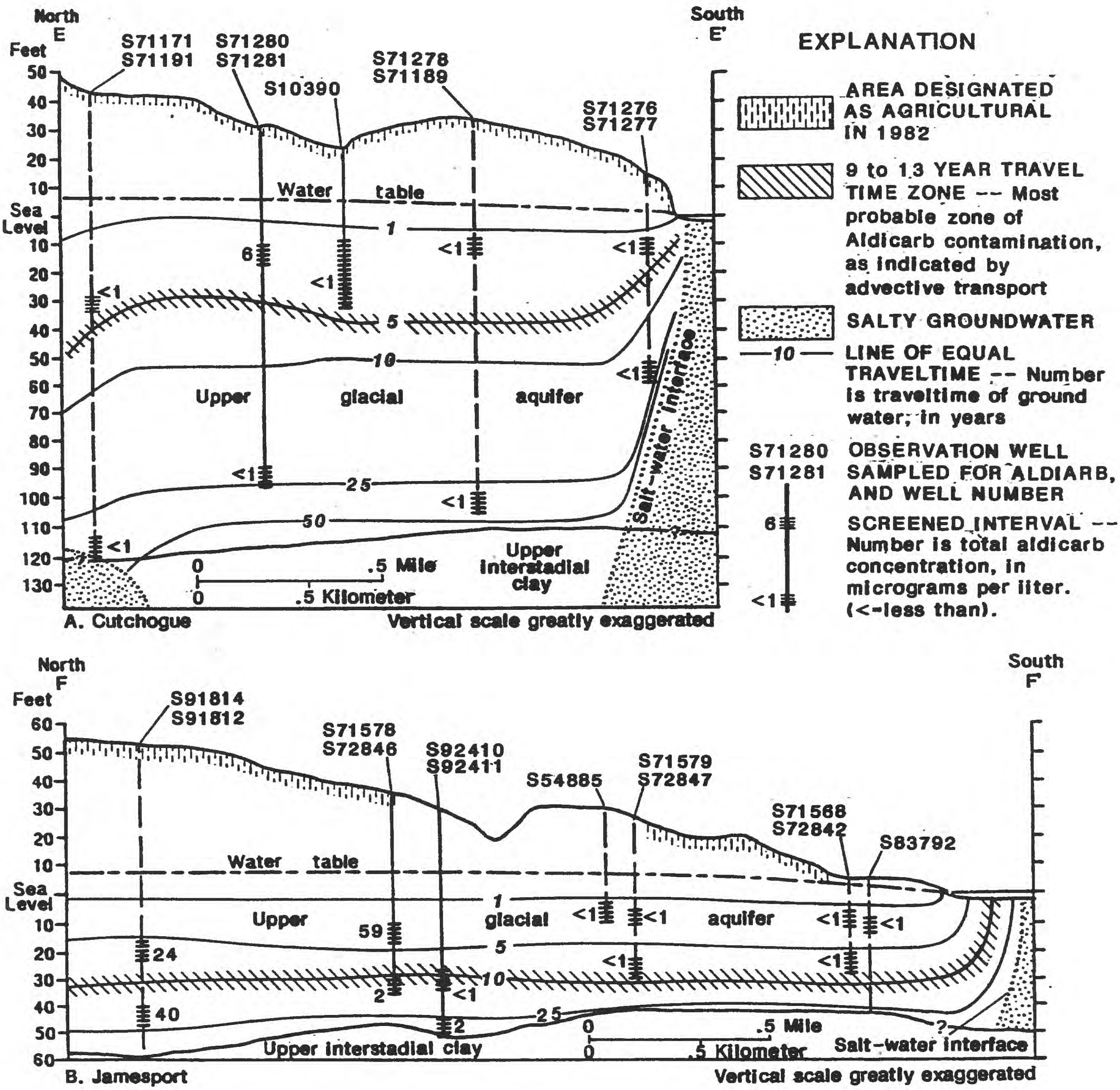



**Figure 18.** Aldicarb concentrations in ground water during November-December 1988 and simulated traveltime of ground water along sections E-E′ (Cutchogue) and F-F′ (Jamesport), Long Island, N.Y. (Locations are shown in fig. 11.)

A numerical modeling technique was used to calculate flow nets along two vertical sections along ground-water flow paths in Cutchogue and Jamesport. Traveltime distribution was calculated from the flow nets. Although the simulations were based on highly idealized conditions of the flow system, they provide a reliable basis from which to qualitatively evaluate the dispersal of aldicarb in ground water.

Flow nets generated from the model results indicate that ground-water flow in both sections had large vertical components—downward beneath the water table and upward beneath the offshore discharge boundary. Traveltimes calculated from model results increase with depth beneath the water table and with distance offshore. Most ground water in the Jamesport area was found to be younger than 25 years old; most ground water in the Cutchogue area was younger than 50 years old. Ground-water ages estimated from tritium concentrations in samples collected in November-December 1988 indicated all ground-water samples from both sections was less than 35 years old in 1988.

Aldicarb concentrations along the sections at Cutchogue and Jamesport indicate that the aldicarb front is largely horizontal and that aldicarb dispersed conservatively during 1975-82. Data collected along the Jamesport section in 1988 indicate that, even though aldicarb has dissipated at some wells, it has persisted within the aquifer in the northern part of the section—an area in which downward movement is probably accelerated by pumping for irrigation during the growing season. Although the data appear to indicate that aldicarb in the Cutchogue section has dissipated, no wells are screened in depth zones of water 9 to 13 years old—the age of ground water that was affected by aldicarb.

## REFERENCES CITED

Baier, J.H., and Moran, Dennis, 1981, Status report on aldicarb contamination of groundwater as of September 1981: Hauppauge, N.Y., Suffolk County Department of Health Services, 45 p.

Baier, J.H., and Robbins, S.F., 1982a, Report on the occurrence and movement of agricultural chemicals in groundwater—north fork of Suffolk County: Hauppauge, N.Y., Suffolk County Department of Health Services, 71 p.

____1982b, Report on the occurrence and movement of agricultural chemicals in groundwater—south fork of Suffolk County: Hauppauge, N.Y., Suffolk County Department of Health Services, 68 p.

Bradbury, K.R., 1991, Tritium as an indicator of ground-water age in central Wisconsin: Ground Water, v. 29, no. 3, p. 398-404.

Buxton, H.T., and Modica, Edward, 1992, Patterns and rates of ground-water flow on Long Island, New York: Ground Water, v. 30, no. 6, pl. 857-866.

Christian, J.T., 1980, Flownets by the finite element method: Ground Water, v. 18, no. 2, p. 178-181.

Crandell, H.C., 1963, Geology and ground-water resources of the Town of Southold, Suffolk County, New York: U.S. Geological Survey Water-Supply Paper 1619-GG, 36 p.

Fogg, G.E., and Senger, R.K., 1985, Automatic generation of flow nets with conventional ground-water modeling algorithms: Ground Water, v. 23, no. 3, p. 336-344.

Franke, O.L., and Cohen, Philip, 1972, Regional rates of ground-water movement on Long Island, New York, *in* Geological Survey Research 1972: U.S. Geological Survey Professional Paper 800-C, p. C271-277.

Frind, E.O., and Matanga, G.B., 1985, The dual formulation of flow for contaminant transport modeling, 1. Review of theory and accuracy aspects: Water Resource Research, v. 21, no. 2, p. 159-169.

Harbaugh, A.W., 1991, A generalized finite-difference formulation of the U.S. Geological Survey modular three-dimensional finite difference ground-water flow model: U.S. Geological survey Open-File Report 91-494, 60 p.

Hendry, J.M., 1988, Do isotopes have a place in ground-water studies?: Ground Water, v. 26, no. 4, p. 410-415.

Hoffman, J.F., 1961, Hydrology of the shallow ground-water reservoir of the Town of Southold, Suffolk County, Long Island, New York: New York State Water Resources Commission Bulletin GW-45, 49 p.

Jensen, H.M., and Soren, Julian, 1974, Hydrogeology of Suffolk County, Long Island, New York: U.S. Geological Survey Hydrologic Investigations Atlas HA-501, 2 sheets, scale 1:250,000.

Knott, J.F., and Olimpio, J.C., 1986, Estimation of recharge rates to the sand and gravel aquifer using environmental tritium, Nantucket Island, Massachusetts: U.S. Geological Survey Water-Supply Paper 2297, 26 p.

Long Island Regional Planning Board, 1982, Land use 1981—quantification and analysis of land use for Nassau and Suffolk Counties: Hauppauge, N.Y., Long Island Regional Planning board, 47 p.

Lusczynski, N.J., 1961, Filter-press method of extracting water samples for chloride analysis: U.S. Geological Survey Water-Supply Paper 1544-A, 8 p.

McClymonds, N.E., and Franke, O.L., 1972, Water-transmitting properties of aquifers on Long Island, New York: U.S. Geological Survey Professional Paper 627-E, 24 p.

McDonald, M.G., and Harbaugh, A.W., 1984, A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 83-875, 528 p.

Miller, J.F., and Frederick, R.H., 1969, The precipitation regime of Long Island, New York: U.S. Geological Survey Professional Paper 627-A, 21 p.

Nemickas, Bronius, and Koszalka, E.J., 1982, Geohydrologic appraisal of water resources of the South Fork, Long island, New York: U.S. Geological Survey Water-Supply Paper 2073, 55 p.

Payne, B.R., and Halevy, E., 1968, Guidebook on nuclear techniques in hydrology: Vienna, Austria, International Atomic Energy Agency, p. 1-21.

Reilly, T.E., Buxton, H.T., Franke, O.L., and Wait, R.L., 1983, Effects of sanitary sewers on ground-water levels and streams in Nassau and Suffolk Counties, New York—part 1, geohydrology, modeling strategy, and regional evaluations: U.S. Geological Survey Water-Resources Investigations Report 82-4045, 45 p.

Soren, Julian, and Stelz, W.G., 1984, Aldicarb-pesticide contamination of ground water in eastern Suffolk County, Long Island, New York: U.S. Geological Survey Water-Resources Investigations Report 84-4251, 34 p.

Talmage, A.N., 1977, The growth of agriculture in Riverhead Town, Suffolk County, New York: Riverhead, N.Y., Suffolk County Historical Society, 43 p.

Thatcher, L.L., Janzer, V.J., and Edwards, K.W., 1977, Methods for determination of radioactive substances in water and fluvial sediments: U.S. Geological Survey TEchniques of Water-Resources Investigations, book 5, chap. A5, 95 p.

Union Carbide Corporation, 1975, Technical information, Temik aldicarb pesticide, 63 p.

Wang, H.F., and Anderson, M.P., 1982, Introduction to groundwater modeling, finite difference and finite element methods: San Francisco, Calif., W.H. Freeman, 237 p.

**Table 2.** Records of selected wells in Suffolk County, N.Y.

[°, degrees; ′, minutes; ″, seconds; G, upper glacial aquifer; M, Magothy aquifer; (LS), land-surface elevation given where no measuring point is available; --, no data available; F, fire well; A, agricultural well; O, observation well; T, test hole; I, industrial well. Locations are shown on pl. 1]

| Well number | Latitude ° ′ ″ | Longitude ° ′ ″ | Well depth (feet) | Screen interval (in feet below land surface) | Aquifer | Measuring point (feet above sea level) | Date completed | Well use |
|---|---|---|---|---|---|---|---|---|
| 681 | 405606 | 723618 | 255 | 240 to 255 | G | 10.0 (LS) | 8/26/36 | F |
| 6558 | 405835 | 723256 | 38 | -- | G | 15.54 | 10/14/49 | F |
| 10390 | 410057 | 722920 | 26 | 31 to 51 | G | 25.87 | 1/5/63 | F |
| 15015 | 405738 | 723906 | 134 | 114 to 134 | G | 64.0 (LS) | 8/16/56 | A |
| 16756 | 405843 | 723529 | 62 | 59 to 62 | G | 60.77 | 7/ /74 | O |
| 32390 | 410056 | 723026 | 550 | 250 to 279 | G | 37.73 | 3/4/68 | T |
| 33073 | 405725 | 723629 | 460 | 439 to 459 | M | 50.2 | 7/22/68 | T |
| 39269 | 405924 | 723215 | 11 | 47 to 67 | G | 15.90 | 4/28/71 | F |
| 40407 | 405636 | 723448 | 140 | 119 to 139 | G | 10.0 (LS) | 3/20/72 | T |
| 47231 | 405541 | 723753 | 40 | 24 to 34 | G | 24.00 | 3/30/73 | O |
| 50399 | 405723 | 723754 | -- | -- | -- | -- | 12/7/73 | T |
| 51322 | 405717 | 723748 | 200 | 169 to 200 | G | 33.0 (LS) | 7/3/74 | I |
| 51568 | 405808 | 723854 | 70 | 58 to 68 | G | 54.08 | 8/13/74 | O |
| 51572 | 405651 | 723929 | 43 | 31 to 41 | G | 32.58 | 7/3/74 | O |
| 51581 | 405722 | 723420 | 45 | 32 to 42 | G | 27.43 | 7/31/74 | O |
| 51582 | 405853 | 723539 | 84 | 72 to 82 | G | 61.08 | 7/ /74 | O |
| 51587 | 405809 | 723709 | 80 | 66 to 76 | G | 57.32 | 7/26/74 | O |
| 51588 | 405634 | 723805 | 60 | 47 to 57 | G | 34.61 | 7/31/74 | O |
| 51589 | 405704 | 723614 | 43 | 30 to 40 | G | 24.85 | 7/15/74 | O |
| 53322 | 410057 | 723155 | 100 | 79 to 99 | G | 52.59 | 11/11/74 | O |
| 53324 | 410104 | 723033 | 62 | 49 to 59 | G | 42.51 | 10/17/74 | O |
| 53325 | 410007 | 723319 | 68 | 53 to 63 | G | 40.26 | 11/11/74 | O |
| 53326 | 410229 | 722957 | 92 | 79 to 89 | G | 61.79 | 10/22/74 | O |
| 53327 | 410022 | 722936 | 44 | 32 to 42 | G | 22.55 | 10/10/74 | O |
| 53329 | 410140 | 722816 | 71 | 56 to 71 | G | 22.21 | 2/6/75 | O |
| 53332 | 405843 | 723243 | 45 | 33 to 43 | G | 22.00 | 10/3/74 | O |
| 53333 | 405924 | 723423 | 74 | 62 to 72 | G | 48.94 | 11/7/74 | O |
| 53334 | 405959 | 723039 | 53 | 41 to 51 | G | 30.37 | 10/8/74 | O |
| 53336 | 410017 | 723155 | 42 | 30 to 40 | G | 19.61 | 11/4/74 | O |
| 54478 | 405906 | 723528 | 125 | 92 to 125 | G | 65.0 (LS) | 3/ /75 | T |
| 54885 | 405706 | 723456 | 20 | 16 to 20 | G | 11.15 | 4/10/75 | O |
| 58429 | 405923 | 723541 | -- | -- | -- | -- | 5/18/76 | T |
| 60682 | 405754 | 723412 | 105 | 95 to 105 | G | 40.00 | 1/25/77 | A |
| 65605 | 410101 | 723030 | 44 | 41 to 44 | G | 40.46 | 9/19/78 | O |
| 65606 | 410225 | 722837 | 51 | 46 to 51 | G | 37.01 | 9/18/78 | O |
| 68831 | 410138 | 722959 | 203 | 190 to 200 | G | 53.13 | 4/17/80 | O |
| 69761 | 410138 | 722958 | 100 | 94 to 99 | G | 42.54 | 9/10/80 | O |
| 71044 | 410158 | 723040 | -- | -- | -- | -- | 9/23/80 | T |
| 71045 | 410138 | 722958 | 66 | 63 to 66 | G | 42.96 | 6/24/81 | O |
| 71087 | 405946 | 723212 | 6 | | G | 7.39 | 7/13/81 | O |
| 71089 | 405955 | 723207 | 12 | 10 to 12 | G | 6.81 | 7/15/81 | O |
| 71090 | 410002 | 723207 | 12 | 8 to 12 | G | 17.78 | 7/6/81 | O |
| 71091 | 410015 | 723155 | 12 | 10 to 12 | G | 11.46 | 7/2/81 | O |
| 71170 | 410123 | 723002 | -- | -- | -- | -- | 7/7/81 | T |
| 71171 | 410122 | 723000 | 73 | 70 to 73 | G | 41.94 | 7/13/81 | O |

**Table 2.** Records of selected wells in Suffolk County, N.Y.--continued

| Well number | Latitude ° ′ ″ | Longitude ° ′ ″ | Well depth (feet) | Screen interval (in feet below land surface) | Aquifer | Measuring point (feet above sea level) | Date completed | Well use |
|---|---|---|---|---|---|---|---|---|
| 71189 | 410040 | 722913 | 132 | 127 to 132 | G | 32.99 | 8/14/81 | O |
| 71191 | 410121 | 722959 | 156 | 151to 157 | G | 42.06 | 7/16/81 | O |
| 71274 | 410013 | 722858 | 30 | 20 to 30 | G | 5.80 | 7/22/81 | O |
| 71275 | 410011 | 722857 | 25 | 20 to 24 | G | 5.69 | 7/20/81 | O |
| 71276 | 410038 | 722842 | 25 | 20 to 24 | G | 14.41 | 7/27/81 | O |
| 71277 | 410036 | 722841 | 67 | 62 to 66 | G | 15.03 | 7/29/81 | O |
| 71278 | 410044 | 722913 | 44 | 42 to 44 | G | 33.01 | 7/30/81 | O |
| 71279 | 410044 | 722913 | -- | -- | -- | -- | 7/30/81 | T |
| 71280 | 410106 | 722937 | 45 | 42 to 45 | G | 30.04 | 8/19/81 | O |
| 71281 | 410106 | 722938 | 121 | 116 to 121 | G | 30.07 | 8/21/81 | O |
| 71283 | 410151 | 723048 | 77 | 73 to 77 | G | 53.83 | 9/10/81 | O |
| 71284 | 410152 | 723050 | 149 | 144 to 149 | G | 53.79 | 9/11/81 | O |
| 71285 | 410158 | 723100 | 77 | 73 to 77 | G | 53.88 | 9/4/81 | O |
| 71286 | 410207 | 723115 | 77 | 73 to 77 | G | 53.36 | 8/31/81 | O |
| 71287 | 410205 | 723114 | 134 | 129 to 134 | G | 53.21 | 9/1/81 | O |
| 71566 | 405602 | 723538 | 25 | 21 to 25 | G | 11.98 | 2/4/82 | O |
| 71567 | 405623 | 723501 | 17 | 15 to 17 | G | 9.14 | 1/26/82 | O |
| 71568 | 405639 | 723425 | 17 | 15 to 17 | G | 21.54 | 1/6/82 | O |
| 71569 | 405655 | 723347 | 32 | 30 to 32 | G | 21.54 | 1/27/82 | O |
| 71570 | 405728 | 723424 | 52 | 50 to 52 | G | 29.13 | 1/28/82 | O |
| 71571 | 405752 | 723448 | 44 | 42 to 44 | G | 37.27 | 2/4/82 | O |
| 71572 | 405811 | 723504 | 56 | 52 to 56 | G | 46.68 | 2/4/82 | O |
| 71573 | 405811 | 723504 | 75 | 70 to 75 | G | 46.62 | 7/1/82 | O |
| 71574 | 405851 | 723538 | 109 | 105 to 109 | G | 62.91 | 2.16.82 | O |
| 71575 | 405851 | 723538 | 64 | 59 to 64 | G | 63.12 | 6/30/82 | O |
| 71576 | 405801 | 723544 | 59 | 57 to 59 | G | 51.06 | 12/28/81 | O |
| 71578 | 405730 | 723517 | 46 | 42 to 46 | G | 30.19 | 2/2/82 | O |
| 71579 | 405701 | 723452 | 26 | 24 to 26 | G | 15.69 | 12/30/81 | O |
| 72840 | 405602 | 723538 | 45 | 40 to 45 | G | 12.17 | 6/21/82 | O |
| 72841 | 405623 | 723501 | 40 | 35 to 40 | G | 8.67 | 6/22/82 | O |
| 72842 | 405639 | 723425 | 34 | 29 to 34 | G | 7.14 | 6/22/82 | O |
| 72843 | 405655 | 723347 | 40 | 35 to 40 | G | 21.16 | 6/23/82 | O |
| 72844 | 405752 | 723448 | 60 | 55 to 60 | G | 37.39 | 7/2/82 | O |
| 72846 | 405730 | 723517 | 65 | 60 to 65 | G | 30.78 | 6/30/82 | O |
| 72847 | 405701 | 723452 | 45 | 40 to 45 | G | 15.54 | 6/23/82 | O |
| 72848 | 405820 | 723600 | 75 | 70 to 75 | G | 53.40 | 7/7/82 | O |
| 83709 | 405641 | 723416 | 161 | 153 to 158 | G | 5.94 | 7/1/86 | O |
| 83792 | 405638 | 723416 | 18 | 16 to 18 | G | 6.29 | 6/16/86 | O |
| FW#11 | 410010 | 723229 | 34 | -- | G | 36.74 | Pre 1981 | F |
| FW#15 | 410056 | 723258 | 11 | 29 to 49 | G | 13.47 | Pre 1981 | O |
| 91812 | 405803 | 723544 | 99 | 91 to 96 | G | 50.48 | 7/11/88 | O |
| 91813 | 405801 | 723544 | 199 | 191 to 196 | G | 50.67 | 7/21/88 | O |
| 91814 | 405805 | 723544 | 77 | 62 to 67 | G | 50.90 | 7/27/88 | O |
| 91815 | 405842 | 723411 | 299 | 291 to 296 | G | 46.02 | 8/11/88 | O |