ALDICARB-PESTICIDE CONTAMINATION OF GROUND WATER IN EASTERN SUFFOLK COUNTY, LONG ISLAND, NEW YORK

By Julian Soren and William G. Stelz

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(in pocket)

CONVERSION FACTORS AND ABBREVIATIONS

Multiply inch-pound units	by	To obtain SI units
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
quart (qt)	0.9464	liter (L)
gallon (gal)	3.785	liter (L)
	Flow	
gallon per minute (gal/min)	0.06308	liter per second (L/s)
	Hydraulic Conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
pound, avoirdupois (lb)	0.4536×10^6	microgram (μg)
	Temperature	
degree Fahrenheit (°F)	°C = 5/9 (°F-32)	degree Celsius (°C)
	Other	
pound (avoirdupois) per acre (lb/acre)	1.121	kilogram per hectare (kg/ha)

Miscellaneous Abbreviations

ai - active ingredients
h - hour
I.D. - inside diameter
mg/L - milligrams per liter
NGVD - National Geodetic Vertical Datum of 1929 (mean sea level)
ppb - parts per billion
μg/L - micrograms per liter
yr - year

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ABSTRACT

Aldicarb, a highly toxic oxime-carbamate pesticide, was used to control the Colorado potato beetle and golden nematode in potato farms over large areas of eastern Long Island, N.Y., during 1975-79. The pesticide was believed to have a short half-life and small soil penetration and was therefore considered incapable of causing ground-water contamination. However, widespread contamination of ground water by aldicarb was confirmed by extensive sampling during 1979-80 in the upper glacial aquifer, the principal source of drinking water in the area.

After the discovery of aldicarb in 1979, the New York State Department of Health set an interim maximum aldicarb concentration in drinking water at 7 parts per billion, equivalent to 7 micrograms per liter (μg/L). The manufacturer of aldicarb subsequently installed carbon filters on drinking-water supplies that contained more than 7 μg/L of aldicarb to alleviate the health hazard. Aldicarb concentrations as high as 515 μg/L were found by 1980, and the U.S. Environmental Protection Agency revoked its approval of the use of aldicarb on Long Island in early 1980 at the manufacturer's request.

A small area on the north fork of eastern Long Island, in the vicinity of Jamesport, Town of Riverhead, was selected for a detailed study of aldicarb contamination in the area's upper glacial aquifer during 1981-82. The study showed that aldicarb had penetrated to a depth of about 40 feet below the water table and was present beneath most of the study area. Aldicarb concentrations ranged from not detected to as much as 180 μg/L in the Jamesport area and to as much as 239 μg/L further east in Suffolk County. Clayey and silty deposits in the upper part of the aquifer seem to have prevented the movement of aldicarb into the lower part of the upper glacial aquifer and the underlying Magothy aquifer.

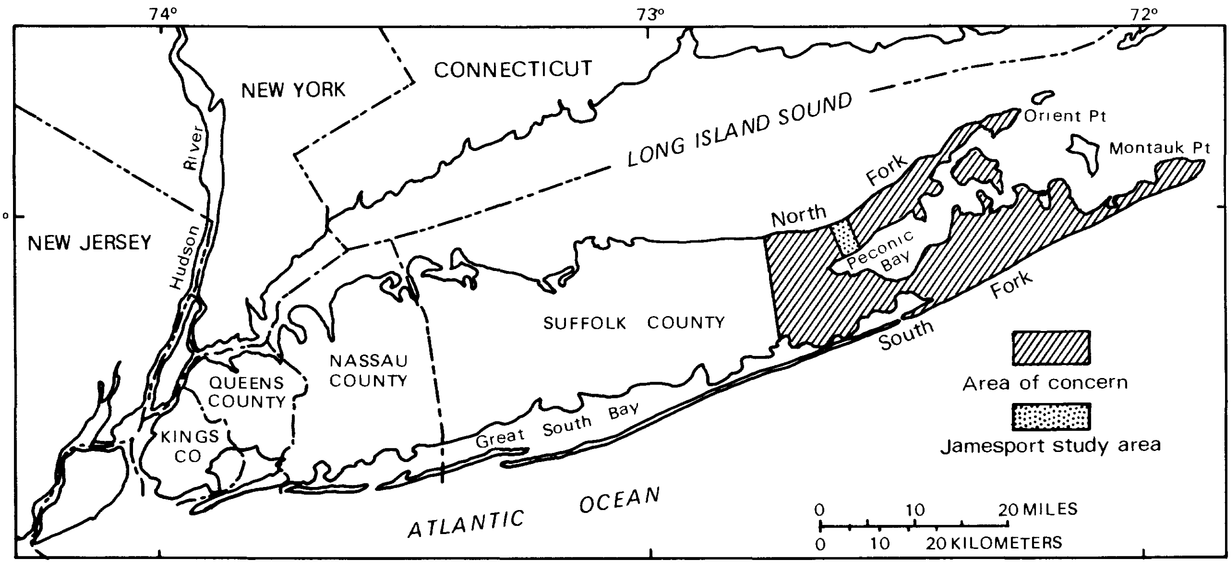
The duration of excessive aldicarb concentrations in the ground water of eastern Long Island has not been precisely determined and is still under investigation. Current estimates suggest that between the years 1990 to 2030, aldicarb concentrations will be less than 7 μg/L everywhere in the area.

An uncontaminated fresh ground-water supply on the north fork is available in the lower part of the upper glacial aquifer, which is protected from percolation of aldicarb by beds of clay, and freshwater in parts of the underlying Magothy and Lloyd aquifers can meet current domestic needs in the Town of Riverhead. Water above the clay beds could still be used for irrigation and commercial purposes.

INTRODUCTION

Aldicarb is the generic name for TEMIK , a highly toxic oxime-carbamate pesticide developed by the Union Carbide Corporation[1] for agricultural use. Aldicarb was used in potato farming on about 24,000 acres in eastern Suffolk County (fig. 1) during 1975-79 to control the Colorado potato beetle and golden nematode. The pesticide was believed incapable of leaching into ground water; however, in 1979, several ground-water samplings by the Cornell University Agricultural Research station at Riverhead revealed an unanticipated contamination of the area's upper glacial aquifer, which has been the area's principal source of water supply. Subsequent ground-water sampling through 1980 by the Suffolk County Department of Health Services showed the contamination to be widespread.

The contamination led to a revocation of aldicarb's approval for use on Long Island by the U.S. Environmental Protection Agency (USEPA) in February 1980 at the manufacturer's request, and the New York State Department of Health set an interim maximum of 7 ppb (equivalent to 7 μg/L) for aldicarb in drinking water. Much of the ground water in the area was found to contain aldicarb exceeding the maximum concentration, and as a result, the manufacturer, in agreement with the Suffolk County Department of Health Services (SCDHS), provided for installation of more than 1,000 activated-carbon filters on well systems to bring concentrations within standards and agreed to provide filters through June 1983 for any well system found to contain more



Base from U.S. Geological Survey State base map, 1974, 1:500,000

Figure 1.--Area of aldicarb investigation in eastern Suffolk County, N.Y.

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[1] Use of the brand name and the manufacturer's name in this report is for identification purposes only and does not constitute criticism or endorsement by the U.S. Geological Survey.

than 7 µg/L of aldicarb (Baier and Moran, 1981, p. 35-36). However, the manufacturer has continued to provide the filtering systems beyond June 1983 (Dennis Moran, SCDHS, May 2, 1984, oral commun.).

In response to public concern over the presence of aldicarb in the aquifer, the U.S. Geological Survey in November 1980 entered into a cooperative program with the Suffolk County Department of Health Services (SCDHS) and the Suffolk County Water Authority to study the depth and concentration of aldicarb in ground water in relation to its rate of application and to correlate these findings with ground-water flow and recharge patterns to estimate the rate of removal from the aquifer.

Much previous work had been done by SCDHS in locating aldicarb-contaminated areas, and the manufacturer had provided more than 8,000 analyses of ground water from wells in eastern Long Island and made the results available to the county. The Geological Survey selected a small representative area in the Jamesport vicinity of the north fork (fig. 1) to assess the recharge patterns and the rate and directions of ground-water flow. The Jamesport area's hydrogeology is typical of most of eastern Long Island; therefore, the interpretation of the findings in that area are probably applicable to eastern Long Island.

Effects of Aldicarb on Humans

The acute symptoms of aldicarb overdosage in humans may be expected to include headache, giddiness, nervousness, blurred vision, weakness, nausea, cramps, and discomfort in the chest. Other signs of overdosage include sweating, myosis, tears, salivation, excessive respiratory secretions, vomiting, impaired breathing, muscle twitching, convulsions, and coma (Union Carbide Corp., 1975, p. 53). To date (1984), no cases of signs or symptoms of aldicarb poisoning in Suffolk County that could be traced to drinking of water have been documented.

Purpose and Scope

This report discusses the degree and mode of the aldicarb contamination in relation to the local hydrogeology and describes the ground-water-contamination pattern in the Jamesport area through a series of illustrations and tables. It also presents chemical data and discusses the chemical degradation rates to enable a preliminary estimate of the time needed for aldicarb to leave the system.

Location and Extent of Area

Most of the aldicarb contamination occurred on Long Island's north fork in the Towns of Riverhead and Southold (pl. 1); significant contamination also occurred on the island's south fork, mainly in the Town of Southampton but also in the southeastern part of the Town of Brookhaven and the southwestern part of the Town of East Hampton. Locations of the aldicarb-contaminated areas and their concentrations in shallow ground water are shown in plate 1.

The SCDHS investigations of aldicarb contamination made to 1982 (Baier and Robbins, 1982a and 1982b) revealed similarities of contamination in affected areas. The Jamesport area (fig. 1), a 1.5-mi-wide strip across the north fork containing about 900 acres of farmed land, approximately 600 of which are used for potato growing, was selected for detailed study because it had not been included in detail in the SCDHS study. The degree of aldicarb contamination in the Jamesport area seemed to be similar to that in the SCDHS-studied areas, according to the analyses done by the manufacturer.

Methods of Investigation

Test Drilling

Thirteen exploratory drilling sites were established from north to south along Manor and Herricks Lanes and from west to east along Peconic Bay Boulevard (fig. 2). Most of the drilling reached to depths of 160 ft; at one site (10 ft north of well S71577, fig. 2) drilling was extended into the Magothy aquifer below the upper glacial aquifer to a depth of 586 ft to obtain data on the position of the saltwater front in this part of eastern Suffolk County.

Sampling Procedures

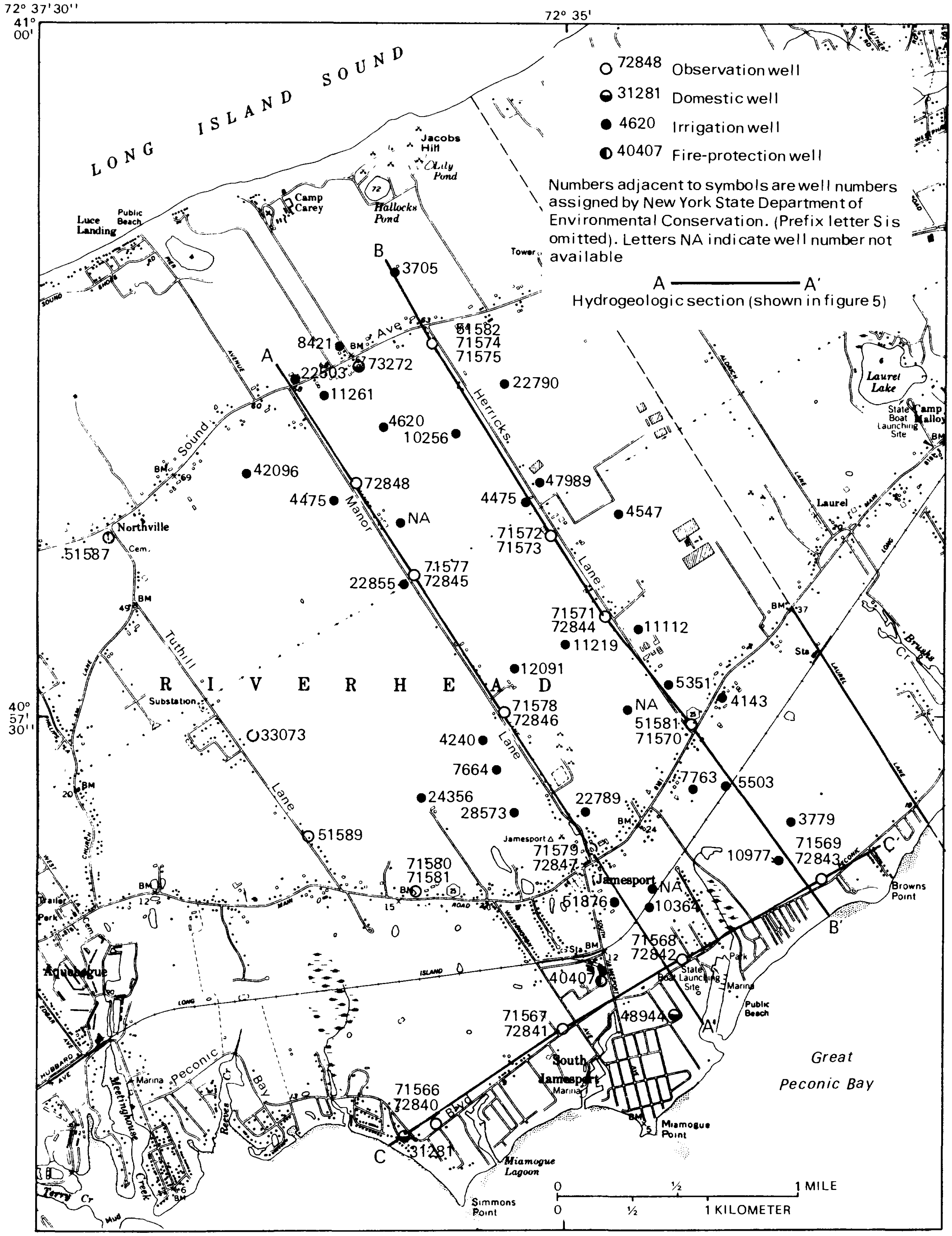
Water samples were taken at about 20-ft intervals from the bottom up by installing a 2-in. I.D. casing with a 2-ft-long screen in the 6-in. diameter drilled hole, which was backfilled after the installation. Each screen setting was developed to obtain maximum well yield before sampling. Samples were pumped by compressed-air lift where the water table was more than 25 ft deep, and by suction lift with a portable centrifugal gasoline-powered pump or hand-operated pitcher pump where the water table was shallower. An amount of water equal to or more than three times the casing-water volume was pumped to ensure that representative formation water was obtained. The screen was pulled up to the next setting after each sample was collected. Samples for aldicarb analyses were collected in 1-qt polyethylene containers and were frozen for storage and shipment to laboratories. (According to information from the manufacturer and several other laboratories, aldicarb is not affected by the pumping, collection, storage, or shipping methods used.)

Several private wells in the area (mainly irrigation and domestic) were also sampled for aldicarb analyses. Installation of observation wells and collection of water samples were done from August 1981 through August 1982.

Because available information at the time of well installations and water sampling indicated that aldicarb penetration below the water table then was not more than several tens of feet, water samples taken from below 160 ft were analyzed only for chloride concentrations to locate the freshwater-saltwater interface in the Jamesport area.

Laboratory Analyses and Quality Control

The laboratory procedure for aldicarb analysis is complex. The process was developed and described by Union Carbide Corp. (1975, p. 48). To check the reliability of analytic data, split-sample analyses were done on more than



Base from U.S. Geological Survey
Mattituck, NY, 1:24,000, 1981

Figure 2.--Locations of selected wells in the Jamesport area.

10 percent of the samples collected. Split samples were collected in 5-qt containers, shaken vigorously and poured into 1-qt containers, and handled as described above. Most of the split samples were analyzed by laboratories of Union Carbide Corp., Research Triangle Park, N.C., the Geological Survey, Doraville, Ga., and H2M Corp., Melville, N.Y.; a few split samples were analyzed by the Geological Survey and SCDHS and by the Geological Survey and Union Carbide Corp.

All laboratories except that of SCDHS used the Union Carbide analysis method. SCDHS developed its own method in early 1982, and Union Carbide Corp. adopted this method late in 1983. Both methods yielded similar results, but the SCDHS method can be performed more rapidly (R. R. Romine, Union Carbide Corp, oral commun., January 4, 1984.) Many of the split-sample analyses showed large concentration discrepancies that made interpretation difficult as to degree of aldicarb contamination at many sites. Results of the split-sample analyses are given in tables further on.

Previous Reports

Many reports have been written on aldicarb in ground water, but few pertain to Long Island. Geography and soil characteristics have been found to be important factors in ground-water contamination by aldicarb. Back and others (Union Carbide Corp., written commun., 1982) state that of 18 sites examined in 16 States, those on Long Island have the greatest potential for leaching of aldicarb to the aquifer. For example, the potential on Long Island is 2.8, 2.5, and 4.5 times higher than in Aroostook County, Me., Delmarva, Va., and Southampton County, Va., respectively; 3 times higher than in the Central Sands area of Wisconsin; 5.5 times higher than in central Florida; 10 times higher than in Minidoka County, Idaho; and 49 times higher than in Parmer County and Rio Grande Valley, Tex.

Other pertinent reports on aldicarb in ground water are Rothschild and others (1982), Baier and Robbins (1982a and 1982b), and Baier and Moran (1981). These reports summarize the extent of ground-water contamination by aldicarb in eastern Long Island.

Acknowledgments

The authors express grateful thanks to "Phil" Bucher and Sven Hansen, well driller and auger operator, respectively, of SCDHS, who went beyond their required duties to assist in the gathering of data at the operations sites. R. R. ("Buck") Romine of Union Carbide Corp. provided excellent cooperation in performing split-sample analyses, and Russell Jones, also of Union Carbide Corp., provided valuable information on the behavior of aldicarb in the soil zone. Robert J. O'Reilly of the New York State Department of Environmental Conservation provided extensive data on wells in the study area.

HYDROGEOLOGY

The occurrence, movement, and fate of aldicarb within the ground-water system depend largely on the character of the geologic units. Therefore, a brief discussion of the areal hydrogeology is presented as a basis for explaining the probable directions and rates at which the aldicarb moves through the unsaturated zone and the ground-water body.

Hydrogeologic Setting

Upper Glacial Aquifer

Long Island is underlain by upper Pleistocene glacial deposits of the Wisconsinan glacial stage, which form the upper glacial aquifer. The Wisconsinan deposits of the north fork seem to have been laid down in three stades (substages). From the oldest to youngest they are: (1) Ronkonkoma-stade, mainly sandy and gravelly outwash, which the authors attribute to recession of the Ronkonkoma ice sheet, early in the Wisconsinan stage, which left a terminal moraine that forms the south fork. (2) Interstadial beds of mainly clay and silt in the north-fork area separated by about 80 ft of sandy beds; the upper clayey beds have a combined thickness of 20 to 65 ft, whereas the lower clayey beds are about 40 ft thick. These clay beds were deposited in lacustrine and marine environments that formed between a receding Ronkonkoma ice front and its terminal moraine as sea level fluctuated in the time between the Ronkonkoma ice retreat and the later Harbor Hill ice-front advance. (3) Mainly sandy and gravelly terminal-moraine and outwash deposits on the north fork, laid down by the Harbor Hill-stade glacial advance and retreat late in the Wisconsinan stage.

The interstadial beds are probably correlative with the "clay unit of Smithtown" of Lubke (1964, p. 22 and p. 26), also called the Smithtown clay by Soren (1971, p. 14), and the "20-ft clay" of Perlmutter and Geraghty (1963, p. 36-37). The 20-foot clay seems to represent a wholly marine phase of deposition in the interstade (Soren, 1978, p. 11).

Clay beds.--Interstadial clay beds seem to be continuous from the Riverhead vicinity, 4 mi west of Jamesport, eastward into the Town of Southold to at least the vicinity of Cutchogue (pl. 1) (Baier and Robbins, 1982a, p. 42), but detailed mapping by examination of well records and exploratory drilling would be needed to completely delineate these beds eastward on the north fork.

Interstadial clay beds on the south fork do not seem to be extensive. The Ronkonkoma terminal-moraine deposits that form the south fork were mostly too high for interstadial deposition; erosion of this material after the retreat of the Ronkonkoma ice sheet contributed material for deposition in the lower areas north and south of the south fork. A general absence of thick clay beds beneath the south fork is noted by Nemickas and Koszalka (1982, pl. 3).

Terminal-moraine deposits.--Harbor Hill terminal-moraine deposits form a small ridge reaching to altitudes of about 110 ft along the north shore, north of Sound Avenue (fig. 2). Harbor Hill outwash underlies a gently rolling, sloping plain that extends southward from the ridge to Great Peconic Bay. The thickness of the sequence of upper Pleistocene deposits in the Jamesport area ranges from 200 to 300 ft and is shown in figure 3.

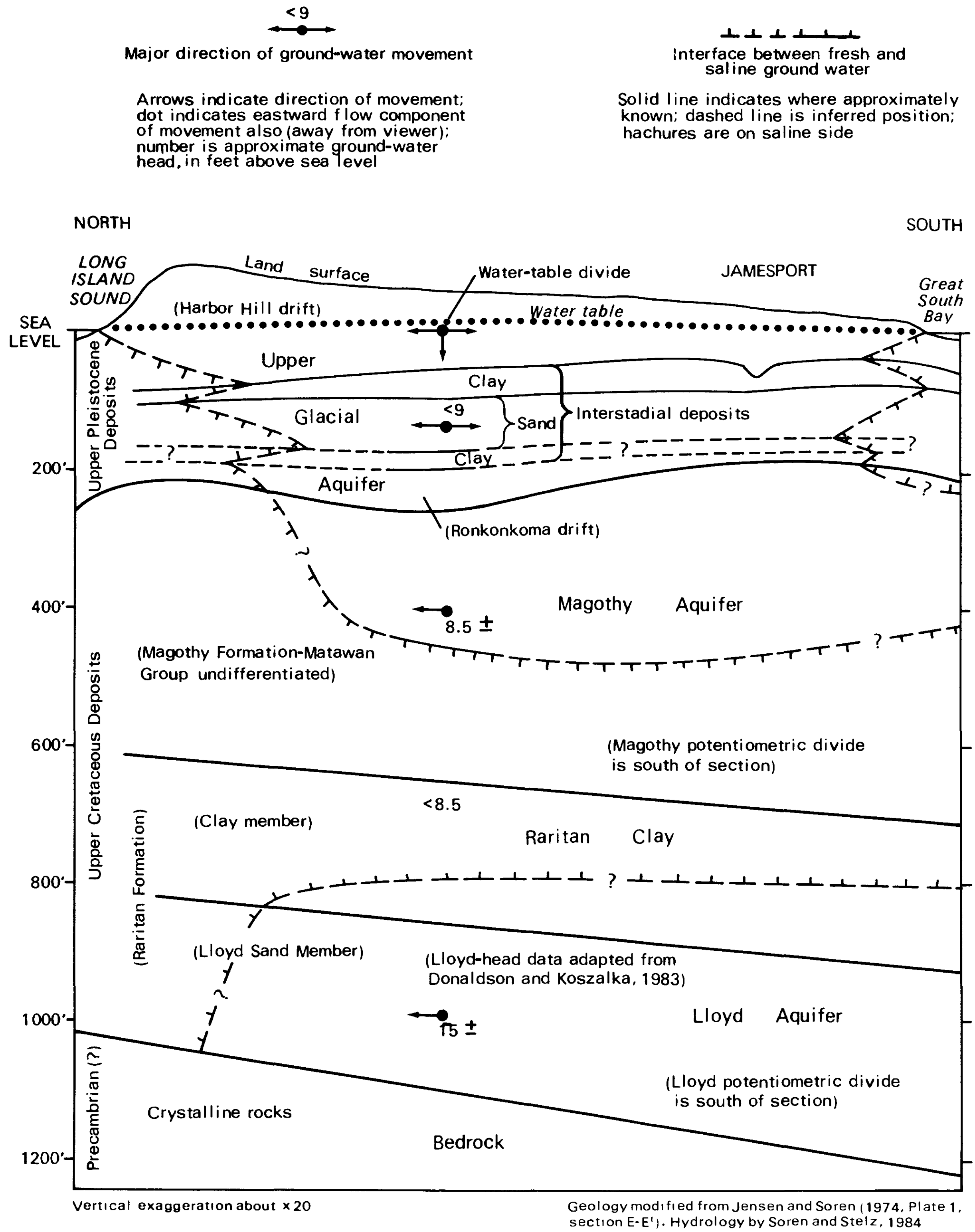


Figure 3.--Hydrogeologic sections showing stratigraphy, hydrologic units, directions of major ground-water movement, and position of interface between fresh and saline ground water under natural (nonpumping) conditions in the Jamesport area.

Magothy Aquifer

Beds of the Upper Cretaceous Magothy Formation-Matawan Group undifferentiated (Magothy aquifer) unconformably underlie upper Pleistocene deposits. A test boring (S71576, not shown in fig. 2) at the site of well S71577 on Manor Lane (fig. 2) penetrated the Magothy aquifer surface at a depth of 246 ft below sea level. The Magothy aquifer's surface generally lies from about 150 ft to more than 300 ft below sea level in the north and south forks, and the aquifer is little used for water supply at present. The top of the Magothy aquifer in the Jamesport area undulates gently between 200 and 250 ft below sea level (fig. 3). No water is tapped from the Magothy in the Jamesport area.

Ground water in the Magothy aquifer in the central part of the Jamesport area was found to be fresh to a depth of 486 ft below land surface. Below this depth, chloride concentrations increased from 31 mg/L to 1,700 mg/L at 506 ft.

Lloyd Aquifer

Beds of the Lloyd Sand Member of the Raritan Formation of Upper Cretaceous age (Lloyd aquifer) underlie the Magothy aquifer from which it is separated by the clay member (fig. 3) of the Raritan Formation (Raritan clay). The Raritan clay confines water in the Lloyd. The Lloyd lies from about 800 to 900 ft below sea level in the Jamesport area, and it is not tapped for water supply in the area.

Bedrock

Crystalline bedrock of Precambrian(?) age unconformably underlies the Lloyd aquifer and is considered for practical purposes to constitute the floor of the ground-water reservoir on Long Island. In the Jamesport area, the bedrock lies from about 1,000 to 1,200 ft below sea level (fig. 3).

Jensen and Soren (1974, sheet 1) describe the general surficial geology of eastern Long Island and the subsurface units down to the crystalline bedrock. Additional details on the Pleistocene deposition are given by Fuller (1914) and Suter and others (1949).

Precipitation and Recharge

The long-term average annual precipitation of about 45 in. (Miller and Frederick, 1969, pl. 1) is the source of natural recharge in the Jamesport vicinity. The average annual precipitation from 1975 (the first year of aldicarb use) through 1982 was the same as the long-term annual average.

Much of the precipitation is returned to the atmosphere by evaporation and plant transpiration (evapotranspiration), and a small amount runs off the land surface directly into a few small streams that discharge into tidewater. The ground-water reservoir is recharged when precipitation penetrates the land surface and percolates through unsaturated glacial deposits to the water table.

The water table is the upper boundary of the ground-water reservoir. All spaces between the rock materials below the water table are saturated down to the crystalline-bedrock floor.

The percentages of precipitation that recharge the ground-water reservoir, that are lost by evapotranspiration, and that run off to streams are imprecisely known. Cohen and others (1968, p. 36, 40, and 44) estimate evapotranspiration, direct runoff, and recharge to average about 46, 5, and 50 percent of the annual precipitation, respectively, but state that these values may vary significantly with time and place.

Direction and Rate of Ground-Water Movement and Discharge

Water that infiltrates to the water table moves laterally and vertically within the system in its path toward seaward discharge. The movement of ground water is determined by head differences within the system; water flows from areas of higher head to areas of lower head. Head values in the system are measured in terms of water-level altitudes in wells screened at different depths and locations. Water moves more readily through sand and gravel than through clay; consequently, head loss in water moving through clay is much greater than head loss in water moving through sand and gravel.

In the Jamesport area and in much of the north fork, the interstadial clay beds significantly retard the vertical movement of water between the upper glacial aquifer and the Magothy aquifer. Another thick sequence of clay beds, the Raritan clay, lies between the Magothy and underlying Lloyd aquifer on Long Island, retarding vertical movement between these aquifers. The arrangement of the aquifers in the Jamesport area is shown in figure 3.

Aldicarb seems to have migrated only within the upper glacial aquifer, and, in the north fork area, only above the upper interstadial clay beds. Nearly all of the wells in use on the north fork are screened above the upper interstadial clay. Therefore, discussion of the direction and rate of movement of ground water in this report deals mainly with this upper part of the aquifer. Data on heads below the upper interstadial clay and in the underlying Magothy and Lloyd aquifers are insufficient to permit more than general statements about the directions and rates of water movement in these deeper aquifers.

Direction of Ground-Water Movement Above the Upper Interstadial Clay Beds

Ground water in the Jamesport area above the upper interstadial clay bed mostly moves laterally toward tidewater from a ground-water divide that trends east-northeast along the central area of the north fork (fig. 4). In the area of the divide, ground water contains a downward flow component (fig. 3). An upward movement develops near the shore as the seaward-flowing ground water nears landward-sloping saline ground-water interfaces. Between the divide and shore, ground-water flow is essentially parallel to the water table and the surface of the upper interstadial clay.

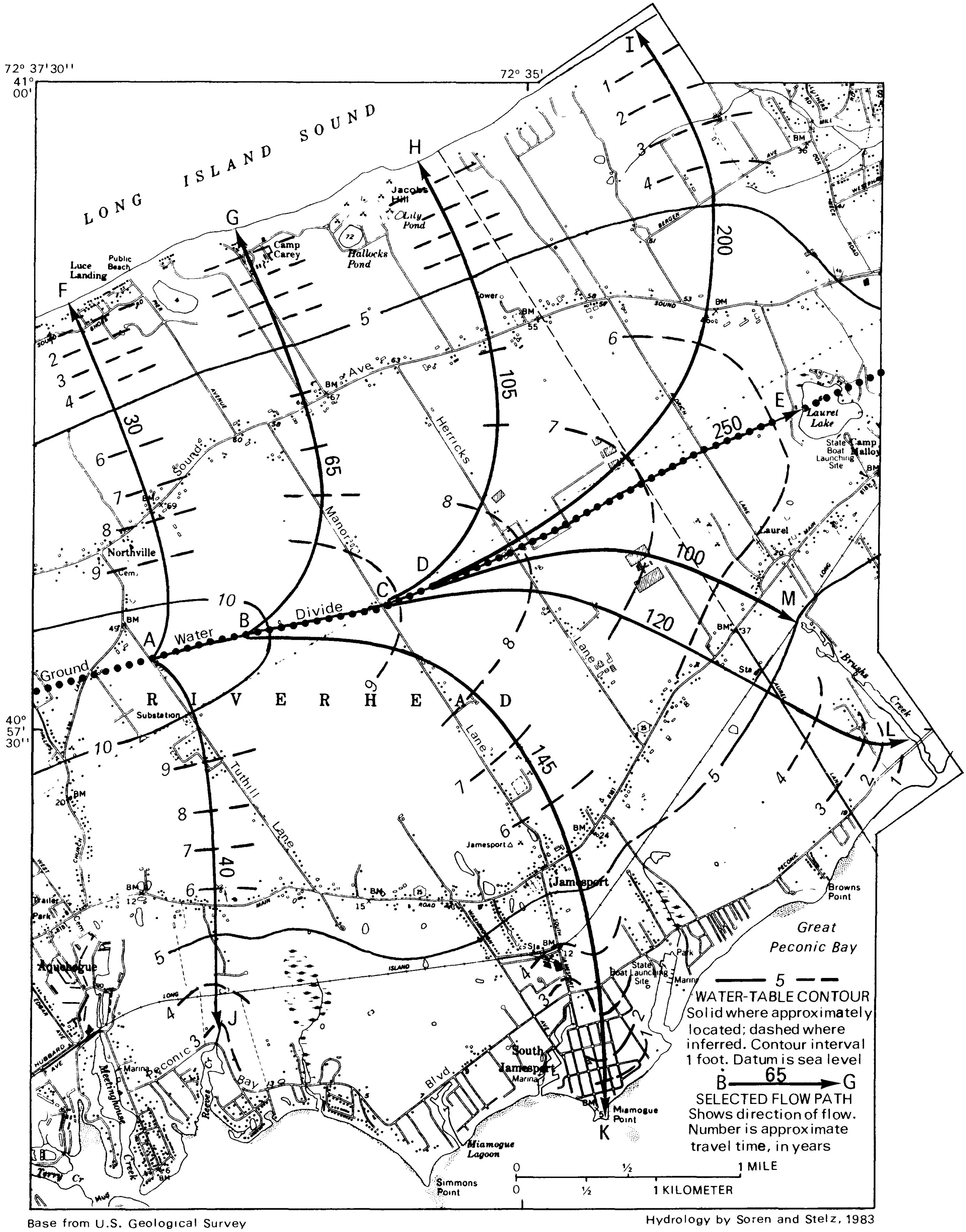


Figure 4.--Average water table in early spring (1975-82), approximate directions of ground-water flow at the water table, and estimated traveltime from the ground-water divide to discharge points under natural (nonpumping) conditions in the Jamesport area.

The direction of lateral flow from the ground-water divide is controlled by the configuration of the water table (fig. 4). Under natural (nonpumping) flow conditions, the flow is essentially perpendicular to the water-table contours shown in figure 4. The curves in the water-table contours cause the flow from the divide to follow gently to greatly curved paths northward and southward toward tidewater. Ground water follows a nearly straight line northward and southward from the divide in the Aquebogue-Northville vicinity; the only other straight-line flow is eastward along the divide (fig. 4).

Rate of lateral ground-water movement.--The rate at which ground water moves laterally is determined by the horizontal hydraulic conductivity of the aquifer, the hydraulic gradient through which the water moves, and the aquifer's porosity.

Horizontal hydraulic conductivity.--The average horizontal hydraulic conductivity of the upper glacial aquifer was estimated to be 159 ft/d by Fetter (1971, p. 47) and 275 ft/d by Franke and Cohen (1972, p. C271); Nemickas and Koszalka (1982, p. 41) estimated a range from 200 to 750 ft/d in the upper glacial aquifer at wells screened in sand and gravel. The sand and gravel penetrated during the observation-well installations of this study contained much disseminated silt and very fine sand; therefore, the horizontal hydraulic conductivity of the upper glacial aquifer above the upper interstadial clay is considered to be about 200 ft/d.

Hydraulic gradient.--Hydraulic gradient is measured by the loss in head that occurs within a specified distance; it is expressed in feet of head loss per foot traveled (ft/ft).

Lateral-flow gradients vary from place to place in the Jamesport area and can be determined from the spacing of the water-table contours in figure 5. (Gradients are steeper where contours are closely spaced and flatter where more widely spaced.) The flow gradients along selected flow paths in figure 4 range from highs of 0.002 to 0.003 ft/ft near the shore in the Northville and Brushs Creek areas to a low of about 0.0003 ft/ft along the ground-water divide near Laurel Lake.

Rate of water movement.--At a constant estimated horizontal hydraulic conductivity of 200 ft/d and an estimated aquifer porosity of 32 percent (typical for the upper glacial aquifer), the flow rate varies with the hydraulic gradient, as expressed in the equation:

$$V = \frac{K_h I}{p} \qquad (1)$$

where: V = velocity (rate of movement), in ft/d;
K_h = horizontal hydraulic conductivity, in ft/d;
I = hydraulic gradient, in ft/ft; and
p = aquifer porosity, in percent (expressed as a decimal).

Traveltime.--Figure 4 shows selected travel paths of water at the water table from the ground-water divide to discharge points (the number of paths is infinite). Approximate traveltimes along the selected paths can be computed from the following equation:

$$T = \frac{D}{V}, \qquad (2)$$

where: T = time of travel, in days;
D = distance traveled, in ft; and
V = velocity, in ft/d (obtained from eq. 1).

Dividing the resulting T by 365 (d/yr) gives the time of travel, in years.

Computed approximate traveltimes of flow along the water table on the selected paths in figure 4 range from 30 yr (path A-F) to 250 yr (path A-E). Traveltime of water beneath the water table is longer because of the time taken to reach lower depths. Water that moves downward to the surface of the upper interstadial clay could take more than a decade longer to reach a discharge point than water at the water table. Recharge (and aldicarb) that enters the flow system closer to discharge areas will discharge sooner, and recharge that enters the system a few feet from the shore will leave the system in a few days.

The flow rates and times of flow given in this section are approximate minimums required for water between the water table and the surface of the upper interstadial clay to move from the divide to discharge points under natural (nonpumping) conditions. In most of the Jamesport area, ground-water pumping, mainly for irrigation, probably retards the flow locally.

Direction and Rate of Ground-Water Movement Below the Upper Interstadial Clay Beds

Upper glacial aquifer.--The interstadial clay beds constitute confining layers within the upper glacial aquifer. Water between the clay beds moves essentially parallel to them, probably in about the same directions as the unconfined water above the upper clay, shown in figure 4. Although the horizontal hydraulic conductivity between the clay beds is about the same as in the sandy and gravelly beds above, data on heads between the clay beds are insufficient to enable measurement of the hydraulic gradients or rate of water movement between them.

Flow patterns.--In the Jamesport area, as well as in other heavily farmed areas of eastern Long Island, the natural movement of ground water is disrupted by much irrigation pumping during the growing season, which on eastern Long Island is 180 to 195 days from April through October (Mordoff, 1949, p. 20-21). This heavy pumping distorts the natural flow paths and keeps much of the the ground water recirculating within the upper glacial aquifer.

The 3.75-mi^2 area centered around Manor and Herricks Lanes contains 30 irrigation wells (fig. 2)--a density of eight wells per mi^2. The wells have pumping capacities ranging from 250 to 700 gal/min and average 425 gal/min. Irrigation pumpage in the Jamesport area is typical for the other farmed areas of eastern Long Island; the New York State Department of Environmental Conservation (NYSDEC) at Stony Brook, N.Y., reports that irrigation wells on eastern Long Island are used from 40 to 80 days in the growing season, depending on precipitation, and may operate from 4 to 16 hours per day (Anthony Candela, NYSDEC, oral commun., November 1983).

Irrigation pumpage creates cones of depression in the water table and draws back water that has moved 18 to 180 ft downgradient from the wells since the end of the previous growing season (about 6 months at velocities ranging from 0.1 to 1 ft/d, depending on location). Accordingly, irrigation pumping can significantly increase the residence time of ground water in the farmed areas. Also, irrigation pumping will prevent much of the aldicarb now in the ground-water system from reaching a discharge point; only that near the shores will be readily discharged. However, any repumped aldicarb would be subjected to further degradation by aeration (oxidation) during spraying, exposure to sunlight, and soil-zone and plant metabolism processes; such degradation would assist in reducing the amount of aldicarb in the ground water.

Vertical velocity.--The vertical hydraulic conductivity of fluvial sediments (as in the upper glacial aquifer) is less than the horizontal conductivity. Vertical hydraulic conductivity of the glacial outwash has been estimated to range from about one-third of the horizontal conductivity (Morris and Johnson, 1967, p. D37, table 12, washed drift) to one-tenth of it (Franke and Cohen, 1972, p. C271, table 1, upper glacial aquifer). The steepest ground-water gradient (under nonpumping conditions) is beneath the ground-water divide. Downward hydraulic gradients from the divide to the upper interstadial clay in an area similar to Jamesport, at Cutchogue, about 7 mi east of the Jamesport vicinity (pl. 1), have been observed to average 0.0005 ft/ft (Baier and Robbins, 1982a, appendix D, p. D-4, wells S71171 and S71191). The velocity of downward movement in the Jamesport divide area would thus be between 0.03 ft/d and 0.1 ft/d. This range seems excessively high, however, as evidenced by the depth of penetration by the aldicarb, which would indicate the ratio of vertical hydraulic conductivity to the estimated average horizontal conductivity to be 1:20. (See section "Reevaluation of vertical conductivity of the upper glacial aquifer based on aldicarb movement," p. 26).

Magothy aquifer.--Head measurements in the Magothy aquifer in the Jamesport area have been made at two wells--well S71576 at the site of S71577, and well S33073, about 1 mi west-southwest of S71577 on Tuthill Lane (fig. 2); the heads average 8.5 and 9.5 ft above sea level, respectively, indicating a local east-northeast hydraulic gradient of about 0.0002 ft/ft. The average horizontal hydraulic conductivity of the Magothy has been estimated to be 50 ft/d (Franke and Cohen, 1972, p. C271). Applying these values and an assumed porosity of 32 percent to equation 1 yields a flow rate of approximately 0.03 ft/d between wells S33073 and S71576.

The Magothy is probably not recharged by water moving downward through the interstadial clay from higher heads above because the head loss in water moving through clay would be too great. Nor is upward flow into the Magothy from higher heads in the underlying LLoyd aquifer likely, for the same reason. (See "Lloyd aquifer," which follows, and fig. 3.) Therefore, the Magothy in the Jamesport area (and probably all the north-fork area from Riverhead to about Mattituck) is probably recharged by direct eastward flow from the Magothy to the west.

The glacial sand and gravel deposits below the lower interstadial clay probably function hydraulically as part of the Magothy aquifer in the Jamesport area (fig. 3) because the deposits seem to be in better hydraulic continuity with the Magothy than with the glacial deposits above the interstadial clay.

Lloyd aquifer.--No head measurements of the Lloyd aquifer in the Jamesport area are available. However, extrapolation of Lloyd heads given in Donaldson and Koszalka (1983, pl. 1B) in the Riverhead vicinity, 4 mi west of Jamesport, indicate that the local Lloyd head is about 15 ft above sea level and that the direction of water movement in the aquifer is east-northeast. Water from the Lloyd is unlikely to move into the Magothy aquifer through the intervening Raritan Clay because the head loss within the Raritan clay would be too great; a head loss of 11.5 ft across the clay in the Ronkonkoma area, about 27 mi west of Jamesport, is indicated by Soren (1971, p. 17).

The hydraulic gradient in the Lloyd in the Riverhead vicinity (Donaldson and Koszalka, 1983, pl. 1B) is about 0.0002 ft/ft; Franke and Cohen (1972, p. C271) estimate the average horizontal hydraulic conductivity of the Lloyd to be 40 ft/d; applying these values and an assumed porosity of 32 percent to equation 1 gives an estimated water velocity of 0.025 ft/d in the Lloyd aquifer in the Jamesport area.

ALDICARB IN THE UPPER GLACIAL AQUIFER

In early 1979, the Long Island Horticultural Research Laboratory at Riverhead (a branch of Cornell University, Ithaca, N.Y.), which had expressed concern about the effect of aldicarb on ground water, sent samples of ground water to Union Carbide Corp. for analysis. In August 1979, Union Carbide Corp. informed the U.S. Environmental Protection Agency (EPA) that samples from a few of the areas contained aldicarb (Baier and Moran, 1981, p. 2). Between August 1979 and mid-March 1980, SCDHS collected and analyzed 270 water samples from shallow wells near potato farms; nearly one-third of the samples showed aldicarb contamination greater than 7 μg/L. In February 1980, Union Carbide Corp. asked EPA to revoke approval of aldicarb, which EPA did almost immediately (Baier and Robbins, 1982a, p. 11). SCDHS then conducted a monitoring program from April through June 1980 that included collection of water samples from 7,809 wells on the north and south forks; of these samplings, 13.1 percent had aldicarb concentrations exceeding 7 μg/L, and 13.3 percent contained traces (1 to 7 μg/L) (Baier and Moran, 1981, p. 9).

Rate of Aldicarb Applications

The precise amounts of aldicarb applied to potato fields during 1975-79 are not known. The manufacturer recommended 2 to 3 lb active ingredients (ai) per acre applied to the soil at planting time and a similar application to the soil as foliage developed (Union Carbide Corp., 1975, p. 24). Baier and Moran (1981, p. 1) state that, typically, an application of 4 lb ai/acre was made at planting, followed by the later application of 1 to 2 lb ai/acre. Guerrera (1981, p. 198) states that an application of 5 lb ai/acre at planting was approved by New York State in 1975-78, and that an additional application of 2 lb ai/acre as a later side dressing was approved in 1979. The actual applications of aldicarb were not supervised by any regulatory agency, and the authorized amounts may have been exceeded sometimes by individual farmers. However, estimates based on sales of aldicarb on Long Island indicate that an average of 5 lb ai/acre was used seasonally (Russell Jones, Union Carbide Corp., oral commun., April 11, 1983).

Aldicarb in the Ground Water

The occurrence of aldicarb in ground water of the Jamesport vicinity was assessed by sampling water from test wells at 13 exploratory boring sites and at 15 other wells in the vicinity (fig. 2). Drilling and sampling operations are described in the section "Methods of Investigation." A total of 132 water samples were obtained from 101 well-screen settings ranging in depth from about 6 ft to about 146 ft below the water table.

Degradation Compounds

Aldicarb readily degrades, after application, to the oxidized products aldicarb sulfoxide and aldicarb sulfone. The sulfoxide's toxicity is comparable to that of aldicarb, but the sulfone is considerably less toxic (Union Carbide Corp., 1975, p. 5 and 55). All three compounds are looked for in aldicarb analyses, and the constituents are reported collectively as aldicarb. Degradation products of the sulfoxide and sulfone are not considered to be toxic. Recent studies by Union Carbide Corp. (J. L. Hansen and M. H. Spiegel, 1982, written commun., p. 10) state that aldicarb itself has not been found in the ground water; rather, the water contained nearly equal parts of the sulfoxide and sulfone.

Results of Chemical Analyses

Concentrations of aldicarb in samples collected during this study ranged from not detected to 180 µg/L; results are given in table 4 (at end of report). Samples of water collected at 20 of the screen settings were split for analysis by several laboratories to check precision of analyses. Eleven of the splits were analyzed by the Union Carbide Corp., the Geological Survey, and H2M Corp. laboratories; five were analyzed by Union Carbide Corp. and the Geological Survey, and four were analyzed by the Survey and the Suffolk County Department of Health Services. Results of the split-sample analyses are given in table 1.

Differences among the Geological Survey, Union Carbide, and H2M analyses of split-samples are summarized in table 2A. For comparison, the analyses by Union Carbide Corp. were used as the reference values because this company developed the chemical. The Union Carbide and Geological Survey analyses in table 2B (January-February 1982) show greater uniformity in percentage differences than those in table 2A (November 1981-August 1982). The differences between Suffolk County Department of Health Services and Survey analyses (table 2C) are similar to those between Union Carbide and the Geologicial Survey (table 2B). Concentrations determined by the Union Carbide Corp. laboratory generally were higher than those reported by H2M Corp. or the Geological Survey. In table 2C, SCDHS values were selected as reference values because of their similarity with values of Union Carbide Corp. (See section "Laboratory Analyses and Quality Control".)

The preceding discussion of analyses for aldicarb by different laboratories suggests that analyzing for low concentrations (several µg/L) of a complex constituent that undergoes multiple degradations in the ground-water system presents difficulties in interpretation of the degree of aldicarb contamination. The maximum allowance of 7 µg/L allows for a conservative uncertainty factor of 100 times the allowance (Baier and Moran, 1981, p. 5-6).

Table 1.--Results of split-sample analyses for aldicarb by different laboratories, November 1981 through August 1982.

[Well locations are shown in fig. 2]

Well No.	Date of sample	Depth of well below land surface (ft)	Concentration (µg/L)[1]				Approximate depth below water table (ft)
			USGS	UCC	H2M	SCDHS	
S31281	8- 3-82	43	2.1	2.	3.	--	39
51581	8- 3-82	43	30	--	--	49.	18
51582	8- 3-82	82	<1	--	--	<1.	25
51587	8- 3-82	78	55	--	--	73.	27
51589	8- 3-82	41	76	--	--	77.	26
71566a	1-27-82	45	ND	13	<1.	--	36
71567c	1-26-82	22	18	35.	34.	--	16
71568	1- 7-82	17	87	137.	--	--	12
71569	1-27-82	32	40	65.	--	--	12
71569a	1-27-82	42	ND	ND	<1.	--	22
71570	1-22-82	62	do.	do.	--	--	37
71571	1-19-82	44	41	61.	--	--	16
71574	2-16-82	109	2.2	ND	<1.	--	52
71577	11- 9-81	59	35	54.	45.	--	17
71577a	11- 9-81	79	<1	1.	<1.	--	37
71578	2- 2-82	46	ND	3.	<1.	--	23
71579	12-30-81	26	do.	ND	<1.	--	15
71580	2-17-82	24	33	54.	--	--	14
72842	8-30-82	34	69	74.	44.	--	31
73272	8-30-82	83	<1	5.	4.	[2]--	22

[1] USGS, U.S. Geological Survey, Doraville, Ga.;
UCC, Union Carbide Co., Research Triangle Park, N.C.;
H2M, H2M Corp. Laboratory, Melville, N.Y.;
SCDHS, Suffolk County Department of Health Services, Hauppauge, N.Y.

[2] A concentration of 9 µg/L was analyzed in July 1982 by SCDHS on a sample provided by well owner.

Table 2.--Differences among split-sample analyses for aldicarb.

[Well locations are shown in fig. 2]

A. Samples collected from November 9, 1981 through August 31, 1982

Well number	Laboratory[1] UCC Standard concentration (µg/L)	Laboratory[1] H2M Difference from standard (percent)	Laboratory[1] USGS Difference from standard (percent)
S31281	2	+50	+ 0.05
71566a	13	--[2]	--[2]
71567c	35	- 3	-49
71569a	ND[3]	0	0
71574	ND	0	--[4]
71577	54	-17	-35
71577a	1	[5]0	[5]0
71578	3	0	0
71579	ND	0	0
72842	74	-41	- 7
73272	5	-20	--[2]

Note: Analysis <1 µ/gL considered as not detected for practical purposes.

[1] UCC, Union Carbide Corp.;
H2M, H2M Corp. Laboratories;
USGS, U.S. Geological Survey.

[2] Aldicarb <1 or not detected (near 100 percent to theoretically infinite percentage lower).

[3] ND, not detected

[4] Aldicarb 2.2 µg/L, no significant difference (although theoretically infinite percentage higher).

[5] Analyses of <1 µg/L are not considered to have a significant difference when compared to a standard of 1 µg/L.

B. Samples collected from January 7 through February 17, 1982

Well number	Laboratory[1] UCC Standard concentration (µg/L)	Laboratory[1] USGS Difference from standard (percent)
S71568	137	-36
71569	65	-38
71570b	ND	0
71571	61	-33
71580a	54	-39

C. Samples collected on August 3, 1982

Well number	Laboratory[1] SCDHS Standard concentration (µg/L)	Laboratory[1] USGS Difference from standard (percent)
S51581	49	-39
51582	<1	0
51587	73	-25
51589	77	- 1

Note: Analysis <1 µg/L considered as not detected.

[1] UCC, Union Carbide Corp.;
USGS, U.S. Geological Survey;
SCDHS, Suffolk County Department of Health Services.

Distribution and Movement of Aldicarb within the Ground-Water System

Movement of Aldicarb Through the Soil and Unsaturated Zone

Before aldicarb came into wide use on Long Island, the manufacturer believed that (1) aldicarb would not penetrate much deeper than 3 ft into the soil, (2) its half life was less than 7 days, and (3) it would degrade to undetectable levels within 21 days after application (Union Carbide Corp., 1975, p. 38). Thus aldicarb was not expected to leach into the ground water. However, the discovery of large concentrations of aldicarb in the upper glacial aquifer in 1979 required reexamination of aldicarb's leaching and degradation characteristics.

Aldicarb is more mobile in the sandy deposits of Long Island, which contain little or no organic material, than in clayey, loamy, and organic soils in other areas. Its degradation to harmless products is hastened by increased temperatures, organic matter, and basic conditions in the environment.

At temperatures typical for eastern Long Island, where the mean air temperature for the growing season is 65° F (Mordoff, 1949, p. 22) and the water temperature in the upper glacial aquifer ranges from 43 to 59° F (Soren, 1977, p. 29), the solubilities of aldicarb and its sulfone are each less than 1 percent, but that of the sulfoxide is about 30 percent (Union Carbide Corp., 1975, p. 44), nearly the same as sugar and common table salt.

The ground water of Long Island is acidic in most places. Water collected in 1973-75 from 137 wells tapping the upper glacial aquifer from the Town of Brookhaven eastward had a pH range of 5.1 to 7.8; only six of the analyses showed pH values of 7 or higher (Soren, 1977, p. 11-12 and 14-17). Seven of the samples in that report (p. 14) were in the Jamesport vicinity and had a pH range of 5.2 to 5.9. The generally acidic condition (pH less than 7) of the ground water in this area retards aldicarb degradation, enabling longer duration and thus greater movement in the aquifer.

The leaching potential of aldicarb's hydrolysis products to the ground water on Long Island is enhanced by the high permeability of the unsaturated zone and by the general lack of organic material. The high hydraulic conductivity of the glacial deposits provides considerable vertical and lateral mobility for aldicarb in the upper glacial aquifer, and the acidity of the ground-water environment (commonly lower than pH 6) decreases aldicarb's rate of degradation. Heavy rain or overirrigation shortly after application would accelerate the downward movement of aldicarb and its degradation products, especially the more soluble sulfoxide, to the water table. More than one-third of the mean annual precipitation on eastern Long Island, about 18 to 20 in, falls during the growing season, mostly in the spring (Mordoff, 1949, p. 26-27). Therefore, the leaching potential of the aldicarb is probably greatest at the times of its application in the growing season.

The traveltime of water moving from land surface to the water table is shortest when soil-moisture requirements in the unsaturated zone above the water table are satisfied (rock grains are coated with water) and significant precipitation or overirrigation occurs. The rates of infiltration beneath recharge basins on Long Island under these conditions have ranged from 3.3 ft/h in winter to as high as 6.8 ft/h in summer (Seaburn and Aronson, 1974, p. 42). Water usually becomes ponded in recharge basins during precipitation and remains so for a time afterward; consequently, the infiltration rates below recharge basins become higher than those below natural ground surface. However, quadrupling the depth of ponding from 0.5 ft above the basin floor to 2 ft above it did not seem to even double the infiltration rate (Seaburn and Aronson, 1974, p. 41). It is therefore likely that the traveltime to the water table below land surface in the farmed areas of Long Island can readily be as high as 3 ft/h in the growing season.

Because aldicarb is soluble and not strongly adsorbed by soil and rock particles (Russel Jones, Union Carbide Corp., oral commun., 1983), it probably moves at the same rate as the water in which it is dissolved. In the farmed parts of the Jamesport area, depths to the water table range from less than 10 ft to about 60 ft. At an infiltration rate of 3 ft/h, aldicarb could have reached the water table within a day or several days after application if soil-moisture conditions were conducive and if heavy precipitation or overirrigation followed application.

Not all aldicarb in the unsaturated zone is transmitted to the water table immediately; some of it lags in transit through the unsaturated zone but eventually is carried to the water table with recharge. Sand samples were collected from the unsaturated zone to a depth of about 85 ft at the Cornell University Research Farm, 6 mi west of the Jamesport area, in November 1980 (more than a year after the last aldicarb application) and analyzed for aldicarb content (N. M. Trautmann and "Hank" Hughes, Cornell University, Ithaca, N.Y., written and oral commun., June 1983). The sand samples, analyzed by Cornell University, were reported to contain aldicarb concentrations ranging from less than 5 ppb to about 10 ppb. In that study, the detection limit for aldicarb in soil was stated to be 5 ppb, and the concentrations in the soil samples were equivalent to as much as 300 µg/L in water.

The 1980 soil sampling by Cornell University was the only study of its type in the area; whether any aldicarb remains in the unsaturated zone is unknown at present (1984).

Distribution and Movement of Aldicarb Below the Water Table

Vertical distribution.--The maximum depths of aldicarb penetration below the water table in the Jamesport vicinity generally seemed to be about 40 ft in 1982, as shown in figure 5. The analyses in table 4 (at end of report) show that 67 percent of the samples collected from depths of 7 to 39 ft below the water table had aldicarb concentrations greater than 7 µg/L. From depths of 40 to 146 ft below the water table, water from 16 percent of the wells at 25 sites had aldicarb concentrations greater than 7 µg/L, and all samples exceeding 7 µg/L were from irrigation wells that produce large drawdowns in the water table, commonly as much as 20 ft. All samples indicating aldicarb at depths greater than 40 ft below the water table were from irrigation wells or test wells close by. Concentrations and depths of aldicarb penetration below the water table are summarized in table 3. Discrepancies among laboratory analyses tend to be large when concentrations are low; small concentrations (several µg/L) are considered to be insignificant.

The traces to small quantities of aldicarb shown in and below the interstadial clay deposits in figure 5 are attributed to contamination during drilling operations, discrepant laboratory analyses, or both.

The highest aldicarb concentrations in the Jamesport area in 1981-82 were from <10 to 30 ft below the water table. The weighted average of the reported concentrations (as used in table 3) in the top 40 ft of the ground-water body is 26 µg/L. Of the 37 samples that exceeded the weighted average, only one was from less than 10 ft below the water table, and only three were from below 30 ft.

The depth of ground-water penetration by aldicarb in the Jamesport vicinity, as described above, seems typical of all potato-farming areas in eastern Suffolk County. Baier and Robbins (1982a, p. 53, and 1982b, p. 56) report similar depths of penetration in most other affected areas of the county.

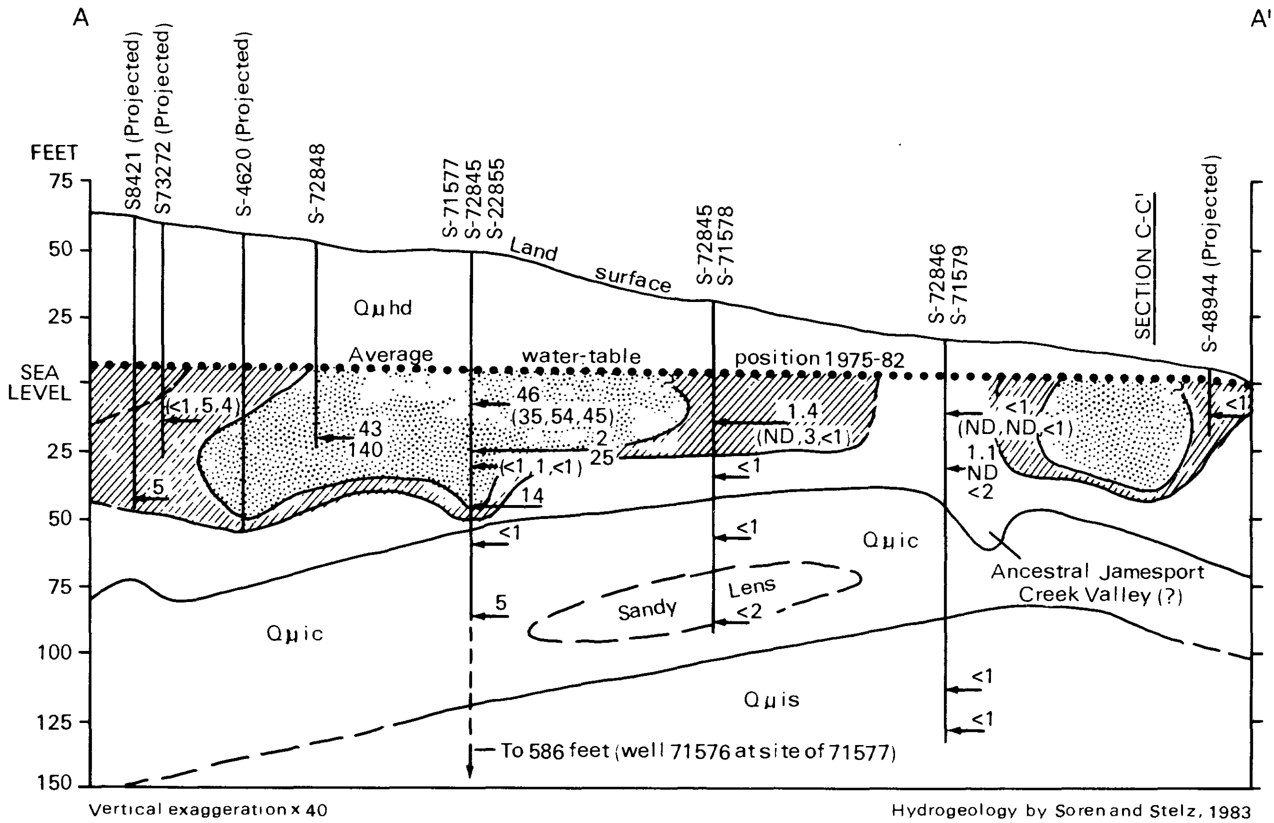
Lateral distribution.--The distribution of aldicarb in ground water in the Jamesport vicinity is depicted in three hydrogeologic sections in figure 5; these sections indicate the greatest depths of penetration (more than 40 ft) to be near irrigation wells near the ground-water divide, which are screened deeper than 40 ft below the water table. The depth of penetration is generally less near the shore (the southern ends of sections A-A' and B-B' and the ends of section C-C' in fig. 5C); the lesser penetration is probably the result of the diminishing downward gradients away from the ground-water divide and upward flow paths in the nearshore discharge areas.

Table 3.--Total aldicarb concentrations in relation to depth below the water table in the Jamesport area, Suffolk County, N.Y., 1980-82.

[Data summarized from table 4]

Depth below water table (ft)	Number of analyses	Aldicarb concentration (µg/L)		
		Range[1]	Mean	Median
<10 to 20	40	ND to 180	42	35
21 to 30	33	ND to 140	24	3
31 to 40	28	ND to 55	6	1
41 to 50	4	ND to 6	1.5	ND
51 to 60	11	ND to 14	5	3
61 to 70	2	ND	0	0
71 to 80	3	ND to 1	1	1
81 to 90	--	--	No samples obtained	--
91 to 100	3	1 to 5	3.5	1
>100 (to 146)	8	ND to 1	0	0

[1] ND, not detected, considered to be 0. Concentrations less than (<) 1 are considered as ND; concentrations <2 are considered as 1 for practical purposes in this table.



EXPLANATION

Section locations are shown in figure 2

QUATERNARY SYSTEM / PLEISTOCENE SERIES / Wisconsinan Stage / Upper Pleistocene deposits

- Qµhd — HARBOR HILL STADE DRIFT DEPOSITS (Water bearing)
- Qµic — UPPER INTERSTADIAL CLAYEY BEDS (Confining unit)
- Qµis — INTERSTADIAL SANDY DEPOSITS (Water bearing)

Upper glacial aquifer

Solid lines are approximate contacts; dashed lines are inferred contacts

S-71569

5
(ND,3,<1)
1.1
ND
<2

Well number(s) are at top. Number(s) next to arrows are aldicarb concentrations, in micrograms per liter (µg/L) at depths indicated. Numbers in parentheses are split-sample analyses results. Where more than one analysis is shown at a depth, the most recent is at top. (See table 1 for sample dates)

ALDICARB-CONTAMINATED GROUND WATER

Lined pattern indicates aldicarb concentrations from more than (>) 1 µg/L to 7µg/L; dotted pattern indicates concentrations >7µg/L

GROUND WATER NOT CONTAMINATED BY ALDICARB

Aldicarb concentrations generally not more than 1 µg/L; the higher aldicarb concentrations shown in this zone are considered to be contamination resulting from drilling operations, discrepant analyses or both

Figure 5A. Hydrogeologic section A-A' showing distribution and concentrations of aldicarb in 1982.

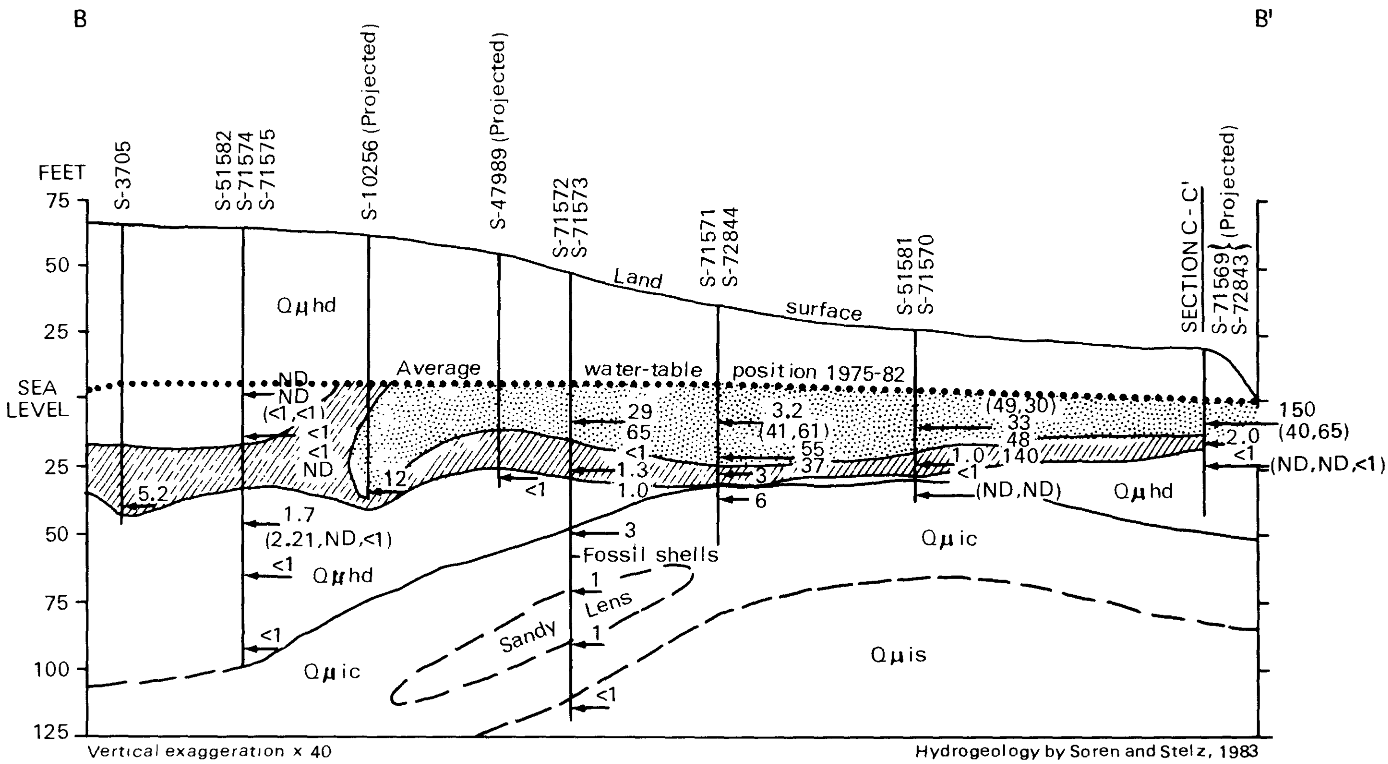


Figure 5B. Hydrogeologic section B-B' showing distribution and concentrations of aldicarb in 1982.

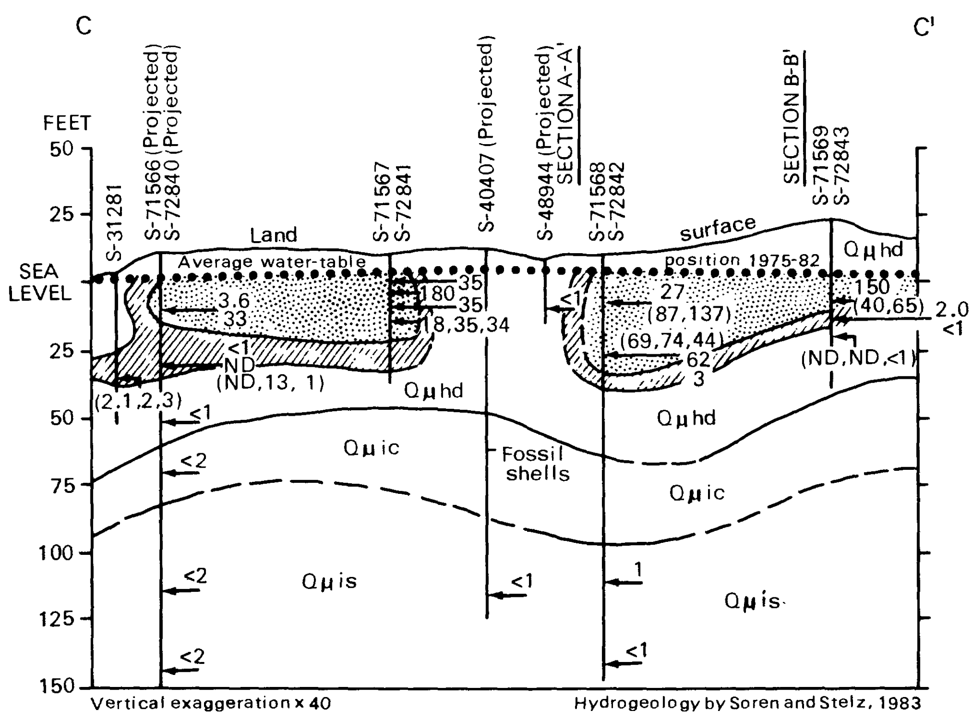


Figure 5C. Hydrogeologic section C-C' showing distribution and concentrations of aldicarb in 1982.

Effects of clay beds.--The interstadial clayey and silty deposits within the upper glacial aquifer (fig. 3) should restrict movement of aldicarb-contaminated water to the ground water below. The slight penetration of aldicarb in concentrations less than 7 μg/L into a small part of the interstadial deposits indicated in section B-B' (fig. 5B) is attributed to well-installation operations, discrepant laboratory analyses, or both.

The head loss in water moving through the interstadial clay beds in the Jamesport area is unknown. However, head loss across a 190-ft thickness of the Raritan clay under natural conditions in the ground-water divide area at Ronkonkoma, about 28 mi west of Jamesport, was 11.5 ft (Soren, 1971, p. 17). The Raritan clay (Upper Cretaceous) is much older and more tightly compacted than the Pleistocene interstadial clay beds; therefore its vertical hydraulic conductivity would be considerably lower than that of the interstadial clays. Consequently, a head drop of 1 to 2 ft across 40 to 60 ft of the interstadial clays under natural hydrologic conditions is likely in the Jamesport area. From assumed vertical hydraulic-conductivity values of 0.001 and 0.01 ft/d (which are typical values for clayey and silty beds), a porosity of 60 percent, and a head loss of 1.5 ft across 40 ft of interstadial clay beds, water would take between 175 and 1,750 years under natural conditions to penetrate into the sand beds between the interstadial clays. Inducing a head drop of 10 ft across the beds by heavy pumping below them would reduce traveltime of water through 40 ft of the clay beds to between 26 and 260 years. (Traveltime through the sand beds between the interstadial clays would be insignificant in relation to that through the clays.)

At present, all pumpage in the Jamesport area is from deposits above the upper interstadial clay. During the 175 or more years' traveltime under present conditions, any aldicarb could decrease to below the detection limits or to insignificant amounts by degradation, by diffusion and dilution, or by combinations of such factors.

A map of the upper clay unit's surface altitude is given in figure 6; the thickness is shown in the hydrogeologic sections in figures 3 and 5. Only one well in the Jamesport area is known to be screened below this unit (S40407, fig. 2); this well is used only as a standby source for emergency fire protection at an agricultural-chemical warehouse and is seldom pumped. The concentration of aldicarb from this well was below the detection limit of 1 μg/L (table 4).

Residence Time of Aldicarb in the Upper Glacial Aquifer

The duration of aldicarb contamination in the upper glacial aquifer of eastern Long Island is imprecisely known. Aldicarb's rate of degradation (commonly called "half life") varies with environmental conditions (unlike the half life of radioactive decay, which is constant). For example, aldicarb was determined not to be significantly harmful to the ground water when used properly in Florida; although its use was banned there in January 1983 when it was discovered at some agricultural sites, the ban was removed in January 1984 because environmental conditions there were determined to be conducive to rapid degradation (Environmental Science and Technology, 1983, v. 17, no. 11, p. 513A). Higher temperature and higher pH of the ground water in Florida, and probably the organic matter in the fossiliferous calcareous rocks there,

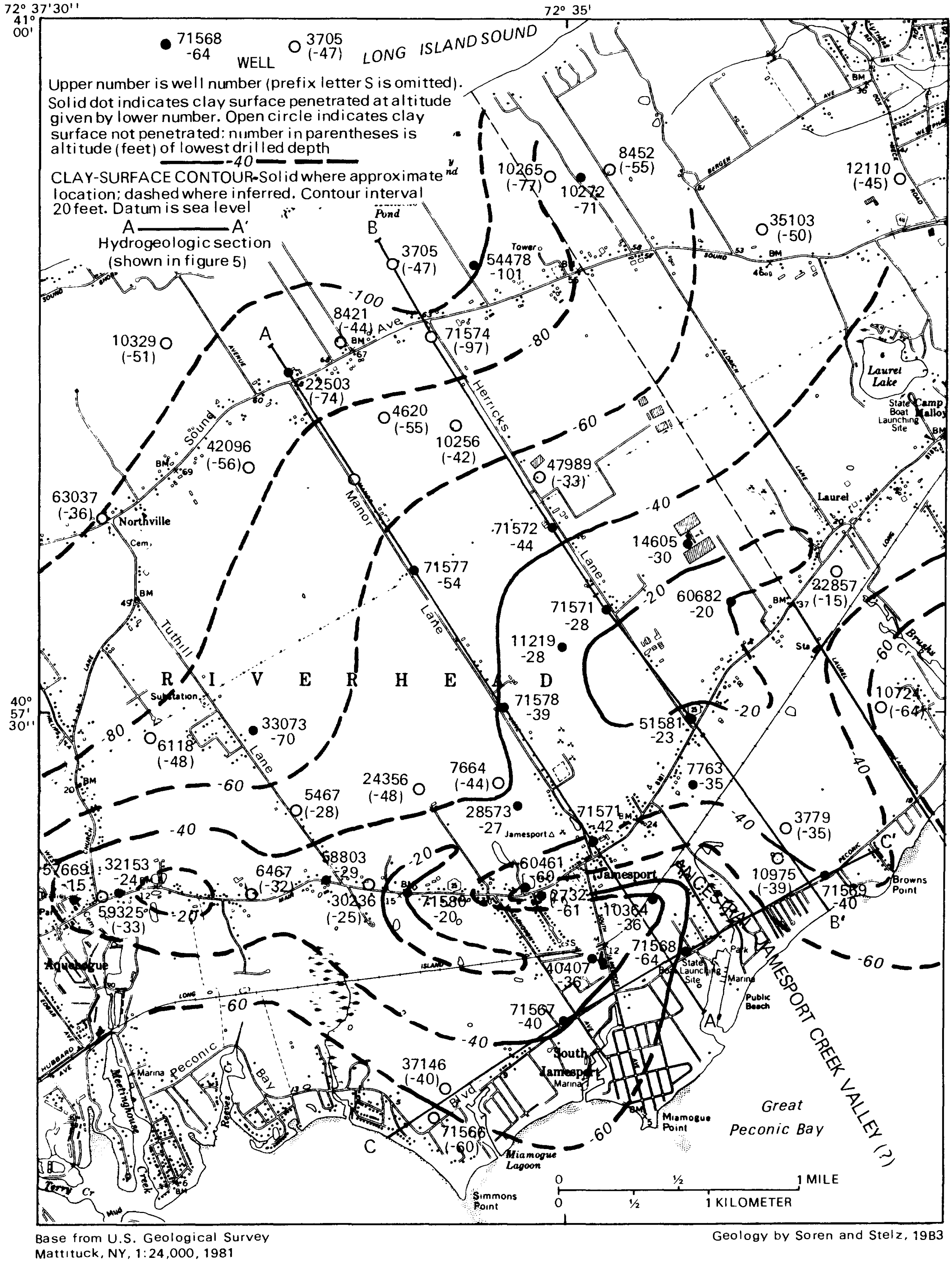


Figure 6.--Surface altitude of the Wisconsinan upper interstadial clay deposit in the Jamesport area. (Thickness of the deposit is shown in figs. 3 and 5.)

to aldicarb's rapid degredation. In contrast, the rock matter that forms the aquifers on Long Island are mainly silicate, with little or no organic matter below a thin surficial soil zone, and the ground-water temperature and pH are significantly lower.

The half life of aldicarb in Long Island's environment probably ranges from a few years to about a decade, rather than days to months, as in Florida. Degradation of aldicarb on Long Island remains under investigation. The manufacturer estimates its half life to be 2 to 3 years (Russell Jones, Union Carbide Corp., oral commun., February 1, 1984), which would cause the highest aldicarb concentrations to decrease to below 7 μg/L by about 1990. A study by Cornell University, Ithaca, N.Y. (Trautmann and others, 1983a, p. 43), presents an intermediate example of aldicarb's half-life (between best and worst cases, a half life of 3 years to infinity) at 10 years; the report also states that a 10-yr half life would decrease the highest aldicarb concentrations to below 7 μg/L by the year 2010. (The authors of this report compute the year to be about 2030 at the 10-year half life estimate). The Cornell University, investigators, however, are reevaluating aldicarb's half life (Trautmann and others, 1983b, p. 53).

The slow rate of ground-water movement to the shore, together with the retarding effect of ground-water pumpage, will cause most of the aldicarb to remain in the aquifer until degradation below concentrations of 7 μg/L occurs. As long as the aldicarb remains in the ground-water system, it will move deeper below the water table at a rate of 5 to 6 ft/yr in the ground-water-divide area, from which it will move laterally with the areal ground-water movement pattern. Until all aldicarb concentrations decline below 7 μg/L, concentrations at individual wells will probably fluctuate widely with the movement patterns of the ground water, both from natural and ground-water-pumpage conditions.

Reevaluation of Vertical Conductivity of the Upper Glacial Aquifer based on Aldicarb Movement

The downward gradient of ground water in the divide area and the lowest vertical hydraulic-conductivity values (one-third to one-tenth of the horizontal conductivity) given in the section "Direction and rate of ground-water movement and discharge" indicate that the depth of aldicarb penetration below the water table after 7.3 years (the time between aldicarb's first use in May 1975 and the last water samplings of this study in August 1982) should be between 80 and 270 ft. Because the depth of penetration is about 40 ft (except near irrigation wells), and the downward gradient and porosity of the aquifer are approximately known, the upper glacial aquifer's average vertical hydraulic conductivity must be nearer to 10 ft/d, about 1/20 of the horizontal-conductivity estimate of 200 ft/d given by Franke and Cohen (1972, p. C271).

POTENTIAL FOR ALTERNATIVE FRESHWATER SUPPLY ON NORTH FORK

A source of uncontaminated water would be preferable to the use of filters. In the Jamesport area, a usable supply of uncontaminated fresh ground water was found in the upper glacial aquifer below the upper interstadial clay beds in the ground-water divide area near the center of the north fork, and in the Magothy aquifer to a depth of 486 ft below land surface. The high hydraulic head shown in the Lloyd aquifer and the tightly confining Raritan clay above it (fig. 3) indicate that the Lloyd may also contain a significant amount of freshwater. The downward movement of salty ground water from the Magothy aquifer into the Lloyd (fig. 4) would be greatly retarded, but heavy pumping from the Lloyd would cause infiltration of salty ground water from the north.

The quantity of water in the upper glacial aquifer below the upper interstadial clay beds and in the Magothy and Lloyd aquifers from Riverhead to the Riverhead-Southold town boundary (pl. 1) is probably sufficient for current domestic needs in the Town of Riverhead. At present, few supply wells are screened below the upper interstadial clay beds. The upper glacial aquifer above the upper interstadial clay beds could be continued in use for irrigation and for commercial and industrial use, such as for cooling; contamination from such use will probably not affect water quality below the interstadial clay beds at the current stage of development in the Town of Riverhead. The extent of the interstadial clay surface eastward in the Town of Southold, and the depth to which freshwater is present in the Magothy and Lloyd aquifers, would require further investigation.

SUMMARY AND CONCLUSIONS

The highly toxic carbamate pesticide aldicarb (trademark TEMIK , Union Carbide Corp.) was used to control the Colorado potato beetle and golden nematode in the potato fields of eastern Long Island during 1975-79. Aldicarb at the time was believed incapable of reaching the water table. However, samplings of ground water in 1979 revealed moderate to excessive concentrations of the pesticide in water from many wells. Results from an extensive sampling program that continued into 1980 confirmed extensive areal contamination on both the north and south forks of Long Island.

New York State's Department of Health set a maximum concentration of aldicarb in drinking water at 7 µg/L. Samplings in the 1979-80 sampling survey showed aldicarb concentrations as high as 515 µg/L. As a result, the U.S. Environmental Protection Agency revoked its approval of the use of aldicarb on Long Island in February 1980 at the request of the manufacturer. To mitigate the effects of aldicarb contamination, the manufacturer installed activated-charcoal filters on drinking-water supplies containing more than 7 µg/L of aldicarb to bring concentrations below 7 µg/L.

The Jamesport area in the Town of Riverhead was selected as a study site for determining the extent of aldicarb contamination and its probable residence time in the aquifer. Exploratory drilling and installation of observation wells were done in 1981-82, and 132 water samples were collected from 101 well-screen settings for aldicarb analyses from depths to 160 ft below land surface. Samples were also collected from several local domestic and irrigation wells. The aldicarb concentrations among samples ranged from below detection limit to 180 µg/L.

By 1982, aldicarb had penetrated the upper glacial aquifer to a depth of about 40 ft below the water table in most places. High-capacity irrigation wells, which cause large water-table drawdown, have caused local deeper penetration. Aldicarb has been detected at similar depths in other areas of eastern Long Island by the Suffolk County Department of Health Services. Although aldicarb concentrations are diminishing with time through degradation, the pesticide will continue to move along ground-water flow paths and deeper into the upper glacial aquifer.

The test borings in the Jamesport area revealed a substantial thickness of Pleistocene interstadial clay beds whose undulating upper surface lies 40 to 85 ft below the water table. Water below the clay beds is free of aldicarb and is likely to remain so. Except for one well installed for emergency fire protection (seldom pumped), no wells in the area tap ground water from below the clay beds.

Aldicarb degrades in time, and concentrations at individual wells will probably fluctuate with the ground-water flow pattern and as degradation occurs. Estimates of aldicarb's rate of degradation on Long Island range from half lives of 2 to 10 years, which would indicate its presence in the aquifer until between 1990 and 2030. However, the degradation of aldicarb depends on environmental conditions, and its half life on Long Island is imprecisely known at present (1984).

The duration of aldicarb in concentrations of more than 7 µg/L in the ground water of eastern Long Island has been estimated to end between 1990 and 2030 but is still under investigation. As long as aldicarb is in the ground-water system, it will travel deeper into the upper glacial aquifer near the ground-water divide at a rate of 5 to 6 ft/yr and will move from there laterally along the ground-water flow paths toward shore discharge areas. The traveltime of ground water through the aquifer from the ground-water divide to the shore (the greatest distance) ranges from decades to centuries. Most of the aldicarb now in the system will probably degrade to negligible concentrations of less toxic compounds before it reaches the shores. Only the small amounts of aldicarb that are now near shores will reach the sea before decomposing.

A potential uncontaminated and protected supply of fresh ground water is available from Riverhead to at least as far east as the Southold Town boundary. This water is in the basal part of the upper glacial aquifer and in parts of the Magothy and Lloyd aquifers. The supply is "protected" by the interstadial clay beds in the upper glacial aquifer and is probably sufficient for current domestic needs in the Town of Riverhead, and probably to a small extent in the western part of the Town of Southold, at the current stage of development in the area. The aquifer above the interstadial clay beds, in which virtually all wells on the north fork are now screened, could still be used for irrigation and for other commercial and industrial supply.

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.

Cohen, Philip, Franke, O. L., and Foxworthy, B. L., 1968, An atlas of Long Island's water resources: New York Water Resources Commission Bulletin 62, 117 p.

Donaldson, C. D., and Koszalka, E. J., 1983, Potentiometric surface of the Lloyd aquifer, Long Island, New York, in January 1979: U.S. Geological Survey Open-File Report 82-162, 2 sheets.

Environmental Science and Technology, 1983, v. 17, no. 11, p. 513A.

Fetter, C. W., Jr., 1971, Hydrogeology of the South Fork of Long Island, New York: Bloomington, Indiana, Indiana University, unpublished Ph.D. dissertation, 236 p.

Franke, O. L., and Cohen, Philip, 1972, Regional rates of ground-water movement on Long Island, New York: U.S. Geological Survey Professional Paper 800-C, p. C271-C277.

Fuller, M. L., 1914, The geology of Long Island, New York: U.S. Geological Survey Professional Paper 82, 223 p.

Guerrera, A. A., 1981, Chemical contamination of aquifers on Long Island, New York: American Water Works Association Journal, v. 73, no. 4, p. 190-199.

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.

Lubke, E. R., 1964, Hydrogeology of the Huntington-Smithtown area, Suffolk County, New York: U.S. Geological Survey Water-Supply Paper 1669-D, 68 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., 1 pl.

Mordoff, R. A., 1949, The climate of New York State: Ithaca, N.Y., Cornell University Extension Bulletin 764, 72 p. (Reprinted 1953).

REFERENCES CITED (continued)

Morris, D. A., and Johnson, A. I., 1967, Summary of hydrologic and physical properties of rock and soil materials, as analyzed by the Hydrologic Laboratory of the U.S. Geological Survey, 1948-60: U.S. Geological Survey Water-Supply Paper 1839-D, 42 p.

Nemickas, Bronius, and Koszalka, Edward 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., 9 pls.

Perlmutter, N. M., and Geraghty, J. J., 1963, Geology and ground-water conditions in southern Nassau and southwestern Queens Counties, Long Island, New York: U.S. Geological Survey Water-Supply Paper 1613-A, 205 p.

Rothschild, E. R., Mauser, R. J., and Anderson, M. P., 1982, Investigation of aldicarb in ground water in selected areas of the central sand plain of Wisconsin: Groundwater, v. 20, no. 4, p. 437-445.

Seaburn, G. E., and Aronson, D. A., 1974, Influence of recharge basins on the hydrology of Nassau and Suffolk Counties, Long Island, New York: U.S. Geological Survey Water-Supply Paper 2031, 66 p., 1 pl.

Soren, Julian, 1978, Subsurface geology and paleogeography of Queens County, Long Island, New York: U.S. Geological Survey Water-Resources Investigations 77-34, 17 p.

__________ 1977, Ground-water quality near the water table in Suffolk County, Long Island, New York: Hauppauge, N.Y., Suffolk County Department of Environmental Control, Long Island Water-Resources Bulletin 8, 33 p., 1 pl.

__________ 1971, Results of subsurface exploration in the mid-island area of western Suffolk County, Long Island, New York: Oakdale, N.Y., Suffolk County Water Authority, Long Island Water Resources Bulletin 1, 60 p.

Suter, Russell, deLaguna, Wallace, and Perlmutter, N. M., 1949, Mapping of geologic formations and aquifers on Long Island, New York: Albany, N.Y., New York State Department of Conservation, Water Power and Control Commission Bulletin GW-18, 181 p.

Trautmann, N. M., Porter, K. S., and Hughes, H. B., 1983a, Protection and restoration of ground water in Southold, N.Y.: Ithaca, N.Y., Cornell University Center for Environmental Research, 54 p.

__________ 1983b, Southold demonstration site, New York State fertilizer and pesticide demonstration project: Ithaca, N.Y., Cornell University Center for Environmental Research, 74 p.

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

Table 4.--Aldicarb analyses of water from wells in the Jamesport vicinity, Town of Riverhead, Suffolk County, N.Y., 1980-82.

[Use of water: DOM, domestic; FP, fire protection; IRR, irrigation; OBS, observation, TEST, water sample obtained and well screen moved to other depth. Well locations are shown in fig. 2. A well whose use is given as TEST is at the site of the numbered well.]

Well number	Depth of well below land surface (ft)	Use of well	Date sampled	Aldicarb analysis: Concentration (µg/L)	Aldicarb analysis: Laboratory[1]	Approximate depth of well below water table (ft)
S3705	114	IRR	8-16-82	5.2	USGS	54
4620	114	do.	do.	9.2	do.	59
8421	109	do.	do.	5	do.	54
10256	104	do.	8-24-82	12	do.	52
10364	52	do.	7-29-82	18	do.	40
22855	96	do.	7- 7-82	14	do.	52
[2] 31281	43	DOM	8-31-82			39
40407	140	FP	8-20-82	<1	USGS	134
47989	86	IRR	do.	<1	do.	39
48944	17	DOM	8-31-82	<1	do.	12
51581	43	OBS	3-17-80	140	USEPA[3]	18
51581	do.	do.	6-29-81	48	H2M[3]	18
51581	do.	do.	2- 1-82	33	H2M	18
[2] 51581	do.	do.	8- 3-82			18
51582	82	do.	3-17-80	ND[4]	USEPA[3]	25
51582	do.	do.	6-29-81	<1	H2M[3]	25
51582	do.	do.	2-17-81	<1	H2M	25
[2] 51582	do.	do.	8- 3-82			25
51587	78	do.	3-17-80	ND	USEPA[3]	27
51587	do.	do.	7- 7-81	13	H2M[3]	27
[2] 51587	do.	do.	8- 3-82			27
51589	41	do.	3-17-80	ND	USEPA[3]	26
51589	do.	do.	7- 7-81	63	H2M3	26
[2] 51589	do.	do.	8- 3-82			26

[1] USGS, U.S. Geological Survey Laboratory, Doraville, Ga.;
H2M, H2M Corp. Laboratory, Melville, N.Y.;
USEPA, U.S. Environmental Protection Agency Laboratory, Division of Preventive Medicine, South Carolina Pesticide Epidemologic Studies Center, Medical University of South Carolina, Charleston, S. Car.

[2] Split-sample analysis; see results in table 2.

[3] Oral communications, S. V. Cary and Richard Markel, Suffolk County Department of Health Services, 1982, from analyses provided by USEPA.

[4] Not detected.

Table 4.--Aldicarb analyses of water from wells in the Jamesport vicinity, Town of Riverhead, Suffolk County, N.Y., 1980-82.--continued

[Use of water: DOM, domestic; FP, fire protection; IRR, irrigation; OBS, observation, TEST, water sample obtained and well screen moved to other depth. Well locations are shown in fig. 2. A well whose use is given as TEST is at the site of the numbered well.]

Well number	Depth of well below land surface (ft)	Use of well	Date sampled	Aldicarb analysis: Concentration (µg/L)	Aldicarb analysis: Laboratory[1]	Approximate depth of well below water table (ft)
S71566	25	OBS	1-27-82	33	H2M	16
71566	do.	do.	8- 3-82	3.6	USGS	16
[2] 71566a	45	TEST	1-27-82			36
71566b	66	do.	do.	<1	H2M	57
71566c	87	do.	do.	<2	do.	78
71566d	129	do.	do.	<2	do.	120
71567	17	OBS	8- 3-82	180	USGS	11
71567a	12	TEST	1-26-82	35	H2M	6
71567b	19	do.	2-18-82	35	do.	13
[2] 71567c	22	do.	1-26-82			16
[2] 71568	17	OBS	1- 7-82			12
71568	do.	do.	8- 4-82	27	USGS	12
71568a	37	TEST	1- 7-82	3	H2M	32
71568b	120	do.	do.	<1	do.	118
71568c	151	do.	1- 6-82	<1	do.	146
[2] 71569	32	OBS	1-27-82			12
71569	do.	do.	8- 4-82	150	USGS	12
[2] 71569a	42	TEST	1-27-82			22
71570	52	OBS	8- 4-82	1	USGS	27
71570a	54	TEST	2-18-82	<1	H2M	29
[2] 71570b	62	do.	1-22-82			37
[2] 71571	44	OBS	1-19-82			16
71571	do.	do.	8-10-82	3.2	USGS	16
71571a	63	TEST	1-19-82	3	H2M	35
71571b	71	do.	do.	6	do.	43
71572	56	OBS	2- 8-82	65	do.	17
71572	do.	do.	8-10-82	29	USGS	17
71572a	76	TEST	2-28-82	1	H2M	37
71572b	97	do.	do.	3	do.	58

[1] USGS, U.S. Geological Survey Laboratory, Doraville, Ga.;
H2M, H2M Corp. Laboratory, Melville, N.Y.;
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[2] Split-sample analysis; see results in table 2.

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Well number	Depth of well below land surface (ft)	Use of well	Date sampled	Aldicarb analysis: Concentration (µg/L)	Aldicarb analysis: Laboratory[1]	Approximate depth of well below water table (ft)
S71572c	118	TEST	2-28-82	1	H2M	79
71572d	139	do.	do.	1	do.	100
71572e	159	do.	do.	<1	do.	120
71573	75	OBS	7- 1-82	1.3	USGS	36
71573	do.	do.	8-10-82	<1	do.	36
[2] 71574	109	do.	2-16-82			52
71574	do.	do.	8-10-82	1.7	USGS	52
71574a	129	TEST	2-16-82	<1	H2M	72
71574b	158	do.	do.	<1	do.	101
71575	64	OBS	6-30-82	ND	USGS	7
71575	do.	do.	8-11-82	do.	do.	7
[2] 71577	59	do.	11- 9-82			17
71577	do.	do.	8-12-82	46	USGS	17
[2] 71577a	79	TEST	11- 9-81			37
71577b	107	do.	do.	<1	H2M[3]	65
71577c	138	do.	do.	5	do.	96
[2] 71578	46	OBS	2- 2-82			23
71578	do.	do.	8- 5-82	1.4	USGS	23
71578a	66	TEST	2- 2-82	<1	H2M	43
71578b	87	do.	do.	<1	do.	64
71578c	118	do.	do.	<2	do.	95
[2] 71579	26	OBS	12-30-81			15
71579	do.	do.	8- 4-82	<1	USGS	15
71579a	46	TEST	12-30-81	<2	H2M	35
71579b	130	do.	do.	<1	do.	119
71579c	145	do.	do.	<1	do.	134
71580	22	OBS	8- 6-82	28	USGS	12

[1] USGS, U.S. Geological Survey Laboratory, Doraville, Ga.;
H2M, H2M Corp. Laboratory, Melville, N.Y.;
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Well number	Depth of well below land surface (ft)	Use of well	Date sampled	Aldicarb analysis: Concentration (µg/L)	Aldicarb analysis: Laboratory[1]	Approximate depth of well below water table (ft)
[2]S71580a	24	TEST	2-17-82			14
71580b	34	do.	do.	37	H2M	24
71581	35	OBS	7- 2-82	18	USGS	25
71581	do.	do.	8- 5-82	19	do.	25
72840	45	do.	6-21-82	ND	do.	36
72840	do.	do.	8- 3-82	<1	do.	36
72841	40	do.	6-22-82	4.7	do.	34
[2] 72842	34	do.	8-30-82			31
72843	40	do.	6-23-82	<1	USGS	20
72843	do.	do.	8- 4-82	2	do.	20
72844	60	do.	7- 2-82	37	do.	32
72844	do.	do.	8-10-82	55	do.	32
72845	75	do.	6-28-82	25	do.	33
72845	do.	do.	8-12-82	2	do.	33
72846	65	do.	6-30-82	ND	do.	42
72846	do.	do.	8- 5-82	do.	do.	42
72847	45	do.	6-23-82	do.	do.	34
72847	do.	do.	8- 4-82	1.1	do.	34
72848	75	do.	7- 7-82	140	do.	29
72848	do.	do.	8-11-82	43	do.	29
[2] 73272	83	DOM	8-30-82			22

[1] USGS, U.S. Geological Survey Laboratory, Doraville, Ga.;
H2M, H2M Corp. Laboratory, Melville, N.Y.;
USEPA, U.S. Environmental Protection Agency Laboratory, Division of Preventive Medicine, South Carolina Pesticide Epidemologic Studies Center, Medical University of South Carolina, Charleston, S. Car.

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