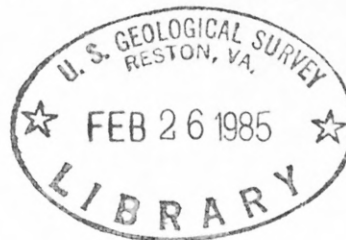UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

DISTRIBUTION OF POLYCHLORINATED BIPHENYLS

IN THE HOUSATONIC RIVER AND

ADJACENT AQUIFER, MASSACHUSETTS

Open-File Report 84-588

Prepared in cooperation with the

COMMONWEALTH OF MASSACHUSETTS

WATER RESOURCES COMMISSION

DEPARTMENT OF ENVIRONMENTAL QUALITY ENGINEERING

DIVISION OF WATER POLLUTION CONTROL

TECHNICAL SERVICES BRANCH

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UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

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ILLUSTRATIONS

METRIC CONVERSION FACTORS

The following factors may be used to convert inch-pound units to the International System of Units (SI).

Multiply inch-pound units	by	To obtain SI Units
	Length	
inch (in)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
million gallons per day per square mile [$(Mgal/d)/mi^2$]	1,460	cubic meter per day per square kilometer [$(m^3/d)/km^2$]
	Mass	
pound, avoirdupois	453.6	gram (g)
	Water temperature	
degree Fahrenheit (^oF)	$^oC = 5/9(^oF-32)$	degree Celsius (^oC)
	Datum	

NGVD of 1929 (National Geodetic Vertical Datum of 1929): A geodetic vertical datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level." NGVD of 1929 is referred to as sea level in this report.

DISTRIBUTION OF POLYCHLORINATED BIPHENYLS IN THE HOUSATONIC RIVER

AND ADJACENT AQUIFER, MASSACHUSETTS

By Frederick B. Gay and Michael H. Frimpter

ABSTRACT

Polychlorinated biphenyls (PCBs) are sorbed to the fine-grained stream-bottom sediments along the Housatonic River from Pittsfield, Massachusetts, southward to the Massachusetts-Connecticut boundary. The highest PCB concentrations, up to 140,000 micrograms per kilogram, were found in samples of bottom material from a reach of the river between Pittsfield and Woods Pond Dam in Lee, Massachusetts. Sediments in Woods Pond have been estimated to contain about 11,000 pounds of PCBs. Approximately 490 pounds per year of PCBs have also been estimated to move past the Housatonic River gaging station at Great Barrington.

The distribution of hydraulic-heads, water-temperatures, and concentrations of dissolved-oxygen, ammonia, nitrate, iron, and manganese in ground water show that industrial water-supply wells in a sand and gravel aquifer adjacent to a stretch of the river called Woods Pond have been inducing ground-water recharge through the PCB-contaminated bottom sediments of the pond since late 1956. These data indicate that, at one location along the shore of the pond, the upper 40 feet of the aquifer contains water derived from induced infiltration. However, this induced recharge has not moved PCBs from the bottom sediments into a vertical section of the aquifer located 5 feet downgradient from the edge of Woods Pond. Samples taken at selected intervals in this section showed no PCBs sorbed to the aquifer material or dissolved in the ground water within the detection limits of the chemical analyses.

INTRODUCTION

The Housatonic River forms in Pittsfield, Massachusetts, where the Southwest, West, and East Branch Housatonic Rivers join. The river flows southward through Berkshire County in western Massachusetts for about 50 river miles. The river crosses into Connecticut about 1 mile north of Canaan, Connecticut, then continues about 85 river miles southward through western Connecticut to Long Island Sound. The Housatonic River drains 504 mi^2 in western Massachusetts, 217 mi^2 in eastern New York, and 1,232 mi^2 in western Connecticut (fig. 1). For many years, large quantities of industrial and municipal wastes were disposed of in the river, degrading water quality and limiting the use of the river. Since the mid 1960's, water quality has improved through efforts to limit the discharge of untreated and poorly treated wastewater. Presently, river water is being used for (1) water supply through induced infiltration to wells for industries and municipalities; (2) generation of electricity; (3) disposal of treated industrial and municipal wastewater; (4) recreational fishing, particularly in Connecticut; (5) canoeing; and (6) nature studies.

73°15'

BERKSHIRE CO.

West Branch

East Branch

Southwest Branch

PITTSFIELD

Woods Pond

42°15' — LEE — 42°15'

Rising Pond

MASSACHUSETTS

GREAT BARRINGTON

NEW YORK

42°00 — CANAAN — 42°00'

CONNECTICUT

HOUSATONIC RIVER

EXPLANATION

▲ Continuous-record stream-gaging station

—··— Basin boundary

——— State boundary

—·— County boundary

41°30' — 41°30'

73°15

LONG ISLAND SOUND

NORTH

0   5   10   15   20 MILES
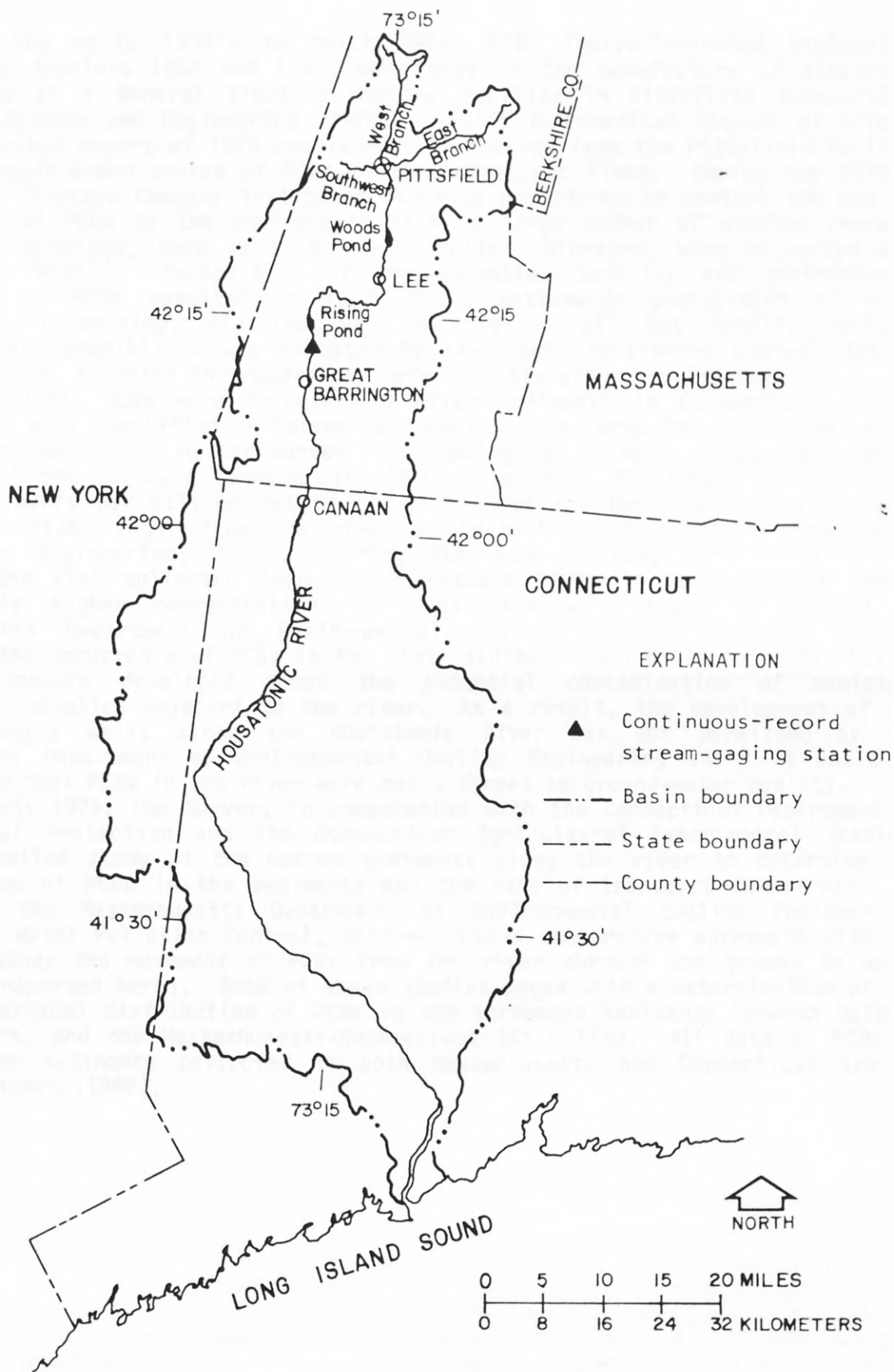
0   8   16   24   32 KILOMETERS

Figure 1.--Location of Housatonic River drainage basin.

From the early 1930's to March 1977, PCBs (polychlorinated biphenyls), particularly Aroclors 1254 and 1260, were used in the manufacture of electrical transformers at a General Electric Company facility in Pittsfield (Connecticut Academy of Science and Engineering, 1978). A CASE (Connecticut Academy of Science and Engineering) report of 1978 concluded that leakage from the Pittsfield facility was the largest known source of PCBs to the Housatonic River. During the 1970's, the General Electric Company instituted rigorous procedures to control the use and the leakage of PCBs to the environment after a large number of studies revealed that health problems, such as a skin rash called chloracne, were connected with exposure to PCBs[1]. Recognition of the potential toxicity and environmental persistence of PCBs resulted in 1977, in a nationwide prohibition of their manufacture, processing, distribution, and use in all but totally enclosed systems. This prohibition was mandated by the Toxic Substances Control Act of 1976, PL 94-469, to which the reader may refer for its other provisions.

In 1974-75, PCBs were detected in river sediments in Connecticut and in 1976-77 PCBs were identified in bottom sediments in the large impounded lakes along the river in Connecticut by the Survey (U.S. Geological Survey). These data are in the files of the Survey's Connecticut office. In 1977, PCB levels exceeding the limit of 5 parts per million set by the U.S. Food and Drug Administration were detected in fish caught from the river in Connecticut (Connecticut Academy of Science and Engineering, 1978). During the same period, samples of bottom sediments and fish collected from the Housatonic River in Massachusetts showed significantly higher concentrations of PCBs than were found in Connecticut (Massachusetts Department of Environmental Quality Engineering data files). Because of the occurrence of PCBs in the river sediments and their potential health problems, concern developed about the potential contamination of municipal ground-water supplies adjacent to the river. As a result, the development of new municipal-supply wells along the Housatonic River was not permitted by the Massachusetts Department of Environmental Quality Engineering until it could be demonstrated that PCBs in the river were not a threat to ground-water quality.

In early 1979, the Survey, in cooperation with the Connecticut Department of Environmental Protection and the Connecticut Agricultural Experimental Station, began a detailed study of the bottom sediments along the river to determine the concentration of PCBs in the sediments and the rate of transport downstream. In late 1979, the Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, entered into a cooperative agreement with the Survey to study the movement of PCBs from the river through the ground to wells (the study reported here). Both of these studies began with a determination of the areal and vertical distribution of PCBs in the streambed sediments between Dalton, Massachusetts, and the Massachusetts-Connecticut State line. All data on PCBs in stream-bottom sediments collected in both Massachusetts and Connecticut are in Frink and others (1982).

1/ Further information on these health issues may be found in reports by Connecticut Academy of Science and Engineering (1978), Westin (1979), Environmental Criteria and Assessment Office (1980), and Miller (1983).

Purpose and Scope

The purpose of this report is to determine the effects of the PCBs from the stream-bottom materials in the Housatonic River on an adjacent aquifer under conditions of induced infiltration. The study described in this report was done at a well site adjacent to a ponded stretch of the river where PCB concentrations in the stream-bottom materials are high and cover a large area, and where industrial water-supply wells have induced stream-water infiltration for a number of years. The site chosen is a sand and gravel aquifer adjacent to Woods Pond on the Housatonic River in Lee, Massachusetts. The report describes the chemistry of PCBs, the distribution of PCBs in bottom sediments and water in the Housatonic River and in Woods Pond, and the effects of PCBs in the Housatonic River on adjacent ground water.

Acknowledgments

The authors wish to acknowledge and thank the many persons and organizations who have kindly given time and information to this study. Particular thanks is given to Richard Krueger, General Manager of the P. J. Schweitzer Division, Kimberly-Clark Corporation, located in Lee, Massachusetts, for granting permission to use their well field located on the south side of Woods Pond. Other individuals within Schweitzer Division who were very cooperative and helpful are: John Cahalen, Technical Manager; John Hansen, Assistant Technical Manager; and Joseph Rock. Other individuals who provided important assistance were: Everett Buffoni, Superintendent, Lee Water Department; and Frank Macy, Plant Manager of the Lane Construction Corporation in Lee.

Geohydrologic Setting

The Housatonic River basin is underlain by metamorphic and sedimentary rocks. Quartzite, schist, and gneiss, that are resistant to erosion, form the uplands. Carbonate rocks, such as limestone, dolomite, and marble, which are more easily eroded generally underlie the major valleys. A thin mantle of unconsolidated glacial deposits covers the bedrock surface. These deposits are composed predominantely of till in the upland areas and stratified drift in the valleys. The stratified drift is composed of coarse-grained sediments that are well sorted, porous, and permeable. Where the saturated thickness of the stratified drift exceeds 25 feet, the drift forms an aquifer capable of sustaining municipal or industrial water supplies. A more complete description of the aquifers in the Housatonic River basin is given by Norvitch and others (1968).

The mean annual precipitation in the Housatonic River basin in Massachusetts is about 46 inches, and in an average year about half of that water is returned to the atmosphere by evaporation and transpiration. Of the remaining half, about 50 percent flows through the basin's unconsolidated deposits and bedrock and discharges to the river, and about 50 percent flows over the land surface to the river (Norvitch and others, 1968).

Water that enters the ground from precipitation flows through the bedrock, till, and stratified drift, and discharges into streams and ponds as shown in figure 2. Wells that are finished in and pump from the stratified-drift can intercept this ground-water discharge. A heavily pumped well adjacent to a stream or pond will intercept ground-water discharge and may also induce stream water to infiltrate through the streambed and enter the aquifer as shown in figure 3.
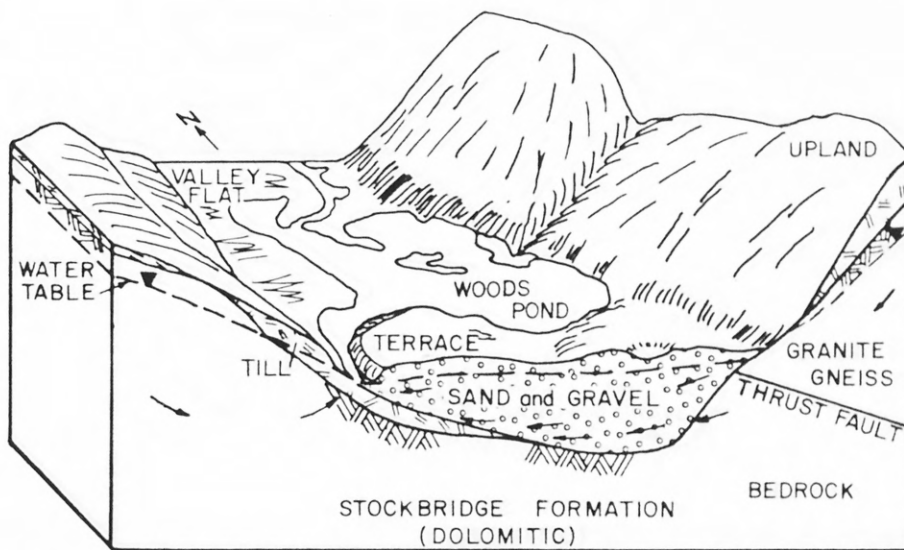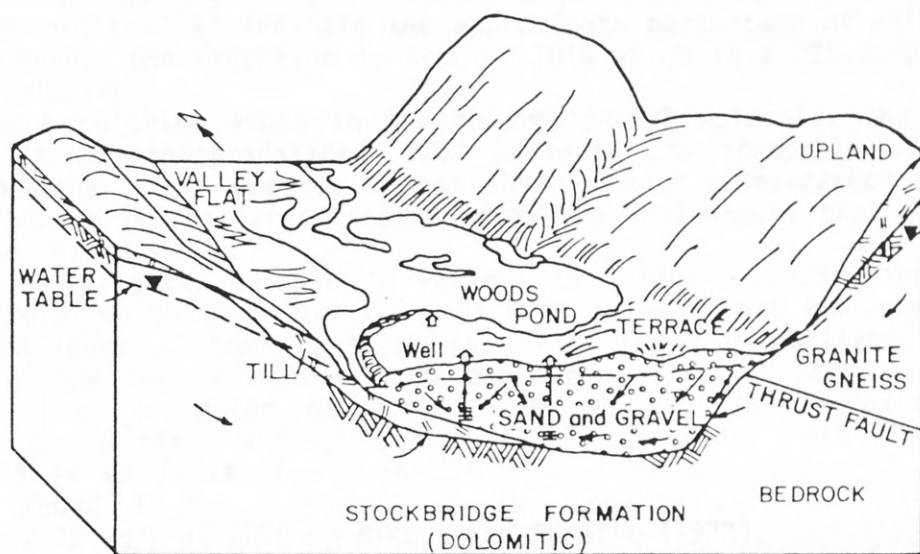
EXPLANATION

⟵ Direction of ground-water
flow

─▼─ Water table

Figure 2.--Idealized pattern of ground-water flow under natural conditions.

EXPLANATION

___ Direction of ground-water flow

_▼_ Water table

⚲ Pumped well

Figure 3.--Idealized pattern of ground-water flow under pumping conditions.

PCB is a generic name for a class of aromatic chlorinated organic compounds. PCBs are formed by first linking two benezene rings by covalent bonding between two carbon atoms to form a biphenyl molecule, then substituting chlorine atoms for one or more hydrogen atoms to form a chlorobiphenyl molecule as shown in figure 4. PCBs were manufactured in this country by Monsanto Chemical Company and marketed under the trade name "Aroclor," followed by a four-digit number, such as Aroclor 1254. The first two digits "12" indicate a polychlorinated biphenyl compound and the last two digits "54" indicate the approximate percentage of chlorine by weight in that compound. One exception is Aroclor 1016 which is a PCB compound containing 41 percent chlorine.

The more chlorine atoms in the chlorobiphenyl molecule, the more resistant the isomer is to biodegradation. Most bacteria are incapable of degrading PCB compounds because their enzymes cannot shear the chlorine-carbon bond. However, there have been a few bacteria isolated from the environment that can degrade PCBs (Griffin and Chian, 1980).

PCBs are slightly soluble in water. In general, researchers have found an inverse correlation between solubility of PCBs in water and the number of chlorine atoms in the isomer. However, there is a wide range in published values for the solubility of the same Aroclor. Haque and others (1974) determined the solubility of Aroclor 1254 in water at room temperature to be approximately 56 ug/L (micrograms per liter), whereas Schoor (1975) concluded that the solubility of Aroclor 1254 in water is less than 0.1 ug/L. The solubility of Aroclor 1260 in water was found to be 2.7 ug/L at $25^{\circ}C$ by MacKay and Wolkoff (1973) and approximately 25 ug/L at $20^{\circ}C$ by Nisbet and Sarofim (1972).

PCBs have a strong affinity for soils, sediments, and particulate matter present in the environment (Haque and others, 1974). The degree of sorbtion of PCBs by the solid seems to be positively correlated to the total organic carbon content and to the ratio of surface area to weight with total organic carbon being the more important. In addition, Haque and Schmedding (1976) noted that sorbtion by the solid increases as the number of chlorine atoms attached to the PCB molecule increase.

PCBs have been shown to be volatile compounds in water (Uhlken and others, 1973), but markedly less volatile in the presence of sediments (Oloffs and others, 1973). In addition, it seems that as the chlorination of the PCB molecule increases, volatility decreases.
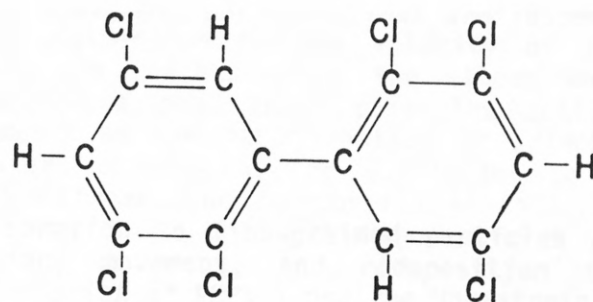
Figure 4.--Typical chemical structure of a chlorobiphenyl molecule.

Bottom sediments

Analyses for PCBs in bottom sediments from the Southwest and West Branch Housatonic Rivers and East Branch Housatonic River upstream of the General Electric Company facility in Pittsfield (fig. 5) showed a range of concentration from 30 to 47 ug/kg (micrograms per kilogram of bottom material) and a mean of 40 ug/kg, or about 40 parts per billion. These values are considered background concentration levels of PCBs in river sediments in this area. The probable sources of these PCBs are volatilization during incineration of solid wastes at temperatures too low to alter the chemical composition of PCBs (Crump-Wiesner and others, 1973), and volatilization of PCB compounds from soil and water both followed by transport and deposition from the atmosphere (Nelson and others, 1972). These volatile PCBs (aerosols) are transported by the wind, but much of the PCBs are deposited from the atmosphere onto land and water surfaces near the source.

When PCBs are discharged into a river, they are readily sorbed by the fine-grained organic or inorganic particles that are suspended in the water. These particles are held in suspension by the velocity of the river water and are transported downstream. In reaches along the stream where the stream velocity decreases, such as behind a dam, these particles settle and form a layer of PCB-laden bottom sediments on the stream bottom or adjacent flood plain. During floods, the stream-water velocity may be sufficient to resuspend the PCB-laden sediments, move them downstream, and redeposit them in another reach of the river. This process of PCB sorbtion to fine-grained particles and movement downstream, deposition, resuspension, movement, and redeposition is responsible for the transport and the distribution of PCBs along the Housatonic River.

The highest concentrations of PCBs detected in the bottom sediments along the entire Housatonic River in Massachusetts, up to 140,000 ug/kg, were found deposited in a stretch of the river between Pittsfield, Massachusetts, and the Woods Pond Dam in Lenox, Massachusetts (fig. 5). Woods Pond is the first significant impoundment on the Housatonic River below Pittsfield that acts as an effective sediment trap. The pond was created when the Woods Pond Dam was built in 1901 (Frink and others, 1982). In Woods Pond, some of the highest concentration of PCBs, up to 110,000 ug/kg, were found in the black, organic bottom sediments. The thickness of this organic sediment ranges from 6 inches to 6 feet. From below the Woods Pond Dam to the Massachusetts-Connecticut State line, the concentration levels of PCBs in the bottom sediment decrease sharply, but are as high as 9600 ug/kg. The higher concentrations of PCBs along this stretch of the river are in Rising Pond and the oxbow sections of the river south of Rising Pond.

The significant decrease in PCB concentration in the river below Lee/Lenox, Massachusetts, is attributed to the dam that creates Woods Pond (fig. 6). This impoundment has a relatively flat water-surface profile extending a considerable distance upstream from the dam. A flat water-surface profile is associated with low streamflow velocities, which coupled with its longitudinal extent, allows sufficient time for the fine-grained sediment in the river water to settle and collect on the bottom of the pond. The emerging wetland deposits at the inlet of Woods Pond is an indication that this abrupt change in velocity is ongoing.
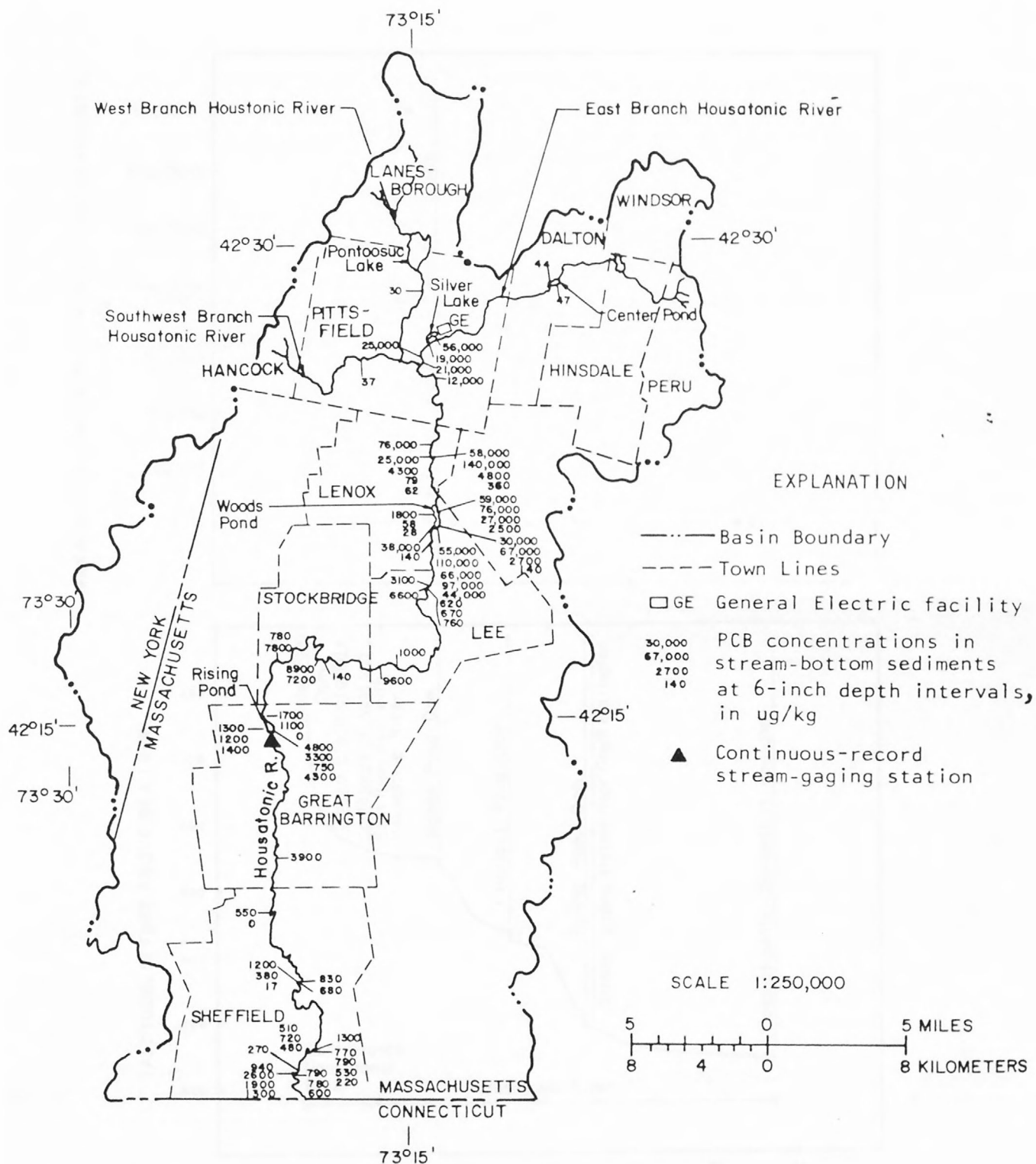
Figure 5.--Concentration of PCBs sorbed to bottom sediments along Southwest, West, and East Branch Housatonic Rivers and the Housatonic River in Massachusetts.
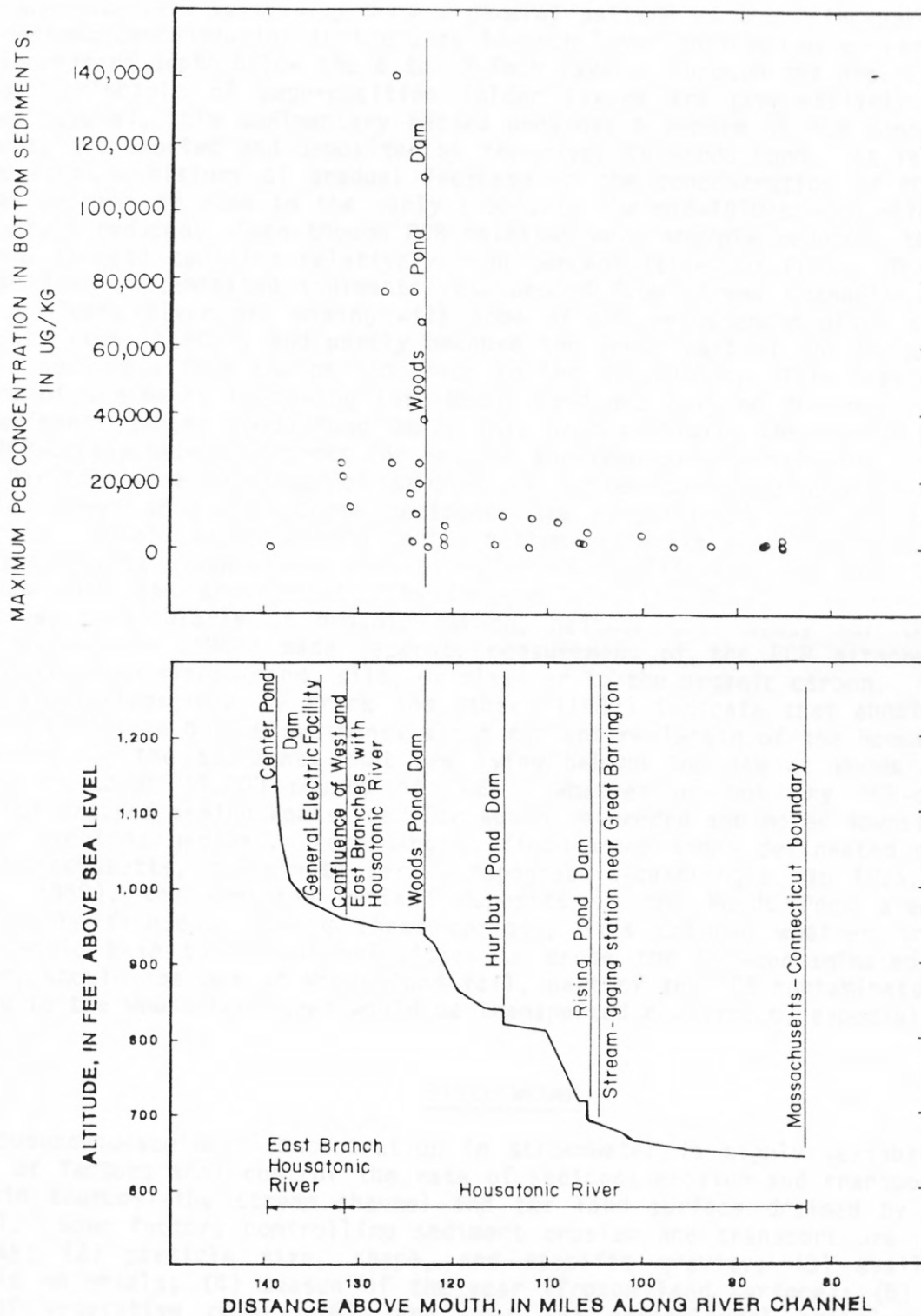
Figure 6.--Maximum PCB concentration in bottom sediments and altitude above sea
level of the water surface along the East Branch Housatonic River and
the Housatonic River in Massachusetts.

The concentration of PCBs attached to the bottom sediments of Woods Pond differs considerably from place to place along the width and length of the channel. However, PCB concentrations in the bottom sediments of Woods Pond taken at 6-inch intervals vertically show a general pattern of sharp increase with depth to a maximum concentration in the 6 to 12-inch layer followed by a gradual decrease with increasing depth below the 6 to 12-inch layer. Through the application of the geologic principle of superposition (older layers are progressively overlain by younger layers), this sedimentary record provides a record of PCB concentration in sediments transported and deposited by the river in Woods Pond. It is interpreted to represent a history of gradual increase in the concentration of PCBs from the initial release of PCBs in the early 1930's to the mid-1970's when release of PCBs was sharply reduced. Even though PCB releases were sharply reduced, the top layer (0 to 6 inches) contains relatively high concentrations of PCBs. This is partly because less contaminated sediments resuspended from stream channels tributary to the Housatonic River are mixing with some of the resuspended older stream-bottom sediments rich in PCBs, and partly because the lower part of the 6-inch layer may contain sediments from the period prior to the mid-1970's. This less contaminated mixture of sediments is moving into Woods Pond and burying the more contaminated PCB sediments behind Woods Pond Dam. This process limits the availability of the more PCB-contaminated sediments for erosion and transport downstream.

Particle-size analyses of samples of bottom sediments containing PCBs and organic carbon show that these sediments are composed of sand sized or smaller particles. Total organic carbon in the bottom sediments along the Housatonic River in Massachusetts ranged from 2.2 to 320 mg/L (milligrams per liter). Although previous work has shown that PCBs have a strong affinity for the finer-sized particles, particularly of organic carbon, neither this study nor the study by Frink and others (1982) made separate measurement of the PCB attachment to the individual grain sizes (sand, silt, or clay) or to the organic carbon.

Calculations made by Frink and others (1982) indicate that about 50 percent of all the PCBs in bottom sediments along the entire length of the Housatonic River are sorbed to the sediments that are lying behind the dam at Woods Pond. This amounts to about 11,000 pounds of PCBs. Whether or not any PCB-contaminated sediments trapped behind Woods Pond Dam would be eroded and moved downstream during a flood event is unclear. According to flood-prone areas delineated on the East Lee, Massachusetts, 7.5-minute series topographic-quadrangle map (U.S. Geological Survey, 1969), the emerging wetland deposits in the Woods Pond area would be occasionally flooded. During these periods, it's unknown whether or not flood waters would have sufficient velocities to erode the PCB-contaminated sediments. However, should the dam at Woods Pond fail, part of the PCB-contaminated sediments trapped in the Woods Pond area would be transported downstream, especially during a flood.

River Water

Suspended-sediment concentration in streamwater is highly variable due to a number of factors that control the rate of sediment erosion and transport from its two main sources--the stream channel and the land surface drained by the stream channel. Some factors controlling sediment erosion and transport are (1) stream velocity; (2) particle size, shape, and specific gravity; (3) availability of erodable materials; (4) season of the year (frozen land surface); (5) amount and type of vegetative cover; (6) land use; (7) agricultural practices; and (8) intensity of rainfall and (or) snowmelt. Most of the following discussion focuses on the movement of stream-channel deposits.

Movement of stream-channel deposits are dependent on the energy exerted by the flowing water on the individual noncohesive or cohesive particles that comprise the streambed materials. Noncohesive materials usually are composed of coarse-grained particles, such as sand, and the resistance of this type of material to movement by flowing water is related to the size, shape, and specific gravity of the particle and to the slope of the streambed. Cohesive materials usually are composed of fine-grained particles, such as clays, and the cohesive and adhesive forces, such as surface tension, between these fine-grained particles must first be overcome before these particles can be suspended and transported. The force required to move cohesive particles is usually greater than what is needed to maintain these particles in suspension. This phenomenon is clearly demonstrated by the Hjulstrom graph (Task Committee on Preparation of Sedimentation Manual, Committee on Sedimentation, 1966, p. 299), where the critical velocity necessary to suspend and to move clays and gravels from a streambed is higher than what is needed to suspend and to move sand-sized particles from a streambed.

Normally, increased streamflow results in increased sediment transport, and decreased streamflow results in decreased sediment transport. This is partly because (1) there is a direct relationship between streamflow and velocity, (2) there is a direct relationship between streamflow and wetted perimeter (cross-sectional length of streambed inundated by flowing water), (3) most streambed sediments are usually composed of a mixture of fine- to coarse-grained materials that will become suspended at various streamflow velocities, and (4) the stream channel receives sediment eroded from the land surface. Because the bulk of the PCBs are sorbed to the bottom sediments along the Housatonic River, it is expected that these sediments will be suspended and moved downstream by streamflow when the proper velocities are reached for the various particle sizes. To obtain an idea of the amount of PCBs that is being transported downstream with the streamwater, suspended-sediment concentrations were determined from daily samples collected at a continuous-record stream-gaging station located near Great Barrington, Massachusetts, about 20 river miles below Woods Pond Dam. In addition, dissolved and total concentrations of six Aroclors of PCBs (1016, 1221, 1232, 1242, 1248, 1254, and 1260) were determined in water samples collected from the river during some storm events. Because of the limited number of storms, as well as a lower-than-average flow, only a small number of samples were collected. Sixteen water samples were collected over a flow range from 235 to 2980 ft^3/s and a suspended-sediment-concentration range of from 18 to 226 mg/L.

The concentration of dissolved material in water was determined from samples that had passed through a membrane filter having a 0.45 micrometer pore size. The concentration of total material in water, both dissolved and suspended, was determined from unfiltered samples. The dissolved concentration was subtracted from the total concentration to determine the amount of PCBs sorbed to suspended-sediment particles greater than 0.45 micrometer in diameter.

In the water samples taken at high flow near Great Barrington, only trace concentrations of total PCBs, less than 0.4 ug/L, were found for the individual Aroclors of 1248, 1254, and 1260. Aroclor 1260 predominated in 15 of 16 samples. Aroclor 1248 is the next most predominant Aroclor, being detected in 10 of 16 samples, but in lower concentrations than Aroclor 1260. In contrast, Aroclor 1254 was found only in one sample. This is consistent with the stability of Aroclor 1260, as it has the most chlorine atoms by weight of the PCB compounds used by General Electric Company in Pittsfield. Dissolved PCBs were found in 6 of the 16 samples, and only at 0.1 ug/L for Aroclors 1248 and 1260. The detection levels for the analytical methods used in the chemical analysis of both dissolved and total PCBs are 0.1 ug/L (Wershaw and others, 1983). Aroclor 1248 was not reported to be used in Pittsfield (Frink and others, 1982) and its source is uncertain. However, the Environmental Criteria and Assessment Office (1980, p. A9) stated in reference to PCBs that, "The purified product is a complex mixture of the chlorobiphenyls, the precise composition depending on the conditions under which the chlorination occurred." Therefore, it is possible that Aroclor 1248 was formed during the manufacturing process and was also present in either or both Aroclors 1254 and 1260 reported to have been used in Pittsfield.

The total sum of Aroclors 1248, 1254, and 1260 did not exceed 0.6 ug/L for any samples. Substracting the maximum concentration of dissolved PCBs (0.1 ug/L) from the maximum concentration of total PCBs (0.6 ug/L) indicates that most PCBs are sorbed to the suspended-sediment particles moving downstream. Frink and others (1982) have calculated that even with this low concentration about 490 pounds per year of PCBs move past the gaging station in Great Barrington.

Analyses of the suspended-sediment/PCBs data at the Great Barrington gaging station show that a maximum of 0.6 ug/L of total PCBs were found in river water at streamflows up to 2980 ft^3/s. This low concentration indicates that very little of the PCB-contaminated sediments in the stream channel are eroded and moved downstream at streamflows of less than 3000 ft^3/s. It also indicates that streamflows greater than 3000 ft^3/s would be required to move higher concentrations of PCBs downstream. However, flows around 3000 ft^3/s are not rare events. For example, the annual peak streamflow will exceed 3000 ft^3/s at intervals averaging 1.4 years in length, and the probability of the annual peak streamflow exceeding 3000 ft^3/s in any 1 year is about 70 percent (fig. 7). On a daily mean streamflow basis, this streamflow has been exceeded about 0.7 percent of the time (about 170 days) during the last 68 years of record, as shown in figure 8.
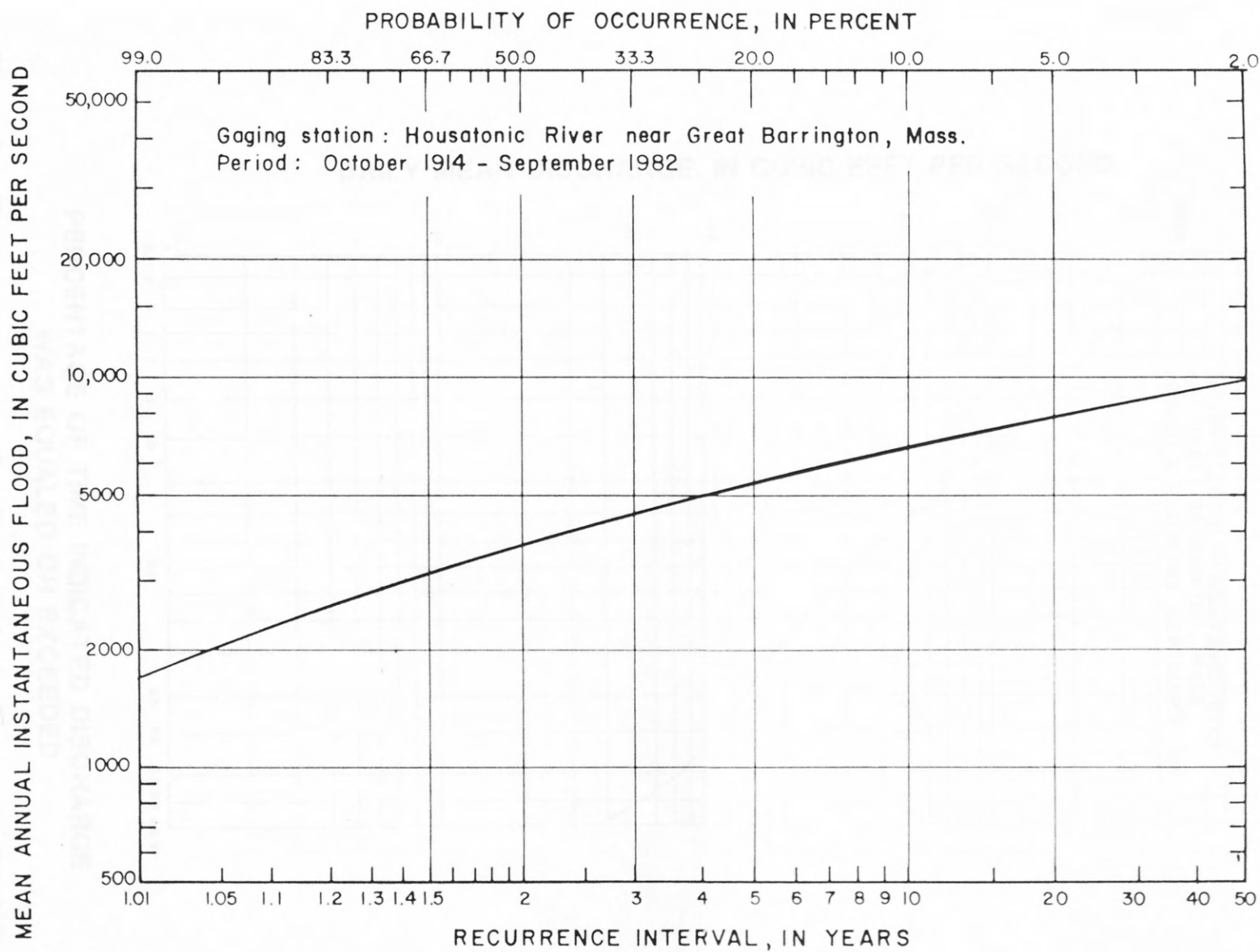
Figure 7.--Annual peak-streamflow frequency curve for the Housatonic River near

Great Barrington gaging station for water years 1914-82.

GAGING STATION: HOUSATONIC RIVER
near GREAT BARRINGTON, MASS.
PERIOD: OCTOBER 1913 - SEPTEMBER 1981

DAILY MEAN DISCHARGE, IN CUBIC FEET PER SECOND

PERCENTAGE OF TIME INDICATED DISCHARGE
WAS EQUALED OR EXCEEDED
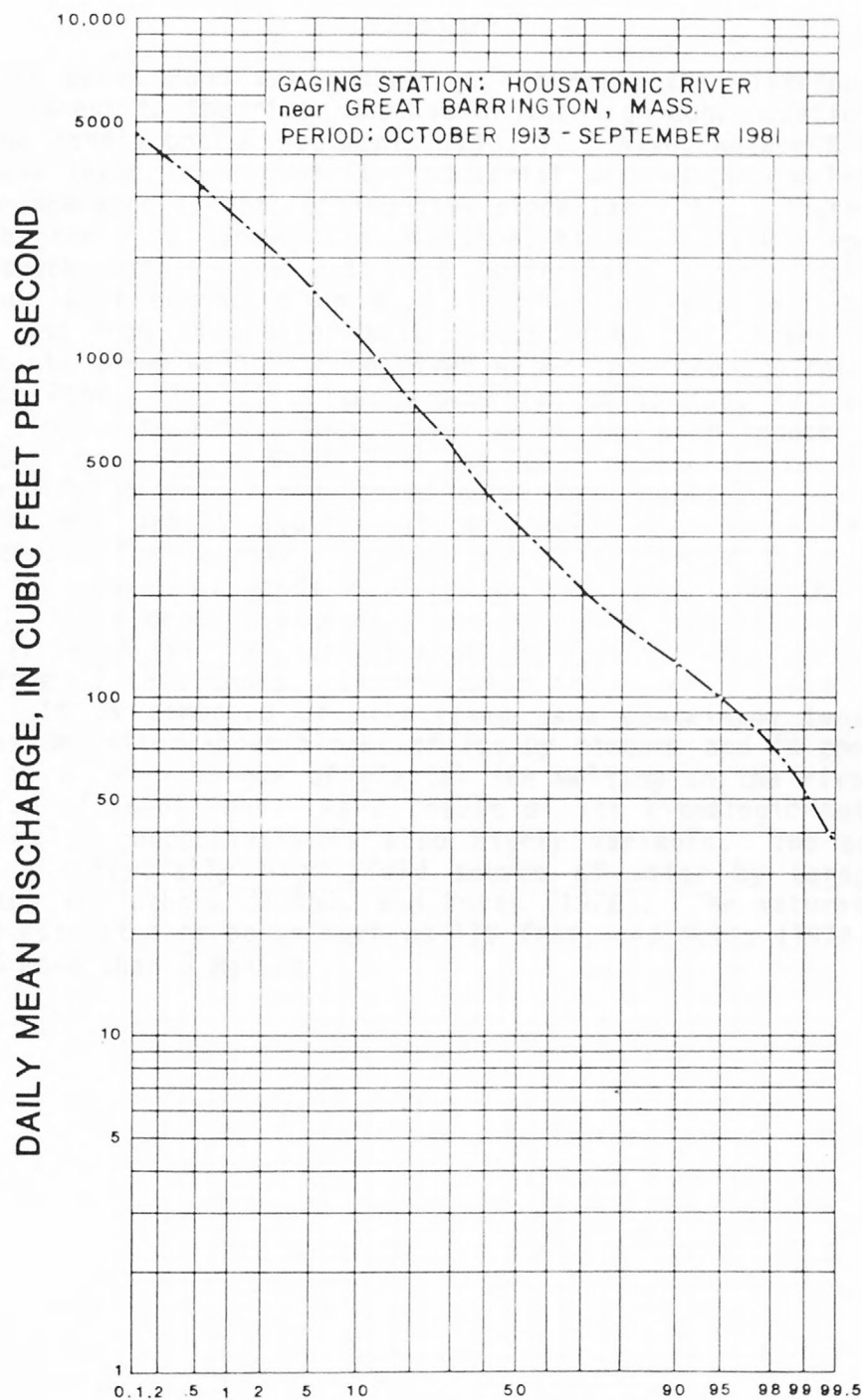
Figure 8.--Flow-duration curve for the Housatonic River near Great Barrington

gaging station for water years 1914-81.

Description

A site at Woods Pond was chosen to determine the distribution of PCBs in ground water adjacent to the river because of the high concentration levels of PCBs measured in the pond's bottom sediments (fig. 9). Also, adjacent to the pond is a well field where three large capacity industrial water-supply wells, pumping about 2 Mgal/d, have operated almost continuously since late 1965. These wells are owned and operated by the P. J. Schweitzer Division, Kimberly-Clark Corporation, located in Lee, Massachusetts. Analysis of water-level data collected from a well-performance test conducted on No. 3 production well in 1965 (Geraghty and Miller, 1965) and from an aquifer test conducted by the Survey in December 1981 indicates that all three wells induce river water into the aquifer along the south shore of Woods Pond. The first two production wells (No. 1/4 and 2) have been pumping water since late 1956. Thus, river water has been induced to flow through PCB-laden bottom sediments in Woods Pond and into the aquifer for about 25 years at the time the aquifer materials and ground water were sampled.

The sand and gravel aquifer at the well site is a kame terrace, an ice-contact deposit that constricts the Housatonic River's flood plain from 2000 feet wide in the center of Woods Pond to 200 feet wide near the outlet of Woods Pond (fig. 10). This deposit extends from about 110 feet below to as much as 110 feet above river level (fig. 10) and is about 0.54 mi^2 in areal extent.

The surface of this deposit is irregular and marked by several terraces and kettle holes. It is composed of stratified sand containing lenses of silt and gravel. It was deposited about blocks of ice by streams and in ponds of meltwater to the south of a large tongue of glacial ice melting in the river valley at the present location of Woods Pond. As a result of its lithologic heterogeneity, the aquifer's hydraulic conductivity is also highly variable. The aquifer has been identified as a potentially high yield source of water by Geraghty and Miller (1965), Norvitch and others (1968), and Motts (1972). The saturated thickness of the deposit is estimated to be as much as 110 feet, and Motts (1972) estimated that it could yield more than 5 Mgal/d.
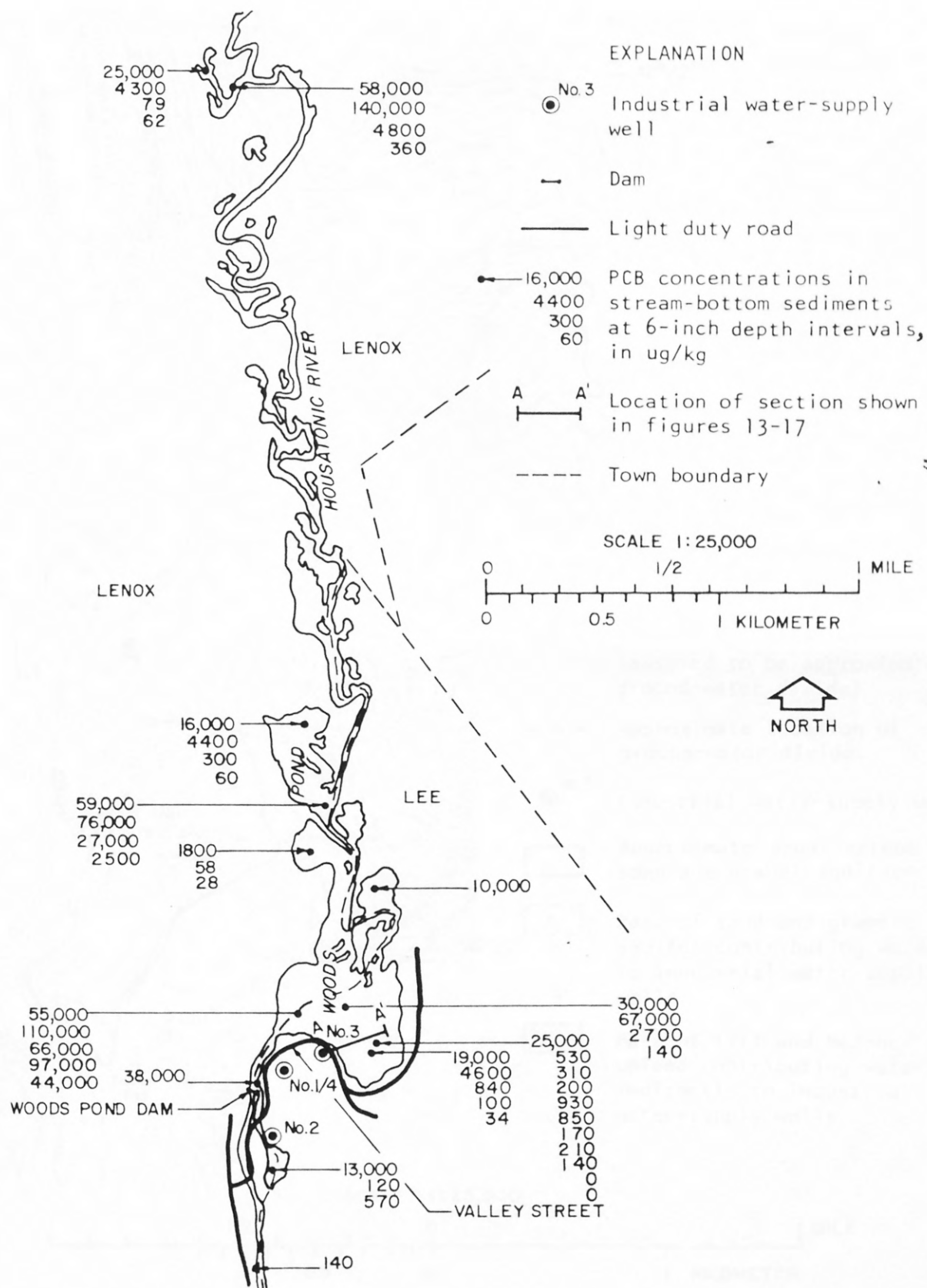
Figure 9.--Concentration of PCBs sorbed to bottom sediments in Woods Pond and

immediately upstream and downstream.

EXPLANATION

—··— Surface-drainage boundary
(assumed to be approximate
ground-water divide)

— — — Approximate location of
ground-water divide.

⊙No.3 Industrial water-supply well

☐ Approximate areal extent of
sand and gravel aquifer

A Part of sand and gravel
aquifer contributing water
to industrial water-supply
wells

▒ Part of till and bedrock
upland contributing water
indirectly to industrial
water-supply wells

SCALE 1:25,000

1/2   0   1 MILE

1   0.5   0   1 KILOMETER

Figure 10.--Locations of industrial water-supply wells and areal extent

of the aquifer.

The quantities of water derived from different sources of water to wells pumping from part of this aquifer can be estimated from a water-balance analysis. Sources of inflow to the sand and gravel aquifer are (1) direct recharge from precipitation onto the kame terrace; (2) recharge of overland runoff from the adjacent till and bedrock upland area onto the kame terrace; (3) leakage of ground water from the till and bedrock into the kame terrrace; and (4) induced infiltration from Woods Pond and Housatonic River into the kame terrace. An inflow of 2 Mgal/d is needed from all these sources to balance the 2 Mgal/d withdrawal by the three industrial water-supply wells. Ground-water recharge through sandy soils receiving similar amounts of precipitation is estimated to be about 1 $[(Mgal/d)/mi^2]$ (Guswa and LeBlanc, 1981; Cohen and others, 1968). The area of the sand and gravel aquifer that contributes water to the wells is about 0.20 mi^2. This area of the aquifer (fig. 10) is bounded on the east by till and bedrock, on the north by Woods Pond, on the west by the Housatonic River and on the so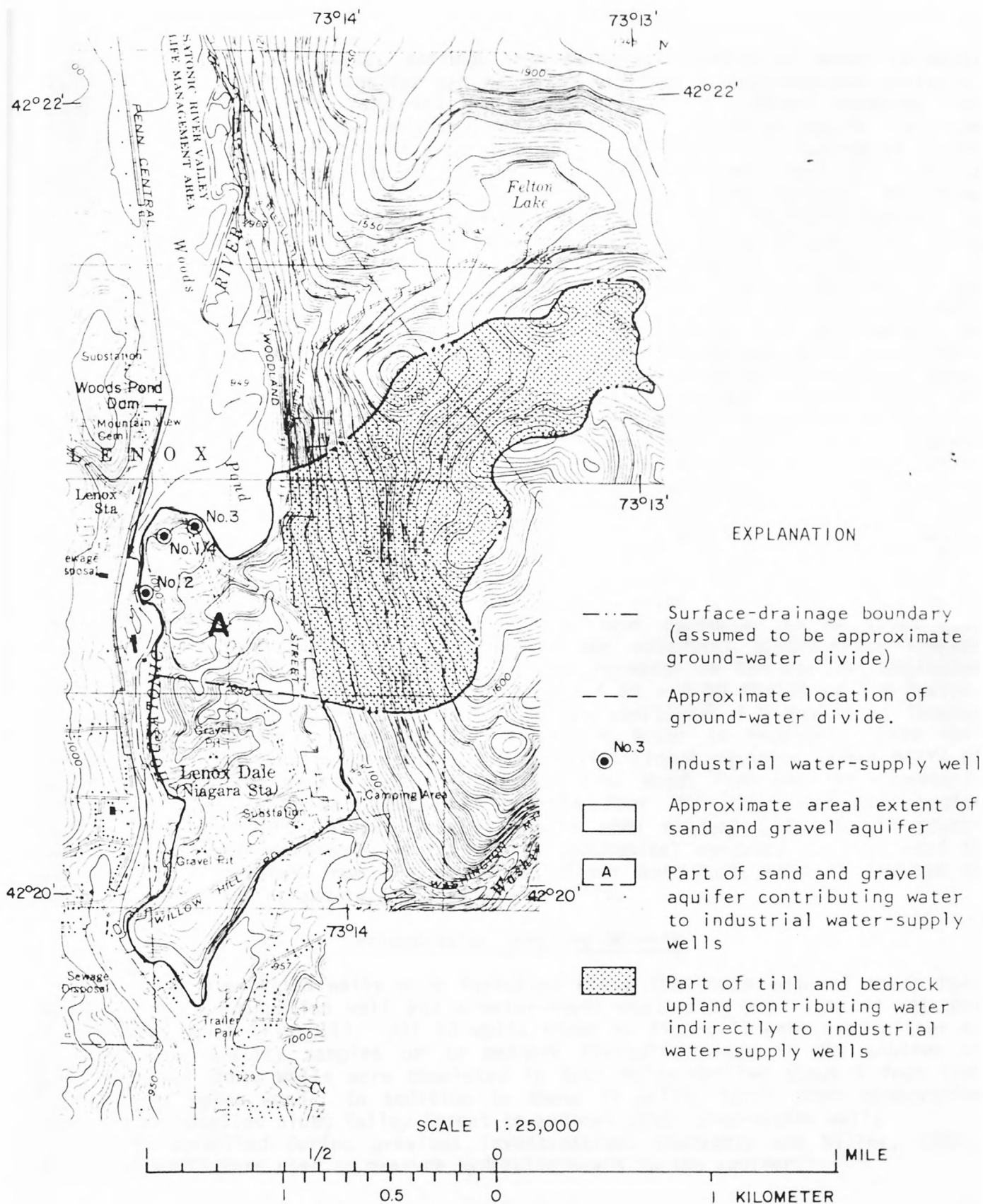uth by a ground-water divide whose approximate location was determined on the basis of water levels in observation wells from two aquifer tests conducted in March/April and August 1979. This aquifer test data are in the files of the Massachusetts Division of Water Resources. Because the land surface area of this sand and gravel aquifer (kame terrrace) is about 0.20 mi^2, the recharge to it directly from precipitation is estimated to be about 0.20 Mgal/d. The potential contributing drainage area of till and bedrock upland east of the aquifer is about 0.64 mi^2. Because the mean annual runoff from similar terraces in the Berkshire Highlands (Sykes Brook gaging station at Knightville, Mass., in the Westfield River basin) is 0.96 $[(Mgal/d)/mi^2]$, the runoff from this contributing upland area is estimated to be about 0.60 Mgal/d. The mean annual ground-water leakage from till and bedrock to sand and gravel aquifers in New England has been estimated to be about 0.30 $[(Mgal/d)/mi^2]$ (Morrissey, 1983). Therefore, the potential ground-water leakage to the aquifer is about 0.20 Mgal/d. The total recharge to the aquifer, exclusive of induced recharge, is therefore about 0.20 + 0.60 + 0.20 Mgal/d or 1.0 Mgal/d. To balance the withdrawal rate of 2 Mgal/d, an additional 1.0 Mgal/d as induced infiltration from Woods Pond and the Housatonic River is required. From this water-balance analysis, it is estimated that a significant quantity (about half) of the water withdrawn by the wells is derived from Woods Pond and the Housatonic River. If PCBs could be induced to migrate from the river and pond bottom sediments, this field laboratory site should show evidence of PCBs in ground water. In a later section of this report, geochemical evidence is also used to demonstrate that water from the Housatonic River and Woods Pond is induced to infiltrate the aquifer and is produced by the wells.

Ground-Water Sampling Network

Eleven observation wells were installed along the south edge of Woods Pond opposite No. 3 production well and a water-level monitoring well located adjacent to the pump house (fig. 11). All 13 wells shown in figure 11 were used either to collect water-quality samples or to measure hydraulic heads in the aquifer or both. Ten of these wells were completed in test holes drilled about 5 feet from the edge of Woods Pond. In addition to these 11 wells, three other observation wells were installed along Valley Street to augment other observation wells (fig. 12) installed during previous investigations (Geraghty and Miller, 1965). All these wells were used to measure hydraulic heads in the aquifer.
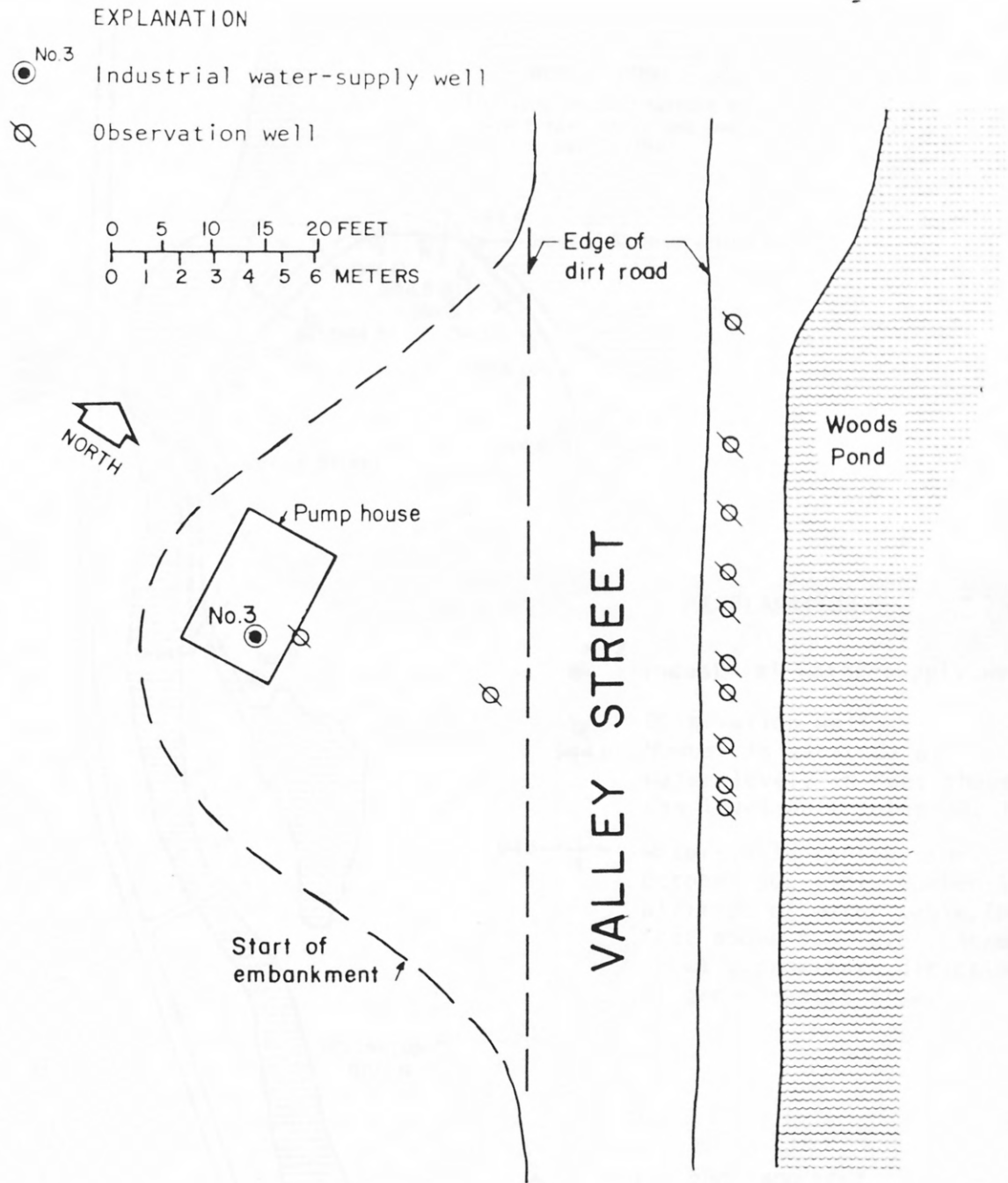
Figure 11.--Location of the observation-well network used to sample for PCBs in the aquifer adjacent to Woods Pond.

WOODS POND
(Altitude of pond surface was
948.5 feet above sea level
on October 30, 1981

944.4
Group of 10 observation wells

945.0
944.8 ⊙
No. 3
944.5
No. 1
4
940.2
944.6
945
944.8
945

Woods
Pond
Dam

Valley Street

Dam
No. 2

HOUSATONIC
RIVER

EXPLANATION

No. 2
⊙ Industrial water-supply well

⊘
944.8
Observation well.
Number is altitude of
water level, in feet above
sea level on October 30, 1981

945 ——↓
Water-table contour for
October 30, 1981. Number is
altitude of water table, in
feet above sea level. Arrow
shows approximate direction
of ground-water flow.

0   200   400 FEET
|————|————|

⬆
NORTH
0   60   120 METERS
|————|————|

Figure 12.--Location of wells, altitude of water table, and direction of

ground-water flow in the peninsula adjacent to Woods Pond.

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Several precautions were taken during well installation to prevent PCB contamination of the aquifer. Individual wells were placed in separate test holes augered to just above the depths where the well screens were to be placed. Prior to placement of the well screens at selected depths in the aquifer, a split-spoon sample of aquifer material was collected for PCB analysis. The 10 observation wells that are parallel to the shore of Woods Pond were screened at different depth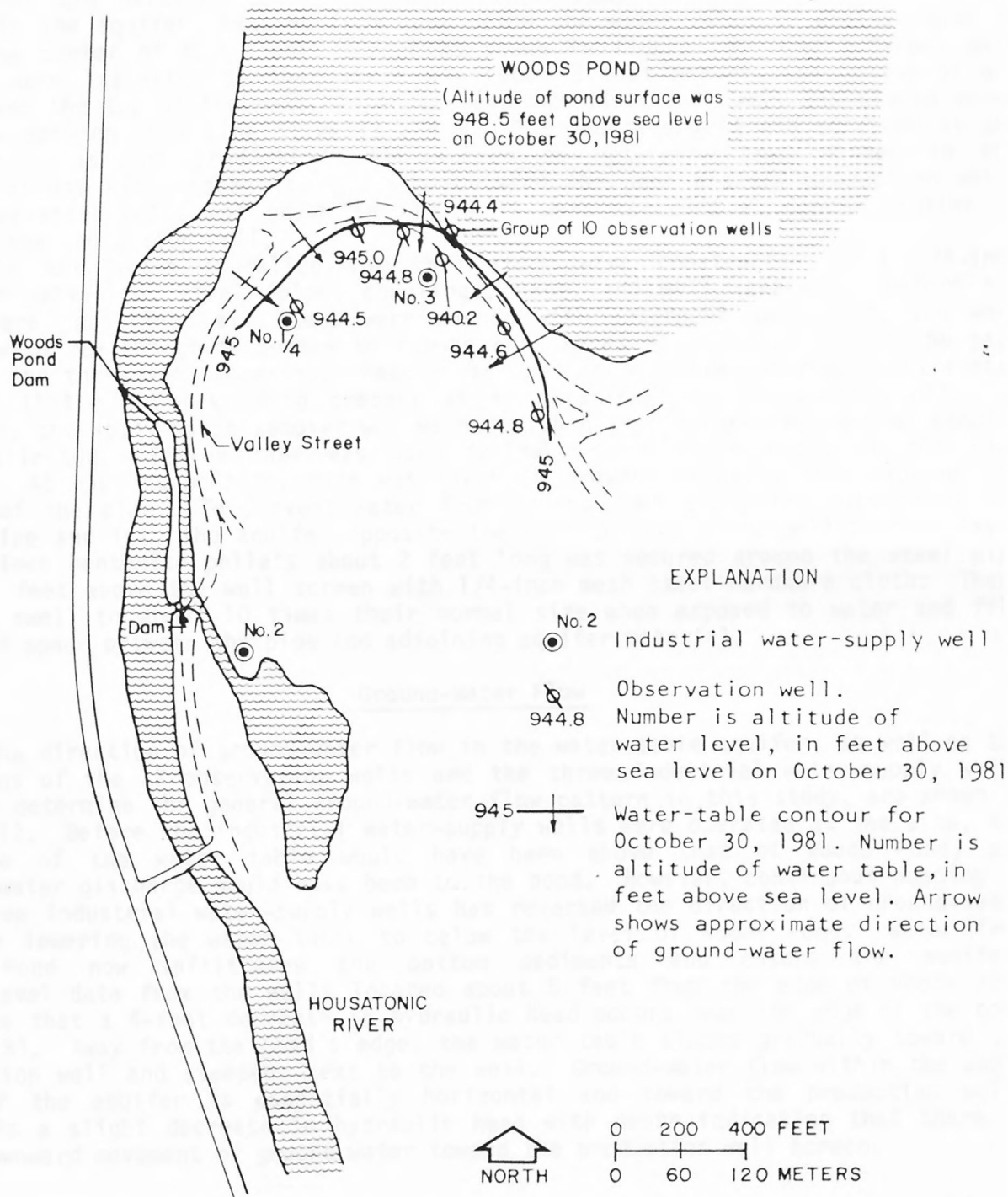s in the aquifer, ranging from just below the water table to depths equal to about the center of No. 3 well screen as shown in figure 13. The 2.5-foot well screens were installed so that there was about 3 feet between the bottom of one screen and the top of the next deeper screen. An additional well was placed about half-way between this line of wells and No. 3 production well and screened at the same depth as the production well screen to determine any changes in PCB concentrations with respect to distance between the pond and the production well. The observation wells not shown in figure 13 were screened at depths similar to that of the production well.

All the wells installed for this study were constructed of 1 1/4-inch diameter galvanized steel (pipe, couplings, caps, and well screens). Before the wells were installed, all items were washed with detergent and water, and were rinsed with reagent-grade hexane to remove any traces of oil used during the pipe cutting and threading processes. Hexane was used to dissolve and remove any traces of PCBs that might have been present as a contaminant in the cutting oil. In addition, the split-spoon sampler was washed with hexane before the aquifer samples were collected. Teflon tape was used to make water-tight seals at the pipe joints. At each connection, care was taken to prevent exposing this tape on the inside of the pipe. To prevent water from moving down along the outside of the steel pipe and into the aquifer opposite the well screen, a one pellet thick layer of 1/2-inch bentonite pellets about 2 feet long was secured around the steel pipe about 2 feet above the well screen with 1/4-inch mesh steel hardware cloth. These pellets swell to about 10 times their normal size when exposed to water and fill any void space between the pipe and adjoining aquifer material.

Ground-Water Flow

The direction of ground-water flow in the water-table aquifer, as well as the locations of the 17 observation wells and the three industrial water-supply wells used to determine the general ground-water flow pattern in this study, are shown in figure 12. Before the industrial water-supply wells were operated at the site, the altitude of the water table would have been above that of Woods Pond, and ground-water discharge would have been to the pond. However, continuous pumping of all three industrial water-supply wells has reversed the direction of ground-water flow by lowering the water table to below the level of Woods Pond. Water from Woods Pond now infiltrates the bottom sediments and enters the aquifer. Water-level data from the wells located about 5 feet from the edge of Woods Pond indicate that a 4-foot decrease in hydraulic head occurs near the edge of the pond (fig. 13). Away from the pond's edge, the water table slopes gradually toward the production well and steepens next to the well. Ground-water flow within the upper part of the aquifer is essentially horizontal and toward the production well. There is a slight decrease in hydraulic head with depth indicating that there is some downward movement of ground water toward the production well screen.
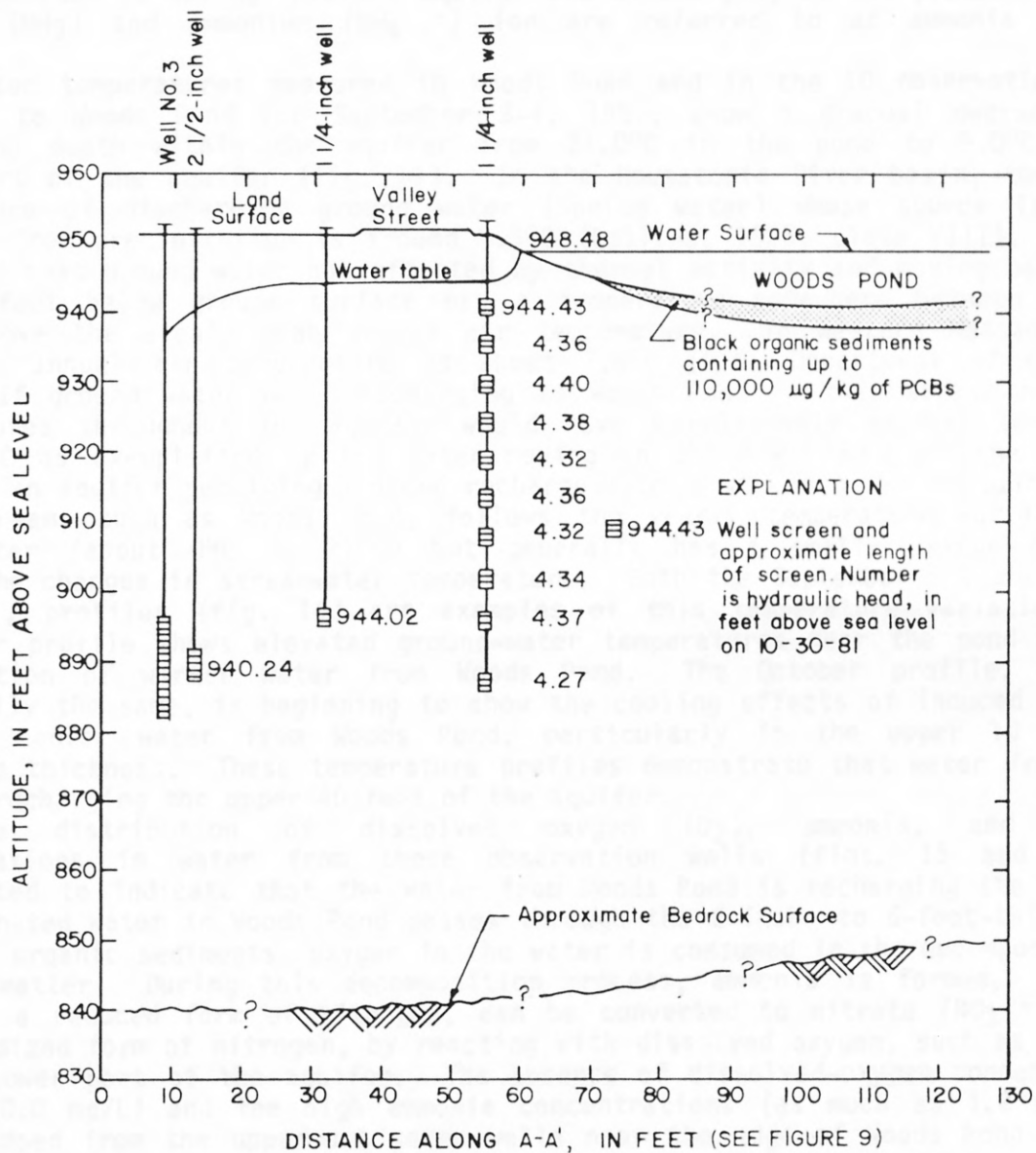
Well No. 3
2 1/2-inch well
1 1/4-inch well
1 1/4-inch well

960

ALTITUDE, IN FEET ABOVE SEA LEVEL

Land
Surface

Valley
Street

950

948.48   Water Surface

Water table   WOODS POND

940   ☱ 944.43

?
?

Black organic sediments
containing up to
110,000 μg/kg of PCBs

4.36

930   4.40

4.38

920   4.32

4.36   EXPLANATION

910   4.32   ☱ 944.43 Well screen and
approximate length
of screen. Number
is hydraulic head, in
feet above sea level
on 10-30-81

4.34

900   ☱ 944.02   4.37

4.27

890   ☱ 940.24

880

870

860

850   ?

Approximate Bedrock Surface

840   ?   ?   ?

830

0   10   20   30   40   50   60   70   80   90   100   110   120   130

DISTANCE ALONG A-A', IN FEET (SEE FIGURE 9)

Figure 13.--Location of well screens and distribution of hydraulic heads in the
aquifer adjacent to Woods Pond.

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Physical and chemical data, including variations in water temperature, and concentrations of dissolved oxygen, ammonia, iron, and manganese show that water from Woods Pond is moving into the aquifer and discharging at the production well. Ammonia (NH_3) and ammonium (NH_4^-) ion are referred to as ammonia in this report.

Water temperatures measured in Woods Pond and in the 10 observation wells adjacent to Woods Pond for September 3-4, 1981, show a gradual decrease with increasing depth within the aquifer from 21.0°C in the pond to 9.0°C in the lower part of the aquifer (fig. 14). In the Housatonic River basin, the normal temperature of discharging ground water (spring water) whose source is direct recharge from precipitation is around 9.5°C (Collins, 1925, plate VIII). Collins concluded that ground water not affected by thermal activity and moving between 30 and 60 feet below ground surface has a temperature somewhere between 1.1 and 1.7°C above the area's mean annual air temperature. In western Massachusetts, the mean annual air temperature is about 7.8°C (U.S. Department of Commerce, 1969). If ground water were discharging to Woods Pond in this area, then water temperatures throughout the aquifer would have a relatively uniform temperature about 9°C as exemplified by the water moving in the lower part of the aquifer. Water in an aquifer receiving induced recharge from a stream or an impounded reach of a stream, such as Woods Pond, follows the yearly temperature variations of streamwater (about 0°C to 21°C) but generally has a smaller range and lags behind the changes in streamwater temperature. Both the September 3-4 and October 27, 1981, profiles (fig. 14) are examples of this temperature variation. The September profile shows elevated ground-water temperatures near the pond owing to infiltration of warmer water from Woods Pond. The October profile, although essentially the same, is beginning to show the cooling effects of induced recharge of much cooler water from Woods Pond, particularly in the upper 10 feet of saturated thickness. These temperature profiles demonstrate that water from Woods Pond is recharging the upper 40 feet of the aquifer.

The distribution of dissolved oxygen (O_2), ammonia, and nitrate concentrations in water from these observation wells (figs. 15 and 16) is interpreted to indicate that the water from Woods Pond is recharging the aquifer. As oxygenated water in Woods Pond passes through the 6-inch- to 6-foot-thick layer of black organic sediments, oxygen in the water is consumed in the decomposition of organic matter. During this decomposition process, ammonia is formed. However, ammonia, a reduced form of nitrogen, can be converted to nitrate (NO_3^-) ion, a more oxidized form of nitrogen, by reacting with dissolved oxygen, such as is found in the lower part of the aquifer. The absence of dissolved-oxygen concentrations (mostly 0.0 mg/L) and the high ammonia concentrations (as much as 1.2 mg/L) in water pumped from the uppermost seven wells near the edge of Woods Pond indicate that this upper zone of the aquifer contains water which is being recharged through the bottom of Woods Pond. In Massachusetts, water in water-table aquifers normally contains dissolved oxygen, some nitrate, and very little, if any, ammonia. For example, ground water recharged from precipitation through sandy soil on Cape Cod, Massachusetts, has median values of 7.0 mg/L of dissolved oxygen, 0.01 mg/L of ammonia as nitrogen, and 0.12 mg/L of nitrate as nitrogen (Frimpter and Gay, 1979).
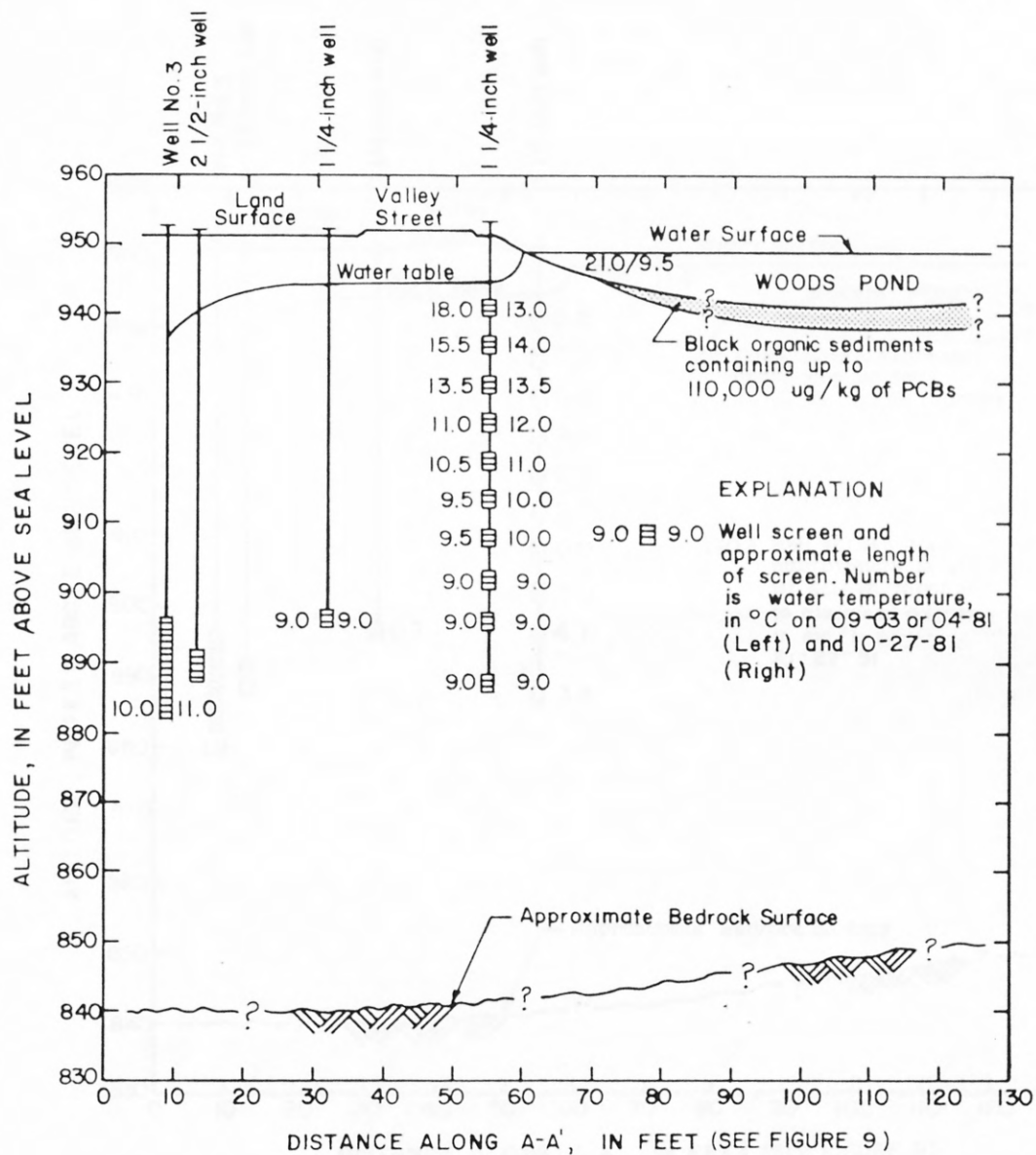
Figure 14.--Distribution of water temperature in Woods Pond and adjacent aquifer.
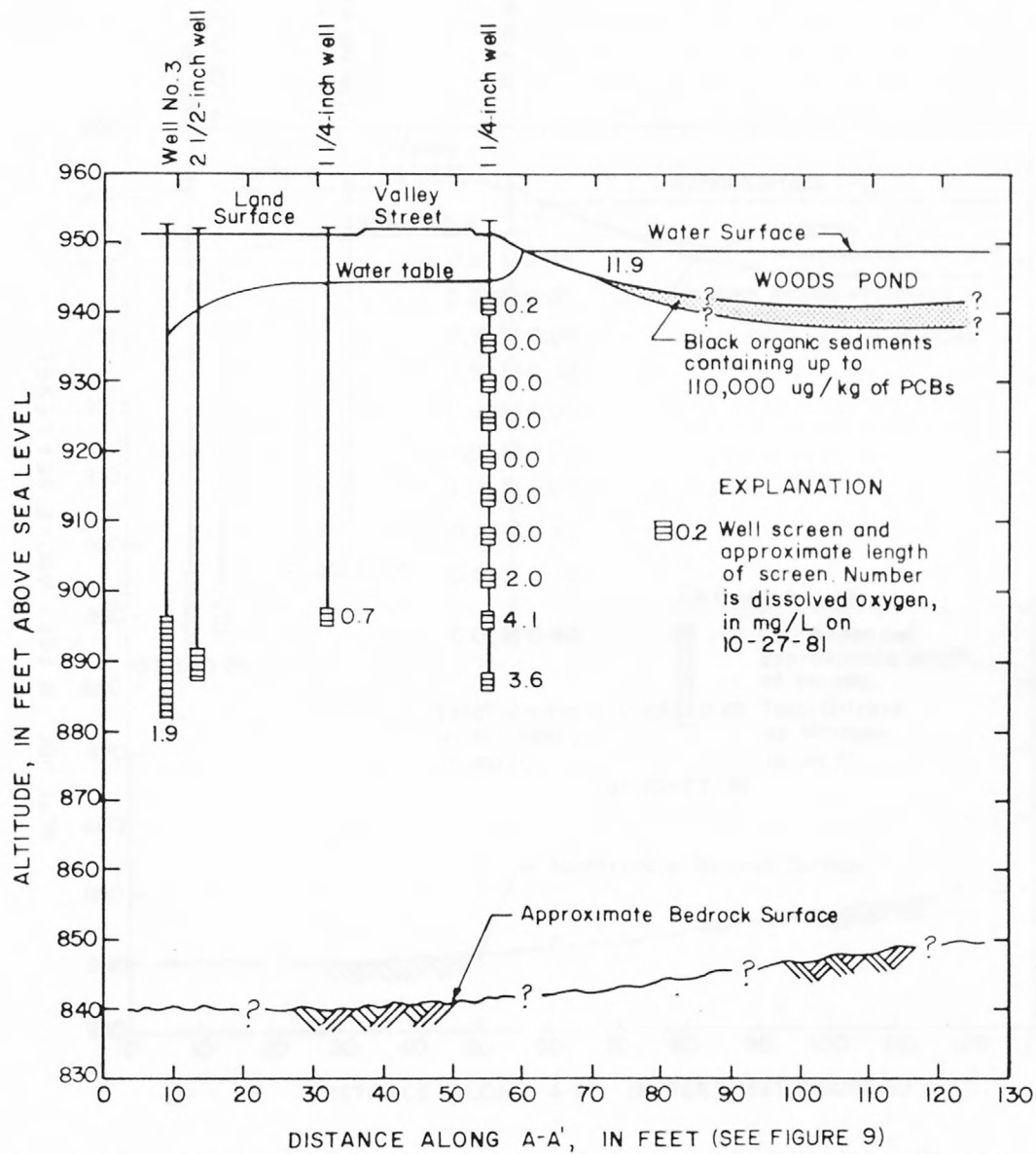
Figure 15.--Distribution of dissolved oxygen in Woods Pond and adjacent aquifer.
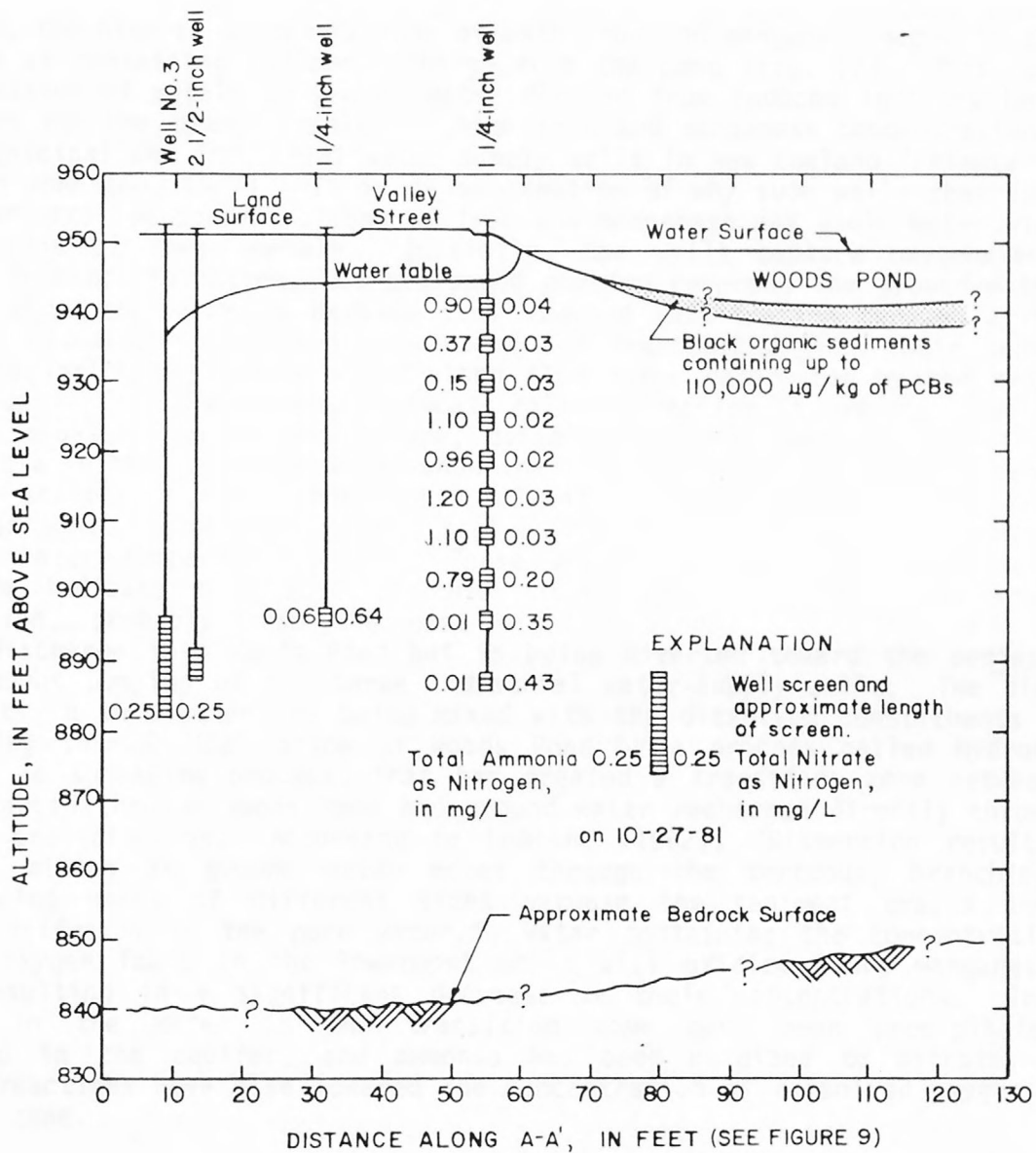
Figure 16.--Distribution of total ammonia and nitrate ions in the aquifer adjacent to Woods Pond.

It is inferred from the absence of dissolved oxygen and the elevated concentrations of ammonia found in the water infiltrated through the pond's bottom sediments that this water has a low oxidation potential. Water with a low oxidation potential is capable of dissolving metals (particularly iron and manganese) during its passage through an aquifer (Frimpter and Gay, 1979). At Woods Pond, the highest concentrations of both iron and manganese occur in the zone identified as containing induced recharge from the pond (fig. 17). This condition of mobilization of metals by ground water derived from induced infiltration is an explanation for the common problem of high iron and manganese concentrations found in some municipal and industrial water-supply wells in New England (Frimpter, 1973; Silvey and Johnston, 1977). It is an explanation of why such wells that initially yield water with low concentrations of iron and manganese may yield water with high concentrations of these metals. Initially, the wells capture oxygenated water recharged from precipitation, but prolonged pumping reverses the ground-water flow direction and some water is derived from induced infiltration through a reducing zone. The dissolved constituents in water are transported from their sources by the flowing (velocity) ground water along flow paths determined by the hydraulics of the ground-water-flow system, a process called advection (a movement process).

The values of water temperature, dissolved oxygen, ammonia, nitrate, iron, and manganese in the top seven wells show that the source of the water flowing past these well screens is from Woods Pond. Only in the lower levels of the aquifer is there water with higher values of dissolved oxygen (2.0 to 4.1 mg/L) and lower values of water temperature ($9^{\circ}C$). These values of dissolved oxygen and water temperature indicate that some of this ground water is direct recharge from precipitation, probably from the east side of Woods Pond. This water would normally discharge into Woods Pond but is being diverted toward the peninsula by the continuous pumping of the three industrial water-supply wells. The dissolved constituents in this water are being mixed with the dissolved constituents in the water moving through the bottom of Woods Pond by a process called hydrodynamic dispersion (a spreading process) that has created a transition zone between pond water recharged through Woods Pond and ground water recharged directly through the soil from precipitation. According to LeBlanc (1982), "Dispersion results from mechanical mixing as ground water moves through the tortuous, branching, and interfingering pores of different sizes between the sediment grains and from molecular diffusion in the pore water." Water containing the concentrations of dissolved oxygen found in the lowermost wells will oxidize iron, manganese, and ammonia resulting in a significant decrease in their concentrations. Iron and manganese in the water in the transition zone have been precipitated and redeposited in the aquifer, and ammonia has been oxidized to nitrate. These oxidation reactions have also lowered the concentration of dissolved oxygen in the transition zone.
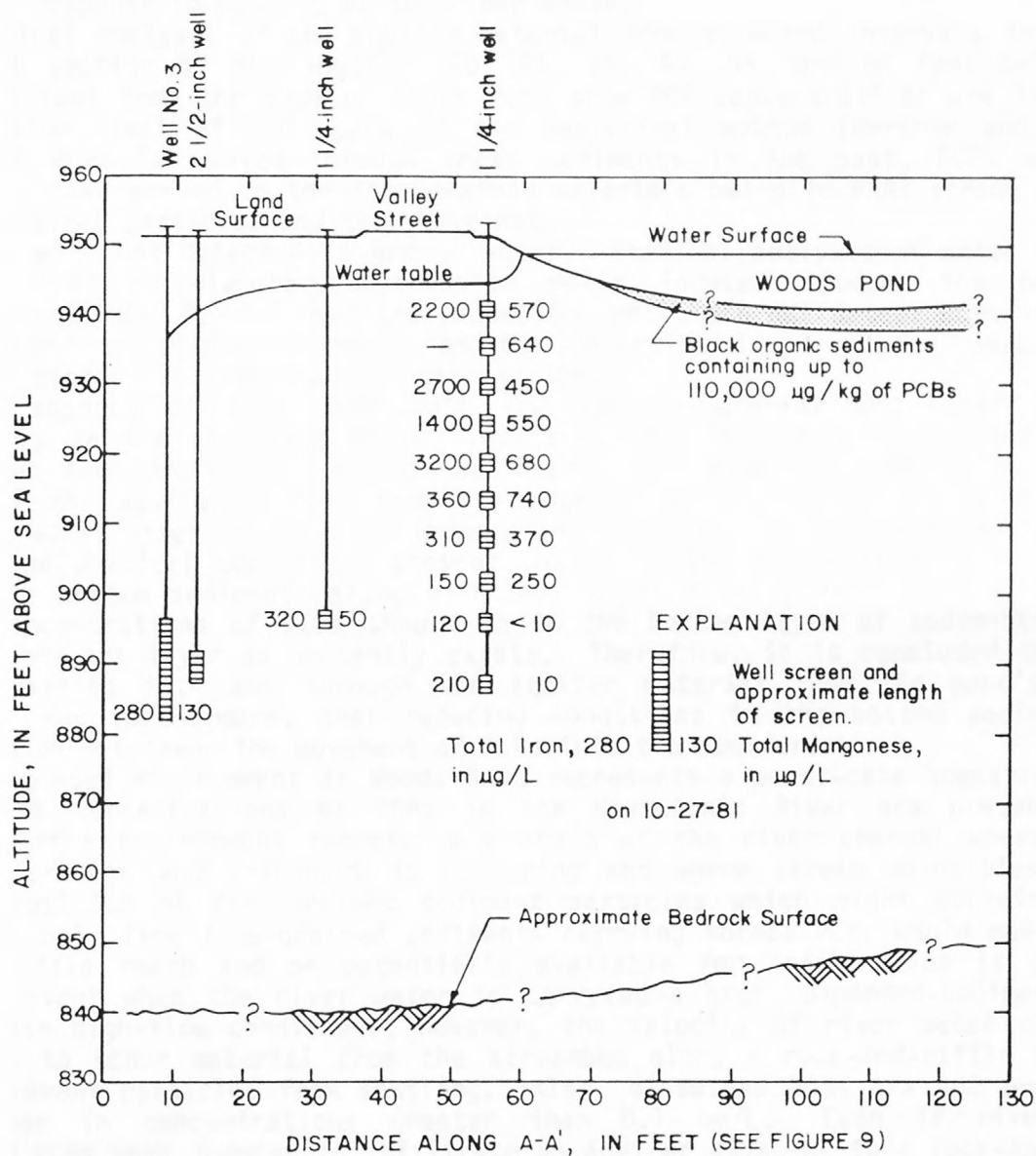
Figure 17.--Distribution of total iron and manganese in the aquifer

adjacent to Woods Pond.

The hydraulic heads in the aquifer adjacent to the pond, together with the water-temperature gradients, dissolved-oxygen concentration, and other water chemistry of the pond and the aquifer indicate that pond water recharges the aquifer in response to pumping as described above.

Chemical analyses of the aquifer material from selected intervals throughout a vertical section of the aquifer (10, 21, 32, 44, 55, and 64 feet below land surface) 5 feet from the edge of Woods Pond show PCB concentrations are less than the detection limit of 1.0 ug/kg of the analytical method (Wershaw and others, 1983). If PCBs had moved through these sediments in the past, PCBs would be expected to have sorbed to the fine-grained materials owing to PCBs strong affinity for fine-grained particles and they have not.

PCBs were not detected in ground water. Chemical analyses of water from the eleven 1 1/4-inch diameter observation wells located between the pond and production well No. 3, and from the production well, did not detect PCBs in either the dissolved or suspended phase, at the detection limit of 0.1 ug/L of the analytical method used (Wershaw and others, 1983).

The absence of PCBs from both the aquifer-material and water samples, particularly in the dissolved phase, indicates that PCBs have not passed through the aquifer from the pond's bottom sediments, and have not reached a vertical section of the aquifer 5 feet from the edge of Woods Pond or the more distant production wells after 25 years of induced infiltration. If PCBs were mobilized by chemical and physical conditions present in the bottom sediments and moved deeper through the bottom sediments along with pond water flowing into the aquifer, the highest concentrations of PCBs should be in the bottom layer of sediments rather than near the top layer as presently exists. Therefore, it is concluded that PCBs are not passing into and through the aquifer material from the pond's bottom sediments, and furthermore, that reducing conditions in the bottom sediments of Woods Pond do not favor the movement of PCBs into the aquifer.

The ponded environment at Woods Pond represents a worst-case scenario, where the highest concentrations of PCBs in the Housatonic River are present. The rock-and-riffle environment represents a reach of the river channel where active streambed erosion and transport is occurring and where stream velocities do not permit deposition of fine-grained sediment particles which might contain sorbed PCBs. The only time fine-grained sediments carrying sorbed PCBs would move over a rock-and-riffle reach and be potentially available for infiltration is during a high-flow event when the river water is carrying a high suspended-sediment load. During these high-flow conditions, however, the velocity of river water should be sufficient to scour material from the streambed along a rock-and-riffle reach as well as prevent particles from settling. Also, dissolved PCBs are not present in river water in concentrations greater than 0.1 ug/L. Even if river water containing PCBs were induced to infiltrate an aquifer adjacent to a rock-and-riffle reach, they would be sorbed to the sediment at the water/sediment interface and removed from the recharge water.

SUMMARY AND CONCLUSIONS

PCBs have accumulated in the river sediments along the entire length of the Housatonic River in Massachusetts. However, the highest concentration of PCBs, up to 140,000 ug/kg, were found in the bottom sediments of the Housatonic River between Pittsfield and Woods Pond Dam in Lee, Massachusetts. The most significant quantities occur in ponded reaches of the river where fine sediment can accumulate. The largest quantity (11,000 pounds) of PCBs, or about 50 percent of all the PCBs in the entire river system, are stored in the bottom materials of Woods Pond. These PCB-laden bottom sediments in Woods Pond are gradually being buried by new, less contaminated sediments. This encapsulating process should limit the amount of PCBs readily available for transport downstream in the future, although dam failure or flooding may resuspend and make them available for transport. However, at present, about 490 pounds per year of PCBs move downstream past the gaging station at Great Barrington. Furthermore, it seems that dissolved PCBs move downstream in the water, but in concentrations at or below the detection limit of 0.1 ug/L for the analytical method used.

PCBs that are sorbed to the bottom sediments (up to 110,000 ug/kg) of Woods Pond have not moved into the aquifer adjacent to the pond under the conditions of induced infiltration that have existed at that site since late 1956. Hydraulic-head gradients between the pond and the aquifer along with water-temperature gradients and oxidation/reduction conditions indicate that pond water moves into the underlying aquifer by induced infiltration caused by pumping wells. At one location along the shore of Woods Pond, the upper 40 feet of aquifer contain water recharged through the pond's bottom sediments. At this site, analysis of aquifer materials and ground water from auger holes and wells drilled between the pond and a production well and screened at various intervals throughout a vertical section of the aquifer 5 feet from the edge of Woods Pond show no PCBs at the detectable levels of 1.0 ug/kg for aquifer material or 0.1 ug/L for water. These data show that PCBs have not moved from the river-bottom sediments containing high PCB concentrations into the underlying aquifer under induced infiltration conditions, and can be used to conclude that because of their strong sorbtion to sediments, PCBs would not be expected to move into an aquifer adjacent to any reach along the river.

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