SUMMARY OF HUDSON RIVER PCB STUDY RESULTS

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I. Background

A. The Study Program

On September 8, 1976, the New York State Department of Environmental Conservation (DEC) and the General Electric Company (GE) signed an agreement bringing to a close the action brought against General Electric relating to discharges of polychlorinated biphenyls (PCBs) into the Hudson River. As a result of this settlement, DEC instituted a series of major studies of the river system related to PCBs and potential actions for managing the problem of extensive in-place sediment contamination.

A history of the problem, the settlement and a description of the study plan has been presented previously[1]. Preliminary results of the studies were presented in Albany on January 18, 19 and 20, 1978. The purpose of this report is to summarize these results along with other information related to the problem of PCBs and the Hudson River.

B. The Hudson River Basin

The Hudson River Basin can be divided into three sub-basins: the Upper Hudson River, the Mohawk River and the Lower Hudson River (Figure 1). The areas and water flows for these three basins are presented in Table 1. From Spier Falls to Troy, the Upper Hudson River is actually a series of low-level dams, and south of Ft. Edward serves as part of the Champlain Canal (Figures 2 and 3). The Mohawk River serves as the eastern portion of the Erie Canal and joins the Hudson River just above the Federal Dam at Troy.

The Lower Hudson Basin is tidal throughout its entire 150 miles (241 km). Average tides are 4.4 feet (1.4 m) at the Battery, 3.0 feet (1 m) at Beacon and 4.8 feet (1.5 m) at Troy. Tidal flows at Poughkeepsie have been measured as 230,000 to 280,000 cfs (6.5 to 7.9 x 10^6 l/sec). Dye studies have shown that the flow actually oscillates with the tide, with a very slow net outflow.

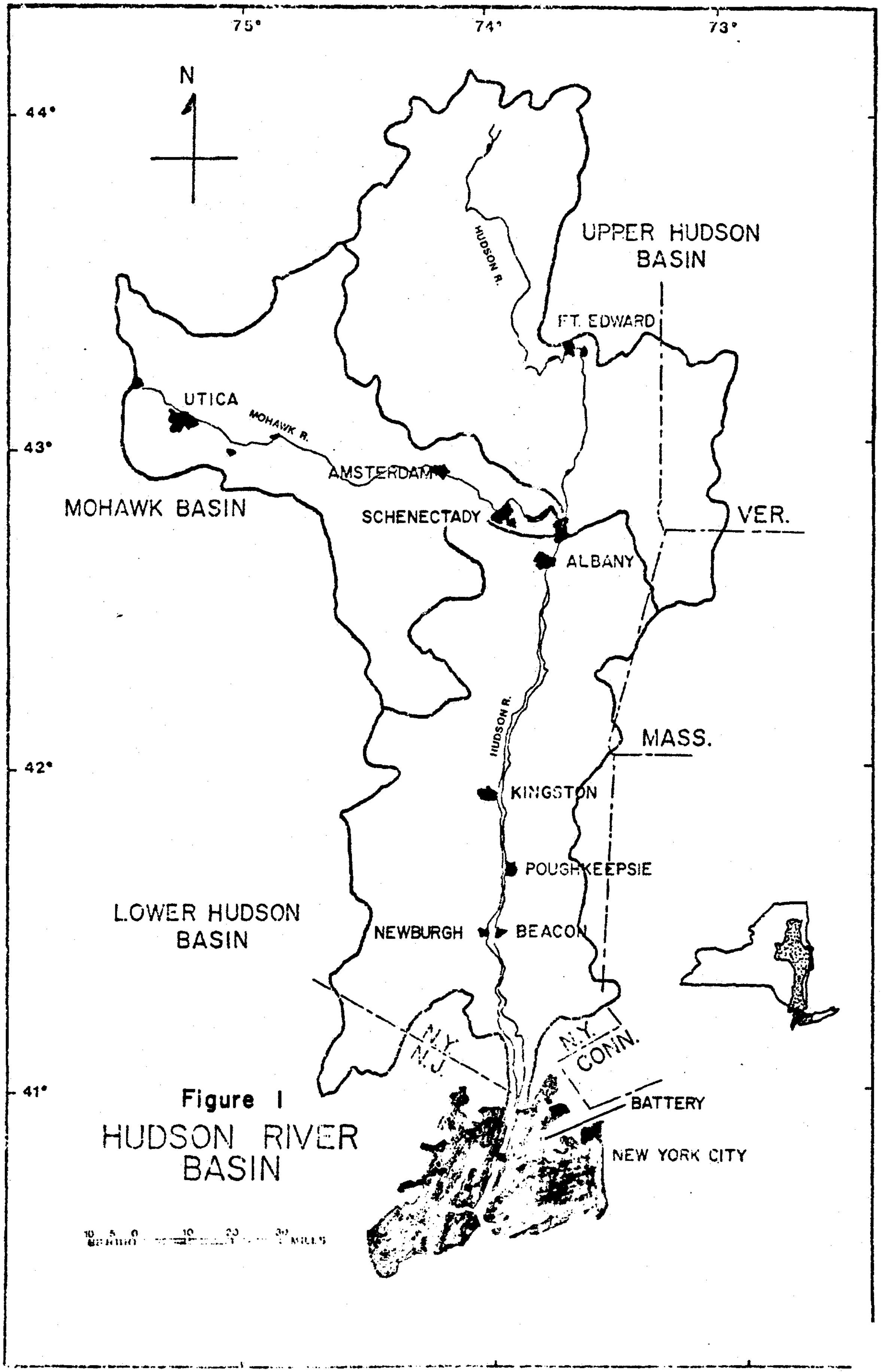


Figure I
HUDSON RIVER
BASIN

100010

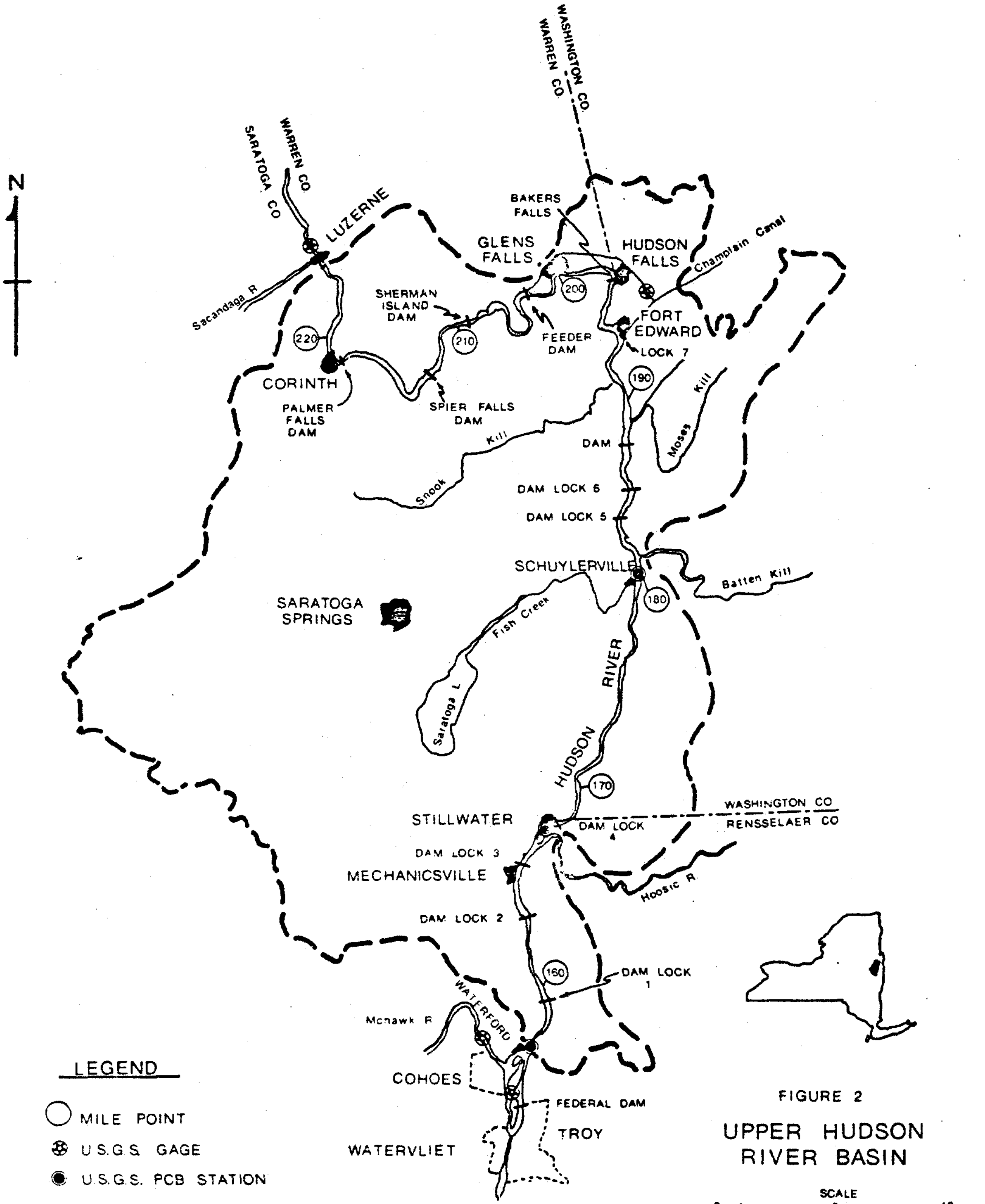
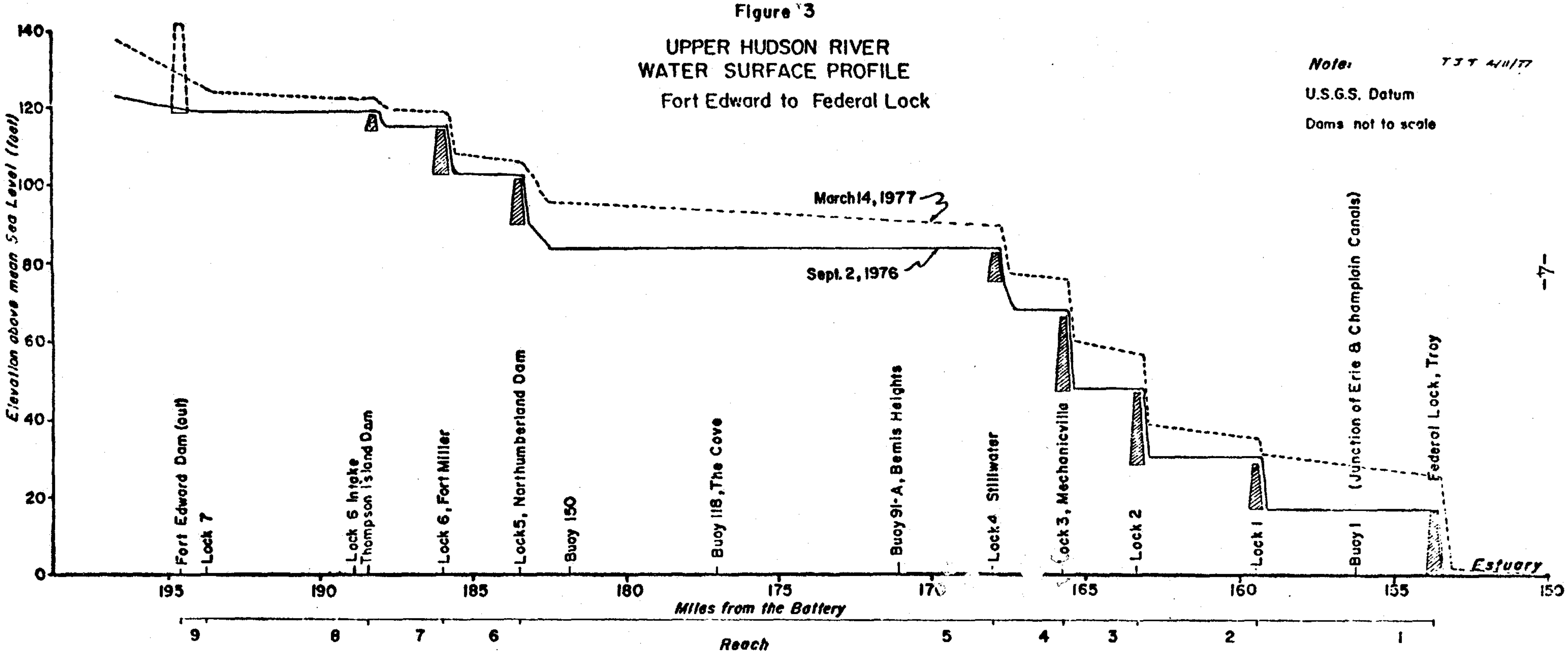


FIGURE 2

UPPER HUDSON RIVER BASIN

Figure 3

UPPER HUDSON RIVER
WATER SURFACE PROFILE
Fort Edward to Federal Lock



100012

Salt-water intrusion extends quite a distance upriver. The 50 mg/l (0.05 o/oo) salinity fluctuates from 20 mi. (32.2 km) above the Battery (near Tappan Zee Bridge) to 70 mi. (112.7 km) inland (south of Poughkeepsie) depending on the freshwater flow.

Table 1: Areas and average flow of the three sub-basins in the Hudson River Basin.

Location	Area mi^2	Area km^2	Average Flow cfs	Average Flow $l/sec \times 10^5$
Upper Hudson Basin	4,620	11,966		
Waterford			7,660	2.17
Mohawk River Basin	3,456	8,951		
Cohoes			5,630	1.59
Lower Hudson Basin	5,300	13,727		
Tributaries			7,100	2.01
Total Hudson Basin	13,376	34,644	20,390	5.77

Source: Data from U.S. Geological Survey[46].

C. Historical Perspective

Although elevated levels of PCB were first discovered in Hudson River biota late in 1969, their importance was not recognized for several years. By 1975, sampling of the river clearly implicated General Electric's capacitor manufacturing facilities at Ft. Edward and Hudson Falls as the major source of PCBs in the Upper Hudson River. On December 18, 1972, General Electric had applied to EPA for a discharge permit, stating that its two plants were discharging an average of 30 pounds per day of "chlorinated hydrocarbons" with a maximum of 47.6 pounds per day.[28] The permit became effective January 31, 1975.

PCB usage by General Electric has been both extensive and long standing. Between 1966 and 1974, these facilities purchased 78 million pounds of PCB, or roughly 9 million pounds each year.[28] These purchases represent approximately 15 percent of U.S. domestic sales during that time.

Although records do not exist for years prior to 1966, PCBs have been used at Hudson Falls and Ft. Edward for more than 25 years. General Electric began capacitor production at Ft. Edward in 1947 and at Hudson Falls in 1952. PCBs have always been the primary capacitor dielectric used.

As part of the 1976 agreement, General Electric constructed a treatment plant for all their wastewater and ceased using PCB. Although PCB discharges in the early 1970s averaged about 30 pounds (15 kg) per day ($\sim$13,000 lbs/year), by 1976 they were reduced to less than 250 grams/day (9 oz/day), and since May 1977 have been less than 1 gram/day.

Until late summer of 1973, the PCB discharged was into a river pool maintained by the Ft. Edward Dam. By October 1973 this dam was removed. The sedimentary regime of that portion of the river was changed and massive volumes of contaminated sediment that had collected behind the dam (remnant deposits) were resuspended and transported downstream.[43] In April 1976 a 100-year flood in that region of the Hudson eroded more of these remnant deposits. These deposits are still unstable and continue to erode and move downstream.

II. Summary of Current Findings

A. Data on River Sediments and Hydrology

Since 1974, more than 1,300 bed sediment samples have been taken from the Hudson River and analyzed for PCBs.[2-7] In the Upper Hudson, DEC staff collected about 200 grab and core samples from 1974-77 following the analysis of a few grab samples collected by EPA in 1973.[3,4] In 1977, approximately 900 grab and core samples were taken in the Upper Hudson by Normandeau Associates and analyzed by O'Brien and Gere Engineers.[2] Sediment cores were taken in the estuary by the EPA, Region II[5] and Lamont-Doherty Geological Laboratories during 1977.[7] Sample density was greatest in the section of the river just below Fort Edward where the PCB concentrations were found to be highest (Figure 5).

1. Upper River

a. Sediments

PCB concentrations in Upper Hudson River sediments appear to be log normally distributed (Figure 4). Given such a distribution, a log mean is the appropriate measure of central tendency because an arithmetic mean gives misleading high values. Figure 5 shows the log mean and variation of the measured PCB concentrations by river reach.

To provide additional insight into the measured concentrations, areas of high PCB concentrations (>50 ppm) were determined and the data stratified into two sets for each river reach; one of the measured values in high-concentration areas (hot spots), and one of measured values in low-concentration areas (cold areas). An analysis of data in each of these subsets indicated that PCB concentration tends to be more normally distributed than the entire data group. The areas and arithmetic means of PCB concentration of each of these subsets are given in Table 2.

100017

Figure 4

FREQUENCY DISTRIBUTION OF SEDIMENT PCB LEVELS
IN THE UPPER HUDSON RIVER

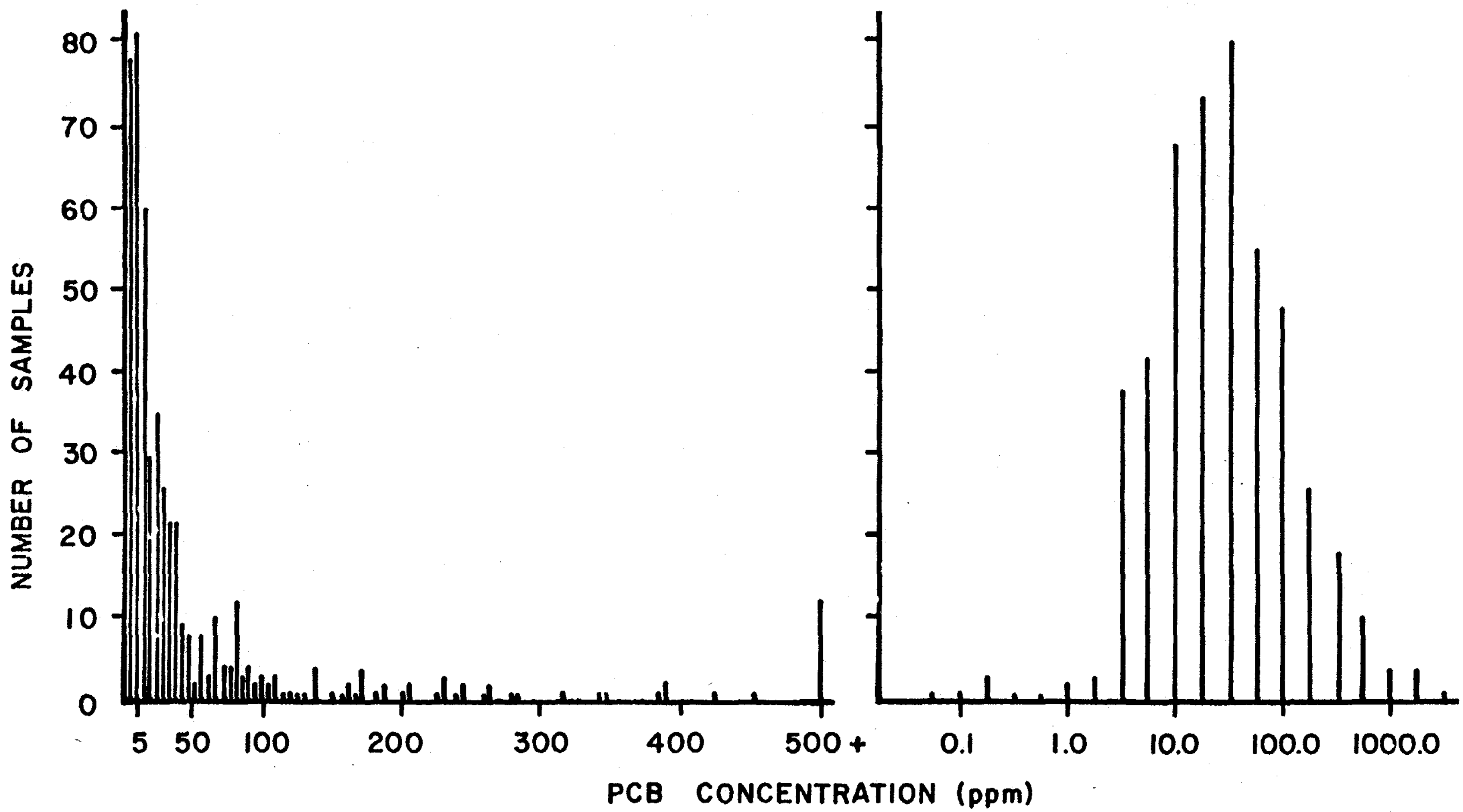


Figure 5

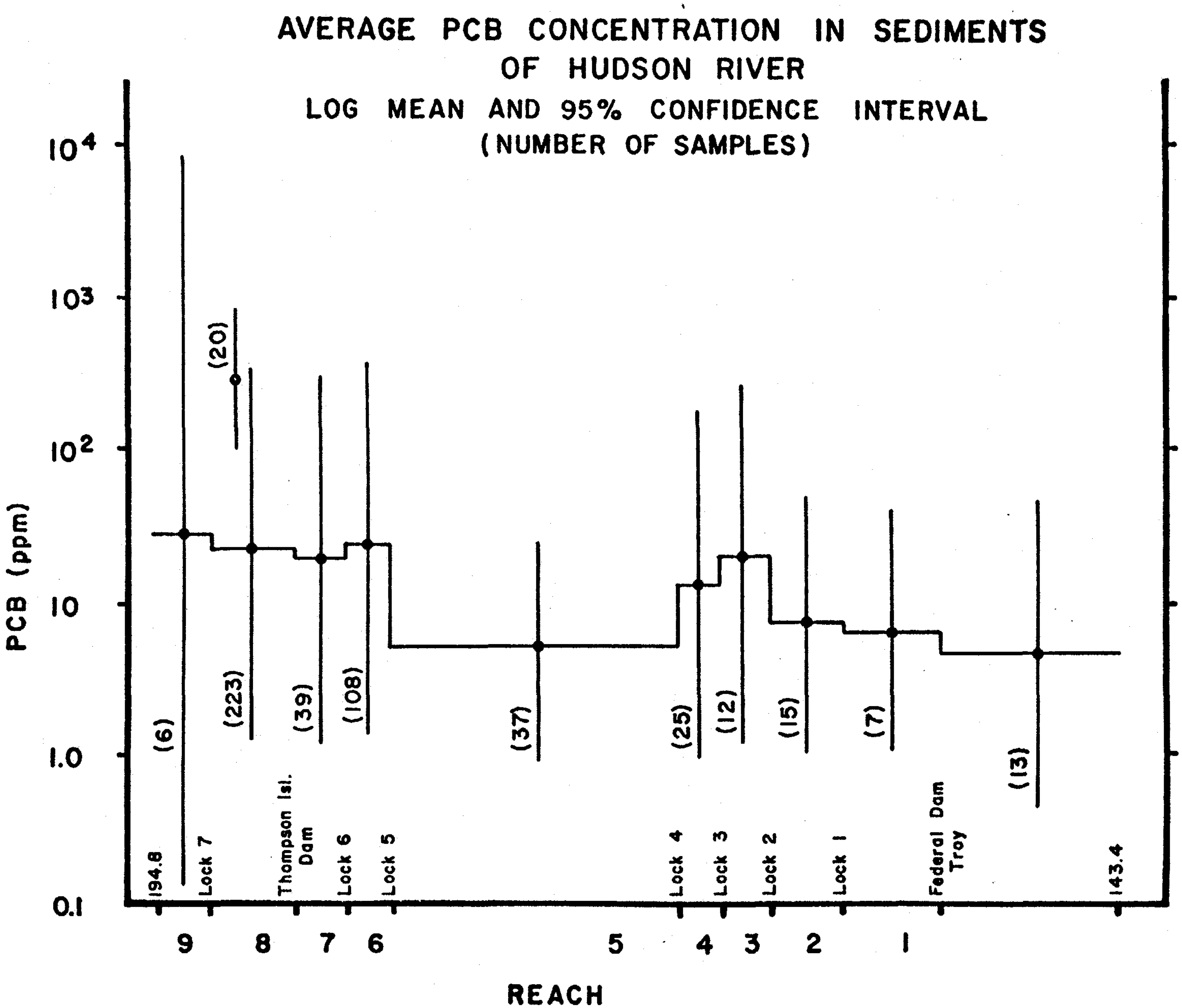

AVERAGE PCB CONCENTRATION IN SEDIMENTS
OF HUDSON RIVER
LOG MEAN AND 95% CONFIDENCE INTERVAL
(NUMBER OF SAMPLES)
PCB (ppm)
10^4
10^3
10^2
10
1.0
0.1
(6)
(20)
(223)
(39)
(108)
(37)
(25)
(12)
(15)
(7)
(13)
194.8
Lock 7
Thompson Isl. Dam
Lock 6
Lock 5
Lock 4
Lock 3
Lock 2
Lock 1
Federal Dam Troy
143.4
9
8
7
6
5
4
3
2
1
REACH

Table 2: The Area and Average PCB Concentration by Reach of Hot Spots (concentration >50 ppm) and Cold Areas (concentration <50 ppm) in Sediments of the Upper Hudson River.

	Total	8	7	6	5	4	3	2	1
PCB Levels**									
Hot spots	--	151	103	163	70	108	159	--	--
Cold areas	--	19.0	20.0	20.0	13.0	13.4	22.6	13.9	9.6
Overall	67.6	86.2	43.6	74.6	11.6	41.9	52.3	13.1	9.67
Area ($x\ 10^6 ft^2$)									
Hot spots	10.86	4.27	0.6	2.59	1.75	1.5	0.15	0	0
Cold areas	120.79	10.73	7.4	5.91	41.2	9.7	10.85	15	20
Total	131.65	15.00	8.0	8.5	42.95	11.2	11.0	15	20

* Reaches are identified in Figure 3.
**Average concentrations for sediment grab samples in ppm.

Table 3: Frequency Tabulations for Sediment Grabs from the Upper Hudson River by Texture and PCB Level.

	Texture					
	0	1	2	3	8	9
	Clay	Silt	Muck	Muck and wood chips	Gravel	Gravel and wood chips
Reaches 6 - 9						
No. of samples	3	52	49	11	61	20
% of PCB levels < 5 ppm	100	7.7	20	0	14.8	10
% of PCB levels <25 ppm	100	25.0	26.5	9.1	78.7	45.0
% of PCB levels >50 ppm	0	55.8	53.1	54.5	4.9	40
Reaches 1 - 5						
No. of samples	0	3	19	10	22	5
% of PCB levels < 5 ppm	-	0	15.8	0	45.5	20
% of PCB levels <25 ppm	-	33.3	52.6	30	90.9	80
% of PCB levels >50 ppm	-	0	31.6	40	0	20

It can be noted from Table 3 that sediment samples consisting primarily of muck and wood chips had PCB levels typically >50 ppm and seldom <25 ppm. Samples consisting of primarily gravel were typically low in PCB, but the PCB level was greater if wood chips were present in the gravel. North of Lock 5 (reaches 6 - 9), coarse sands with wood chips had significantly higher PCB levels than without wood chips (Table 4). This suggests an association of high PCB levels with sediments having an elevated organic content. Additionally, fine-textured sediments have significantly higher ($P < .005$) PCB concentrations than coarse-textured ones (Table 4). This observation is supported by a negative correlation of PCB level with total solids ($r = -.68$) in samples from the northern reaches, thus indicating that a light organic sediment is often high in PCB.

Table 4: Log-mean PCB Levels by Texture Class.

	Texture code*				
	0 - 3	6	7	8	9
Reaches 6 - 9					
Log-mean PCB	1.75	1.05	1.29	1.08	1.52
Antilog (ppm)	56.7	11.1	19.3	11.9	34.9
Reaches 1 - 5					
Log-mean PCB	1.41	--	--	0.70	0.85
Antilog (ppm)	25.6	--	--	5.0	7.0

* A description of the texture code can be found in Table 3 except 6 = sand and 7 = sand and wood chips.

From studying the riverbed, cross-section maps and sediment characteristics, it can be observed that silt deposits are typically near the banks in the lower velocity areas and gravel deposits are generally in the center or navigation section of the channel. The hot-spot areas occurred more frequently near the banks, except for the northernmost river reaches.

Figure 6

PCB PENETRATION IN CORES BY REACH FROM AREAS WHERE PCB > 5 ppm

DEPTH IN CORE (inches)	Reaches 8,9 frequency of PCB > 50 ppm	Reaches 8,9 Mean PCB(ppm)	Reaches 8,9 N	Reaches 6,7 frequency of PCB > 50 ppm	Reaches 6,7 Mean PCB(ppm)	Reaches 6,7 N	Reaches 1-5 frequency of PCB > 50 ppm	Reaches 1-5 Mean PCB(ppm)	Reaches 1-5 N
3	.39	93	87	.40	102	47	.08	22	48
6	.58	112	57	.57	153	23	.20	47	25
12	.36	120	103	.29	130	51	.29	49	62
18	.33	133	63	.18	48	22	.05	14	22
24	.25	75	27	0	6.3	11	0	5	6
36	.22	69	9	0	3.0	1	0	3	1
	0	4.7	7						

From the cores, it can be seen that typically the highest PCB concentration in the sediment is 6 to 12 inches below the surface (Fig. 6). Substantially contaminated material is, however, found deeper in the sediments, particularly in the upper reaches (Fig. 6).

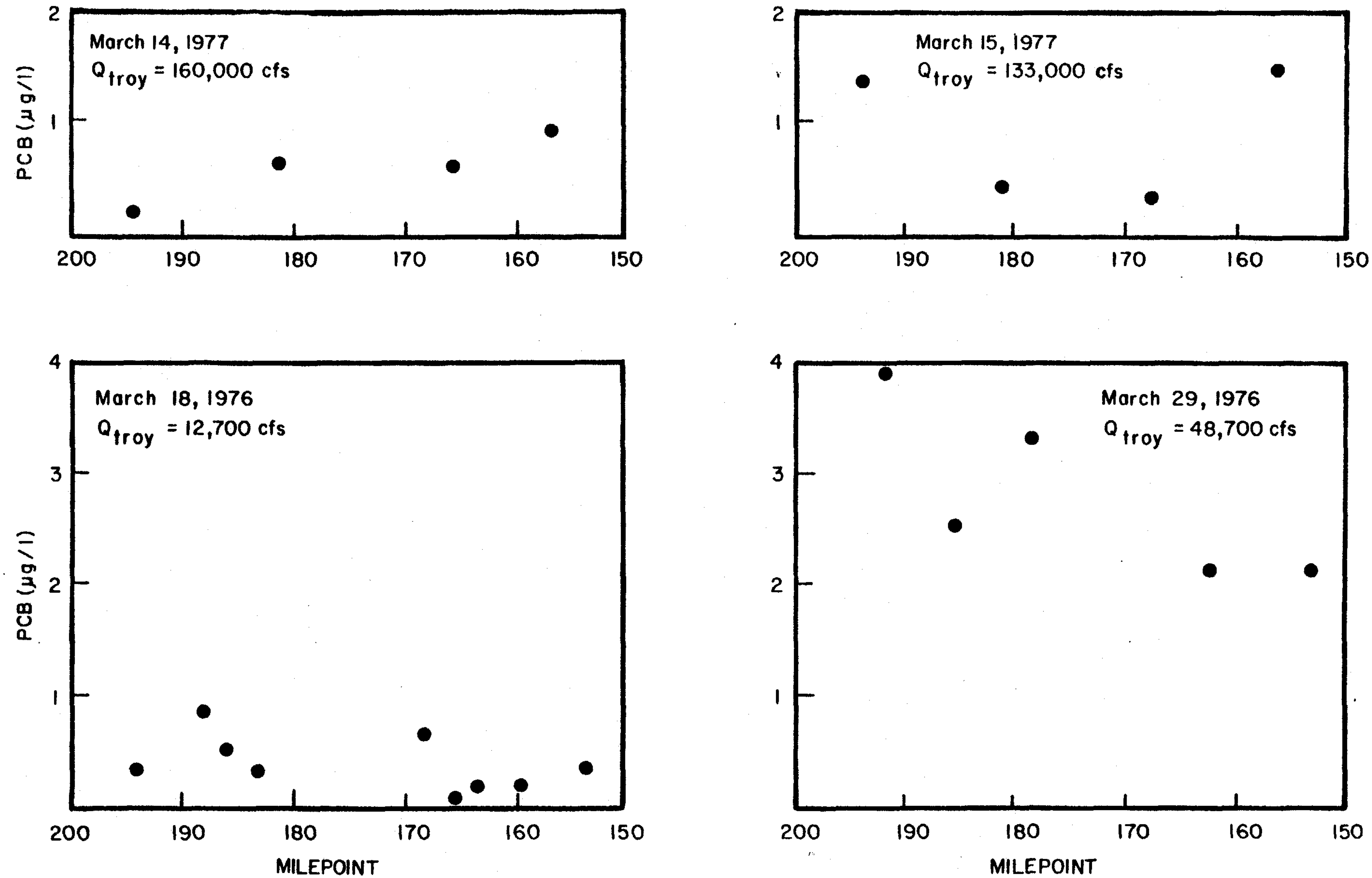
b. Water column

During the 1977 water year, the U.S. Geological Survey operated PCB monitoring and daily suspended-sediment stations at Glens Falls, Schuylerville, Stillwater and Waterford, New York.[8] The Waterford station was operated for the entire year, whereas the other three stations began operation in late March, 1977.

Although no PCBs (<0.1 ppb) were detected in any water samples from the Glens Falls station, PCBs were commonly detected at the other three sites. PCB concentration varied substantially both with flow and river reach (Fig. 7). Throughout the year (late March to September) highest PCB concentrations (>1 ppb) were associated with high flows (approximately 10^6 l/sec), and the lowest PCB concentrations were associated with medium river discharges of 2 to 6 x 10^5 l/sec (Fig. 8). With even lower flows (<10^5 l/sec or ~3500 cfs), PCB concentrations at Stillwater, Schuylerville, and Waterford increase, thus indicating that a relatively constant load of PCBs was being transported except during storm events. This constant low-flow load in the Upper Hudson River was between 4 and 5 kg/day (Table 5). During the major storm at the end of April, daily transport of PCB ranged from 360-390 kg (Table 5). The transport of PCBs at Waterford during the entire year was approximately 2,600 kg (5,720 pounds), half of which occurred at flows less than and greater than 5.6 x 10^5 l/sec (~20,000 cfs).

Figure 7

TOTAL PCB IN WATER COLUMN AT VARIOUS RIVER FLOWS



SOURCE: after Hydroscience,(27)
USGS data

100023

Figure 8

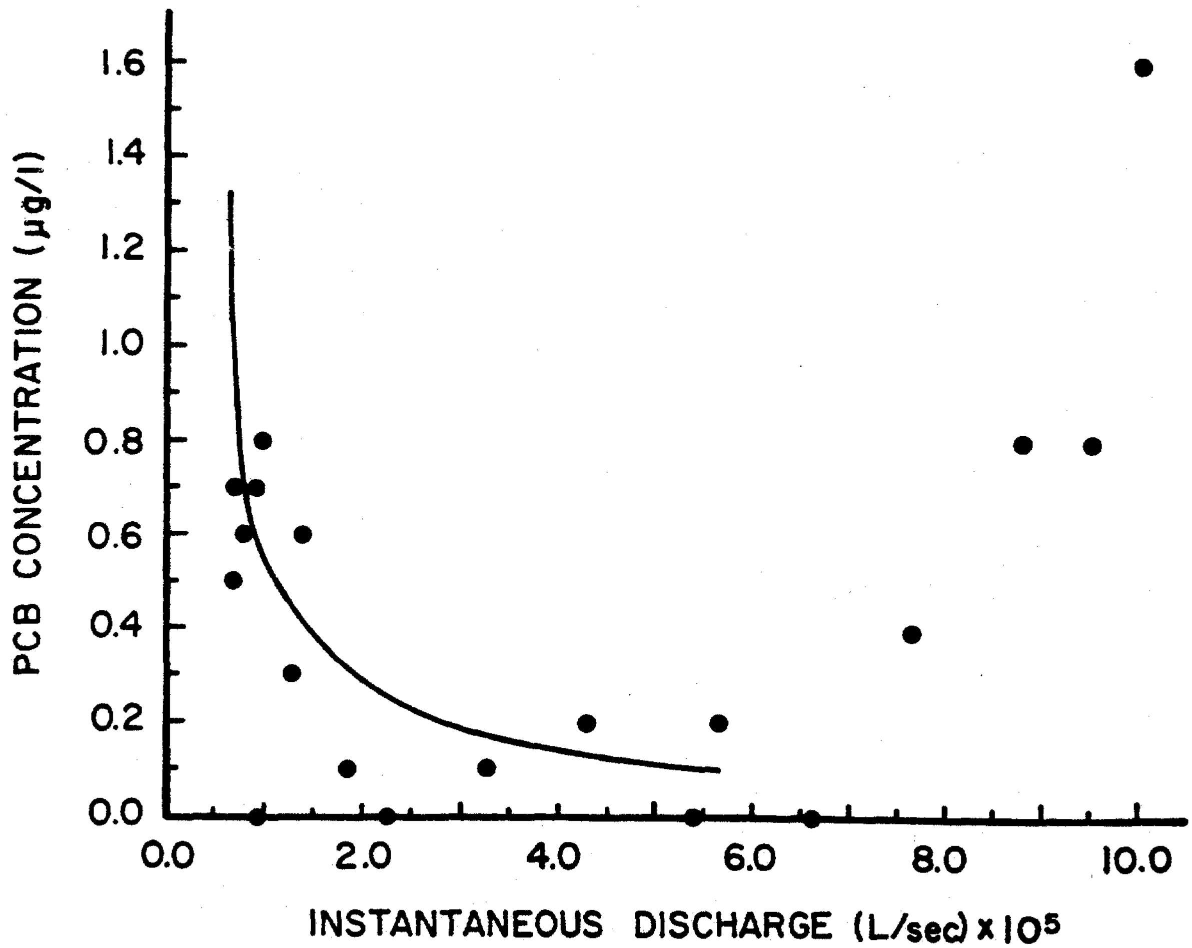
HUDSON RIVER AT SCHUYLERVILLE

PCB CONCENTRATION VS. RIVER DISCHARGE

MARCH 30-SEPTEMBER 27, 1977

regression: $PCB = \frac{5.5 \times 10^4}{Q}$

for $Q < 5.6 \times 10^5$ L/sec



SOURCE: Turk,[8] USGS data

Table 5: Calculated PCB Load in the Upper Hudson River at Selected River Discharges.

Flow	PCB Load in kg/day and (lbs/day) Schuylerville	Stillwater	Waterford
<5.6 x 10^5 l/sec.	4.0 (8.8)	5.2 (11.4)	3.8 (8.36)
April 24-May 2, 1977 (~ 10^6 l/sec.)	370 (814)	360 (792)	390 (858)

Source: data from Turk(8).

Table 6: Summary of Computed Upper Hudson River Sediment Transport by River Reach.

Mile Point	Location	Median Daily Flow (cfs)	90% Flow* (cfs)	Threshold flow for Scour(cfs)	Sediment Transport (tons/day) 50%*	90%*	99%*
193.7	Lock 7	4000	9500		40	120	525
				15000			
188.5	Thompson Is. Dam		--		13	75	580
				>25000**			
186.2	Lock 6		10500		10	50	520
				>25000**			
182.3	Lock 5		--		7	30	520
				>27000**			
168.7	Lock 4		12500		30	80	600
				15000			
166.0	Lock 3		--		100	600	2000
				8000			
163.5	Lock 2		15000		60	880	3800
				25000			
159.5	Lock 1		--		35	900	2800
				10000			
153.9	Federal Dam	8500	27500		500	6500	8000

Source: compiled from results of Lawler, Matusky & Skelly sediment-transport model(9).

* x% flow means the average daily flow is not exceeded x% of the time.

**Flow necessary for scour was not found, maximum flow tested is indicated.

c. Sediment transport

Table 6 provides model estimates of sediment transported and scour by river reach(9). This analysis indicated that the reaches most likely to scour are the reaches from Lock 3 to 2 and from Lock 1 to the Troy Dam.

Figure 9 provides 20 yr. bed change predictions for the Thompson Island to Lock 7 reach. Except for the northernmost 2 miles, less than a foot of deposition is expected to occur in the next 20 years and, thus, does not appear enough to seal the sediment and prevent further PCB leaching and transport during the 20 years. Only limited scour occurs in this reach.

2. Lower River (Estuary)

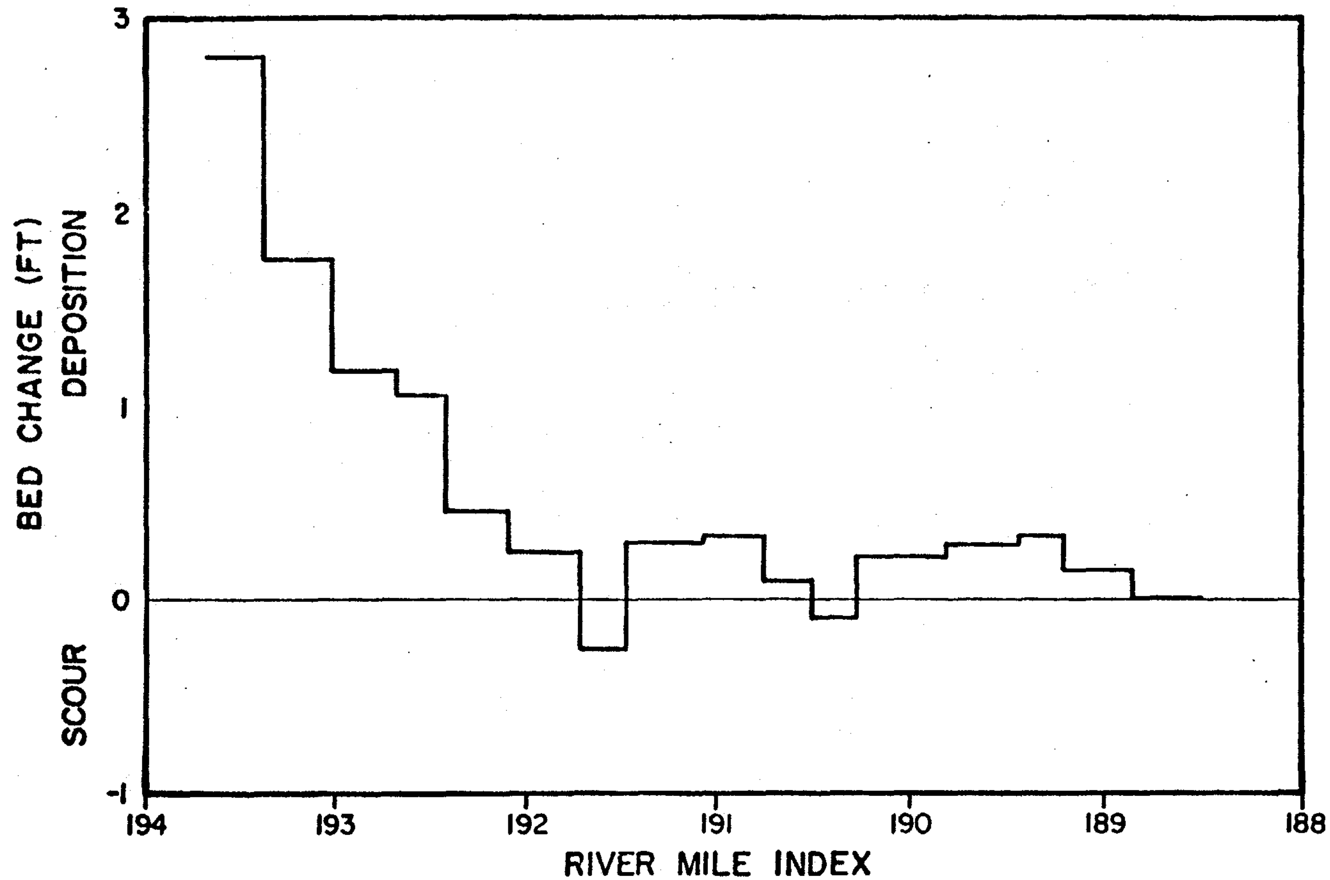
a. Sediments

Richard Bopp(7) has suggested that the Hudson estuary can be divided into three distinct sedimentary regimes. The amounts of recent sedimentation (since the early 1950s) and the proportion of the river in each of these regimes are presented in Table 7. PCB contamination is confined to these recent sediments. Typical cores from these areas are shown in Figure 10.

Estuary PCB concentrations in recent fine-grained sediments decrease from an average of 60 ppm in the Albany Turning Basin to an average of 6 ppm in the New York Harbor. The measurements indicate no other major historic or existing point source of PCBs to the Estuary other than the Upper River. In the core taken in the Albany Turning Basin, changes of Aroclor 1016, 1242 and 1254 through the core are consistent with changes in the Aroclor usages at GE's Ft. Edward and Hudson Falls manufacturing facilities.

Figure 9

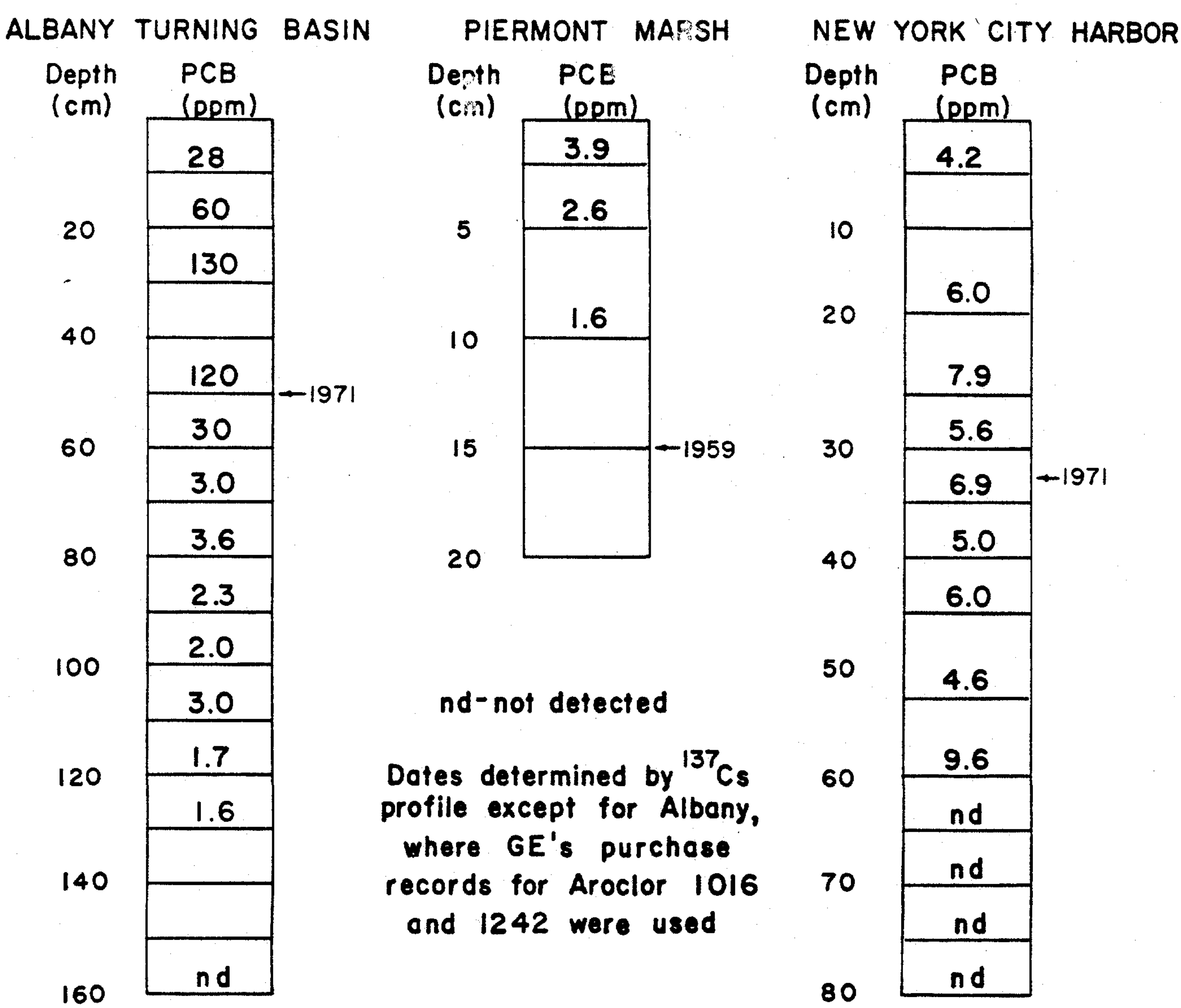
LOCK 7 - THOMPSON ISLAND BED CHANGE
20 YEAR PROJECTIONS



SOURCE: Lawler, Matusky & Skelly[9]

Figure 10

PCB LEVELS FROM SEDIMENT CORES IN THE HUDSON RIVER ESTUARY



SOURCE: data from Bopp[7]

Table 7: Sedimentary Regimes for the Hudson River Estuary Region.

Estuarine sedimentary regime	Depth of recent Sediment Accumulation (cm)	Proportion of river bed (%)
Natural channel & submerged bank	<5	65
Coves and broad shallow areas	15-30	25
New York Harbor area	up to 250	10

Source: data from Bopp[7].

The highest concentration (130 ppm at 20-30 cm) can be associated with the removal of the Ft. Edward Dam in 1973.[7] This suggests that GE discharges have been contaminating the Estuary probably since the facilities have used PCBs (1950), and massive short-term contamination occurred with the removal of the Ft. Edward Dam and the subsequent 100-year flood (1974).

b. Water column

Only limited data exist on PCB concentrations in the estuary water column and are from the Poughkeepsie and Troy area. Values of between 0.11 and 1.1 ppb have been measured[7,44,45].

c. Sediment transport

There is very limited data on estuary sediment transport. A thin organic fluff layer lies on top of the sediment and moves up and down the river with tidal flow. The center of the channel is typically sandy and subject to higher velocities while the coves and broad shallow areas are depositional. With the paucity of hydrologic data and PCB concentration in the sediment, PCB transport down the estuary cannot be quantified.

II. B. River Biota

1. Fish

Fish sampling from various reaches of the Hudson River and subsequent analysis of PCB levels in fish flesh has been directed at determining whether given species of fish could be considered safe for human consumption and whether fish flesh PCB concentrations are affected by PCB discharge reductions or other remedial management actions[10,12].

Earlier analyses[11] (1975-76) indicated that PCB levels were higher in fish taken above Troy than in fish from the estuary (Table 8). All species sampled in 1975-76 had average total PCB concentrations exceeding 5 ppm (the FDA's temporary tolerance limit for PCBs in fish). Upstream of Hudson Falls fish contain only trace amounts of PCB.

Table 8: Total PCB levels in edible flesh of resident species from various regions of the Hudson River. Data from 1975-1976[12].

Location	Species	Number of fish	Total PCB (ppm)*	
			Average	Range
Above Hudson Falls	Smallmouth bass	26	Trace	
	Yellow Perch	15	Trace	
Fort Edward to Troy Lock	Smallmouth bass	11	72.6	41.5-122.9
	Yellow Perch	10	134.6	79.3-299.3
	White Sucker	37	68.2	28.2-131.4
	Largemouth bass	37	61.7	12.5-164.4
Federal Dam to Battery	Yellow Perch	5	5.28	-
	Largemouth bass	10	10.05	1.73-23.74
	White Perch	23	10.08	5.28-19.88

Source: Sloan[12].

* μg PCB/g wet weight.

Table 9: Average total PCB levels in edible flesh of fish taken from the Hudson River. Data from 1977.

Location	Species	Number of fish	Total PCB (ppm)† Average	Range
Thompson Island	Largemouth bass[3]	19	73.4	58.3-86.9*
	Goldfish[3]	19	568	296-872*
Stillwater	Largemouth bass[4]	14	70.7	6.22-235
	Largemouth bass[3]	20	68.1	49.4-86.8*
	Yellow perch[4]	30	12.2	1.57-42.7
	Goldfish[4]	16	576	41.8-1836
	White sucker[3]	17	21.0	16.1-25.1*
	Brown bullhead[5]	30	110	35.5-242
Albany/Troy	Smallmouth bass[4]	9	16.4	0.98-50.36
	Largemouth bass[4]	2	18.3	1.45-35.2
	Yellow perch[4]	20	9.3	1.49-27.3
	White perch[5]	30	118	6.19-372
	White sucker[1]	10	15.8	**
	Brown bullhead[4,5]	30	37.9	3.15-110
	Striped bass[1]	10	21.2	**
Catskill	Largemouth bass[4]	27	29.5	<0.44-85.7
	Largemouth bass[1]	10	4.62	**
	Yellow perch[5]	20	4.25	<0.75-10.6
	Brown bullhead[5]	8	2.04	<0.30-10.03
	White catfish[5]	1	21.9	-
	Alewife[1]	20	1.95	1.88-2.21*
Indian Point	Atlantic tomcod[4]	30	0.96	<0.44-4.48
	American eel[4]	7	151	6.54-263
Poughkeepsie	American shad[3]	2	10.02	**
	American shad[2]	32	6.07	2.21-11.9
Tappan Zee	American shad[3]	19	4.55	3.62-5.22*
	American shad[2]	20	3.20	1.65-5.85
	Striped bass[3]	5	8.00	**

Source: Bureau of Environmental Protection[47].

[1]Report 12, March 20, 1978.
[2]Volume 2, Report 1, April 20, 1978.
[3]Ibid., Report 2, May 20, 1978.
[4]Ibid., Report 3, June 20, 1978.
[5]Ibid., Report 4, July 20, 1978.

* Two analyses on composited fish.
**One analysis of pooled fish.
† µg PCB/g wet weight.

Although PCB analysis of fish collected in 1977 is incomplete, the data presently available demonstrate that fish populations between Ft. Edward and

Troy are more contaminated than those further downstream (Table 9). Even in this river reach, however, some species are much more contaminated than others. Several interesting patterns in the data bear additional investigation.

Sampling throughout New York State [11] from 1970-75 demonstrates that PCB contamination of fish flesh is highest in the Hudson River, but detectable levels of PCBs are present in fish from virtually any river system or large lake. Fish from non-industrialized or lightly industrialized watersheds in New York (Chemung, Susquehanna, Raquette) average less than 1 ppm in their edible flesh; although in the Black River, levels approach 4 ppm. In more heavily industrialized basins (Genesee, Hoosic, Great Lakes), however, PCB levels in fish approach and often exceed 5 ppm.

2. Snapping turtles

Approximately 20 snapping turtles from the Hudson have been analyzed for PCBs[13]. Most of the turtles were collected in June 1977 but a few were collected in June 1976 and May 1977. The animals were collected from eight coves or marshes along the estuary from the Tappan Zee Bridge area to Hudson. Table 10 shows the average and range of PCB concentrations in all the animals. The limited sampling makes any interpretation of the data impossible at this time.

Table 10: Tissue levels of PCBs from snapping turtles collected along the Hudson River estuary.

Tissue	Number of Samples	Total PCB concentration (ppm)	
		Average	Range
Muscle	17	4.24	0.05-27.62
Liver	17	36.7	1.79-174
Eggs	3	25.5	15.7-42.9
Fat	1	712	

Source: Stone[13].

3. Macroinvertebrates

In 1976 multiple-plate samplers were tested as a method for monitoring PCBs in the water column of the Hudson River[14]. Samples were obtained by exposing hardboard artificial substrates for periods of four to five weeks. Organisms and other material which attached to the plates were removed and extracted for PCB analysis which was done by the NYS Department of Health. Two stations (controls) were located upstream from the known point discharges of PCBs; one in the Hudson River and one in the Champlain Canal. The remaining stations were all below the discharges. Five of the stations were located in the tidal zone of the Hudson Estuary. Because the results from 1976 were promising, the project was continued in 1977. Three stations were added, extending the sampling network into Haverstraw Bay, and the Champlain Canal station was dropped.

In the Hudson River samples, macroinvertebrates comprise approximately half of the material attached to the sampling plates; the other half being detritus and attached phytoplankton. Most of the macroinvertebrates (60-70%) are midge larvae (Chironomidae) with the next most abundant organism being oligochaete worms (15-20%)[15].

During all sampling periods for which data are available, consistently higher PCB concentrations have been found in organisms from the Upper Hudson below Ft. Edward than elsewhere in the river (Table 11). PCB levels in fish and sediments are also highest in this region.

Contamination of macroinvertebrates in the Hudson Estuary, while less severe, was well above background levels. In June, July and August 1976, all stations yielded PCBs in excess of six times background levels (Table 11).

Table 11: Ranges of PCB concentrations in macroinvertebrates from the Hudson River. Values are expressed as ppm PCB/dry weight of total residue on the sampler plates.

Date	Background (control stations)	Fort Edward to Troy	Lower Hudson (Estuary)
June 1976	0.4	5.6 - 25.4	2.6 - 4.9
July 1976	0.3-0.6	12.0 - 57.0	5.0 - 11.0
August 1976	0.2-0.5	No data	2.8 - 200.0
September 1976	0.2-1.0	9.0 - 18.8	0.0 - 11.0
August 1977	0.1	2.8 - 10.8	0.8 - 3.4

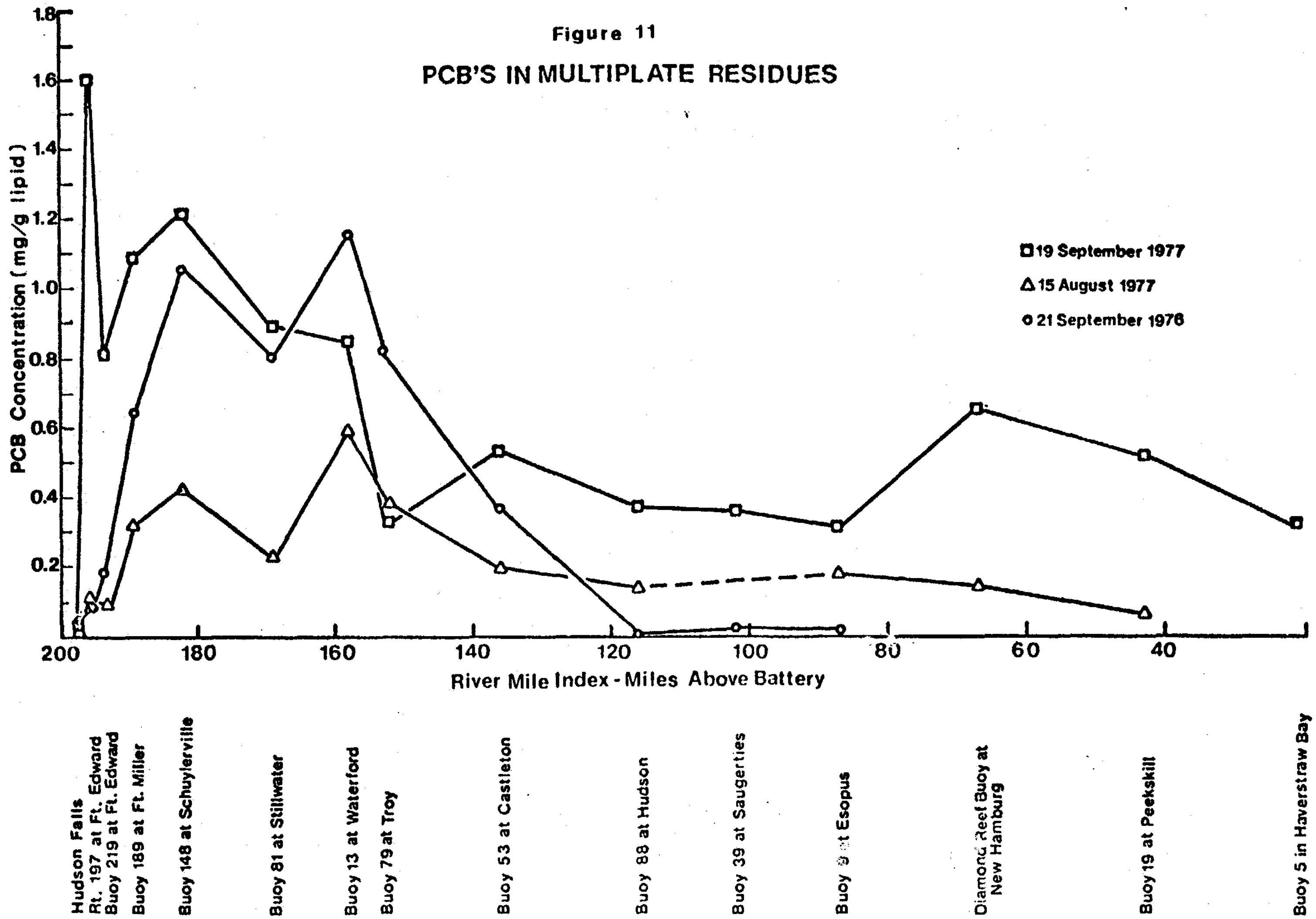
Source: Simpson[15].

Clayton et al.[16] have shown that lipid content is highly correlated with the PCB levels in marine invertebrates, and they contend that lipid content is the most-meaningful normalization parameter for quantification of PCB results. Lipid contents of samples were determined beginning in September 1976. Normalization of the data to lipid content also demonstrates that the greatest PCB contamination is occurring in the Upper Hudson below Ft. Edward. In September 1976 and August 1977, PCB concentrations can be seen to progressively increase from the control station to Schuylerville, decrease slightly at Stillwater, then peak at Waterford and gradually diminish downstream (Figure 11).

An interesting temporal change can also be noted. In September 1977, at all the estuary stations with the exception of Troy, PCB concentrations in macroinvertebrates were higher than during September 1976 or August 1977. This suggests that PCBs are becoming more widely and evenly distributed in the Hudson River. Data from future surveys will help evaluate the significance of this trend.

Figure 11

PCB'S IN MULTIPLATE RESIDUES



SOURCE: Simpson(17)
PCB analyses by N.Y.S. Dept. of Health

Macroinvertebrates from the Ft. Edward area had considerably elevated PCB concentrations in September 1977, but not in August 1977 or the previous year. Dredging north and east of Rogers Island began in early August. Transport of PCBs from this activity undoubtedly accounts for the September increase of PCBs in the macroinvertebrates. The sampling station at Route 197 (Ft. Edward) is located approximately 100 meters downstream of the dredging activity. For more details see Section II.F. and Figure 20.

4. Microbial populations

In late November of 1977, at the request of the Department of Environmental Conservation, General Electric initiated work to determine if PCB degrading microorganisms are present in Hudson River sediment.[18] The approach to this question centers around the development and analysis of catabolic activity of enrichment cultures obtained from core sediment samples from a heavily contaminated region (1000 ppm total PCB) of the Upper Hudson.

Enrichment cultures have been obtained from sediment core samples taken in this heavily contaminated region. The microbial population found in the first 20 cm of core sediments ranged from 10^4 to 10^6 microorganisms per 10 g of wet sediment. Mixed cultures grown on 2% glucose as the primary carbon source were unable to degrade Aroclor 1221, 1016, or 1254 in shake-flask studies. Colonies were observed, however, on agar plates containing Aroclors 1221 and 1254 and shake-flask studies using these organisms (mixed culture) have shown them to be capable of degrading PCBs.[19] Further studies are in progress.

C. Terrestrial Environment

1. Landfills and dredge spoil areas

Studies have been carried out to ascertain the amount of PCB presently in landfills and dredge spoil sites in the Upper Hudson Basin and to estimate the erosion and leaching of PCBs from these sites[20]. Table 12 presents the results to date. Substantial quantities of PCB exist in

Table 12: Estimated amount of PCB in and projected loss of PCB from selected dredge spoil areas and landfills in the Upper Hudson Basin. See text for important reservations about these values.

Site*	Estimated PCB in site (thousands of lbs)	Groundwater loss (lbs/yr)	Erosion loss (lbs/yr)
Dredge spoil sites			
Lock 1	0.95	0.17	0.015
Lock 4	3.85	22.6	20.8
Site 212	3.46	11.3	24.2
Site 518	1.49	4.9×10^{-3}	17.3
S.A. 13	80.7	51.2	4.5
Moreau	45.4	12.4	4.2
New Moreau**	6.8	?	?
Rogers Island†	17.4	?	?
Total	160	98	71
Landfills & dumps			
Fort Miller	119	2×10^{-4}	371
Caputo	1.13	0.343	2.6×10^{-3}
Old Ft. Edward	?	422	0.073
Kingsbury	292	?	5.8
Ft. Edward	116	?	3.2
Total	>528	>422	380

Source: modified from Weston[20] preliminary data.
* Locations depicted in Figure 13.
**Estimated by Horn from NYS DEC data.
† Estimated by Tofflemire from NYS DOT dredging records.
? Insufficient data.

both types of disposal area, but the landfills and dumps contain over 75% of the PCB that was placed on land sites.

Measurable quantities of PCB are also leaching or eroding from these sites. Again the landfills and dumps appear to be larger contributors of PCB to the surrounding environment that the dredge-spoil areas. One must be very cautious in interpreting this information, however, because the groundwater loss estimates do not yet incorporate local soil adsorption properties. The groundwater values are therefore quite possibly considerable overestimates of PCB transport away from the immediate vicinity of the sites. Contaminated groundwater is not presently being used for drinking water at any of these sites.

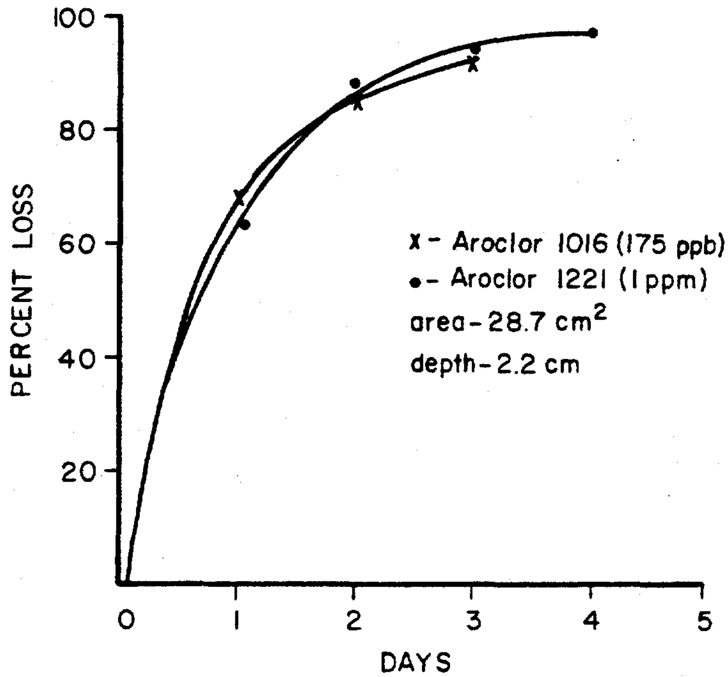
Additionally, the erosional losses from all sites should be considered "worst-case" estimates and also may not transport PCB very far from the site. Very little of the eroded material from the Fort Miller dump, for example, probably reaches the Moses Kill or the Hudson River. On the other hand, because the dredge-spoil sites are immediately adjacent to the Hudson River, most of the eroded material from these sites probably does reach the river.

2. Air and volatilization

During the early phases of General Electric's research, the rate of PCB evaporative loss from pure samples and aqueous solutions was evaluated. The effect of organic particulate matter on the PCB evaporative loss was also studied. It was found that neat Aroclor 1221 volatilizes at a rate of approximately 8 μg/day/cm^2 at 25°C.[18] Monochlorinated homologs are lost from Aroclor 1221 almost twice as rapidly as the dichlorinated homologs. PCBs also evaporated rapidly from saturated water solution (Figure 12), but organic particulate matter strongly adsorbs PCBs and retards the rate of

Figure 12

EVAPORATIVE LOSS OF PCB FROM PCB SATURATED WATER SOLUTION



SOURCE: General Electric[18]

Table 13: Average PCB concentration at five stations in the Upper Hudson Basin.

Dates	Washington County Offices	Fort Hudson Nursing Home	Main Street	Glens Falls	Warrensburg
11/76-6/77	990 (31)	108 (23)	102(24)	<20(32)	<20 (25)
7/77-11/77	305 (15)	25 (10)	67(12)	<20(9)	<20 (7)

Source: Romano[21].
Each sample represents 24 hours of air filtration through a florisil column. Every day of the week is approximately equally represented at each station. Number in parenthesis is number of samples. Concentration in nanograms/cubic meter of air.

evaporation from water. Thus, these observed rates are not applicable to the Hudson River.

Since November 1976 DEC has continuously monitored air for PCBs at five sites (Figure 13) with sample analysis carried out by the NYS Department of Health.[21] PCBs were not detected at the two sites (Glens Falls and Warrensburgh) greater than three miles northwest of the GF Hudson Falls and Fort Edward facilities. Results from the other sites suggest that PCBs are emitted from both GF facilities.

After GE ceased using PCBs at their facilities in June 1977, air emissions decreased substantially (Figure 14) and average ambient air levels have been significantly reduced since July (Table 13).

Figure 15 shows the variation in PCB levels with day of the week in ambient air near the Fort Edward facility. The pattern is consistent with work at that plant. Note that significant decreases in ambient air PCBs since July 1977 only exist during the work week. The roughly 300 ng/m^3 still found near the plant must reflect contamination of the manufacturing plant and/or grounds.

As might be expected, these levels are considerably higher than have been previously found[22]. Over Providence, Rhode Island, the maximum concentration reported was 9.4 ng/m^3; and in the Western North Atlantic over the Grand Banks, levels were usually 100 times less than that.

Dustfall was also sampled in large (4 liter) jars from February to July 1977 at Glens Falls, Warrensburg and the Washington County Office Building adjacent to the Fort Fdward manufacturing facility. Through June, the average PCB load from the atmosphere in dustfall at the Washington County Office Building was approximately 58 μg PCB/m^2/30 days (687 μg PCB/m^2yr) with an average concentration of PCB on the dust of 17 ppm.

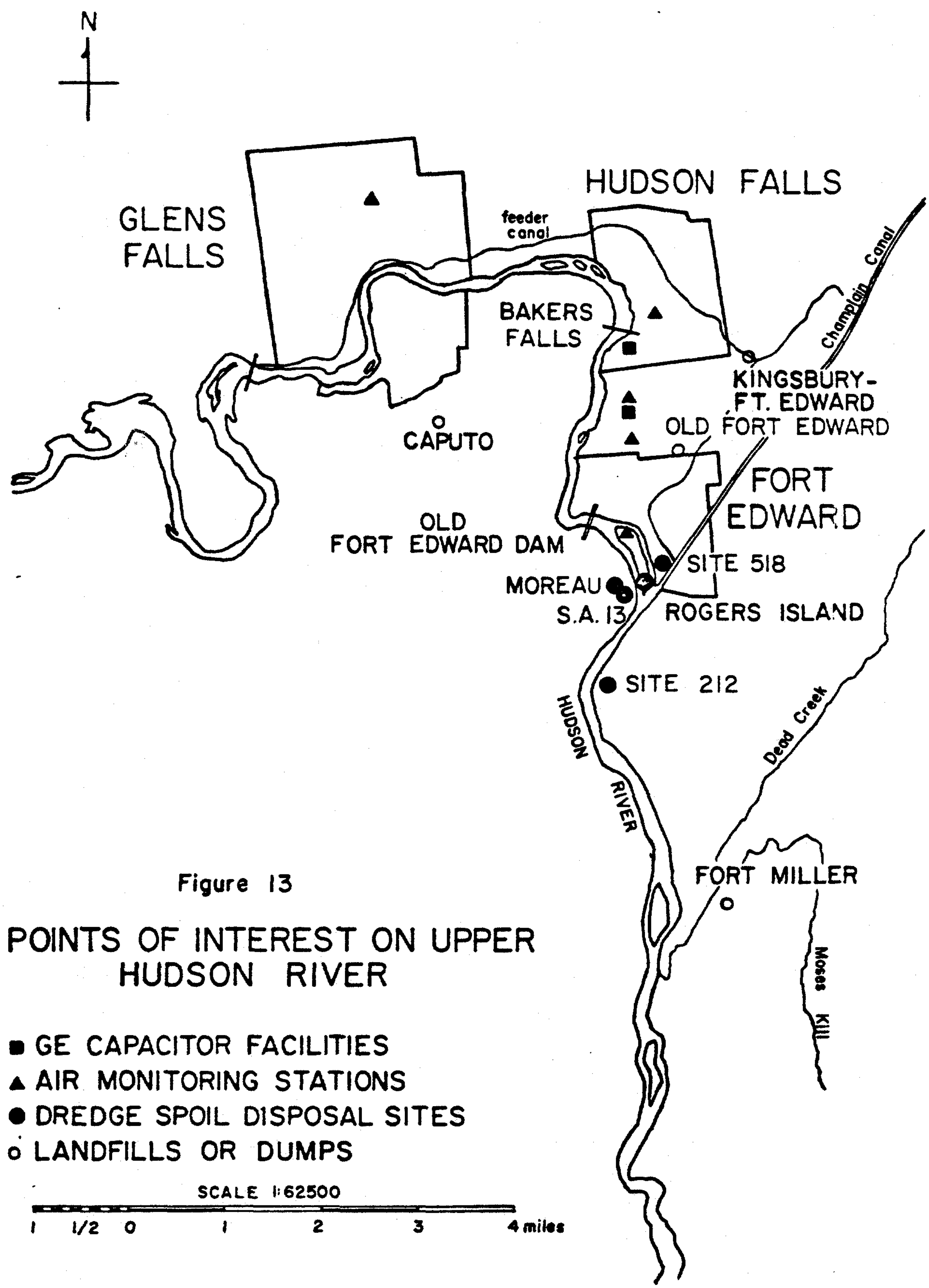


Figure 13

POINTS OF INTEREST ON UPPER HUDSON RIVER

■ GE CAPACITOR FACILITIES
▲ AIR MONITORING STATIONS
● DREDGE SPOIL DISPOSAL SITES
o LANDFILLS OR DUMPS

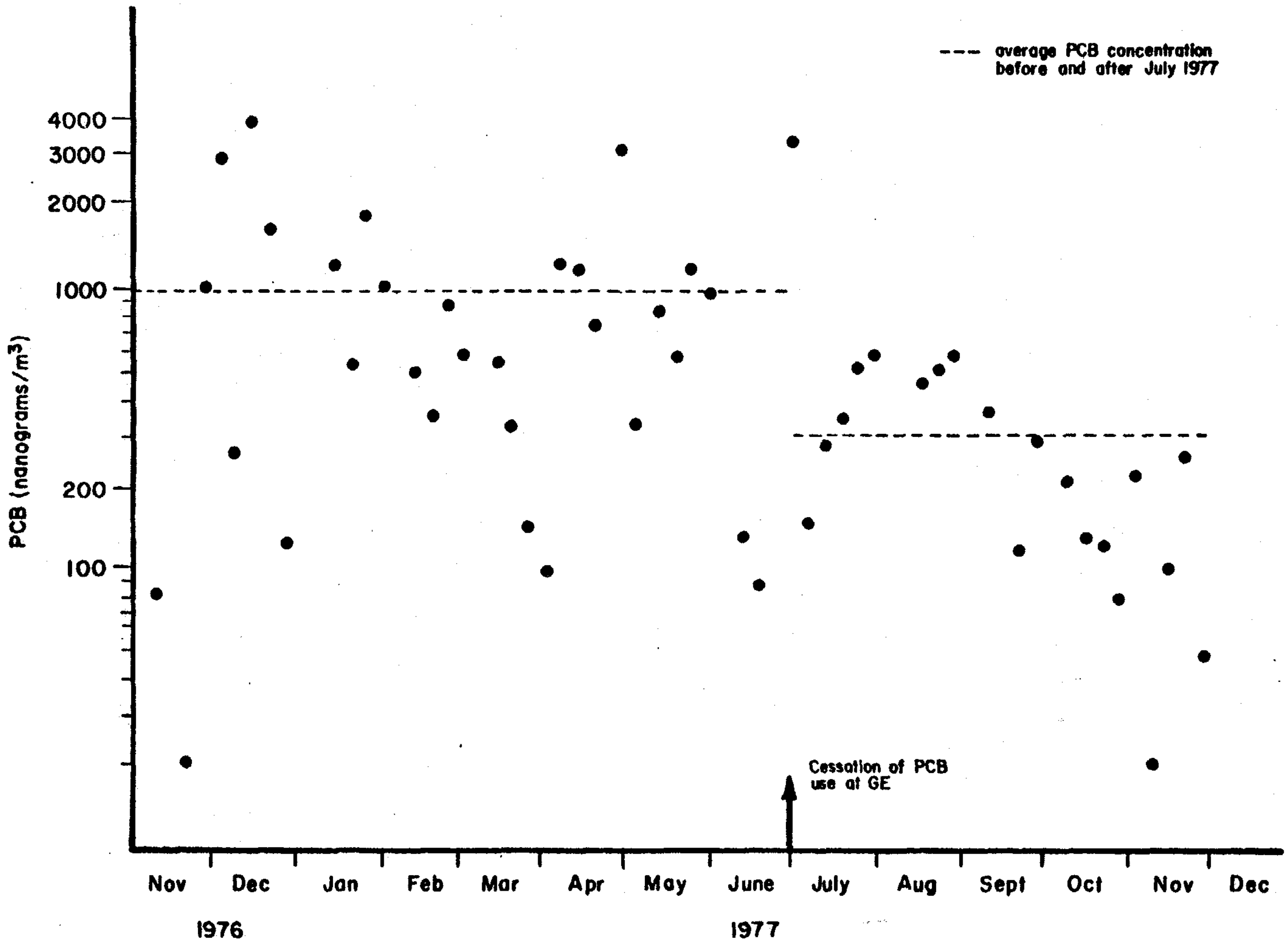
SCALE 1:62500

1 1/2 0 1 2 3 4 miles

100042

Figure 14

PCB CONCENTRATIONS IN AMBIENT AIR AT WASHINGTON COUNTY OFFICES



- sample collection by N.Y.S. DEC
- PCB analysis by N.Y.S. DOH

Figure 15

PCB CONCENTRATIONS IN AMBIENT AIR AT WASHINGTON COUNTY OFFICES BY DAY OF WEEK

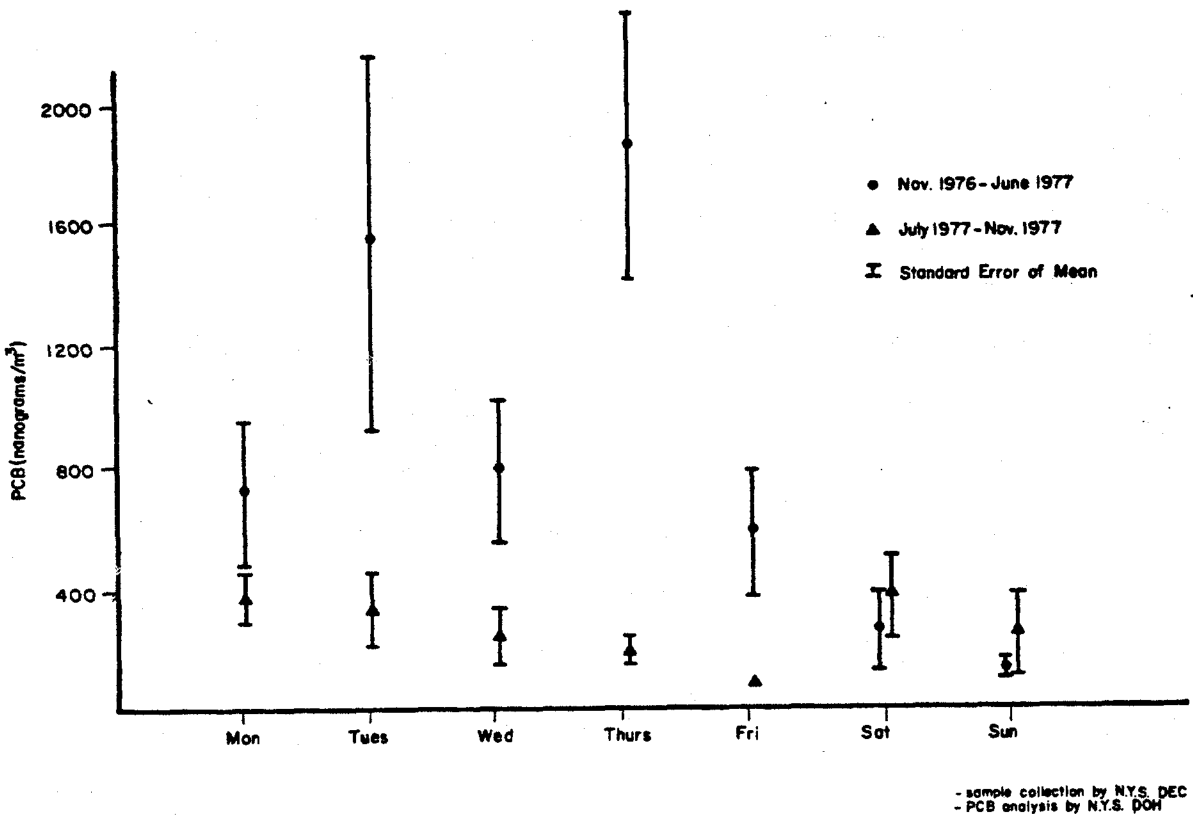


Table 14: Ambient air PCB levels (ng/m^3 of Aroclor 1016) at dump and dredge spoil areas.

	Caputo*	Fort Miller*	New Moreau**
	3000	4400	160
	5900†	1160	50
	4100†	930	110
	1000†		
	2200		
Average:	3240	2160	107

Source: Romano[21]; PCB analysis by N.Y. Department of Health.
† These are 2.5 hr. air samples from one day. All others are 8 hr. samples.
* Dump area.
**Dredge spoil area.

It should be noted that dustfall jars do not quantitatively trap PCBs. They represent a rough field estimate which tends to give low results because during the 30-day sampling period PCB-contaminated particles in the jar can be resuspended and lost, and PCBs are also volatized. The latter is clearly evident in the chromatograms of dust-born PCBs which are enriched with the less volatile components.

These levels are not unprecedented[22]. Airborne particulates in four US cities were found to have from 27 to 230 μg PCB/g of particulates, and a continent-wide mean rate of fallout of 60 to 100 μg PCB/m^2/yr was estimated. Measurements across southern Sweden indicate a range of 7 to 126 μg PCB/m^2/yr. But dry fallout near a DDT manufacturing plant in the Los Angeles area was measured to be 600 μg PCB/m^2/yr. The Ft. Edward levels are comparable to this, but, understandably, above the national average.

In November 1977, air samples were taken at two dump sites (Caputo and Fort Miller) and the Moreau dredge-spoil site. The results are depicted in Table 14 and show that PCBs are clearly being emitted from the landfill sites. Dredge spoil appears to be a much weaker source of PCBs to the atmosphere than the landfills or the manufacturing facilities, but do constitute a definite source at least when recently dredged.

3. Accumulation in plants

Plant samples were gathered at these same landfill and dredge disposal sites[23]. Two dozen plant species were sampled with a large number being common to all sites. Control tissues were collected no closer than several miles west of the Moreau site. Concentrations of PCB in or on plant tissues from these collections varied widely from as high as 2770 ppm (dry weight) to less than detection (Table 15).

Table 15: Average PCB levels associated with plant tissues at dump and dredge disposal sites along the Upper Hudson River. Concentrations are based on dry weight.

Site	Average PCB (ppm)	Number of samples	species	Range
Caputo	502	12	9	2770-28.3
Fort Miller				
on dump	146	9	6	484-11.6
below dump	15.1	7	6	23.4-5.13
hill opposite	6.0	9	7	14.4-1.32
Moreau	0.58	19	10	1.34-0.25
Control	0.23	22	15	1.68-<0.2

PCB analyses by WARF Institute, Madison, Wisconsin.

The extremely high levels of PCBs associated with the plant tissue suggest that surface adsorption of contaminated dust is involved rather than transport of PCBs from the soil. Additionally, supporting this hypothesis is the fact that plants closest to the soil (goldenrod, aster, grasses) have the highest PCB levels at each site; staghorn sumac, the next highest, is very pubescent and somewhat sticky, making it a better dust trap than other plants. Finally, looking at the data from trees at the Caputo site (Table 16), one can note several observations consistent with surface adsorption of volatized PCBs. The lower tissues and the tissues with the greatest surface to volume ratio (leaves) have the highest concentrations of PCBs.

Although root-to-shoot transport might be implicated by the presence of PCBs in xylem wood (cores), three other possibilities exist. PCBs may have diffused through the bark and be associated with the outer surface of the xylem or cambium, transport may be occurring from the leaves to the stem and roots, or possibly, inattention to contamination from handling or coring through contaminated bark could be responsible.

Table 16: Total PCB concentrations (μg/g dry weight) of plant tissues from trees at the Caputo site.

Species	Lower leaves*	Upper leaves**	Lower twigs*	Upper twigs**	Cores†
Pitch pine	317	81.2	87.1	17.7	1.2
White pine	215	--	120	--	1.16
Quaking aspen	89.6	28	--	--	--

Source: data from Benenati[23].
* Lower tissues were taken from ground level to 2 m above the ground.
**Upper leaves and twigs were sampled from approximately 5 m above the ground.
† Cores were taken in the trunk of trees between 1 and 1.5 m from the ground and the bark plug discarded.

Even if PCBs are not transported by the plants and merely attached to the surface of the leaves and twigs, any animal which consumes these tissues will also consume the PCBs. Effects on the plant itself appear to be minimal. No gross abnormalities nor obvious signs of chlorosis were noted among the contaminated plants which could be definitely associated with high PCB doses.

D. Mass Balance

1. PCBs in Upper Hudson sediments

As explained in Section A, the Upper Hudson River sediments can be divided into two areas, hot spots (areas of PCB concentration >50 ppm) and cold areas (PCB concentrations <50 ppm). Table 2 provides the average PCB concentration of surface samples taken in each of these areas for each river reach or pool. From Figure 6, however, one can see that much of the mass of PCBs is not in the surface samples, but often buried. Table 17 is constructed from the concentrations shown in Figure 6 and shows the depth to which one must go to account for various proportions of the PCB mass.

Table 17: Depth in sediments of the Upper Hudson River to include various proportions of the total PCB mass.

Percent total PCB mass	Depth in sediment(inches)		
	Reach 8,9	Reach 6,7	Reach 1-5
50	15	7.4	8.4
90	31	16	18
95	34	18	25
99	36	30	34

The total mass of PCB in the hot areas and the cold areas has been estimated[24,26]. The estimates are within 25% of each other and, considering the difficulty in estimating the depth of PCB contamination in sediments not cored and the necessary judgement in defining the extent of hot spot coverage, the agreement is quite acceptable. Table 18 summarizes these mass estimates by reach.

Table 18: Estimated mass of PCB in riverbed sediments of Upper Hudson River.

Reach	PCB mass (thousands of lbs) Total	Hot spot	Cold area	Scourable*
9	3	**	3	2
8	118	98	20	47
7	16	6	10	4
6	49	41	8	9
5	45	11	34	9
4	20	12	8	7
3	18	2	16	11
2	14	0	14	3
1	13	0	13	6
All	296	170	126	98

Source: Tofflemire and Quinn[26].
* Estimated from relative scour velocities determined from sediment transport model[9].
**The average concentration for this reach is 20 ppm, but sampling is inadequate to define hot areas and cold areas. It should probably be considered a cold area.

Approximately 57% of the PCB mass in river sediments between Ft. Edward and Troy is located in hot spots which represent only 8% of the riverbed area. No hot spots have been found in the lower two reaches (below Lock 2), but fewer samples were taken there and small areas could have been missed.

Between the Old Ft. Edward Dam site and Bakers Falls (Figure 20) lie five extensive areas where sediment accumulated when the dam was in place. These deposits (remnant deposits) have been eroding rapidly since 1973, when the dam was removed, except where stabilization efforts were completed in 1975. Approximately 140,000 lbs. of PCB contaminate these deposits.[25]

2. PCB movement from the Upper Hudson to the Estuary

Conceptually PCBs can move from riverbed sediments primarily by two mechanisms: leaching (or desorption) from the sediments into the flowing water and/or erosion of the contaminated bed material. Although these are basically physical phenomena, they may be enhanced by biological activity. Benthic organisms pump water through the surface layer, and microbial fermentation of organic matter produces methane and other gases which can stir up the sediments in rising. Barge traffic during low water also enhances sediment scour.

Erosion (scour) probably provides the primary mechanism of PCB transport in the Upper Hudson River, but the half of PCB transport[8] which occurs at low flows may not be the result of riverbed scour. The amount of PCB vulnerable to scour has been estimated from a computer model of river hydraulics and sediment transport[9]. Approximately one third (33%) of the total PCB in the sediments between Ft. Edward and Troy are subject to scour (Table 18).

Although it is not possible to quantify the relative contribution of the hot spots to this scour, some hot spots do lie in erosional zones. The center of the river channel usually has the greatest potential for scour, but the PCB concentration in these sediments rarely exceeds 50 ppm. (N.B. High concentrations are sometimes found where the cross section of the river is greatly enlarged; the channel areas here act as transient sediment traps which scour under extreme flows.) The river banks and shallow shoreline deposits are depositional areas where 1½ to 3 feet of sediment has collected during the past 68 years. Sediment samples with high PCB levels are more frequently associated with these regions than the channel regions[26].

Although the source is yet to be defined, the total mass of PCB moving into the estuary is well documented. The Upper Hudson basin delivered approximately 6000 pounds of PCB to the estuary in 1977. The sediment-transport model estimated that between 70,000 and 120,000 lbs of PCB will be transported into the estuary during the next 20 years if no remedial action is taken.[9] The relative contribution of each reach to scour is given in Tables 6 and 18. Scour potential is greatest between Locks 2 and 4 (reach 3 and 4) and the Thompson Island Dam and Lock 7 (reach 8) (Table 6). These same reaches can contribute the most PCB (Table 18), with reach 8 alone estimated to contribute almost half (48%) of the scourable PCBs between Ft. Edward and Troy.

The remnant deposits also constitute a source of readily erosible material that in some areas is highly contaminated[25]. Approximately 45,000 lbs of PCB (32% of PCB in remnant deposits) can eventually be transported out of the area by erosion. This is occurring rapidly as the loss of PCB from the remnant deposit is estimated at 8,600 lbs per year.[25] Much of this PCB will probably deposit in lower reaches for now, but some undoubtedly contributes to the present flow of PCB over the Federal Dam at Troy (5,700 pounds per year).

The rate of leaching of PCB from sediments has not been investigated yet. After the scourable contaminated sediments have been swept out of the Upper Hudson Basin or to stable deposits, PCB will move into the water column by leaching. Contamination of the water and, therefore, biota would consequently continue.

3. Summary of PCBs in the Hudson River Basin

A substantial quantity of PCB exists in the Hudson River sediments (estimated to be about 640,000 pounds). The General Electric facilities at Fort Edward and Hudson Falls were discharging an average of 30-40 lbs PCB/day (~13,000 lbs/yr) from 1970 to 1973.[28] If one assumes that both usage and losses of PCB from the General Electric facilities during the peak years prior to 1970 were at least double the post-1970 rate, then a total discharge since 1950 to the river of more than 600,000 pounds of PCB can be calculated. This suggests that virtually all the PCBs discharged into the Hudson River for the 26 years of their use are still in the sediments of the river, and most of the PCB is still within 40 miles of the discharge point (upstream of the Federal Dam at Troy).

But one should be cautious in drawing this conclusion. The EPA suggested[29] that PCBs discharged to the waters of the U.S. since 1929 were about 12% of total cumulative sales of PCB during the same time. General Electric's discharges were only 0.15% of their purchases.

The riverbed, however, is not the only contaminated part of the environment. A slightly larger quantity of PCB can be found in the landfills and dumps near Ft. Edward and dredge spoil areas along the Upper Hudson River (Table 19). But PCB in these sites is not as mobile as that in the riverbed. River sediment PCB appears to be an order of magnitude more erosible. Volatilization rates, however, are probably greater at the landfill sites, but no quantitative values are available.

Finally, Table 19 makes it clear that the biota of the river contains very little PCB relative to the river sediments or dumps. Biomass estimates are not available for the Upper River, but even doubling the estimated total PCBs in biota would make little differences, relatively speaking.

Table 10: Summary distribution of residual PCBs in the Hudson River Basin.

Area	Estimated total PCBs lbs	Estimated securable PCBs lbs	Calculated loss rate* (lbs/yr)
River sediments			
Remnant deposits(25)	140,000	45,000	8,600
Upper Hudson riverbed(26) (Ft. Edward Dam Site to Troy)	300,000	98,000	5,700
Lower Hudson riverbed(7) (Estuary-Troy to New York Harbor)	200,000	?	?
Dredge spoil areas(20) (Upper Hudson)	160,000	?	170
Landfills and dumps(20) (Upper Hudson)	530,000	-	800
Biota Lower River(27)	200 - 2000	-	?
Total	1,330,000		

* Does not include volatilization.

4. Relation of Hudson River to North American PCB use and environmental contamination.

PCB production in the U.S. has rapidly declined since 1970. In that year the Monsanto plant at Sauget, Illinois (sole U.S. manufacturer) produced about 85 million pounds, 73 million pounds of which were sold in the U.S.[29] Since 1929, when PCBs were first introduced, almost one billion pounds of PCB have been sold in North America. Although the data on PCB discharges is very limited, EPA estimates that approximately 590 million pounds have been placed in dumps, 59 million pounds have been discharged to the atmosphere and 120 million pounds have been discharged directly to fresh and coastal waters.[29]

As noted in the introduction, between 1966 and 1974, General Electric's Ft. Edward and Hudson Falls facilities purchased 78 million pounds of PCB or approximately 15% of Monsanto's domestic sales during that time.(29) This might suggests that General Electric's discharges to the Hudson River Basin represent close to 15% of the nationwide total discharges to the environment.

Generally speaking, contamination of the Hudson River Basin exceeds, in level and scope, any other area found to date in the U.S.(30) River sediment concentrations are at least an order of magnitude higher than other contaminated systems (e.g. Lake Ontario; Lake Michigan; Escambia Bay, Florida; and soils from the Monsanto plant). The PCB level at a few other sites (e.g. Waukegan River, Illinois and Housatonic River, Connecticut) are comparable, but the resources contaminated do not appear to be as great as the Hudson River. Estimates of the quantity of PCB in the sediments of the Great Lakes(31) exceed those for the Hudson River (e.g. Lake Ontario, 660,000 pounds; Lake Erie, 4,000,000 pounds; and Lakes Huron and Superior, 35,000 pounds each), but the average sediment concentration of PCB does not exceed 100 ppb for any of the lakes.

140
850
169
650

II. E. Available Control Technology

1. General

Early in formulation of the plan of study[1], a number of potential methods of managing the PCB contaminated sediments were suggested. Although most of these technological alternatives were not studied in detail, their applicability to the Hudson River problem was reviewed[32]. The results of this review are summarized in Table 20. As can be seen, some of these alternatives are not applicable to the Hudson River problem because of high cost and/or impracticality, but most were judged to be insufficiently technically developed to evaluate. Development of sufficient technology to evaluate any of these systems would take five to ten years and cost more than several million dollars. This judgment has since been confirmed in the James River kepone studies.[33] During the time period required for the development of the technology, contaminated sediments would continue to disperse through the river system and become less amenable to any remedial action. Thus, the only management alternate studied in detail was physical removal of PCB contaminated sediments by dredging.

2. Dredging

a. Technology

Dredges in use today can be generally divided into three categories: mechanical, hydraulic and pneumatic.[24] Mechanical dredges normally lift the dredged material above the waterline by means of buckets or scoops of various designs and deposit it in a barge or similar conveyance for transport and disposal. Hydraulic dredges generally move bottom material via a centrifugal pump and pipeline directly toward a disposal area, whereas pneumatic dredges move bottom material by compressed air and pipelines.

Table 20. Suggested methods of managing PCB contaminated sediments.

Alternatives	Status of Technological Development	Potential constraints or environmental problems	Estimated treatment costs
Removal			
Activated carbon adsorption	Laboratory	Technology for application and retrieval has not been proposed.	$300-3000/acre treated
Bioharvesting	Conceptual	The time and costs involved with harvesting enough fish are prohibitive. Tremendous ecological side effects.	$2000/lb PCB removed
Adsorption by oil-soaked mats	Conceptual	Technology for application and retrieval has not been proposed. Tremendous ecological side effects.	Insufficient data
Destruction in place			
Degradation by ultra-violet ozonation	Developed for closed-system applications	Treatment requires closed reaction vessel.	Insufficient data
Biodegradation	Laboratory	Conditions for the natural microbial decompositions of PCB must be optimized.	Potential low cost
Chemical treatment	Conceptual	Possible ecological side effects.	Insufficient data
Fixing in place			
Adsorption	Laboratory	Possible ecological side effects.	Potential low cost
Erosion control of river bottom	Conceptual	------------	Insufficient data
Chemical fixation	Conceptual	Possible ecological side effects.	Insufficient data
Covering PCB contaminated sediments	Conceptual	Massive disturbance of ecosystem. Rupture of seal or ballooning of plastic due to gas formation. Placement of cover difficult.	Particulate matter: $3000-4000/acre Sheeting material: $700-1800/acre

SOURCE: modified from Horstman [31].

Mechanical dredges used in the U.S. include the dragline, the dipper, the grab bucket or clamshell, and the endless-charin dredge. Of these, the clamshell and dragline are the most common. The clamshell dredge consists of a derrick mounted on a barge with a "clamshell" bucket for excavating. The material is removed by forcing the opposing bucket edges into the sediment. The bucket is lifted out of the water and deposits the spoil on a barge or onshore. The dragline dredge is generally composed of a crane having a bucket suspended from a swinging boom mounted on a barge or truck. The dredge operates by scraping the material from the bottom by pulling the bucket towards the stationary crane. The spoil is then lifted and deposited on a barge or on the bank. Both the clamshell and dragline are available in a wide variety of sizes.

The hydraulic suction dredge can be fitted with various mechanisms at the suction pipe inlet to facilitate sediment removal. These mechanisms include rotary cutters or cutterheads, auger-type cutterheads and high-pressure water jets. Mud shields or dustpans are used on some hydraulic dredges in conjunction with the water jets to reduce secondary suspension at the suction inlet. However, these dredges collect only 10 to 30 percent solids, cause considerable sediment agitation when mechanical cutterheads are used, and can induce secondary pollution at the receiving site because of high water content in the dredged material. Consequently, without the use of sediment-control measures, conventional dredging could pose a serious threat for aggravating an existing, but possibly dormant, pollution problem. Some generic types of hydraulic dredges in the United States include the cutterhead, the plain suction, the dustpan, the hopper, the sidecaster and the Mud Cat. The Mud Cat dredge is comparable to the cutterhead, except that, in lieu of a rotating cutter, it features an auger-type horizontal cutterhead. This dislodges the material, and the auger moves it toward the suction pipe. A mud shield surrounds the auger and thereby minimizes mixing of the disturbed bottom sediments with the surrounding water.

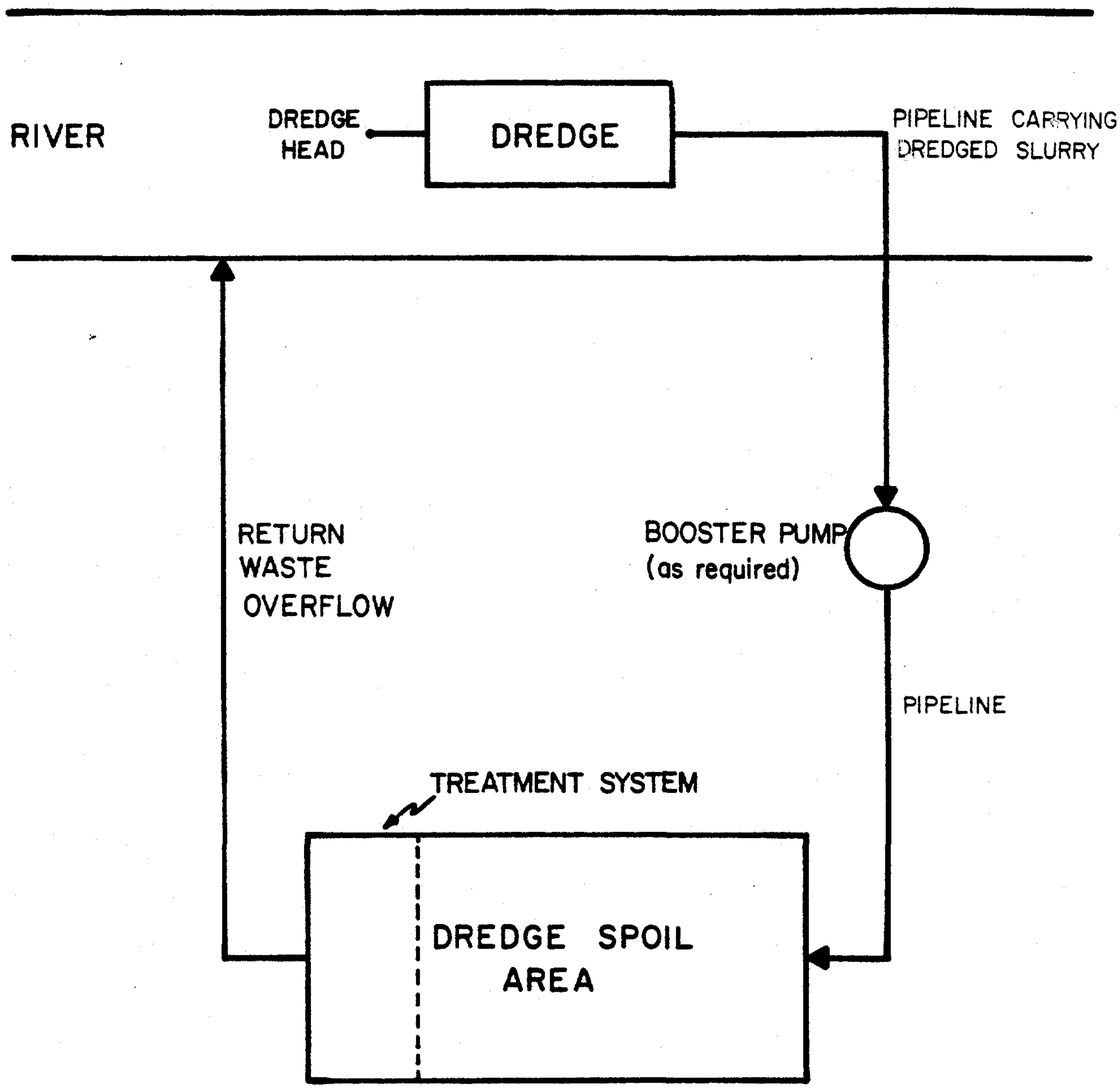
Dredging technology in some foreign countries surpasses that of the United States, especially in Japan, where serious problems with in-place toxic substances prompted the development of a dredge which was designed to remove contaminants rather than to excavate river channels. A significant advancement in dredging technology for removing contaminants was made by improving a pneumatic dredge. The pneumatic or "Pneuma" dredge, originally developed in Italy, uses hydrostatic head pressure and compressed air to remove contaminated sediments. By applying a vacuum to a pneumatic dredge, the Japanese were able to utilize the dredge in shallow water, thereby eliminating the constraint of needing high hydrostatic head pressure. This dredge is called the Oozer dredge.

In general, mechanical dredges can remove bottom material at near-inplace density, whereas, hydraulic and pneumatic dredges have to add dilution water to form the dredged-material slurry. Effective separation of the dredged-material from the water before it is discharged back into the river is necessary. Mechanical dredges, however, tend to resuspend more riverbed material than hydraulic or pneumatic dredges during the dredging operation.

The specific dredging technology applicable to a specific project is dependent on dredging objective, environmental constraints, river and dredge-material characteristics, cost, and equipment availability. A detailed review of these factors in relationship to the Hudson River PCB problem has been made.[24] The findings are summarized in Section III of this report.

Figure 16

SCHEMATIC OF HYDRAULIC DREDGING



SOURCE: modified from Malcolm Pirnie[24]

b. Environmental effects

There are two areas where PCB loss can affect hydraulic dredging removal efficiencies: losses at the dredge head and losses in the return waste overflow from the dredge spoil area (Figure 16).

Full-scale monitoring of DOT hydraulic dredging in 1976 and 1977 in the Upper Hudson showed that dredge-head losses are minimal (Table 21). Table 22

Table 21: Measured PCB losses at the dredge head caused by hydraulic dredging in the Upper Hudson River near Lock 4.

	River Cross Section	Dredge Head	Increase in River Below Dredge Head
Area	1,600 $ft.^2$	16 $ft.^2$	---
Water velocity	.65 fps	.65 fps	---
Total PCB	.1-.4 ppb	2.1 ppb	0.018 ppb 0.096 lbs/day
Suspended Solids	15-35 mg/l	120 mg/l	1 mg/l

Source: Tofflemire.[34]

shows the return flow loss at three monitored dredging sites in the Upper Hudson. These studies show that one hour of sedimentation can provide 90% removal of the PCB-laden suspended solids in the return flow. This was further improved by the addition of a cationic polymer to promote rapid destabilization of suspended particles. Surface scums that developed during the dredging operation were found to be very high in PCBs. PCB concentrations were as high as 18,000 ppm, but the total mass was small. Their collection and removal was found to be desirable and relatively easy with proper placement of an oil boom.[6, 35]

Table 22: Summary of hydraulic dredging performance at three sites on Upper Hudson River.

Parameter	Buoy 212	Lock 4	Lock 1
Silt and clay			
(% passing #200 sieve)	5	25	26
Lagoon flow-through time			
(typical, by salt tracer)	45 min.	55 min.	15 min.
Lagoon influent			
average % solids	5	3	1
PCB in solids (μg/g)	100	20	15
Lagoon effluent			
Without polymer			
Suspended solids (mg/l)	500	460	2000
PCB (μg/l), composite	100	3.0	40
With polymer			
Suspended solids (mg/l)	250	230, 20*	400
PCB (μg/l), composite	50	<1.5	8
Removal efficiencies (%)			
Without polymer			
Suspended solids	99	98	80
PCB	98	99.5	73
With polymer			
Suspended solids	99.5	99, 99.9*	96
PCB	99	99.8	95

Source: ammended from Tofflemire.[6]
* Polymer fed between lagoons.

DEC also monitored the 1977-78 dredging near Rogers Island which involved a dragline dredge and power shovels (see Figure 20 for location).[36] This 200,000 cu. yd. project and its environmental effects have been evaluated in detail.[37] The adverse effects appeared to be minimal and removal efficiencies were slightly better than the original estimates. These effects were generally limited to within one river mile below the project area. Table 23 summarizes a portion of these data.

Table 23: Performance of dredging project at Fort Edward Channel during the Summer of 1977. Comparison of actual dredging performance with predictions of Environmental Assessment (36) when the project was approximately 45% complete.

Parameter	Predicted	Actual
Total suspended solids added to river by dredging	8700 tons assuming 5% fines 5220 tons assuming 3% fines	~3000 tons (4% fines)
PCBs		
In river	5 ppb at low flow	0.02 - 1.14 ppb
Disposal site leachate	3 ppb at 1500 gpd	0.47 ppb at 750 gpd*
Heavy metals	Very low increase predicted under "worst-case" conditions.	Insignificant increases through project area.
Esthetics	Noise, appearance of work area were recognized as temporary factors.	Degraded appearance localized; environmental impact not proportional.

Source: Mt. Pleasant.(37)
* The disposal area could not be covered before winter. Once the site is complete, a clay cover should reduce this loss.

The experience and data collected from the above full-scale Hudson River dredging projects clearly indicate that with proper precautions, the Upper Hudson River may be dredged with minimal adverse environmental effects, i.e., PCB and suspended-solids losses can be kept to insignificant levels.

3. Disposal

Three methods of final disposal of PCB-contaminated sediments removed from the Hudson River were studied and evaluated: incineration, biodegradation and engineered encapsulation.

a. Incineration

General Electric has investigated the technical, economic and environmental feasibility of destroying PCBs in river sediment using a gas-fired multiple hearth furnace.[38] All PCBs were destroyed when the afterburner temperature exceeded 1800°F (982°C) with 0.5 sec residency time of the exhaust gases. Although other unidentifiable chlorinated hydrocarbons were produced, they were destroyed by use of an afterburner and scrubber system. Heavy-metal losses were also monitored and not found to be a problem.

Although technically and probably environmentally possible, burning river sediments is an expensive undertaking. Fuel costs alone (current prices) would be approximately $10/yd^3. In order to minimize operating and investment costs, the furnace would have to have a capacity of at least 10^5 tons/year (114,000 yd^3).

Wright-Malta Corporation of Ballston Spa, New York has devised a gasifier-gas turbine system which can generate electric power from solids and liquid wastes.[39] The process chemistry has been proven in batch and continuous bench-scale equipment. Tests demonstrated that process conditions providing 1100°F, 300 psi, an alkaline catalyst and 1 hour dwell time would completely destroy PCPs absorbed in paper.

A one megawatt pilot plant could be constructed with operation to commence within two years. It would handle a mixture of 20 tons of solid waste and 30 tons of sewage sludge per day or 15 tons of solid waste and 35 tons of dredge spoil per day. Approximately, 10,000 tons (11,000 yd^3) of dredged material could be treated per year at an estimated total annual operating cost of $650,000. Subtracting revenues from electricity generated, the cost would be approximately $50/ton ($57/yd^3) of dredge spoil assuming no cost was assigned to concommitant solid waste disposal.

b. Biodegradation

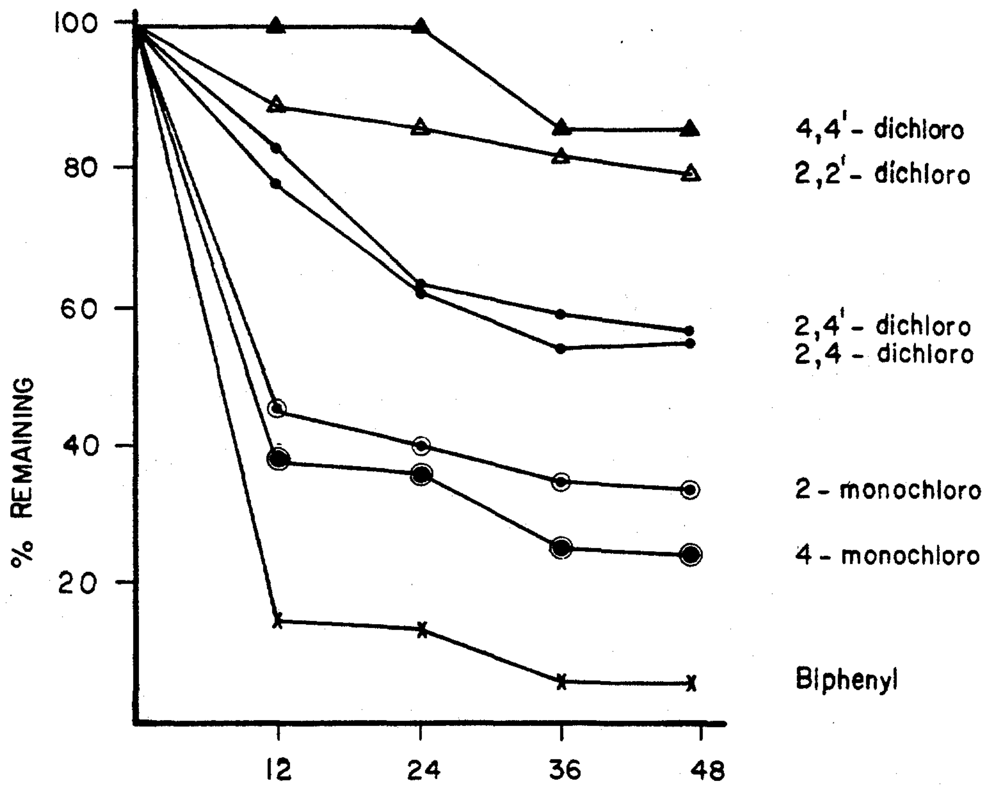
Research has been carried out by GE to explore the possibility of using naturally occurring microorganisms to reclaim PCB-contaminated Hudson River dredge spoils. This research was predicated upon the development of PCB-degrading enrichment cultures isolated from various contaminated sources and the study of practical methods of enhancing biodegradation rates of PCB in soil.[18,38]

Twenty-two strains (6 species) of naturally occurring microorganisms that degrade PCBs have been isolated and purified. PCB degradation was confirmed by measuring the loss of PCB and the formation of yellow-colored metabolic intermediates. Measureable PCB biodegradation rates were observed in shake-flask studies using pure and mixed cultures (Figure 17). Satisfactory mixed culture growth was observed in the presence of metal ion concentrations similar to those observed in dredge-spoil samples. Mixed-culture pH optima varied from about 5 to 8 and should be compatible with conditions attainable in dredge spoils. Certain surfactants have been shown to significantly enhance PCB biodegradation rates.

Biochemical Corporation of America has reported that they successfully applied an adapted strain of bacteria to degrade the PCBs in a

Figure 17

RELATIVE BIODEGRADABILITY OF 1221 COMPOUNDS



SOURCE: General Electric(18)

sample of a sewage sludge received from the City of Bloomington, Indiana(40). The sludge, containing 15% solids and 198 ppm PCB, was distributed into chemically clean Ehrlenmeyer flasks to which were added minimal salts for nutrients plus the specialized culture (except for the control flask). After two days of shaking, the PCB level was reduced to 54 ppm (74% reduction). No degradation occurred in the control flask (without the culture). A similar flask was run at the same time except that the sludge was diluted with five parts water. After five days of shaking with the culture, the

PCB level was less than detectable (99.9% reduction).

They conclude from this that PCBs in sewage sludge can be degraded by bacterial cultures and that the extent of this reduction is a function of time. These tests imply that other sludges could also be handled in a similar manner given proper conditions.

Because of the rapid development in this area, it is difficult at this time to assess the actual practicability of biodegradation as a disposal alternate. Although sufficient information does not now exist to design for biodegradation, its environmental acceptability and potential low cost make it a highly desirable option, and it would be unwise to take any management action at this time that would preclude its use in the future.

c. Engineered encapsulation

1. General description

Engineered encapsulation of contaminated dredged materials involves placing the contaminated material in a land burial facility in such a manner that it is permanently removed from man's normal environment. Within recent years, governments have issued detailed regulations regarding the design and operation of chemical landfills which are applicable to encapsulation of Hudson River PCB contaminated dredged sediments. These criteria relate to three aspects of the design of such a facility, i.e. site selection, lining and leachate prevention, and long-term operation and maintenance.

2. Design criteria

a. Site Selection

Potential sites for landfilling PCB-contaminated sediment from the Upper Hudson River Study area were identified based on the criteria

Table 24: Criteria used to select an adequate site for an engineered encapsulation facility to contain PCB-contaminated dredge spoil.

Parameter	Unacceptable	Ideal
Soil	Permeability $>10^{-5}$ cm/sec, less than 3 ft thick in situ. ($<1.4 \times 10^{-4}$ cm/sec overlayed) Class I or II agricultural soils.	Permeability $<10^{-7}$ cm/sec, in situ thickness >10 ft, soil passing # 200 sieve >30%, liquid limit >30, plasticity index >15.
Slope	Deep gullies, slope over 15%.	Slope <10%.
Surface water	Closer than 300 ft to any pond or lake used for recreational or livestock purposes, or any surface water body officially classified under state law. In special flood hazard areas or recognized wetlands.	>1000 ft from any surface water body. > 200 ft from intermittent streams.
Bedrock	Closer than 30 ft to highly fractured rock or carbonates, closer than 10 ft to all other rock.	More than 50 ft to highly fractured rock or carbonates.
Groundwater	Closer than 10 ft to groundwater, wells tapping shallow aquifers, closer than 1000 ft to any water supply well. Flow towards site.	>50 ft to groundwater, no wells or only deep bedrock wells within 2000 ft radius.
Committed land	Closer than 1000 ft to parks, cemeteries, residential areas, historic sites, etc.	>1500 ft away.
Biologically sensitive areas	Endangered plant or animal habitats, unique or regionally significant environments.	No woodlands, no locally significant features.

Source: Malcolm Pirnie, Inc.[24].

shown in Table 24. Using these criteria, 40 parcels of land with a total of 3200 acres were found to be generally acceptable as sites.[24] Detailed field studies would be required before final site selection can be made. Because the size and location of a disposal site depend on the actual dredging program selected, the detailed field studies and final site selection must await selection of an actual dredging program.

b. Lining and leachate prevention

Figure 18 illustrates potential paths through which PCB can be lost to the environment from a poorly-designed spoil site or landfill. Proper design of an engineered encapsulation site secures the contaminated material so that the potential for these losses are minimized. This includes placing an impermeable barrier beneath the contaminated materials and an impermeable cap above it to prevent excessive infiltration of precipitation from entering the contaminated spoils. The concept of limiting infiltration and percolation to the greatest possible extent is a necessary part of the design plans for any facility.

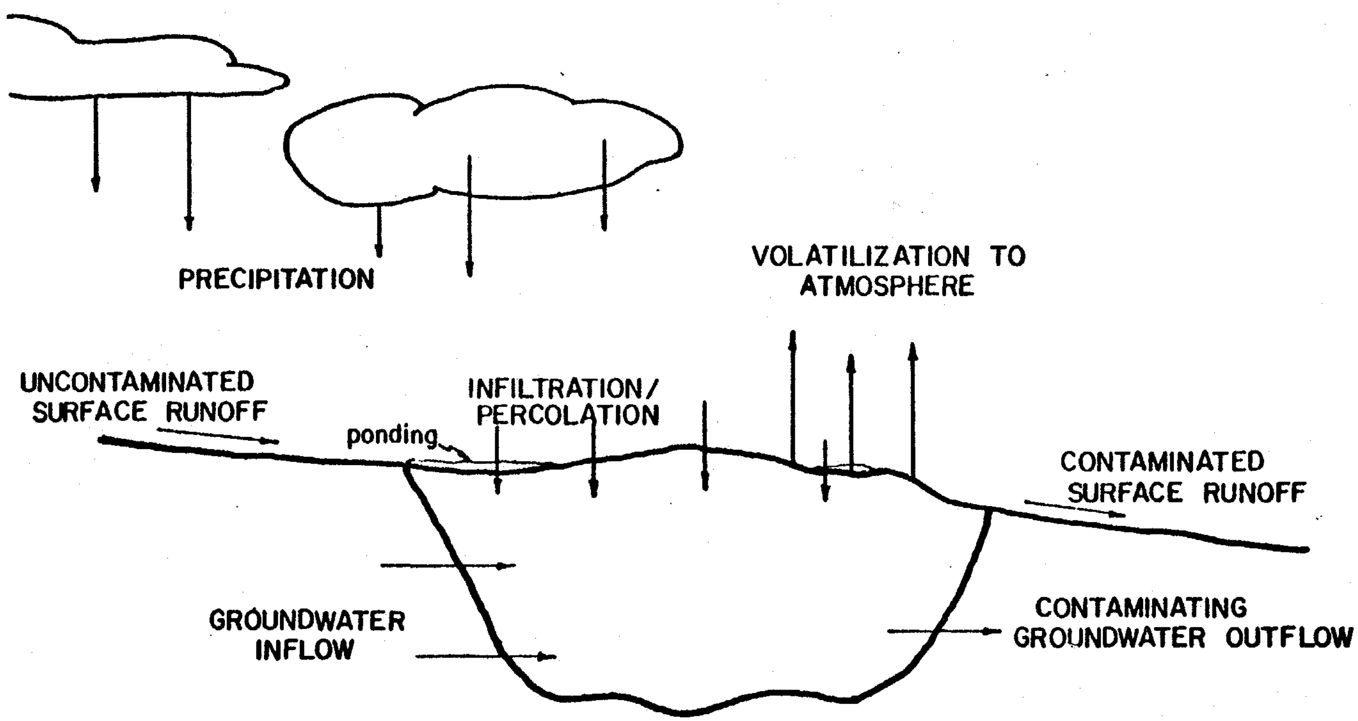
A leachate-collection system should also be installed beneath the spoils and a leachate-treatment facility designed for these sites to collect and treat any leachate that may be produced. An extensive groundwater monitoring system should be installed prior to deposition of any wastes to detect any contamination that might leach from the site and enter the groundwater system.

Figure 19 shows a sketch of a typical engineered encapsulation site. Features of such a site include:

- A natural impermeable layer ($K<10^{-7}$ cm/sec) at least 4 ft thick over the bottom of the site.
- Dikes (average height 14 ft) lined with at least 2 ft of impermeable material ($K<10^{-7}$ cm/sec).

Figure 18

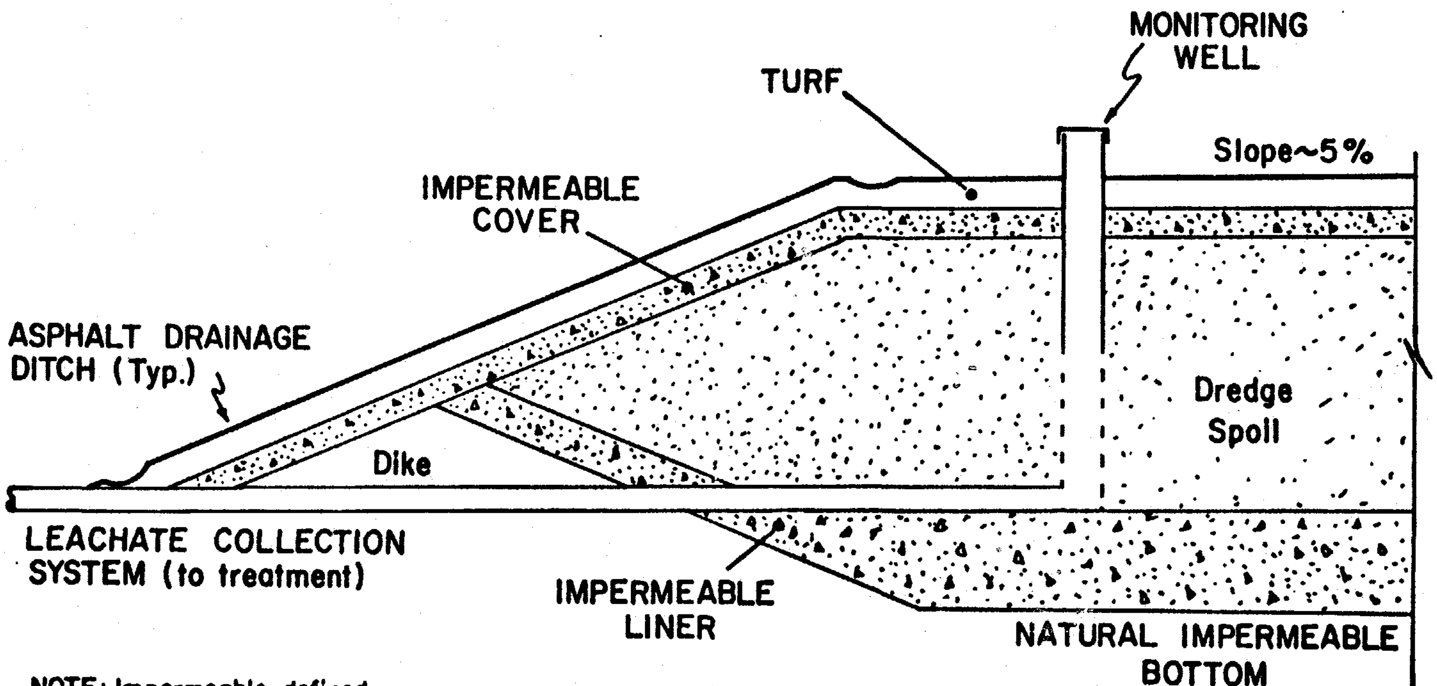
TYPICAL LANDFILL PROBLEMS SHOWING PRIMARY ROUTES OF CONTAMINANT LOSS



SOURCE: modified from Leis[20]

Figure 19

CONSTRUCTION OF TYPICAL ENGINEERED ENCAPSULATION SITE



NOTE: Impermeable defined as $K < 10^{-7}$ cm/sec

SOURCE: modified from Malcolm Pirnie[24]

-An impermeable cover ($K<10^{7}$ cm/sec) at least 18 in. thick over the top of the site. This, together with the 5 percent slope given the top of the dredged material will facilitate runoff and minimize the amount of rainfall penetrating the fill.

-An 18-inch layer of select material for turf establishment over the top of the site. This will be seeded and graded and a vegetative cover established to stabilize the site.

-A system of monitoring wells into the site to monitor leachate generation, and collect leachate for treatment.

-A system of groundwater-monitoring wells to detect contamination that might leach from the site and contaminate groundwater (not shown).

A model disposal site for containing PCB-contaminated spoils taken from the channel at Rogers Island was designed and put into operation in 1977.[36,37] This site's design varied somewhat from the criteria described above in that it was designed before these criteria were available. Preliminary data indicate that PCB losses from the site are and will continue to be minimal. Additional monitoring of the site is planned.

c. Long-term operation

An engineered encapsulation site is a manmade structure and as such will require long-term maintenance and operation. Essential elements of a maintenance and operation program include:

-Continued compatible use of the land surface (e.g. ecological study, recreation, material storage, etc.).

-Structural maintenance sufficient to insure the integrity of the impermeable barrier.

-Proper collection and disposal of any leachate developed (either via on-site treatment or by removal to an adequate, off-site treatment facility).

-Monitoring to insure that PCB losses to the environment are not occurring (i.e. air, biota, ground and surface water).

There is little experience with long-term operation of such facilities; and thus, there are uncertainties regarding operational costs. If no major problems occur, such costs should be minimal; however, if unforeseen problems occur, costs could be high.

III. Management Alternatives

A. Overview

Although an infinite number of alternate dredging programs for removal of PCB-contaminated sediments from the Hudson River are possible, distribution of PCBs, existing technology and practical considerations limit the number of actual practical alternatives. Four alternatives which appear feasible are outlined in Table 25. The following is a description of each of these alternatives along with the technologies and an assessment of the effectiveness of each in removing PCB from the river.

1. Maintenance dredging

Even if no action is taken to dredge PCB-contaminated sediments from the Upper Hudson, dredging will occur there in the future. The New York State Constitution gives the State Department of Transportation (DOT) the task of maintaining and improving the State canal system. DOT generally maintains a 12-foot deep channel 200 feet wide. The dredging history from 1950 to 1976 for the Champlain Canal from Troy to Ft. Edward has been summarized by DOT.[36] In the last 25 years, about 650,000 cu. yds. were dredged from this reach of the canal and wet-dumped inside designated areas. Another 1,600,000 cubic yards were dredged and placed in upland disposal sites.

In 1973, when the Ft. Edward Dam was removed, dredging quantities near the Rogers Island and Ft. Edward area greatly increased. From 1950 to 1970 dredging in this area totaled 550,000 cu. yds. However, the total from this area between 1974 and 1976 was 650,000 cu. yds.[36] Floods in 1976 and 1977 necessitated dredging of the river near Rogers Island again in 1977 and 1978, removing an additional 170,000 cubic yards.

Table 25: Summary description and evaluation of possible management strategies for the Hudson River.

Possible Management Action	Yd^3 Dredged from River (1978-1988)	Lbs. PCBs Removed from River System (1978-1988)	Types of Technology	Status
1. Further study - No management action	916,000	50,800	Modified DOT maintenance dredging program to assure permanent removal of >90% of PCPs dredged from river as part of maintenance program.	Continuous DOT maintenance dredging necessary for Barge Canal operation.
2. Stabilize and/or remove remnant deposits.	1,082,000* (888,000)**	165,000* (97,500)**	Bank stabilization and/or remove remnant deposits and modified DOT maintenance dredging program as outlined above.	Environmental assessment prepared; 2-year program anticipated (1978-79).
3. Remove remnant deposits and remove all river sediments with PCB concentrations greater than 50 ppm (hot spot dredging).	1,660,000	313,000	Removal of remnant deposits and hot spot dredging technology to vary from small specialized hydraulic dredges to large clamshell dredges. Maximum practical PCB containment technology would be used.	Remnant deposit environmental assessment prepared; 2-year program anticipated; hot spot environmental assessment under preparation; 3-year program anticipated (1979-81).
4. Removal of all river deposits greater than 1 ppm (>5 ppm in remnant deposit areas).	15,000,000	410,000	Massive clamshell dredging effort. Maximum practical PCB containment technology would be used.	Environmental assessment not as yet authorized; 10-year program anticipated (1979-89).

Source: calculated from Malcolm Pirnie[24, 25, 36] and Tofflemire and Quinn[26].
* Assumes area 3, 3A, and 5 are removed from the basin.
**Assumes area 3A and 5 are removed and area 3 is stabilized.

Using the past dredging experience and assuming that no other extensive dredging occurs, DOT will have to dredge and remove from the river more than 900,000 yd^3 of sediment in the next 10 years. Assuming a PCB concentration in the sediment of 35 ppm and a 90% removal efficiency, this activity will remove approximately 51,000 pounds of PCB from the river system.

2. Remnant deposits

The remnant deposits are those deposits between the former Fort Edward Dam site and Bakers Falls Dam, 2 miles upstream. These deposits, formed by sediment settling in the former Ft. Edward Dam pool, are highly erosible now that the dam has been removed, and during high river flows, material continues to be eroded and move downstream. The deposits reside in five distinct areas (areas 1 through 5) which can be handled by removal or covering and stabilization (Figure 20). Soils in areas 1, 2 and 4 have PCB concentrations of 1-20 ppm; whereas in areas 3 and 5, the soil is contaminated to about 25-200 ppm. Area 3A has a surface (top 12 inches) contamination which averages approximately 1000 ppm.

Because of their variable PCB concentration and erosibility, each of the remnant deposit areas should be treated differently.[25] No structural action is planned for areas 1, 2 and 4 because of their low PCB content. Area 5, although high in PCBs, has been previously stabilized and is not now actively contributing PCBs to the river. However, Niagara Mohawk Power Corporation is considering rebuilding the Ft. Edward Dam, and they would have to remove much or all of area 5 to construct the dam.

Because of its high PCB content, the surface sediments in area 3A would be removed immediately (1978). Area 3 is now eroding, but a combination of further stabilization efforts and removal would be able to treat the variable contamination there. Excavation of areas 3, 3A and 5 would remove approximately 124,000 pounds

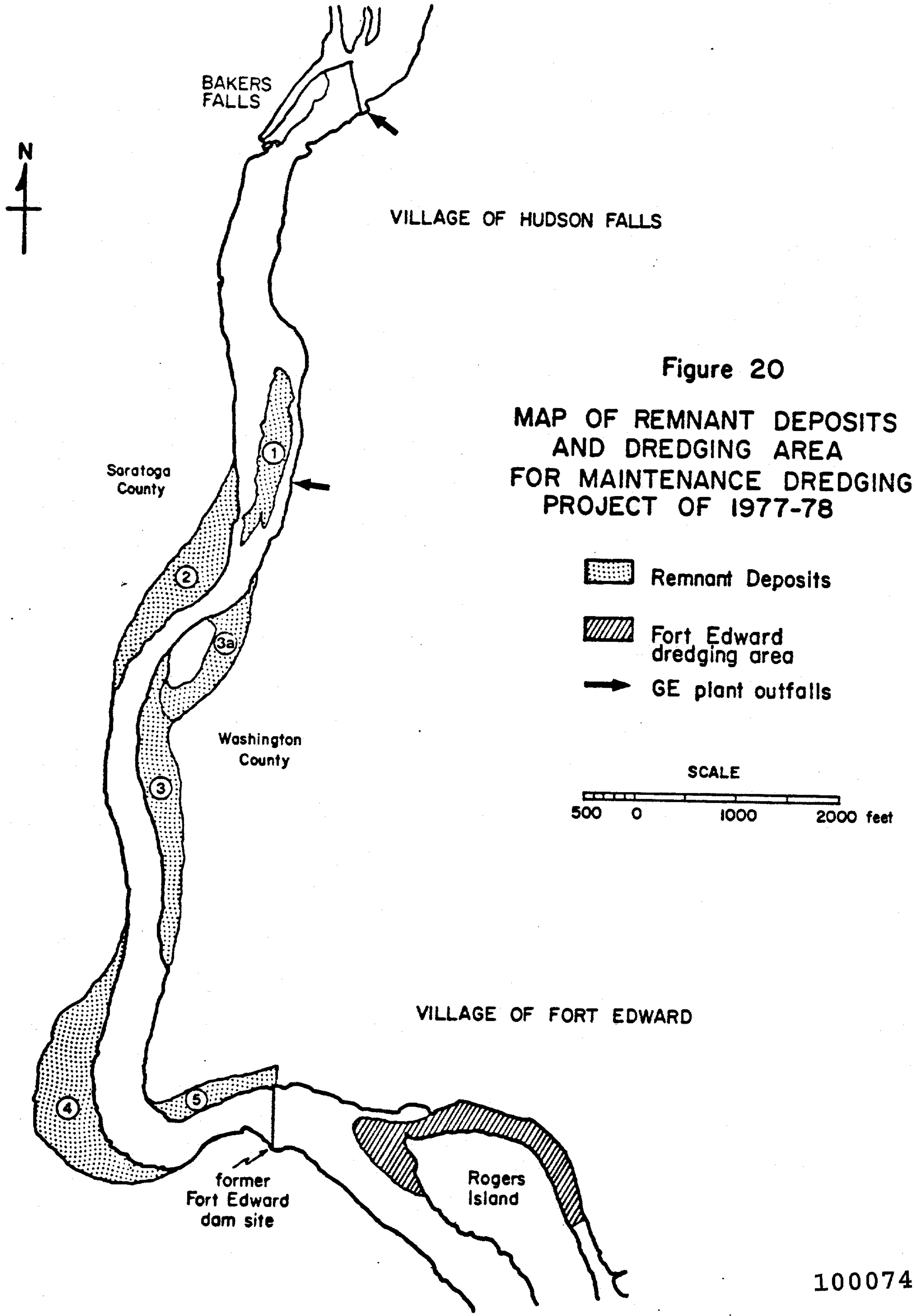


Figure 20

MAP OF REMNANT DEPOSITS AND DREDGING AREA FOR MAINTENANCE DREDGING PROJECT OF 1977-78 of PCB from the river. Normal maintenance dredging during the next 10 years is estimated to remove an additional 41,000 pounds. Whether stabilized or removed, losses of PCB from the remnant deposits would be reduced by about 75%.[25]

3. Contaminant removal

a. Hot-spot dredging

Areas of the river where the PCB level in the sediments exceeds 50 ppm have been referred to as hot spots. Dredging only these areas was considered because the greatest PCB removal can be achieved with the least environmental disruption and at the same time the unit costs ($/pound PCB) of removal are lowest. Dredging can be 94% efficient in removing PCB contaminated sediments[24] whether hydraulic or clamshell equipment is utilized. Thus, 160,000 pounds of PCB can be removed from the Upper Hudson River by dredging hot spots which comprise only 8% of the riverbed surface area. Additionally, the remnant deposit program and normal maintenance dredging (for 10 years) is expected to remove an estimated 153,000 pounds of PCB. The total, 313,000 pounds of PCB, represents 72% of the PCB in the Upper Hudson River and 40% of the PCB in the entire riverbed (Table 19 and 25).

This project would require careful examination of each major hot spot so that equipment best suited for each area could be selected. Although some additional sampling would be needed to delineate the hot spots more accurately, the dredging could probably be completed within three years.

b. Complete removal of PCB contaminated sediments

The most extensive reclamation program would involve dredging the entire 40-mile section of the Upper Hudson River from Bakers Falls to Troy. The dredging yardages involved are extensive (Table 25), but essentially all (94%) of the PCB could be removed from the riverbed above

Troy, thus eliminating a major source of PCB to the water and biota of the entire Hudson River. A dredging project of this magnitude would require approximately ten years.

B. Cost

The cost of each of the management alternatives discussed above are given in Table 26.

Table 2b: Total ten-year costs of potential management alternatives. Total costs are in millions of dollars. Unit costs are dollars/pound of PCB removed from the river system.

	Maintenance Dredging[1]		Remnant Deposits		Hot Spot Dredging		Complete Removal		Study and Monitoring[2]	Total Cost[3]	
	Total$	Unit$/lb.	Total$	Unit$/lb.	Total$	Unit$/lb.	Total$	Unit$/lb.		Total$	Unit$/lb.
1. Further study - No management action	2.3	45	--	--	--	--	--	--	0.23	2.5	50
2. Stabilize and/or remove remnant deposits	1.9	46	3.8[4] (2.2)[5]	31[4] (39)[5]	--	--	--	--	0.57[4] (0.41)[5]	6.3[4] (4.5)[5]	38[4] (46)[5]
3. Remove remnant deposits and hot spot dredging.	1.3	45	3.8	31	21	121	--	--	2.61	28.7	92
4. Removal all river sediments			3.8	31	--	--	182	654	18.6	204	499

Source: compiled and modified from Malcolm Pirnie, Inc.(7, 8, 9)

[1]Assumes DOT maintenance dredging cost of $2.50/yd^3$. Maintenance dredging in alternative 4 was assumed to be minimal and not remove substantial amounts of PCB.

[2]Environmental study and monitoring will require 10% of project cost.

[3]Long term maintenance costs are not included.

[4]Assumes removal of areas 3, 3A and 5.

[5]Assumes removal of areas 3A and 5 and stabilization of area 3.

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C. Environmental Impact

1. General considerations

Major contamination of Hudson River water with PCB has been occurring, even in the estuary, for approximately 20 years. As a result, the fishery resource is now largely unavailable to residents and visitors of New York State because of severe PCB contamination of fish flesh. Sport fishing and illegal commercial fishing still do occur on the Hudson River, however, and a reduction of PCB levels in the fish would go a long way towards ameliorating this public-health impact.

Ecological effects of this contamination have not been systematically investigated even during the studies reported here. Subtle, yet serious ecological effects of PCB in the Hudson River may easily have escaped the notice of limited investigation. For example, in the vicinity of Lake Ontario fish eating birds such as herring gulls appear to be suffering reproductive failure caused by embryonic mortality which is correlated with PCB contamination[41].

Whether one is primarily concerned with human health or ecological stability, the known impact of PCB contamination on fish edibility is sufficient to warrant consideration of remedial action. Any action which can reduce PCB levels in fish flesh would also help reduce any ecological effects.

For reasons explained in Section II, dredging was the only form of remedial action given extensive consideration. Two types of environmental impacts would be expected: short term or those associated with the actual dredging activity and long term or the ultimate effect of moving the contaminated dredge spoil from the river to a disposal site. An adequate evaluation requires that the impacts of dredging need to be compared with the effect of no direct management action. The impacts of various alternatives management strategies are summarized in Tables 27 and 28.

2. Short-term impacts (Table 27)

In general, as demonstrated in Section II, dredging programs can be designed such that the short-term impacts are relatively small, local and temporary. Ecological disruption can be limited to the area being dredged and, if timed properly, dredging will affect only the benthic organisms. Some land, the amount depending on the alternative, would have to be cleared and prepared to receive spoil; again a local disruption which would be temporary. (N.B. Replanting can rapidly restore vegetation). PCB levels in the air near the dredging and disposal sites would be elevated. during activity, but the levels would not pose a human health threat, nor create a noticeable effect on surrounding biota. Water supplies should also not be affected. And finally, aesthetic impacts would not be significantly greater than presently experienced with maintenance dredging unless the full dredging program is chosen. Then, 8-10 years of substantial activity could create local, temporary aesthetic problems.

Even if no management action is taken, dredging will occur in the Upper Hudson and the Estuary in order to keep the canal and docks open to navigation. This dredging activity will be much less extensive than either hot-spot dredging or total removal of all river sediments and can be carried out in such a way that short-term disturbances are minimal.

3. Long-term impacts (Table 28)

The long-term impacts of remedial action are much more difficult to assess than the short-term ones. On the positive side PCB-contaminated sediments can be removed from the river in such a way that PCB does not remain in the riverbed and this material can be stored or incinerated with concommitant PCB containment or destruction. Each of the three dredging

Table 27: Summary of short term environmental impact of various management alternatives.

	Aesthetic	Biota	Water Supply	Land
1. Further study, No management action	Minimal disturbance in sections of river dredged as part of DOT maintenance dredging program.	Localized elimination of benthic fauna in maintenance dredging areas.	Minimal increase in PCBs in vicinity of Waterford water supply intake when areas adjacent to water intake are dredged.	Land areas involved are small and land based operation will be local and of minimal environmental significance.
2. Stabilize/remove remnant deposits	Extremely localized.	Temporary increase of PCB levels in macroinvertebrates immediately downstream of dredging.	No short term impact other than as stated above for maintenance dredging.	5-20 acres of land may be completely disrupted.
3. Remove remnant deposits plus hot spot dredging	Local water quality standard for turbidity will be violated during dredging operation (2-3 yrs).	Temporary (1-2 years) loss of benthic fauna in dredged hot spot areas. Short term rise in PCB concentration in biota immediately downstream from dredging area. Temporary increase of PCB levels in macroinvertebrates immediately downstream of dredging.	Since there are no hot spots in vicinity of Waterford intake, no water supply impacts are expected other than the maintenance dredging impact stated above.	75-175 acres of land will be completely disrupted.
4. Removal of all river deposits with PCBs greater than 1 ppm (5 ppm in remnant deposits)	Potentially extensive. Continued local disturbance in the areas under active dredging will cause aesthetic problems for 8-10 yrs.	Temporary elimination of benthic fauna in dredged areas for period of up to 3 yrs after dredging. Temporary increase of PCB levels in macroinvertebrates immediately downstream of dredging.	Temporary increase in PCB concentrations in vicinity of Waterford water supply intake when that segment of the river is dredged.	Up to 1,000 acres of land will be disrupted.

options removes successively more of the PCB (from 32% to 97%) located in the Upper River sediments. Maintenance dredging is estimated to remove only about 11% of the PCB. As the precise regions of sediment that act as a source of PCBs to the estuary is still unknown, comparable reductions in PCB load to the estuary cannot be calculated and may not occur immediately but should be hastened by dredging. PCB levels in fish should respond relatively quickly to reductions of PCB in the water though substantial data to support this statement do not exist[27]. Anadromous fish in the lower Estuary (e.g. striped bass) are expected to recover more quickly than resident species because much of their life span is spent in cleaner coastal waters. In the Upper River, recovery of the fishery (i.e. PCB levels in flesh <5 ppm) will probably take much longer even if all the PCB-contaminated sediment is removed as the fish here are much more contaminated than those in the estuary[27]. Many unknowns, however, cloud these estimates. Food-web dynamics for PCBs are essentially unknown and could prolong the process of recovery. But, volatilization from water and microbial or other biological degradation, might hasten recovery. No quantitative information is available for these processes in the Hudson River.

In addition to these probable improvements expected from dredging several other benefits have been identified. Removal of PCB-contaminated sediment will probably reduce the concentration of PCB carried in the water and suspended sediment, particularly above Troy. Villages (e.g. Waterford) using the river water would therefore have one less problem to contend with, although the present levels are not considered to be an immediate health problem. Estuary water supplies would probably not be affected for several years unless total dredging is accomplished.

In addition to removing PCBs while dredging, a number of other toxic

Table 28: Summary of long term environmental impact of various management alternatives.

	PCB Containment	Biota [27]	Water Supply	Land	Air
1. Further study - No management action	Approximately 51,000 lbs of PCBs will be removed from the riverbed by maintenance dredging, leaving 385,000 lbs (or 88% of the inplace upper river PCBs) to disperse and probably recycle through the environment.	PCB levels in fish and other biota in the upper and lower river will not change in the foreseeable future (upper river >10 yrs, lower river >20); lower river concentrations may rise as highly contaminated PCB sediments move from the upper river into the estuary.	Water column PCB concentrations will continue to cause public health concerns for people using the river as a source of drinking water. Any plans to use the Hudson for drinking water in the future will have to accomodate this contamination.	No long term land impact is foreseen.	Continued probable volatilization from the river and dredge spoil from maintenance dredging.
2. Stabilize/remove remnant deposits	As much as 165,000 lbs of PCBs will be permanently removed from the riverbed leaving 286,000 lbs (or 63% of the upper river inplace PCBs) to disperse and continually recycle through the environment. Stabilization of the remnant deposits will substantially eliminate a known active source of PCBs to the upper river system; will reduce size and PCB complexities of DOT maintenance dredging program.	Will reduce by an unknown amount the time required for PCB levels in the upper river biota to fall. Minimal effects on the lower river biota are anticipated.	May reduce water column PCB concentrations in vicinity of Waterford water intake by reducing an active source to the upper river. Will have only a minimal effect on any lower river water supplies, and planned flood skimming for NYC water supply in the foreseeable future.	5-20 acres of land will be required for spoil disposal. Permanent restrictions on use of the land will be required. Restrictions may be mitigated by using land as a nature preserve or ecological study area. (Permanent restrictions could be changed by technological advancement in PCB bacterial, bio degradation research.)	Reduction of volatilization from river probably slight.
3. Remove remnant deposits & remove all river sediments with PCB concentrations >50 ppm. (hot spot dredging).	Approximately 313,000 lbs of PCBs will be permanently removed from the riverbed leaving 123,000 lbs (or 28% of the upper river inplace PCBs) to disperse and continually recycle through the environment. This option will eliminate all high concentration sediments (>50 ppm) from the river system. It will substantially reduce the size & PCB complexity of DOT maintenance dredging operations. The sediments to be removed are also generally contaminated with organic pollutants & other toxic materials. This project would remove these materials from the river environment.	Can reduce PCB biota concentrations in upper river by 50% to fish flesh levels of 20-40 ppm. In the lower river, fish burdens may drop by about 20% to about 8-12 ppm.	Should substantially reduce water column PCB concentrations in vicinity of Waterford water supply intake. Will have a marginal effect on lower river water supplies, existing & planned in the foreseeable future.	75-175 acres of land will be required for contaminated spoils disposal. Permanent restrictions on use of land will be required. Restrictions may be mitigated by using land as a nature preserve or ecological study area. (Permanent restrictions could be changed by technological advancement in PCB bacterial, biodegradation research).	Should substantially reduce PCB volatilization from the upper river.
4. Remove all upper river deposits >1 ppm (>5 ppm in remnant deposit areas).	About 410,000 (~94%) of the PCBs in the upper river will be permanently removed from the riverbed and the environment. Substantial reductions in the size & PCB complexities of future DOT maintenance dredging programs will occur. Most of the sediments to be removed are also contaminated with other organic pollutants and other toxic materials. This project will remove these materials from the river environment.	Can reduce PCB biota concentrations in the upper river to fish flesh levels of 10-20 ppm. By significantly reducing PCB input into the lower river, it may reduce the body burden of larger fish by about 30-50% to levels close to 5 ppm.	Will substantially eliminate the problem of PCBs in the village of Waterford water supply intake. Will also lower level of other toxic contaminants in Waterford water supply. Can measurably reduce PCB water column problems in vicinity of estuary water supply intakes by stopping active sources of PCBs to the lower river. May reduce PCB problems associated with flood skimming project.	About 1,000 acres of land will be required for contaminated spoil disposal. Permanent restrictions on use of land will be required. Restrictions may be mitigated by using land as a nature preserve or ecological study area. (Permanent restrictions could be changed by technological advancement in PCB bacterial, biodegradation research).	Will eliminate the river as a source of PCBs to atmosphere. Odors associated with extensive sludge beds should also be essentially eliminated.

substances and organic pollutants would be removed. Paper fiber and wood wastes from a variety of industries have accumulated on the river bottom ever since the dams were constructed more than 60 years ago. Heavy metals and other toxic substances have also been identified in these sediments[19,36].

Any dredging to remove PCB-contaminated river sediments will also reduce maintenance dredging requirements in the future. The amount of required future dredging could be considerably reduced and the complexity of handling contaminated material in the future could be substantially alleviated if hot-spot or complete dredging were carried out.

Finally, atmospheric levels of PCB that can be associated with volatilization from the river should be reduced in the long term by dredging. Odors associated with existing sludge beds would also be essentially eliminated when these beds are removed.

Unfortunately, not all the long term-impacts associated with remedial action are positive. The most serious possible environmental problem is what to do with the dredged material. The PCB can be destroyed by proper incineration, leaving an ash which would not constitute an environmental problem. If incineration is used, a disposal site must still be specially constructed to temporarily hold the dredge spoil . This site would have to contain 9000 acre feet (15 million cu. yd) if total dredging occurs, thus requiring more than 1000 acres of land. Hot-spot dredging or removal of the remnant deposits in the Ft. Edward pool will require much less land as would a temporary site for incineration. This land should be set aside as a nature preserve or ecological study area if the material is not eventually incinerated. Although it appears to be unlikely, the possibility still exists that deep-rooted plants can transport PCB from the soil to their leaves. It would be possible to prevent these plants from growing on the site, but it also may not be necessary. Further study of this problem could be carried out on the completed disposal site.

No long-term, negative impacts are foreseen for the river as a consequence of any of the action alternatives. In fact, one should find an improved quality of biota in the Upper River if most of the sludge beds and contaminated sediments are removed.

If no remedial action is taken, some dredging will still occur in the Upper River and the Estuary to maintain the navigation channel. Over the next ten years approximately 40,000 lbs. of PCB (<10% of PCB in the Upper Hudson River) are estimated to be removed from the riverbed.

Additionally, PCB in the sediment will continue to move from the Upper Hudson into the Estuary for at least the next 20 years[9]. Fish throughout the river will therefore still be exposed to PCBs in the water column. PCB levels in fish flesh would probably not begin to decline for at least a decade or two[27]. This recovery would be slower in the Estuary as that would be the last part of the river to be "flushed out" by river flow. Again, unknown aspects of the fate of PCBs in the biota of the Hudson River make these estimates very tentative.

D. Economic Impact to Fishery (written by J.D. Sheppard)

1. Economic value of fisheries

The Hudson River has influenced and continues to influence a variety of recreational and commercial fisheries. The magnitude of this influence is difficult to quantify in certain areas, particularly those involving anadromous and marine species. Nevertheless, it is believed that the actual contributions and related economic values fall within the range of the estimates presented in Tables 29 and 30.

a. Commerical fisheries

The Hudson River is estimated to be currently making a multi-million dollar economic contribution through a variety of commercial and recreational fisheries, both marine and freshwater. In the ten years prior to a ban on a major portion of the commercial fishery in 1976, the commercial finfish fishery (for American shad, striped bass, Atlantic sturgeon, American eel, herring and other species) was reported to be in the order of 300,000 pounds with a landed market value approximating $53,000. However, these statistics should be regarded as the minimum values and, when reporting errors are taken into consideration, the commercial fishery is probably closer to 600,000 pounds and $150,000 - $200,000 in value. In addition, there is an active commercial bait fishery operating in the Hudson River; but, no catches or associated values are available at this time.

Several anadromous and marine mid-Atlantic commercial fisheries could also have a portion of their catches associated with the Hudson River. These fisheries would be those for striped bass, American shad, bluefish, butterfish, winter flounder, summer flounder, menhaden, weakfish, tidal silversides and sea robin. Because no detailed stock assessments are avaiable for most of the species mentioned above, it can only be noted that at least some portion of the New York commercial marine landings (e.g. 1974 New York marine landing: 7.05 million pounds with a landed value approximating $1.8 million dollars) is of Hudson River origin and that the value is in the order of magnitude of at least $100,000's.

b. Recreational fisheries

In comparison to the commercial fisheries, the recreational fisheries associated with the Hudson River are more recent and less under-

Table 29: Summary of past, present and potential values for the commercial fisheries of the Hudson River.

Fishery	Location		Annual value	Annual catch
Finfish (Atlantic sturgeon, Striped bass, shad, eel, herring, carp, etc.)	Estuary	Past	~$150,000 to $200,000	~600,000 lbs.
		Present	~$150,000	~400,000 lbs.
		Future	~$250,000 to $450,000	~1,250,000 - 2,000,000 lbs.
	Marine		$100,000's	Unknown
Shellfish (Blue-claw crabs, clams, mussels and oysters)	Estuary	Past	$ Multi-Million	
		Present	$ 0	
		Future	$ Multi-Million	

Source: Sheppard[42].

Table 30: Summary of present and future values of the recreational fisheries of the Hudson.

Location		Annual Angler-Days	Annual Value
Glens Falls to Troy Dam	Present	0	
	Future	Up to 100,000	Up to $1.25 million Annually
Troy Dam to Poughkeepsie	Present	~30,000	~$300,000
	Future	Up to 1,000,000	Up to $12.5 million
Poughkeepsie to Battery	Present	~135,000	~$1.35 million
	Future	Up to 1,000,000	Up to $12.5 million

Source: Sheppard[42].

stood. Between Glens Falls and the Federal Dam at Troy, there has been a small but unquantified recreational fishery has been reported for black bass, black crappie, walleye, yellow perch, brown bullhead and an occasional striped bass. No estimates of the effort or the related expenditures are presently available for this section of the river.

From the Federal Dam at Troy to Poughkeepsie, it has been estimated that at least 30,000 angler-days are spent annually fishing for largemouth and smallmouth bass,brown bullhead, yellow perch, blueback herring, alewife, rainbow smelt, sunfish, black crappie and incidental catches of striped bass and American shad. Assuming expenditures for an angler-day approximate $10.00, then this freshwater segment of the Hudson River fishery is generating at least $300,000 annually. Below Poughkeepsie, the recreational fishery is dominated by estuarine and anadromous species including striped bass, spots, eels, white perch, blueback herring, alewife and white catfish. Catches of Atlantic tomcod, juvenile bluefish, weakfish, winter and summer flounder and American shad have also been reported; however their importance is presently unknown. Based on limited data, it was estimated that prior to 1976, a recreational effort of at least 135,000 angler-days occurs annually in the 45-mile section between Poughkeepsie and Tappan Zee Bridge. Assuming the current expenditures for an angler-day is approximately $10.00, then a minimum annual economic value of $1.35 million can be associated with this fishery.

As with the marine commercial fisheries, the Hudson River also influences several marine recreational fisheries. However, lack of stock identification precludes any precise estimation except for striped bass. For the striped bass, it has been estimated that contributions could range from 61,000 to 7,058,000 angler-days with a median estimate of 698,000 angler-days with an associated value of $10.5-14.0 million annually.

When the contributions to the marine recreational fisheries for bluefish, American shad, weakfish, flounders and other marine and anadromous fish species which utilize the Hudson River during a portion of their life-histories are finally ascertained, total value for the marine segment could approach $30-40 million annually.

2. Effect of PCB contamination on fisheries

Prior to the discovery of PCBs in Hudson River fish, it is generally agreed that the fisheries on the Hudson River were improving. As noted in Table 29, there is an estimated potential for doubling the commercial fisheries in the Hudson River proper and an unknown potential for the marine sector. At the same time, a tremendous potential for recreational fishing exists in the Hudson River (Table 30). In the section of the Hudson River currently closed because of PCB pollution (Glens Falls to the Federal Dam at Troy), there is an estimated potential for 100,000 angler days with an associated annual economic value of $1.25 million or more. Below the Federal Dam at Troy, an estimated potential of 2.0 million angler-days with an associated economic value in the order of $25 million is not unrealistic. As well, the potential for commercial and recreational shellfish fisheries (e.g. clams, oysters, mussels and blue-claw crabs) in the Hudson River estuary cannot be overstated. With the improvement of water quality, toxic substances (e.g. PCBs) would become the primary limiting factor in the reestablishment of a multi-million dollar industry.

Besides the closure of the Hudson River commercial fishery except for shad, sturgeon greater than 4 feet in length and goldfish, which currently represents a 60% loss based on 1976 data, the continued presence of PCBs in the sediments and water column of the Hudson River also poses a potential threat to both the marine commercial and recreational fisheries for certain anadromous and marine fishes. For example, analyses of striped bass from both Long Island Sound and the New York Bight have shown PCB concentrations generally greater than 2.0 ppm., but less than 5.0 ppm. If the U.S. Food and Drug Administration adopts a 2.0 ppm standard for PCBs, this represents a serious threat for the marine striped bass fisheries.

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