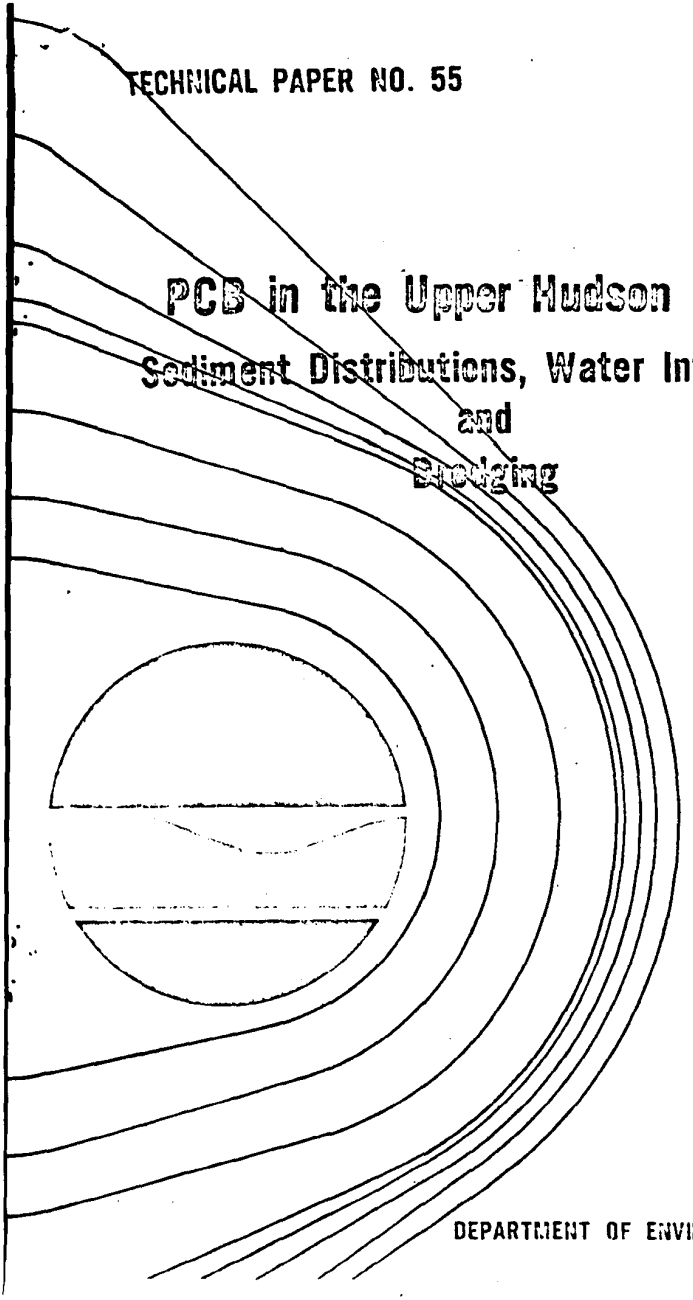
TECHNICAL PAPER NO. 55

PCB in the Upper Hudson River:

Sediment Distributions, Water Interactions and Dredging



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Disclaimer

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This is a version of a paper presented at the 51st Annual Meeting of the Water Pollution Control Federation in Anaheim, California. October, 1978.

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ERRATA SHEET

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pg. 7, Last sentence should read - - - a lower estimate of 29,000 kg (63,800 lb) is possible with only 26,500 kg (58,000 lb) in Areas 3, 3A and 5.[5]

pg. 58, Figure 19,20 and 21:

Air Speeds: 1.4 m/s should be: .338 m/s = .76 mph

3.7 m/s should be: .875 m/s = 1.96 mph

6.9 m/s should be: 1.62 m/s = 3.62 mph

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TECHNICAL PAPER NO. 55

PCB IN THE UPPER HUDSON RIVER: SEDIMENT DISTRIBUTIONS, WATER INTERACTIONS AND DREDGING

by

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PCB IN THE UPPER HUDSON RIVER: SEDIMENT DISTRIBUTIONS, WATER INTERACTIONS AND DREDGING*

Introduction

The purpose of this paper is to summarize some key data for this case study of PCB in the Hudson River. It will highlight findings of more general interest dealing with PCB sediment distributions, water interactions and dredging.

Figure 1 shows the upper Hudson River Basin. The 240 km (150 mile) reach from New York City to Albany is a tidal estuary. The 64 km (40 mile) reach from Albany and the Troy Dam to Fort Edward is the most highly PCB-polluted reach and is segmented by a series of low level dams and locks. The river north of the Fort Edward area is not contaminated with PCB. Figure 2 shows the river at Fort Edward near the sources of PCB discharge. The arrows indicate the two points where the General Electric capacitor manufacturing plant discharged over $.23 \times 10^6$ kg ($.5 \times 10^6$ lbs) over the last 25 years. PCB loss from these plants decreased rapidly from 1974 to 1977 and was phased out completely in 1977.

As noted in Figure 2, there was a Niagara Mohawk Power Corp. dam at Fort Edward before 1973 and a 3.2 km (2 mile) river pool in which some PCB-laden sediment accumulated. The dam was removed in mid 1973, and the river cut a channel into the sediment (primary sand and boards). The sediments remaining were usually above water and termed the "remnant deposits". There were large dragline dredging projects in 1974 through 1978 to remove the portion of these sediments ($.8 \times 10^6$ m^3) that deposited in the Rogers Island area.[1,2]

Figure 3 is a hydraulic profile map of the Upper Hudson which has eight dams from Troy to Fort Edward and also serves as the Champlain Barge Canal. NYS Dept. of Transportation (DOT) maintains a 3.6 m (12 ft) deep by 61 m (200 ft)

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wide navigation channel by dredging. It was in this 40 mile length of river consisting of eight reaches, that most of the PCB became adsorbed to the sediment. However the PCB is slowly being extracted into the water where down river transport and bioconcentration in the fish occurs. Thus, fishing for many species has been banned in the Hudson. PCB is slowly volatilizing from the river and contaminating nearby land areas. Hudson River water supplies are also affected.

In September 1976, NYS Dept. of Environmental Conservation (DEC) and the General Electric Company (GE) signed a legal agreement setting up a 7 million dollar fund to study and solve the PCB problem. An independent PCB Advisory Committee was also set up to advise DEC in this effort.[3] As noted in Table 1, many consultants were retained and studies made. This paper will summarize the consultant studies and DEC studies dealing with PCB sediment distributions, water interaction and dredging for the Upper Hudson. A summary report of broader scope and a detailed report of mapping and sediment relationships are also available.[4,5]

Sediment Distributions

Methods:

Most of the PCB became adsorbed to the sediment and an extensive sampling and mapping program was carried out to determine its locations. There were many sampling expeditions with varying equipment, but Normandeau Associates, Inc. (NAI) did the primary bed sampling and mapping in the summer of 1977, taking 670 grabs and 200 cores. The grabs were taken on transects across the river and the cores in the finer textured sediments near the banks. Sampling

was more frequent near Fort Edward and less frequent down river. Figure 4 shows the NAI boat and Motorola miniranger and transponder system used to provide quick and accurate sample locations. The pulsed radar signals are timed and interpolated automatically and printed out on a tape on the boat. For sampling NAI used a shipek grab sampler and manually forced core tubes while river bottom transects were done with a precision Rayethon DE-719B fathometer.

Additional bed sampling was done by DEC. Figure 5 shows the Leitz range finder used for horizontal locations. It has accuracy comparable to a transit and stadia system. DEC also used a ponar grab sampler, manually forced core tubes and a 7 m long Copper probing pipe 1.0 cm in diameter. The probing pipe proved to be a very quick and reliable tool in determining the depth and nature of the sediments. Cores were typically cut into 5-15 cm (2-6 in.) sections. In reach 8 (Figure 3), 20 DOT clamshell dredge grabs were taken to access the sampling and analysis errors in one location. All sediment samples were given a visual texture code on a scale ranging from 0 for clay to 9 for coarse sand.

Sediment analysis included PCB, total solids, voltile solids and texture. PCB was reported to a 1 ug/g detection limit as three aroclors - 1221, 1016 and 1254 and their total, and a rigorous quality control program was followed.[6] It appeared that the shaker extraction used for PCB gave about 85 percent recovery compared to the soxhlet method. The data including exact locations, depths, and texture were entered on the computer.[5,6]

Results:

It was noted from histograms and log probability plots given in Figures 6 and 7 that the sediment PCB values were log normally distributed. There were

many low PCB values less than 50 ug/g and a few high ones. Thus, for statistical analysis log PCB values were used, but for total mass tabulations a dual averaging system for hot areas greater than 50 ug/g and cold areas less than 50 ug/g was used. Figure 8 shows the variation of PCB across a typical river transect. PCB in ug/g was typically higher in the finer textured sediments near the bank and lower in the coarse sediments in the main channel. The down river variation of PCB values was much less than the across river variation as noted in Figure 9 which shows the log mean PCB values for the grab samples by river reaches. Much of the variation indicated by the 95 percent confidence interval lines is due to across river variations. The variation of 20 DOT clamshell dredge grabs in one area is noted for the upper part of Reach 8. It was concluded that Reaches 8, 7 and 6 were significantly higher in PCB than Reaches 2, 1 and 0. The drop in PCB in Reach 5 appeared partly due to the analysis of primarily center of channel samples there and partly due to the nature of the reach which was typically narrower and higher in velocity. A recent tabulation for Reach 5, employing 79 grabs with good distribution across the river, confirmed that the PCB in Reach 5 was significantly lower than for reaches 6, 7 and 8.

Some key grab sample trends from correlation and analysis of variance program are given in Table 2. The parameter with the highest correlation with log PCB was percent total solids ($r = -.649$), indicating that light, fluffy sediment with a high water content was highest in PCB. For the grab samples, any clear water was poured off the top of the quart jar immediately after sample collection. Sediment PCB concentrations were significantly higher near the bank than in the main channel. About 75 percent of the PCB in the Upper Hudson was aroclor 1016 or its close relative 1242 which was reported as 1016.

There was no noticeable trend of change in the percent 1016 with distance down river from Fort Edward to Troy, but 1254 increased relative to 1221. However individual samples varied considerably in aroclor distribution.

In Table 3, the variation of PCB with visual texture codes was examined. Samples classified as primarily silt or muck were the highest in PCB, followed by samples by samples consisting of coarse sand and wood chips. Sands and gravels without wood chips were significantly lower in PCB. For the lower river reaches, the sediment did not generally contain wood chips. In Table 4, three size fractions for 11 samples were compared for PCB and volatile solids. The coarsest size fraction contained a significantly higher percent of volatile solids due to wood chips and also the highest average PCB content. PCB was typically skip graded in sieved samples and high in the coarse sand size, low in the sand size, and high again in the silt size. The coarse fractions in the Table 4 with over 90 percent volatile solids were mostly wood chips. Sieve analyses on about 670 NAI grabs were entered on the consultants' computers but not on the DEC computer which had only texture codes.[7,11] The mean D_{50} these grabs was .3 mm.[7] The D_{50} is the sieve size that passes 50 percent of the sample. In addition, 20 percent of the grabs had a D_{50} of greater than 2 mm, while 10 percent of the grabs had a D_{50} of less than .06 mm (the silt size division). In Figure 10, the adsorption ability of various materials for PCB was compared, and it was noted that silty soil, wood chips and river sediment adsorbed well compared to Ottawa sand.

While the grabs were used to assess the spread of PCB across river areas, the cores were used to assess the depth of penetration of PCB. Most core samples were taken in silts and sands near the banks. However, probings were made in both center of channel and near bank regions to determine the depths of

sediment present over rock and clay. In Figure 11 all the core data is summarized by frequency tabulations and means. In this tabulation, cores shorter than 15 cm (6 inches) and cores in which all sections had PCB values less than 6 ug/g were omitted to make Figure 11 reflect the depth of PCB penetration in hot spots or near bank contaminated areas. The PCB typically peaked between an 8 and 30 cm depth in the core. In the core sampling it was noted that compression of the sediment in the core tube commonly occurred. It is possible that the actual depth of PCB penetration is up to 30 percent greater than the stated depth. The PCB results on the depth of PCB in the main channel were not yet available but probing data indicated that there was roughly less than .52 m (1.7 ft.) of sediment there on the average, and it was coarser textured. From limited data, the mass of PCB in cold areas was estimated over a .3 m (1.0 ft.) depth.

One set of cores, the NAI winter cores, were sectioned every inch and selected ones analyzed for PCB, Cs 137, heavy metals and size analysis. Two of these are shown in Figure 12, where it was noted that PCB and Cs 137 were correlated. The Cs 137 came from fallout from atomic bomb testing and can be used for roughly dating the sediment layers. It appeared that these near bank areas received 1.5 to 2.5 cm of sediment deposition per year on the average, and this placed the peak PCB deposition period in the 1960s. Cs 137 also followed a log normal distribution in the sediments, so log Cs 137 and log PCB were related for all 12 winter cores in Figure 13, and a correlation coefficient of .82 noted. Certain heavy metals concentrations and percent silt were also positively correlated with PCB.[8]

Areas above 50 ug/g in PCB were designated as "hot spots" and a dividing line drawn between the hot and cold areas on the maps. As noted in Figure 14a, b, and c where the hot spots were exaggerated by dark shading, many hot spots were located in river Reach 8. Further down river, the hot spots were fewer and typically located in large, low velocity areas and marshes near the bank. Table 5 totalizes the PCB masses for the hot and cold areas from Lock 7 to the Troy Dam. The average PCB concentration for the cold areas was typically 10-20 ug/g, while for the hot areas it was 75-200 ug/g. There were no hot spots in Reaches 1 and 2, and over 1/3 of the total PCB in Reaches 1 to 8 were in Reach 8. A more recent hot spot tabulation was made by Malcolm Pirnie which compared favorably with Table 5, except for Reach 3 where the new data increased the hot spot mass to 4,000 kg (8,800 lb) and the total to 135,000 kg (298,000 lb). To this total should be added the PCB from Lock 7 to Fort Edward and the remnant deposits north of this as noted below.

	Hot Spots	Cold Areas	Total Mass	Hot Spot %
Reaches 1-8 -lb	176,100	122,400	298,500	59
Lock 7- Ft. Edward	900	2,100	3,000	30
Remnant Deposits (2)	124,000*	16,000	140,000	88
Total - lb	301,000	140,500	441,500	68
kg	136,800	63,900	200,700	68

*For removal or isolation of Areas 3, 3A and 5.

In Reaches 1-8, 59 percent of the PCB is contained in 8 percent of the river area. In the remnant deposits, a discrepancy between two sets of PCB analyses occurred and a lower estimate of 25,800 kg (57,000 pounds) is possible with only 23,100 kg (50,000 pounds) in Areas 3, 3A and 5.[5]

Sediment-Water Interactions

Two Hudson River sediments with 15-30 ug/g of PCB were mixed with water in 13, 2.8 liter jar tests and the supernatant analyzed after various settling times. A sediment to water ratio in the range of 1/10 was used. The data is plotted in Figure 15 which indicates a direct relationship between the PCB and suspended solids in the supernatant.[9] About 100,500 ml jar tests were conducted to determine the beneficial effects of various coagulants and polymers in removing suspended solids and turbidity.[10] Some of this data is given in Table 6. Without coagulants, the suspended solids ranged from 100-1500 mg/l after 1.5 to 2.5 hours of settling and 50 to 300 mg/l after 18 to 24 hours settling. With 120 mg/l alum, 20 mg/l of cationic polymer or 5 mg/l of Chitosan, the suspended solids were reduced to 20 to 45 mg/l after 1.5 to 2.5 hours settling. For a few sediments containing 100 to 200 ug/g PCB and a high percentage of aroclor 1221, the water PCB values after polymer coagulation were 50 to 100 ug/l. The most cost effective cationic polymers were Nalco 7134, Calgon Cat Floc B and Magnifloc 587C. Chitosan also worked well.

PCB transport in the river, as calculated by a sediment transport model, increased at periods of high flow as noted in Tables 7 and 8. It should be noted that the projected annual transport of PCB over the Troy Dam was 3630 kg (8,000 lb).[11] Annual losses as high as 4,500 kg/yr (10,000 lb/yr) have been measured.[11,12] The lower numbers in the range in table 8 did not take into account desorption of PCB from bottom sediments which would increase the low flow PCB transport. The bottom of Table 9 provides a summary of desorption of PCB from sediment to water. Aroclor 1221, which is more soluble in water, had

a lower partitioning coefficient than 1254. Elutriate tests in which sediment was mixed with water at a 1/10 ratio gave lower coefficients than for river simulation tanks in which the sediment to water ratio was much lower. One would also expect the partition coefficient to vary with the sediment organic carbon, but the values in Table 9 are typical of river sediments.

Figure 16 shows river water monitoring data at Schuylerville from which it was noted that the PCB concentration increased at high flow due to suspended solids transport and also increased at low flow ($<5x10^5$ L/sec) possibly due to bottom desorption or barge traffic. The PCB and flow data can be related by two equations; one for high flow and one for low flow.[13] An alternate regression equation for both high and low PCB transport was given by Lawler Matusky and Skelly.[11] The low flow transport behaved like a constant source at 3-5 kg/day. Since the hot spots cover 8 percent of the river area but have concentrations 7 times that of the cold areas on the average, 56 percent of the bottom desorption may be coming from the hot spots.

GE performed experiments on PCB volatilization which, according to MacKay[14] is governed by a liquid film transfer coefficient. The mass transfer reduces to the formula $N = K(C-P/H)$,

where: P is the partial pressure of the hydrocarbon in the vapor,

H is Henry's Law Constant,

C is the concentration of the hydrocarbon in the water,

K or K_L is the area transfer coefficient-units (L/T).

Typically, the atmospheric concentration of PCB is very low and the formula reduces to $N = KC$ for which units could be:

$N = mg/m^2/hr$,

$K = m/hr$,

$C = mg/m^3 = ug/l$

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The volumetric mass transfer coefficient $\overline{K} = \frac{K}{D}$ where D is the depth. The ratio of the $\overline{K}$ for PCB aroclors to the $\overline{K}_2$ for stream reaeration was relatively constant under different turbulence conditions noted Paris et al.[15] Suspended solids in the water may effect volatilization by adsorbing PCB and reducing soluble water PCB concentrations.[15]

The results of one GE experiment in a series of sponge stoppered flasks at 25°C employing ^{14}C labeled PCB was shown in Figure 17. The approximate rate of loss of 1221 was 0.45 $mg/m^2/hr$ and of the 1016 was 0.08 $mg/m^2/hr$.

A second series of experiments was conducted with a large tank shown in Figure 18 which was .78 m (31 in.) high from the supporting screen to the water surface and .2 m (8 in.) in diameter. The stirrer operated at 60-80 rpm when on. The PCB pickup in the sponges was measured at various time intervals for various wind speeds and temperatures. In the first experiment, the tank was filled with water and an excess amount of aroclor 1242 added to keep the water saturated. The tank was stirred. The volatilization rates increased with temperature and wind speed as noted in Figure 19. In a second experiment, a silty sediment contaminated with PCB in the Hudson River near the Moses Kill was placed to a 30 cm depth above the supporting screen. Sediment from this river location typically had a total PCB of 800 ug/g, 80 percent of which was 1016 and 1242. The stirred tank trials were run first and gave much higher loss rates than the unstirred tank trials, as noted in Figure 20. The suspended solids and total water PCB samples were much higher in the stirred tank, as were the separated clear water PCB samples (620 ug/l stirred versus 270 ug/l unstirred). (16)

Water to air volatilization rates from this experiment and from the literature were compared in Table 10 where considerable variation in the K rates was noted. This could be due to different turbulence conditions or to differences between purely theoretical calculations and measured values. For the 64 km (40 mile) reach of the Upper Hudson at a 3 m depth, total volatilization rates of .45-4.5 kg/day (1-10 lb/day) of PCB were calculated from the GE data. Hydroscience[23] previously estimated peak losses of 15 lb/day for the upper Hudson.

In a third tank experiment, 47 kg sandy sediment from the Buoy 212 area of the Hudson River was placed on the supporting screen to a .77 m depth and the drain at the bottom of the tank opened. Small amounts of water were periodically added to the tank to keep the sediment moist, but drained. Both the rate of PCB loss and the air concentrations of about 1 ug/m^3 were shown in Figure 21. Air concentrations of about .1 ug/m^3 or one-tenth of the laboratory rates were measured over the new Moreau dredge spoil site which contained sediment similar to that used in the tank study.[4] The rate of volatilization has been shown to increase with percent moisture, temperature and wind speed.[24] Air concentrations of 1-10 ng/m^3 have been cited for other areas in the United States and OSHA standards of .5 and 1.0 mg/m^3 for 1254 and 1221 were noted.[4,20,21] NIOSH has recommended that the standards be lowered to a total PCB of 1 ug/m^3. Sediment to air volatilization rates from this experiment and from the literature were also compared in Table 10 and variations noted. From the GE data at 25°C, initial PCB losses over a .93 ha (2.3 acre) uncapped dredge spoil site as high as .68 kg/mo (1.5 lb/mo) were calculated for a sediment concentration of 6.4 ug/g, and higher sediment concentrations would yield proportionally higher PCB losses. Over the long term, the rate of PCB loss would be less due to snow cover and surface PCB depletion. It was observed that air concentrations

greater than or equal to 6 ug/m^3 that workers on PCB dump sites developed headaches and nausea. Additional studies by GE indicated that the rate of volatilization of PCB is much less from silt than from sand and that an organic top soil cap would limit volatilization.

Dredging

The NY State DOT hydraulic dredge with a 1.2 m (4 foot) diameter cutterhead is shown in Figure 22. It was used for routine channel maintenance dredging on the Upper Hudson and monitored at 3 sites - Lock 1, Buoy 212, and Lock 4 by DEC. The dredge pumped about 34-41 m^3/min (20-24 cfs) via a .38 m (15 in.) pipeline to various upland settling lagoons (spoil sites). After settling, the water returned through a wooden box overflow structure to the river. For each of the 3 sites one to two months of daily monitoring data was taken. Measurements of flow, turbidity, suspended solids and PCB on the return water were made along with periodic measurements of influent percent solids, sediment PCB and lagoon retention time. Cationic polymer at 20 mg/l was periodically fed on the dredge to aid in settling the fine solids. The detailed data were given in other reports and summarized in Table 11.[10,26,27] The short retention times and the percent silt and clay in the sediment dredged greatly affected the performance of the dredging lagoons. The polymer typically cut the return flow suspended solids and PCB levels in half. At retention times of 15 min. or less, a flushing of deposited sediment fines occurred after dredge start up. It is recommended that a retention time of 1 hr or more be maintained in spoils lagoons to achieve good removals of suspended solids and limit the flushing out of sediment fines. Permeable sand and shale dikes were also found effective in filtering out suspended fines.

Figure 23 shows the scum retained by an oil boom on the Buoy 212 spoils lagoon. This scum had a PCB content of 18,000 ug/g on a dry weight basis which was extremely high.[10] It was roughly calculated that 10-20 percent of the PCB in the return flow equaled the rate PCB accumulation in the scum. Thus, scum removal for the Hudson River dredging projects was recommended.[26]

Polymer was normally fed on the suction side of the dredge pump, but for the Lock 4 dredging it was alternately fed at an intermediate box between lagoons with excellent results.[27] Figure 24 shows the multiple stage lagoon system used at Lock 4. The lagoons before Box 1 typically provided a retention of about 25 minutes, while the long narrow channel after Box 1 provided a retention of about 30 minutes. The return flow entered the river after Box 2. Figure 25 shows Box 1 where 20 mg/l of Calgon Cat Floc B was fed, and the dredge in the river near Box 2 which was hidden by the trees. When polymer was fed at Box 1, excellent flocculation occurred and the suspended solids were reduced to 20 mg/l at Box 2, as noted in Table 11. Thus, for future dredging of contaminated sediments where polymer addition may be desired, a 2 stage lagoon system is recommended. For this type of lagoon system on the Hudson, the losses of PCB in the return flow were calculated to be less than 1 percent of the PCB dredged.

Dredge head loss was also monitored at Lock 4. A 1 cm diameter copper sampling pipe was installed terminating .6 m (2 feet) behind the dredge head so that water samples could be withdrawn. This was done with the dredge making swings facing into the current so that the maximum turbidity plume downstream of the dredge head was sampled. Many turbidity samples were taken during the dredge swings and six PCB and suspended solids samples were taken compositing the swings. The averages comparing the dredge head values to those of the

river cross section sampling at several depths were given in Figure 26. It was difficult to tell any difference in water samples upstream of the dredge from those downstream of the dredge. Even when assuming that all the solids and PCB suspended in the dredge head sample did not settle, the increase of PCB in the river section and the losses were very low. The swing speed was typically 1.5 m/sec and the sediment silt and clay was 20 to 30 percent. This gave a projected dredge head loss relative to the sediment dredged of less than .2 percent for PCB suspended solids. A DOT clamshell dredge was also monitored in the Lock 4 channel. The dredge head losses for the .3 m^3 clamshell appeared greater than for the hydraulic, but were difficult to accurately quantify.(27)

In addition, a dragline dredging operation at Fort Edward was monitored daily for 4 months. Figure 27 shows the 2.3 m^3 dragline and Figure 28 the seven monitoring stations and the area dredged. Vertically integrated water samples were taken daily from all stations except 4, which was sampled less frequently. Sampling was done in the early morning before dredging and in the afternoon during the dredging. For PCB analysis only, the daily samples were composited into weekly samples. There was little dredging in the west channel which conveyed 80-90 percent of the river flow. Just above sampling station 3, an oil boom was put across the river to trap and scum for removal as noted in Figure 29. The wet scum had a PCB content of 2,000 ug/g which was again very high. The rate of PCB accumulation in the scum was calculated to be about 20 percent of the PCB moving in the total water column at stations 4 and 5. The detailed data were given in another report(28) and summarized in Table 12. The low flow period and high flow periods covered about 8 weeks each, while the no dredging low flow period involved 2 weeks. The mean velocity ranged from .045 to .26 m/s in the east channel and from .14 to .86 m/s in the west channel and

main river. During low flow, the PCB concentrations were definitely elevated by dredging at the below dredge and east channel stations. There was a considerable decrease in PCB and suspended solids with distance downstream in the east channel. The PCB transport rates were about the same during the high flow and low flow for most stations, indicating that the dredging losses behaved like a constant source, although the velocity increased by a factor of 6. The sediment PCB averaged 20 ug/g and the silt plus clay less than 5 percent. The elutriate test soluble PCB values ranged from 2-20 ug/l for this sediment which had about 30 percent wood. The total PCB losses from dredging at Lock 7 were calculated considering a mass balance of all stations and found to be .34 to .82 kg/day or less than 2 percent of the sediment dredged, while the solids losses were 2850-6800 kg/day or less than .5 percent. For both the hydraulic and mechanical dredges, there was a trend of the PCB losses being higher than the solids losses.

Table 13 summarizes the expected dredging losses for both the cutterhead and clamshell dredging of PCB hot spots for sediment averaging 50-60 percent silt and 100-150 ug/g of PCB in the Hudson River. The estimate of solids not picked up during dredging was based on experiments in a small laboratory tank with model dredges. Although the projected losses of 13 percent were about equal, the clamshell dredge seemed better suited to control on a precise grid network determined by a minicomputer in the field. For the clamshell, the optimizing factors appeared to be clam bite overlap spacing and depth of grab. For the hydraulic model, the swing speed and overlap spacing appeared to be the key factors. If the dredge boom is swung too fast, hot sediment is missed but the percent solids pumped is high. If the swing speed is too slow, the dredge pumps a lot of water. In hot spot dredging a .6 m (2 ft) cut plus a .3 m (1 ft)

overcut is planned. The dredge head and return flow losses were determined by the field monitoring data and jar tests and are in the range of reported literature values. For the clamshell, the dredge head losses are higher but the return flow losses lower, than for the hydraulic. Experience with the Duwamish River PCB spill cleanup yielded about 92 percent recovery of the PCB; however, several removals of contaminated sediment were made and a pneuma dredge employed.[29] Malcolm Pirnie estimated a 94 percent recovery for Hudson River dredging.[7]

Discussion

The alternates for dredging the river are summarized in Table 14. With no management, a portion of the remnant deposits will erode and add to the channel maintenance dredging. For the remnant deposits, removal by land based equipment was appropriate and 100 percent removal projected; while for alternates 1 and 4, 90 percent removal was used. For the hot spot removal program from Fort Edward to Lock 2, 85 percent dredging efficiency of the 80,300 kg (177,000 lb) of hot spots was used. A complicated tabulation of quantities involved was done and modified slightly to give the totals in Table 14. Maintenance dredging of sediment at 35 ug/g was incorporated in alternates 2 and 3.[30] The costs of the alternates are given in Table 15. DEC and the PCB Advisory Committee recommended the pursuit of alternate 3 which, if implemented, would remove over 60 percent of the PCB from the river for a $29 million cost. A portion of the remnant deposits have recently been removed and put in a clay lined spoil site in the Town of Moreau. If dredged, the hot spots would be placed in one 40 ha (100 acre) secure land burial facility near Reach 8. The site would have a natural clay bottom and clay and topsoil cap. There would be monitoring wells, a leachate collection and pump out system, and a long-term

maintenance plan. Both hydraulic and clamshell dredging systems are being planned for with a single off loading and treatment facility near the proposed spoil site.(7)

If the no action alternative is taken, it is likely that PCB will continue to desorb from the sediment and erode down river at high flow conditions for decades at a 20-year average transport rate of 3,630 kg/yr (8,000 lb/yr). This PCB will continue to contaminate fish, affect water supplies and volatilize. If the hot spots are removed, the desorption and erosion of highly contaminated sediments would be lessened and water concentrations of PCB in the Upper Hudson cut about in half.(4)

Conclusions

A. Sediment Distributions

1. In mapping sediment distributions in the Upper Hudson, sampling on transects across the river and obtaining precise locations for those samples was found essential. The variation of PCB along a transect was extreme, while the variation down river was more gradual.
2. PCB was log normally distributed in the sediments.
3. PCB was generally highest in the silty sediments, next highest in the coarse sands with wood chips, and lowest in the sand and gravels with no wood chips or organics. In sieved samples containing sand, wood chips and silt, the same trend held.
4. The PCB hot spots above 50 ug/g were typically found in low velocity and near bank areas. For the Upper Hudson, about 68 percent of the total mass of PCB was contained in hot spots which covered only 8 percent of the river area.

5. PCB was positively corrlated with Cs 137, certain heavy metals and volatile solids while negatively correlated with total solids.
6. Cores indicated that the maximum PCB concentrations were typically 8-30 cm below the top. Cs 137 dating put the peak discharge period of PCB in the 1960s. Within the first 10 km of river below the PCB source, PCB rarely extended below 90 cm in depth, while for the rest of the Upper Hudson, PCB rarely extended below 60 cm.

B. Water Interactions

1. In a concentrated sediment-water mixture, the bulk of the PCB was adsorbed on the solids. In going from a 10/1 elutriate test to a more dilute river system, the sediment to water partition coefficient increased, and a higher percentage of the PCB in the mixture became soluble in the water. Aroclor 1221 had a lower sediment to water partition coefficient than aroclor 1254. This has significance for groundwater attenuation, river transport and dredging systems.
2. Cationic polymers and chitosan were helpful in rapidly removing the suspended solids in a sediment-water mixture and reducing the water PCB concentration.
3. In the river, high water PCB concentrations occurred at low flows, which could be explained by desorption from the bottom sediment. The highest PCB concentrations occurred at very high flows which eroded and suspended the bed material. At intermediate flows, the water PCB concentrations were lowest.
4. The projected loss of PCB to the Lower Hudson over 20 years averaged 3,630 kg/yr (8,000 lb/yr), and modeled results indicated that this would go on for decades if no action was taken.

5. The rate of PCB volatilization from the upper river varies with temperature, wind speed and turbulence conditions, and is projected at .45-4.5 kg/day (1-10 lb/day). This is in the range of the total river water transport of PCB at low flow conditions of 3-5 kg/day.

C. Dredging

1. For three full scale hydraulic dredging projects on the Hudson, 20 mg/l of cationic polymer was found effective in boosting the PCB and suspended solids removals in the spoils lagoons. The best results were achieved when the polymer was fed at an intermediate box between two lagoons.
2. For hydraulic dredging in the Hudson, a minimum of one hour retention time is recommended in the spoils lagoon system.
3. Scum removal in the hydraulic spoils lagoons and in the river downstream of a dragline dredge was found essential in the Hudson, because the scum was so high in PCB.
4. Based on monitoring data, hydraulic and mechanical dredging losses to the water column for the hot spot dredging were projected at about 2 percent of the PCB and 1 percent of the solids. The contaminated solids not picked up by the dredge were projected at 5 percent or greater. This loss could be much greater than 5 percent if the operation of the dredge is not precisely controlled.
5. Dredging of the hot spots and routine maintenance dredging in 8 percent of the Upper Hudson are projected to remove over 60 percent of the total mass of 200,000 kg (440,000 lb) of PCB in the upper river.

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TABLE 1. HUDSON RIVER PCB STUDY CONSULTANTS

CONSULTANT OR GROUP	STUDY		STATUS
NORMANDEAU ASSOCIATES BEDFORD, NH	BED SAMPLING AND MAPPING (UPPER HUDSON)		REPORT AND MAPS IN
LAMONT-DOHERTY PALISADES, NY	BED SAMPLING, PCB ANALYSIS, Cs 137 DATING (LOWER HUDSON)		REPORT IN
USGS - ALBANY	RIVER HYDROLOGY WATER PCB AND SUSPENDED LOAD	(1976 & 77) (1978) (1979)	DATA AND PAPERS IN SOME DATA IN
RENSSELAER POLYTECHNIC INST. TROY, NY (DR. T. ZIMMIE)	BEDLOAD SAMPLING (UPPER HUDSON)	(1977)	DATA IN.
HYDROSCIENCE WESTWOOD, NJ	PCB MATH MODELING OF UPPER AND LOWER HUDSON	(1977) (1978 - 79)	REPORT IN BEGINNING
LAWLER, MATUSKY & SKELLY ENG. PEARL RIVER, NY	MODELING SEDIMENT AND PCB TRANSPORT AND HYDROLOGY FOR UPPER HUDSON	(NO ACTION) (DREDGING)	REPORT IN BEGINNING
MALCOLM PIRNIE WHITE PLAINS, NY	DREDGING TECHNOLOGY, PLANS, AND ASSOCIATED IMPACTS		7 REPORTS IN
	FINAL PLANS ANS SPECIFICATIONS FOR HOT SPOT DREDGING		TO BEGIN WHEN FUNDED
WESTON INC. WEST CHESTER, PA	PCB LANDFILLS AND DREDGE SPOIL SITES, SAMPLING AND COMPLETE ENVIRONMENTAL ANALYSIS		REPORT IN
O'BRIEN AND GERE ENG. SYRACUSE, NY	1. PCB ANALYSES SEDIMENT AND WATER MEDIA 2. EFFECT OF PCB ON WATER SUPPLIES (TREATMENT METHODS)	(1977 - 78)	DATA AND REPORT IN IN PROGRESS
RALTECH (WARF) MADISON, WI	PCB ANALYSES - BIOLOGICAL MEDIA		IN PROGRESS

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CONSULTANT OR GROUP	STUDY		STATUS
SYRACUSE RESEARCH CORP.	PCB ANALYSES - SEDIMENT AND WATER MEDIA		BEGINNING
NYS DEC BUREAU OF AIR RESOURCES	PCB AIR SAMPLING	(1977 - 78)	DATA IN
NYS DEC BUREAU OF FISH AND WILDLIFE	FISH DATA ANALYSIS	(1977 - 78)	IN PROGRESS
NYS DEPT. OF HEALTH	MACROINVERTEBRATE ANALYSIS, HEAVY METALS ANALYSIS, LAB QUALITY CONTROL, SOME PCB ANALYSIS, Cs 137 DATING		IN PROGRESS
GENERAL ELECTRIC CORP., RES. & DEV. SCHENECTADY, NY	SEDIMENT INCINERATION, PCB VOLATILIZATION, PCB BIOLOGICAL DEGRADATION, NON-DREDGING PCB RENOVATION OPTIONS		IN PROGRESS WAITING FINAL REPORT
	ENVIRONMENTAL EFFECTS OF PCB SUBSTITUTE-DIELECTROL I, II		REPORT IN
	TOXICITY OF PETROLEUM HYDROCARBONS		BEGINNING
BOYCE THOMPSON ITHACA, NY	SAMPLING VEGETATION AND LAND IN FT. EDWARD TO ALBANY AREA		BEGINNING
FORDHAM UNIVERSITY NYU MEDICAL CENTER SUNY, STONY BROOK, NY	BIOLOGICAL SAMPLING, LABORATORY MODELING AND PROJECTIONS FOR LOWER HUDSON		BEGINNING
*MT. SINAI SCHOOL OF MEDICINE NEW YORK, NY	HEALTH EFFECTS OF GENERAL ELECTRIC FACTORY WORKERS		WAITING FINAL REPORT
CORNELL UNIVERSITY AND AGRICULTURE AND MARKETS ITHACA, NY	ANALYSIS OF CROP AND FOOD DATA		PLANNED

* Not funded by DEC.

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TABLE 2. GRAB SAMPLE TRENDS

A. CORR. COEFF. -R LOG PCB

TOT. SOLIDS	VOL. SOLIDS	SILT CODE
-.649	.394	.462

B. ANAL. OF VARIANCE LOG PCB VS. DISTANCE FROM BANK

REACH	LOG MEAN PCB-UG/G SHORE 1/3 + 1/3	MAIN CHAN. 1/3	F
8	1.45 (28.2)#	1.28 (19.0)	3.84*
7.6	1.48 (30.1)	1.22 (16.6)	5.84*

C. ANAL. OF VARIANCE LOG PCB VS. WATER DEPTH

REACH	LOG MEAN PCB-UG/G <12 FT (3.65 M)	>12 FT (3.65 M)	F
ALL	1.34 (21.9)	1.23 (17.0)	3.08

D. MEAN AROCLOR DISTRIBUTION: 75% 1016 & 1242, 13.5% 1221, 11.5% 1254

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* Significant at .05 level.

( ) values are antilogs.

Table 3. Analysis of Variance Log PCB vs Primary Texture Types for Sediment Grabs

Reaches 6, 7, 8, 9 (North of Lock 5 at Mile 183.2)

Texture	# of Cases	Log Mean PCB	Antilog Mean PCB (ppm)	Variance (Sp^2)	F-Value
0,1,2,3*	115	1.75	56.74	.3148	47.7084
8,9*	81	1.19	15.55		
8**	39	1.03	10.82	.2041	14.9504
9**	13	1.59	39.25		
8*	61	1.08	11.93	.1855	17.6149
9*	20	1.54	34.87		
6*	58	1.04	11.08	.1393	7.8019
7*	28	1.28	19.25		
4*	55	1.53	33.61	.2558	.9696
5*	26	1.41	25.59		

Reaches 1, 2, 3, 4, 5 (South of Lock 5 at Mile 183.2, to Troy Dam at Mile 153.9)

Texture	# of Cases	Log Mean PCB	Antilog Mean PCB (ppm)	Variance (Sp^2)	F-Value
0,1.2.3*	32	1.41	25.59	.3744	18.3302
8,9*	27	.72	5.29		
8**	10	.40	2.51	.5278	.0039
9**	3	.37	2.35		
8*	22	.69	4.96	.4185	.2264
9*	5	.85	7.04		

* Includes all primary textures, regardless of associated secondary textures.
** Includes only those primary textures with missing secondary textures.

Textures Codes:
0 = Clay
1 = Silt
2 = Muck
3 = Muck and Wood Chips(W.C.)
4 = Fine Sand
5 = Fine Sand and W.C.
6 = Sand
7 = Sand and W.C.
8 = Coarse Sand
9 = Coarse Sand and W.C.

Table 4. PCB and Volatile Solids on Size Fractions of Grab Samples

	Sieve size fractions*					
	> 2.0 mm		2.0 to .074 mm		< .074 mm	
Sample	PCB, ppm	V.S. %	PCB, ppm	V.S. %	PCB, ppm	V.S. %
7-8-1	98	85.6	10	3.3	43	6.3
7-9-3	106.2	91.0	80	8.4	37.1	8.1
7-9-4	28.1	32.6	15.0	7.3	---	---
7-10-5	19.0	96.7	37.3	6.7	---	---
7-17-1A	97.5	90.9	50.0	2.3	117.0	2.3
7-19-6	58.7	92.9	148.2	17.2	---	---
7-20-4	---	---	32.1	15.8	37.8	12.5
7-31-5	45.3	94.7	201	77.5	---	---
7-33-6	469.1	85.5	61.4	10.7	313.0	16.3
9/6 Lock 4	23.8	42.1	6.7	2.1	17.9	8.2
T01-Rt.4	36.9	25.7	24.7	4.72	35.6	3.6
Mean	98.26	73.71	60.58	14.18	85.91	8.19
Log Mean	1.78		1.58		1.74	
Std. Dev.	134.36	28.27	61.70	21.60	105.06	8.49
Log S_x	.41		.46		.41	
Corr. Coef. R						
PCB vs. V.S.	.26		.84		.57	

* T values for comparison of the > 2 mm size volatile solids (V.S.) with V.S. for the other two groups were highly significant at the .01 level. PCB values were not significantly different for the three groups although the mean was lower for the middle size range.

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Table 5

PCB Area and Weight Tabulations for High and Low PCB Sediments as of Feb. 27, 1978 Data

Reach	1	2	3	4	5	6	7	8	Total	Metric Total
Mile Pt.	153.9	159.5	163.4	165.8	168.0	183.2	186.0	188.4	193.7	
Length-mi.	5.6	3.9	2.4	2.2	15.2	2.8	2.4	5.3 mi.	39.8	64.0 km
Ave. width-ft.	878	866	990	1142	623	754	752	588		
Area-$10^6 ft^2$	26	17.8	12.5	13.3	50.0	11.15	9.5	16.5	156.7	14.5 m^2
Use area 100%	25.0	18.7	13.7	14.0	53.8	10.6	10.0	18.8	164.6	15.3 m^2
Freq. Dredged Area	.45	.07	0	.64	.13	.15	0	.58	1.89	.17 m^2
Freq. Dredged %	1.8	.4	0	4.5	.2	1.5	0	3.1	1.2	.11 m^2
Use Area 80%	20	15	11	11.2	43	8.5	8.0	15.0	132.5	12.3 m^2
Hot Spot Area # x$10^6 ft^2$ 100%	0	0	.15	1.5	1.75	2.59	.6	4.50	10.9	1.0 m^2
Cold Areas Area $10^6 ft^2$	20	15	10.85	9.7	41.2	5.91	7.4	10.73	120.8	11.2 m^2
PCB conc. ppm	9.6	13.9	22.6	13.4	13-	20.0	20.0	19.		
lb. PCB at 1 ft depth, 65 lb/ft^3	12,500	13,500	15,900	8,500	34,800	7,700	9,600	19,900*	122,400	55,600 kg
lb. PCB in Hot Spots at 16 in depth	--	--	2,000	11,800	10,600	41,200*	6,000*	97,700	169,300	77,000 kg
Total lb. PCB	12,500	13,500	17,900	20,300	45,400	48,900	15,600	117,600	291,700	132,000 kg
% of lb. in Hot Spots	0	0	11.5	58.3	23.3	84.2	38.5	79.7	58.1	

[illegible] 28 in depth used; # hot spot areas planimetered from NAI maps.

Table 6. Summary of Jar Test# Results Using Typical Hudson River Sediments

Sediment Location	Floatables %	Volatiles &	Silt & Clay %	For Settling Times 1.5-2.5 hr. Turb.	1.5-2.5 hr. SS.	18-24 hr. Turb.	18-24 hr. SS.	For Chemical Coagulation* Turb.	Coagulation* SS.
Schuylerville	9	6	2	1000	500	500	300	37	20
Ft. Miller	2	4	1	200	150	100	50	-	-
Buoy 214 Ft. Edward	2.7	2	11	800	450	500	200	45	20
Behind T.I. Dam	17.5	7	45	2500	1500	450	300	55	45
Stillwater	13.4	3	10	300	168	-	-	32	5
Lock 1 in canal	18	24	26	1150	715	162	94	-	-
Waterford Bridge	2.8	5.4	54	675	462	170	150	37	30

* 2½ hours settling.

1-2 mm rapid mix, 5-10 flocculation.

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TABLE 7. PCB Vs DAILY FLOW AT TROY (11)

FREQUENCY*	FLOW AT TROY DAM (m^3/s)	(cfs)	PCB (ug/ℓ)	PCB LOAD (kg/day)	(lb/day)
15% (55 days/year)	620	22,000	0.08	4.5	10
10% (36 days/year)	780	27,500	0.13	9.1	20
1% (3.6 days/year)	1700	60,000	1.90	270.	600
0.2% (18 hours/year)	2260	80,000	3.90	770.	1700

* Credit: Lawler, Matusky and Skelly Engineers. (11)

TABLE 8. ANNUAL PCB LOAD AT TROY Vs YEAR (11)

	YEAR* NUMBER	BASED ON	ANNUAL TORY DAM PCB LOAD (kg)	(lb)
DROUGHT YEAR	9	1965	114#-1050	252#-2300
TYPICAL YEAR	14	1970	1070#-2000	2364#-4400
WET YEAR	16	1972	11,100	24,572
20-YEAR AVE.	1-20		2950-3630	6500-8000

Credit: Lawler, Matusky and Skelly Engineers. (11)
Estimate may be low, since bottow desorption was not considered.

TABLE 9. SEDIMENT TO WATER PCB PARTITIONING COEFFICIENTS

TYPE STUDY	AROCLOR	COEFF.*	AUTHOR
SEDIMENT MIXED AND SETTLED	1242,1016	1.3×10^3	(15) PARIS ET AL. (1978)
MIXED AND SETTLED	1254	6×10^4	(17) HALTER AND JOHNSON (1977)
WATER FLOWS OVER SEDIMENT IN TANK	1254	9×10^5	(17) HALTER AND JOHNSON (1977)
MIXED AND SETTLED (ELUTRIATE)	70% (1016)	10^3-10^4	(18) LMS-GE,HUDSON RIVER (1976)
FLOW OVER IN TANK	70% (1016)	10^{4}#	(18) LMS-GE,HUDSON RIVER (1976)
MIXED AND SETTLED	70% (1016)	10^3-10^4	(9) TOFFLEMIRE (1976)
MIXED AND SETTLED	70% (1221)	10^3	(9) TOFFLEMIRE (1976)
FLOW OVER TANK	80% (1016)	2×10^5	(9) VEITH,HUDSON RIVER (1976)
ELUTRIATE TESTS, HUDSON RIVER	70% (1016)	10^3-10^4	(10) NYS DEPT. OF TRANS. (1976-7)
MIXED AND SETTLED FOR 5 CITIES IN U.S.	70% (1254)	10^3-10^4	(9) FULK ET AL. (1975)
MIXED AND SETTLED	70% (1016)	10^4	(16) GENERAL ELEC.,MCFARLAND (1977-8)
ELUTRIATE TESTS $\frac{1}{10}$, $\frac{1}{10,000}$	70% (1016)	10^3,3×10^4	(19) MALCOLM PIRNIE (1977)

*Dry sediment conc./soluble water conc. (.45μ filter or centrifuge).

#Here there was 200 mg/l of suspended solids in the water tested.

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	1221	1016 & 1242	1254
ELUTRIATE DREDGING SIMULATION	10^3	5×10^5	2.5×10^4
FLOW OVER IN TANK - RIVER SIMULATION	2×10^4	10^5	5×10^5

Table 10. Comparison of K Values for Volatilization of PCB at 25°C

Aroclor	Mol. Wt.	For PCB Saturated Water: Solubility µg/ℓ	Vapor Pressure mm Hg	KCs mg/m²/hr	KCs pure PCB mg/m²/hr	$\bar{K}$ 1/hr	$\bar{K}/\bar{K}_2$
1221	192	(1000)[a] (1000-2000)[e]	= (10^{-2})[e]	(.055-.090)[a]	(3.3)[a]	(.002-.004)[a]	
1242	261	240 (80)[e], (340)[d]	4.1×10^{-4} (9×10^{-4})[e], (3×10^{-4})[d]	13.7 (1.8-5.0)[b]		.057, (.002-.006)[a] (.2-.9)[d], (.0096-.027)[b]	(.22)[d]
1016		(175+)[a], (420)[d]	(3×10^{-4})[d]	(.009-.016)[a]		(.3-1.2)[d]	(.25)[d]
1254	321	12 (56)[c]	7.7×10^{-5}	.8	(8.35)[c]	.067	

Reference (14) Mackay and Leinonen was used unless otherwise noted.
(a) GE-Corp. Res. Niskayuna, NY - Brooks et al.(4)
(b) GE-Corp. Res. Niskayuna, NY - McFarland, et al.(16)
(c) Hague, et al.(22)
(d) Paris, et al. (15)
(e) Huntzinger, et al. (24)

For Sediment or Soil to Air Transfer

Aroclor	Soil PCB µg/g	KC µg/m²/hr	Air Conc. ng/m³	half life in top 10 cm - yrs	Area or Soils	Reference
1254	.01	1.25	1-10	6	LaJalla, Calif.	(21) McClure
1254	10			.1	Ottawa Sand	(22) Hague, et al.
80%(1016)	6.4	126	1200	<.1	Sand & Wood Chips	(16) G.E., McFarland
80%(1016)	20		100		Sand & Wood Chips	(4) DEC-Air Resources
1248	.04		10		Lake Michigan Area	(20) Versar Inc.
1242, 1254	.05			<.05	Sand	(4) GE, Brooks
1242, 1254	.05			>.3	Silt or Top Soil	(4) GE, Brooks

MONS 007824

Table 11

Summary of Dredging Results at 3 Sites

	LOCK 1	BUOY 212	LOCK 4
LAGOON FLOW THRU TIME TYPICAL, BY SALT TRACER	15 min.	45 min.	55 min.
LAGOON INFLUENT			
Average % solids	1%	5%	3%
PCB in solids	15 ug/g	100 ug/g	20 ug/g
LAGOON EFFLUENT			
Suspended solids, without polymer	2000 mg/l	500 mg/l	460 mg/l
Suspended solids, with polymer	400 mg/l	250 mg/l	230, 20*
PCB, composite, without polymer	40 ug/l	100 ug/l	3.0
PCB, composite, with polymer	8 ug/l	50 ug/l	<1.5ug/l
REMOVAL EFFICIENCIES			
Suspended solids, without polymer	80%	99%	98%
Suspended solids, with polymer	96%	99.5%	99, 99.9*
PCB, without polymer	73%	98%	99.5
PCB, with polymer	95%	99%	99.8
SILT AND CLAY			
Percent passing #200 sieve (average)	26%	5%	20-30%

*Polymer fed between lagoons

TABLE 12. FT. EDWARD DREDGING MONITORING - SUMMARY COMPARISON

PARAMETER	BELOW DREDGE	EAST CHANNEL	LOCK 7	UPSTREAM	DOWNSTREAM	WEST CHANNEL
LOW FLOW						
MEAN PCB PPB	3.91	3.00	.714	.543-.204	.29	.092
MEAN S.S. MG/L	23.8	16.4	13.4	7.0	8.5	7.58
*MEAN PCB KG/DAY	1.98	1.52	.362	4.8-1.81	2.57	.78
*MEAN S.S. KG/DAY	16,600	8,300	6,760	61,800	75,200	64,000
HIGH FLOW						
MEAN PCB PPB	.54	.48	.39	.10	.12	.064
MEAN S.S. MG/L	18.3	14.1	10.6	3.86	5.14	6.0
*MEAN PCB KG/DAY	1.63	1.45	1.18	2.06	2.48	1.13
*MEAN S.S. KG/DAY	55,500	42,800	32,200	79,700	109,000	106,000
NO DREDGING LOW FLOW						
MEAN PCB PPB	.36	1.59	.65	.065	.14	.13
MEAN S.S. MG/L	10	13	7.0	9	8.5	8.5
MEAN PCB KG/DAY	.30	1.34	.55	.59	1.27	1.07
MEAN S.S. KG/DAY	8,450	11,000	5,900	81,400	76,800	70,000

THESE ARE INSTANTANEOUS RATES, FOR LONG TERM RATES MULTIPLY BY 10/24.

MONS 007826

TABLE 13. EXPECTED LOSSES IN HOT SPOT DREDGING

	HYDRAULIC		CLAMSHELL	
	PCB	SOLIDS	PCB	SOLIDS
MISSED DURING DREDGING-* NOT PICKED UP	13%	13%	13%	13%
LOST IN DREDGING PROCESS AT DREDGE HEAD	< 1%	< .5	< 2%#	< 1%#
LOST IN RETURN FLOW	1%	.5	.2%	.1%
TOTAL LOSSES	15%	14%	15.2%	14.1%
IMMEDIATE LOSS TO WATER COLUMN	2	1	2.2	1.1%

Shrouding the top of the clamshell could reduce these losses further. Also, on Page 11 of the Japanese reference, "Turbidity Generated by Dredging Works" by Osamu Nakai, the clamshell losses are twice the hydraulic losses at the dredge head.

* These losses were based on results in a small laboratory tank, while the other losses are based on DEC field data and literature data.

Table 14. Summary Description and Evaluation of Possible Management Strategies for the Hudson River.

Possible Management Action	m^3 Dredged from River (1978-1988)	kg PCBs Removed from River System (1978-1988)	Types of Technology	Status
1. Further study - No management action	916,000	23,000	Modified DOT maintenance dredging program to assure permanent removal of >90% of PCBs dredged from river as part of maintenance program.	Continuous DOT maintenance dredging necessary for Barge Canal operation.
2. Stabilize and/or remove remant deposits.	830,000* (680,000)**	75,000* (44,300)**	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)	1,270,000	138,000	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).	11,500,000	186,000	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: Ref (4) modified by the authors.

* Assumes area 3, 3A, and 5 are removed from the basin.

** Assumes area 3A and 5 are removed and area 3 is stabilized.

MONS 007828

TABLE 15. FOUR ALTERNATES AND COSTS

	VOLUME	COST OF PCB REMOVED		
	$10^6 \times m^3$	TOTAL ($1,000,000)	UNIT ($/lb)	($/kg)
NO ACTION	.70	2.5	49	108
REMNANT DEPOSITS	.68-.83	4.5-6.3	38-46	83-101
HOT SPOT + R. D.	1.27	29.0	87	192
COMPLETE REMOVAL	11.5	204	485	1070

MONS 007829

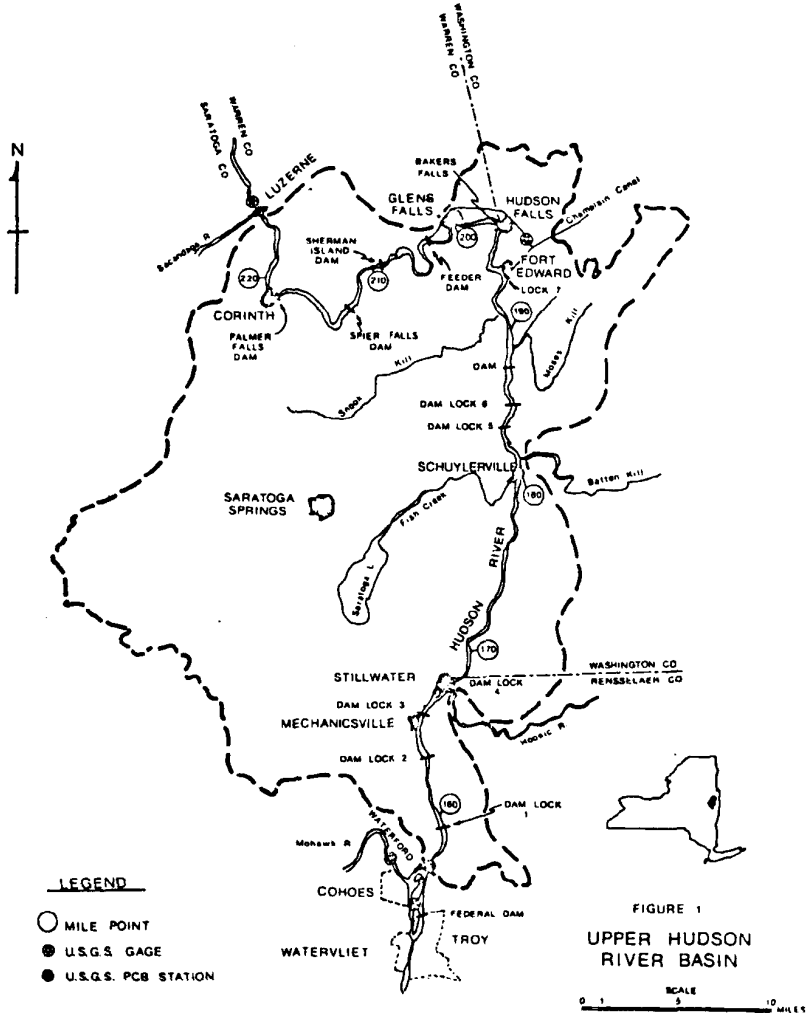


FIGURE 1

UPPER HUDSON RIVER BASIN

MONS 007830

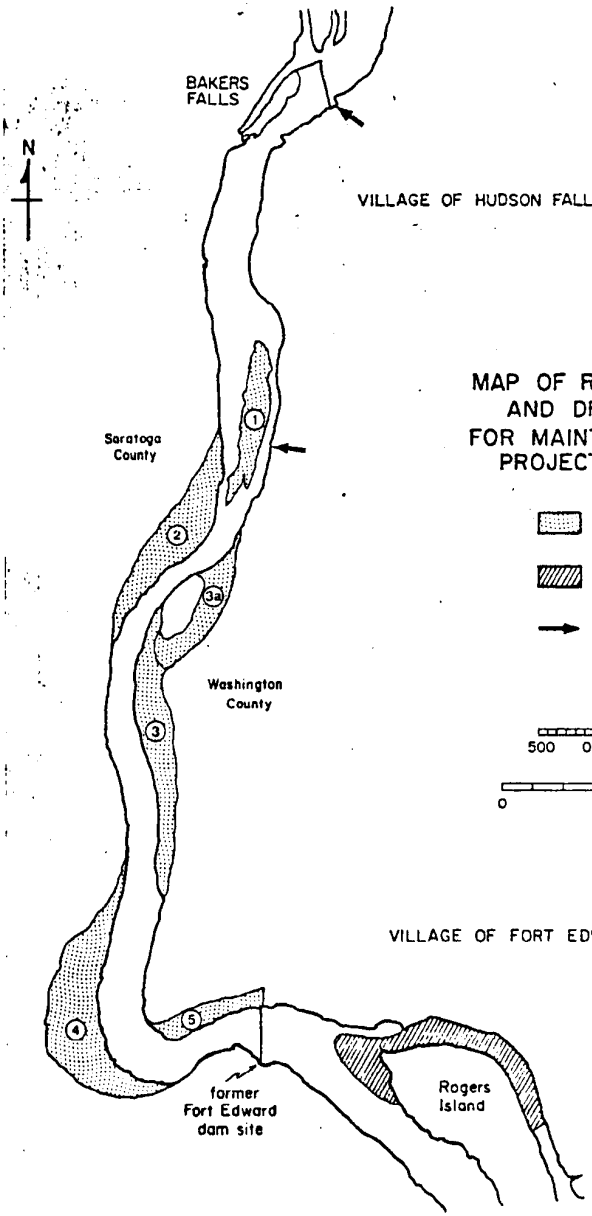


Figure 2

MAP OF REMNANT DEPOSITS AND DREDGING AREA FOR MAINTENANCE DREDGING PROJECT OF 1977-78

Remnant Deposits

Fort Edward dredging area

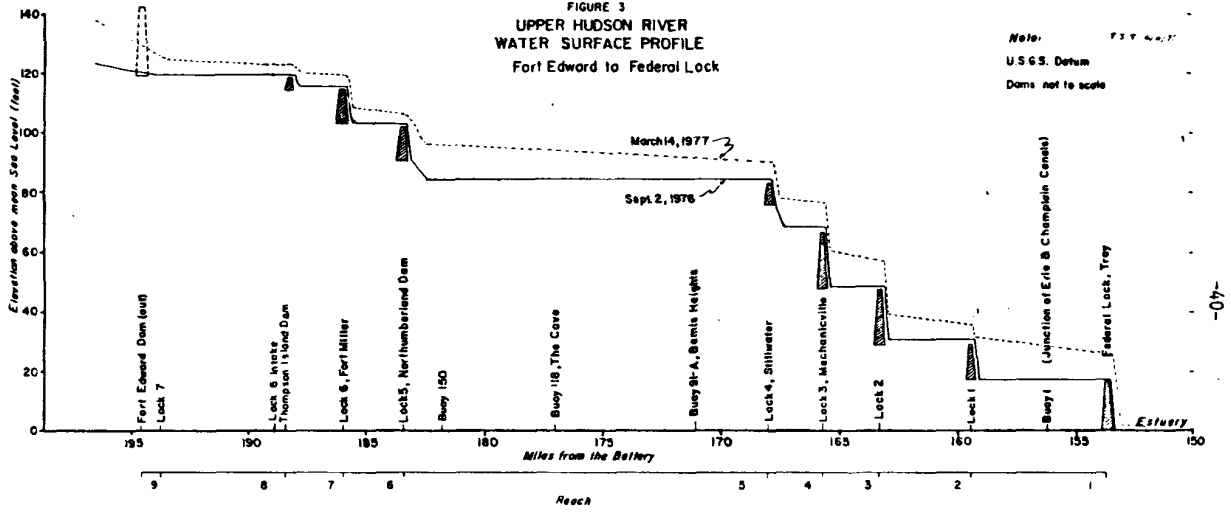
GE plant outfalls

SCALE

500 0 1000 2000 feet

0 500 1000 meters

MONS 007831



-40-

MDNS 007832

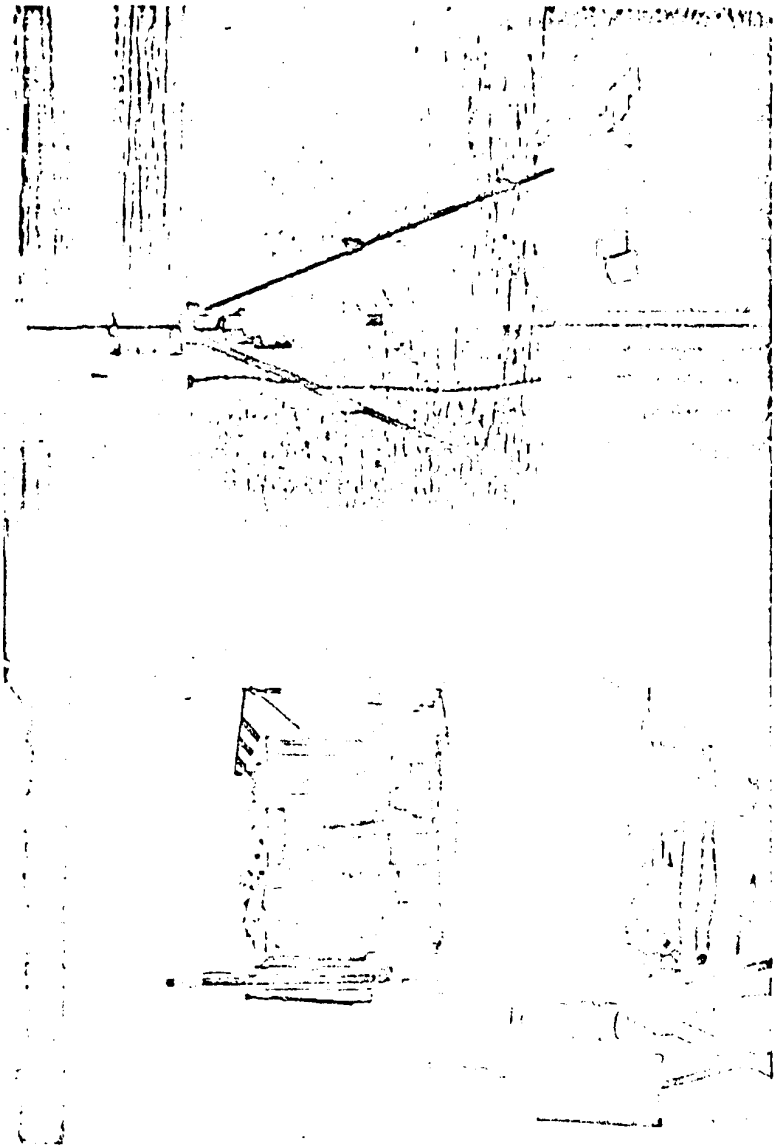
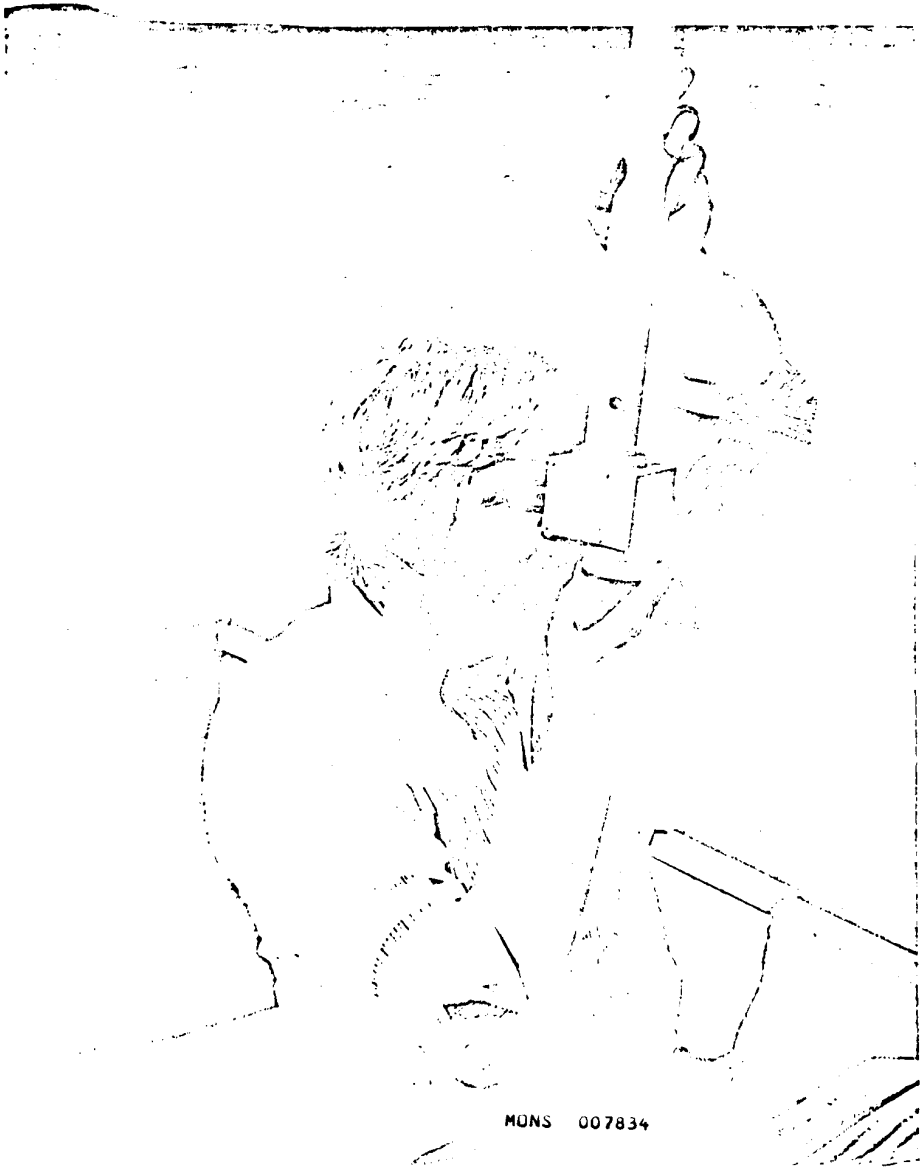


Figure 4. NAI Boat and Transponder

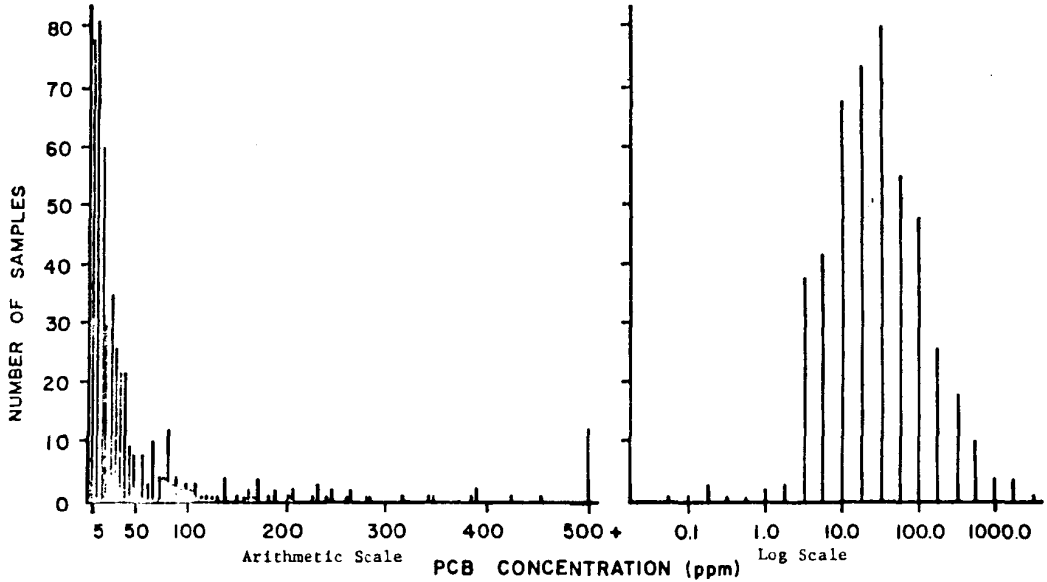
Figure 5. Rangefinder for Measuring Distances



MONS 007834

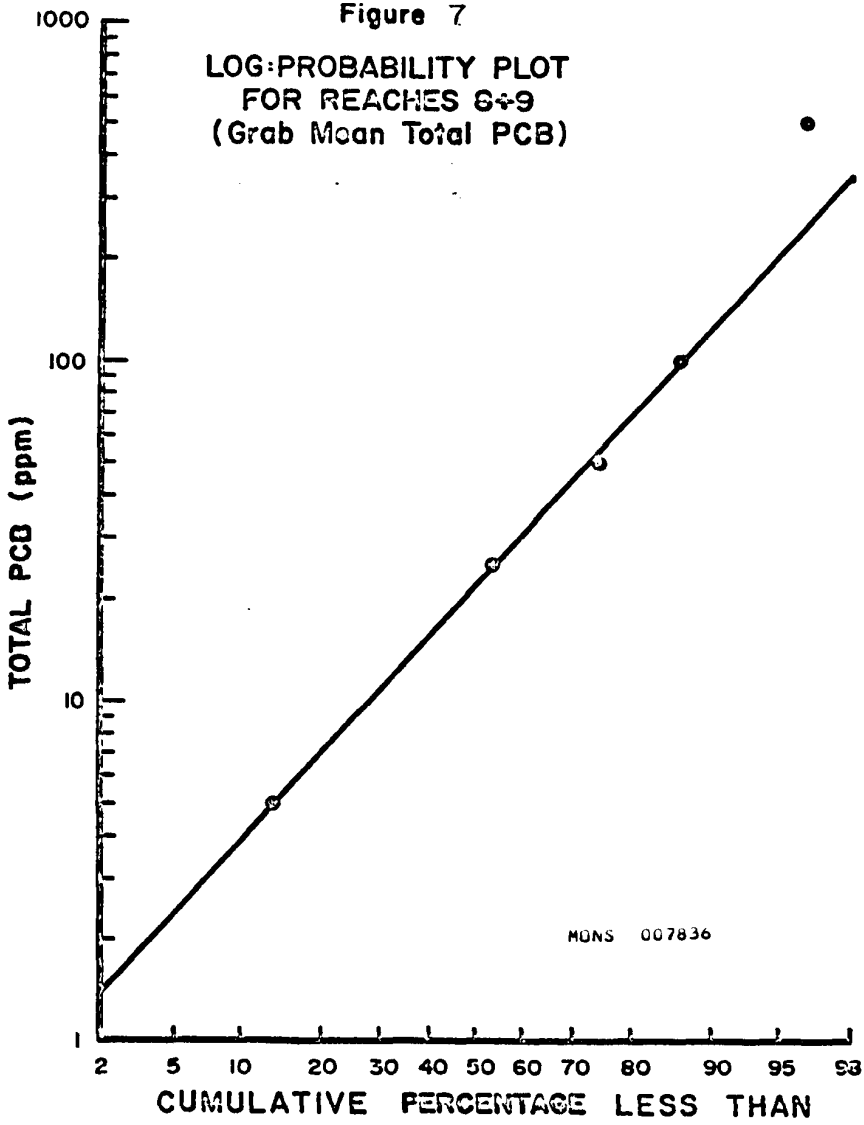
Figure 6

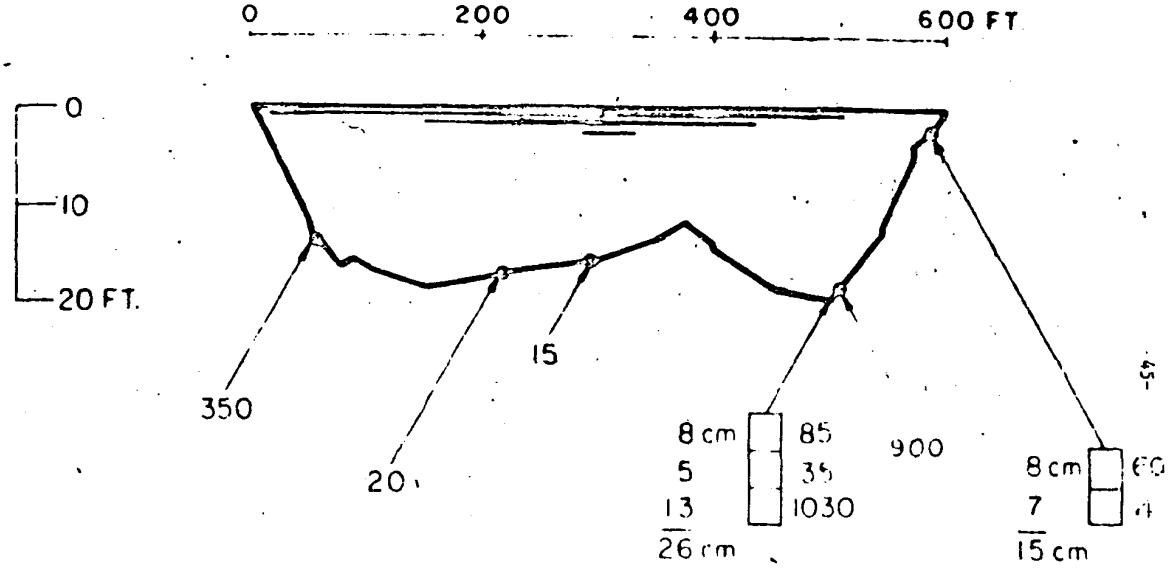
FREQUENCY DISTRIBUTION OF SEDIMENT PCB LEVELS
IN THE UPPER HUDSON RIVER



MDNS 007835

Figure 7


LOG:PROBABILITY PLOT
FOR REACHES 8+9
(Grab Mean Total PCB)
TOTAL PCB (ppm)
1000
100
10
1
2
5
10
20
30
40
50
60
70
80
90
95
98
CUMULATIVE PERCENTAGE LESS THAN
MONS 007836



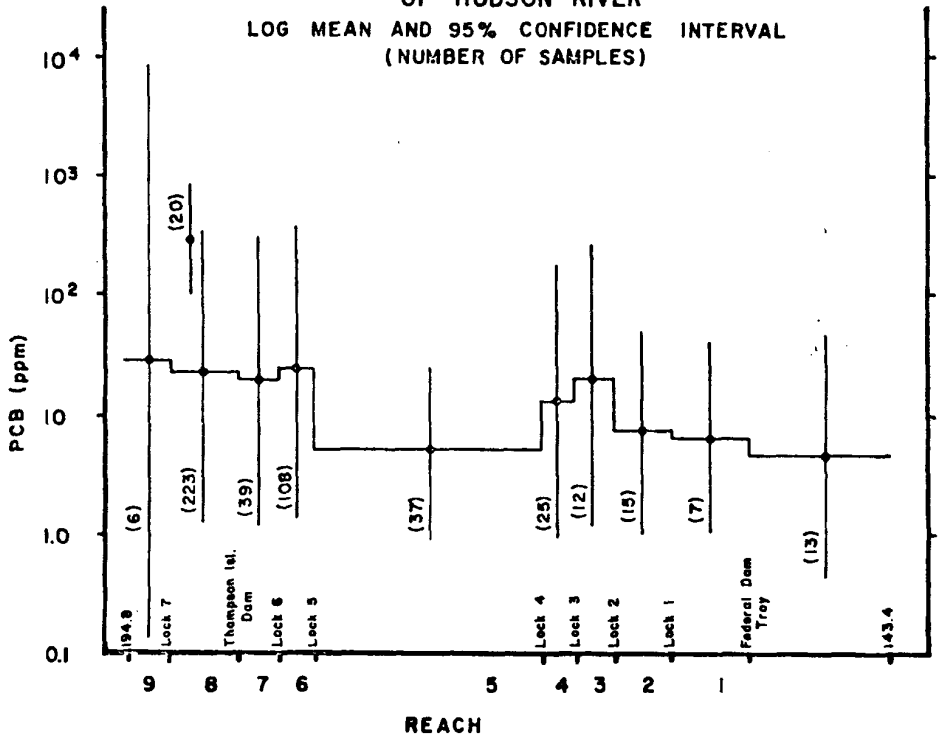
PCB CONCENTRATIONS IN BED MATERIAL
RIVER MILE 189.2

Figure 8

MONS 007837

Figure 9

AVERAGE PCB CONCENTRATION IN SEDIMENTS
OF HUDSON RIVER
LOG MEAN AND 95% CONFIDENCE INTERVAL
(NUMBER OF SAMPLES)



BERLOO SNOW 007838

Figure 10. Adsorption of Aroclor 1242 on Different Adsorbents.

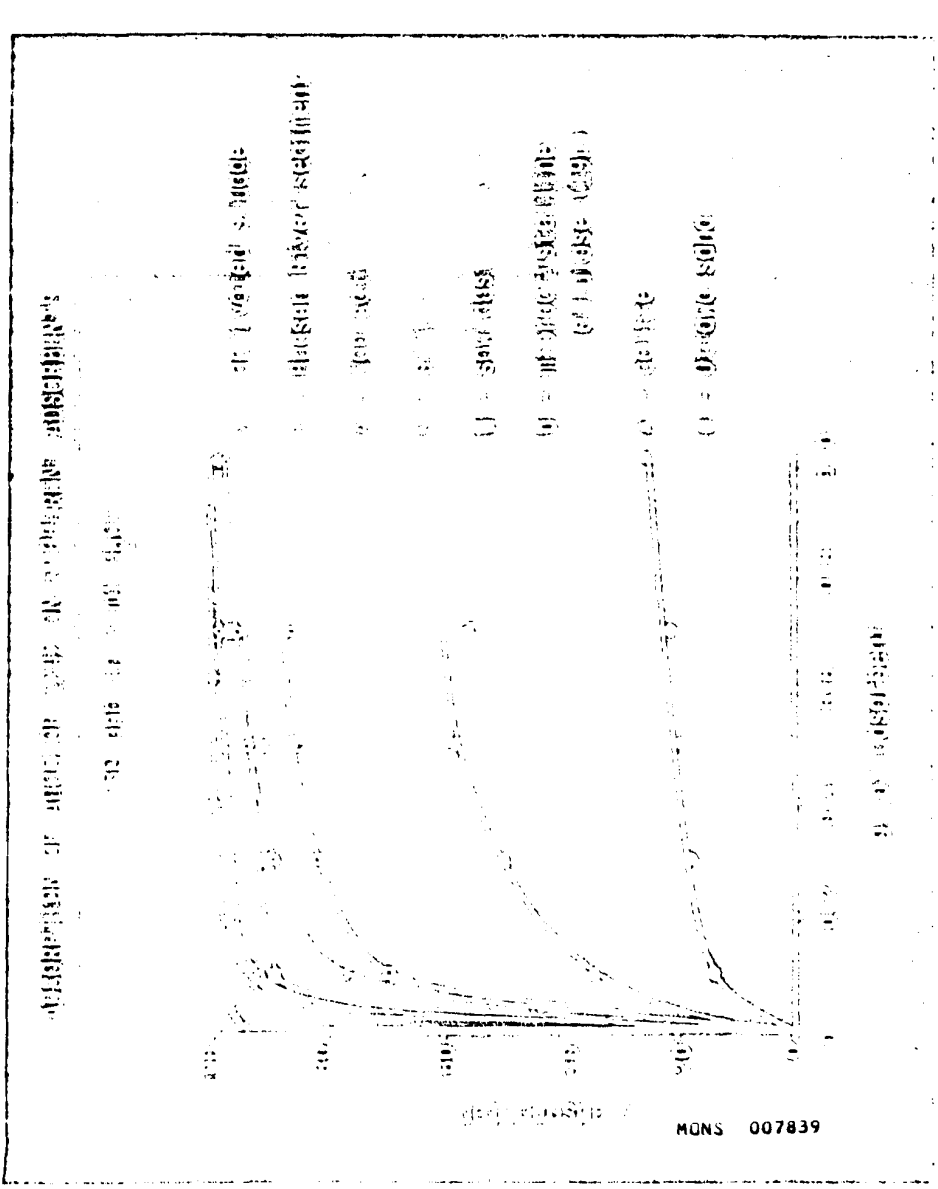


Figure 11

PCB MEANS IN ppm AT DEPTH INTERVALS IN CORES

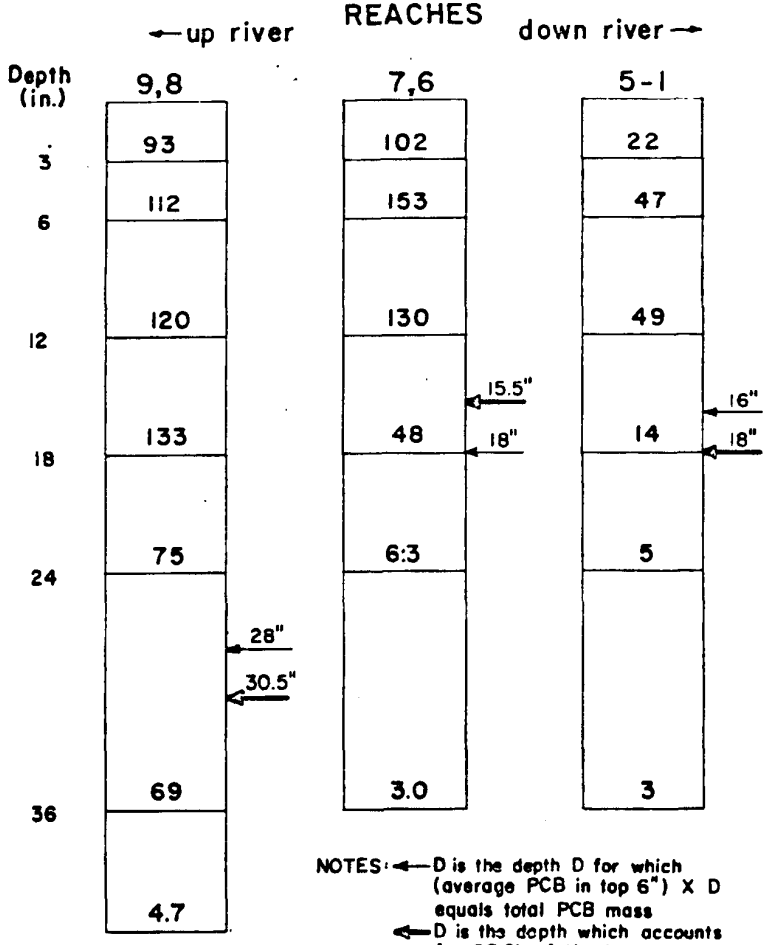


Figure 12

January 1977 Winter Cores Analyzed for PCB, Cs 137, and Texture

Northeast of T.I. Dam
Core 18-8

Depth@ Inches		PCB ppm	Cs 137 Pci/gm	% S&C
1		75	1.9	
2		32	.5	
3		63	1.5	80
4		45.1		
5	1973*	120	2.1	
6		161	1.4	
7		141	3.4	
8		269	2.9	
9		383	4.3	
10		546	9.0	
11		632	4.7	85
12		422	10.4	
13		413	8.3	
14		428	11.9	
15		321	19.2	
16		373	11.7	
17		4.9	19.2	
18		160		
19	1959#	.85	1.0	
20			.7	
21		8.9	<.7	61
22				
23			<.3	
24				
25		.23	<.2	
26			<.2	
27		3.7		25
28			<.4	
29				
30				
31				
32				

Northeast of Rt. 4 Bridge
Core 12-1

Depth@ Inches		PCB ppm	Cs 137 Pci/gm	% S&C
1		177	2.4	
2		47	1.7	
3			1.0	
4	1973*	121	1.6	
5			1.0	58
6			2.1	
7			10.3	
8			1.9	
9			2.6	
10		119	2.5	
11			3.3	
12			6.1	
13		126	3.8	69
14			2.5	
15	1959#		.5	
16				
17		53.5	.4	
18		4.8	.5	
19		2.5		
20		1.5	.7	
21		5.0		33
22		3.0	.3	
23		7.7		
24		5.6		
25			.5	
26		1.2		68
27			.2	
28				
29				
30				
31				
32				

@ 1" = 2.54 cm

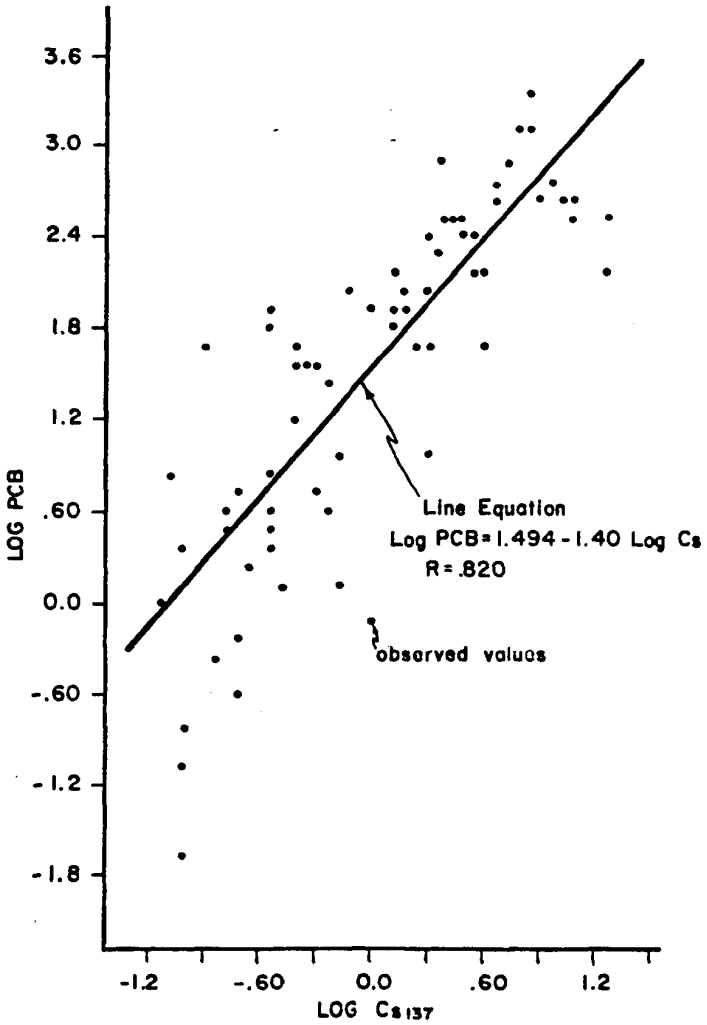
* The 1973 Date is used because of the documented decrease in PCB use at GE after 1973.

\# The 1959 date was used because of the decrease in Cs due to less fallout before 1959. There was still some low level of PCB before 1959 and GE began use of PCB in 1948-51.

If these dates are used, sediment deposition in these near bank areas of 3/4-1"/yr is indicated and the maximum PCB levels passing the Thompson Island occurred in 1962-1967 while the maximum PCB passing the Rt 4 bridge at Northumberland occurred later 1961 thru 1976.

Figure 13

LOG PCB - LOG Cs REGRESSION PLOT



MONS 007842

Figure 14a.
PCB Hot Spots >50 µg/g.

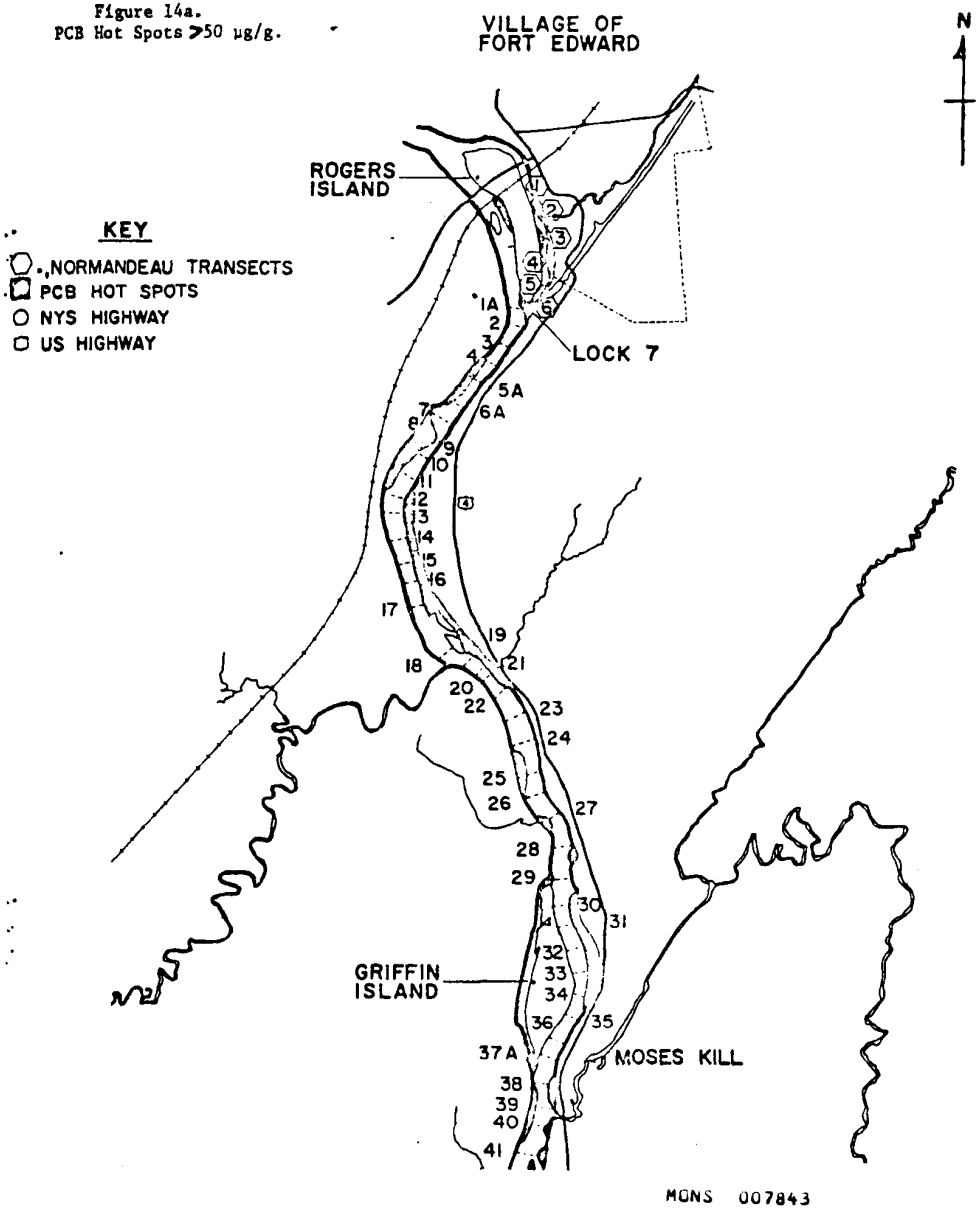
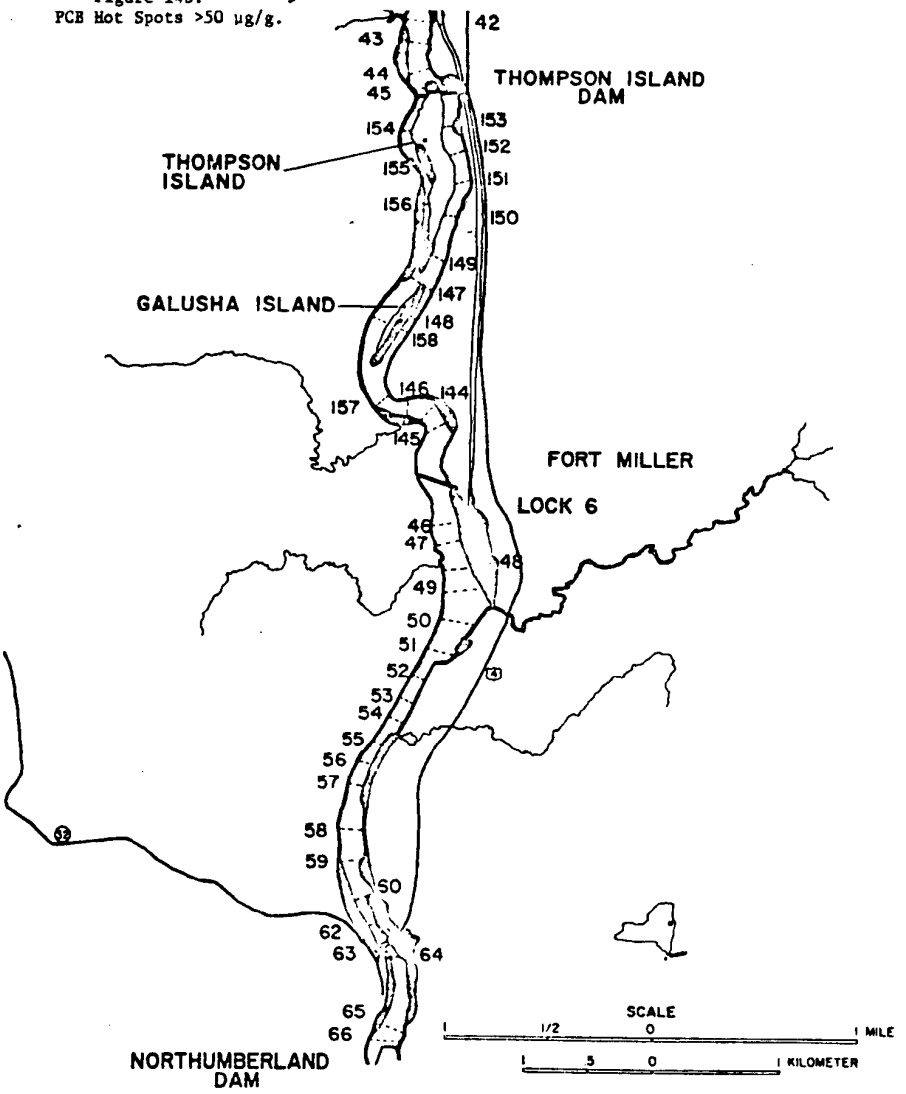


Figure 14b.
PCB Hot Spots >50 µg/g.



MONS 007844

Figure 14c.
PCB Hot Spots >50 µg/g.

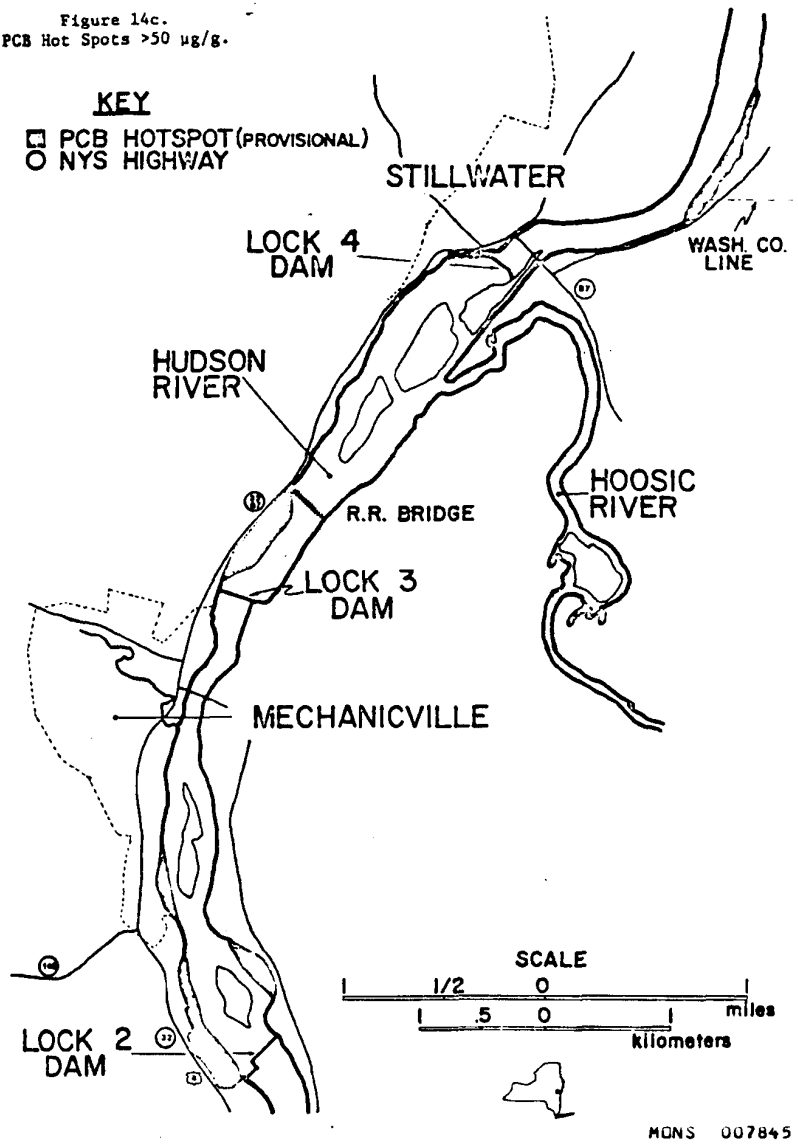


FIGURE 15

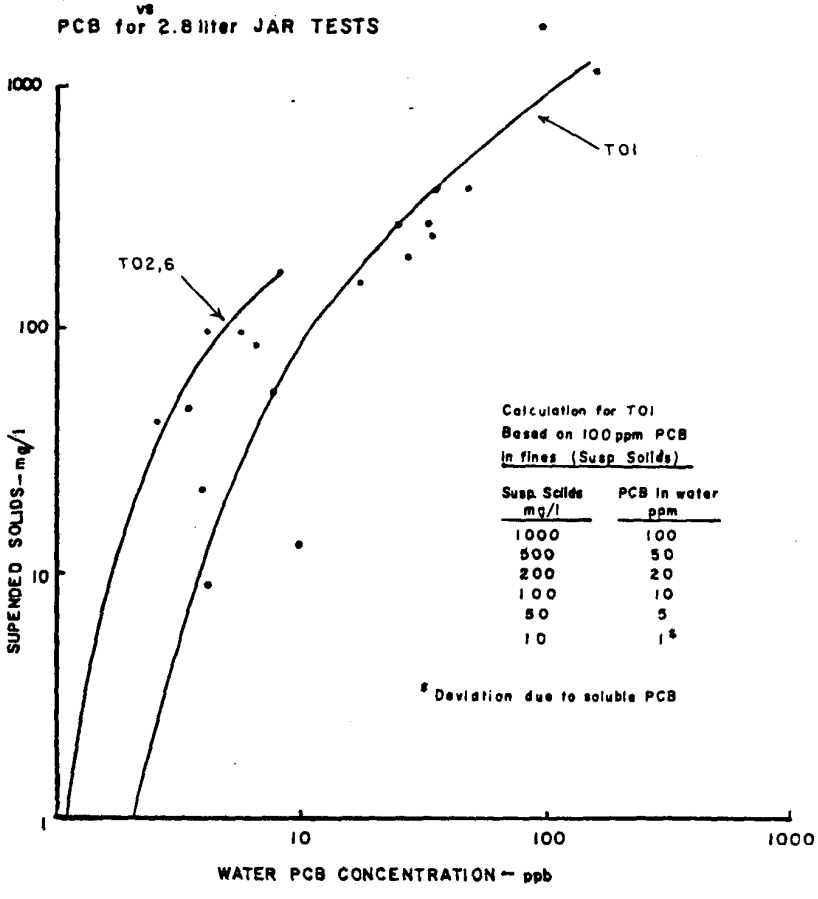
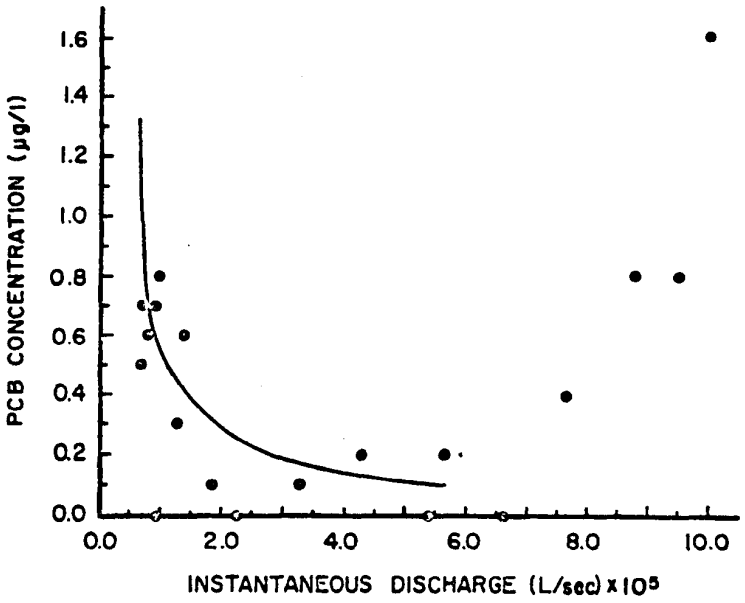

SUSPENDED SOLIDS
vs
PCB for 2.8 liter JAR TESTS
1000
100
10
1
SUSPENDED SOLIDS - mg/l
TO1
TO2,6
Calculation for TO1
Based on 100 ppm PCB
in fines (Susp Solids)
Susp. Solids mg/l
PCB in water ppm
1000 100
500 50
200 20
100 10
50 5
10 1$
$ Deviation due to soluble PCB
10
100
1000
WATER PCB CONCENTRATION — ppb

Figure 16

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

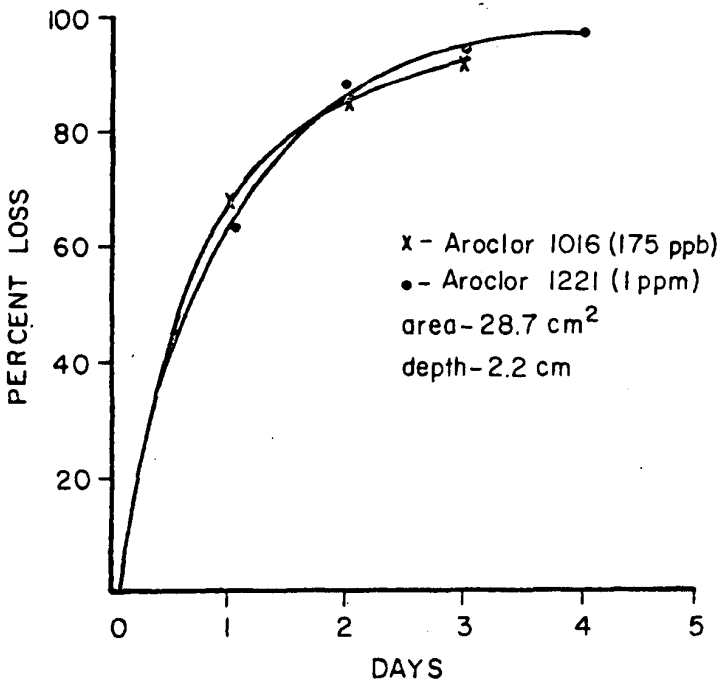


SOURCE: Turk,[13] USGS data

MONS 007847

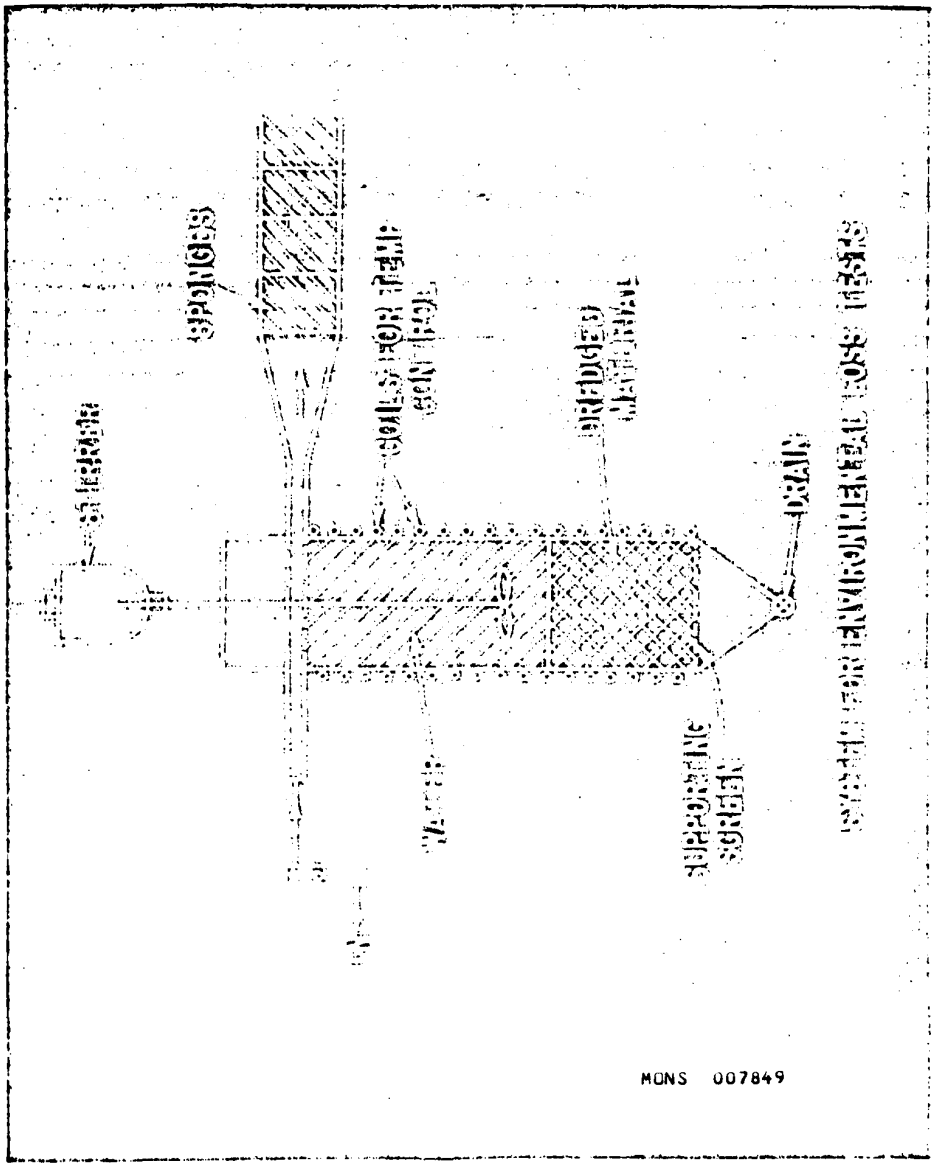
Figure 17

EVAPORATIVE LOSS OF PCB FROM PCB SATURATED WATER SOLUTION



SOURCE: General Electric (16)

Figure 18. Ref (16)



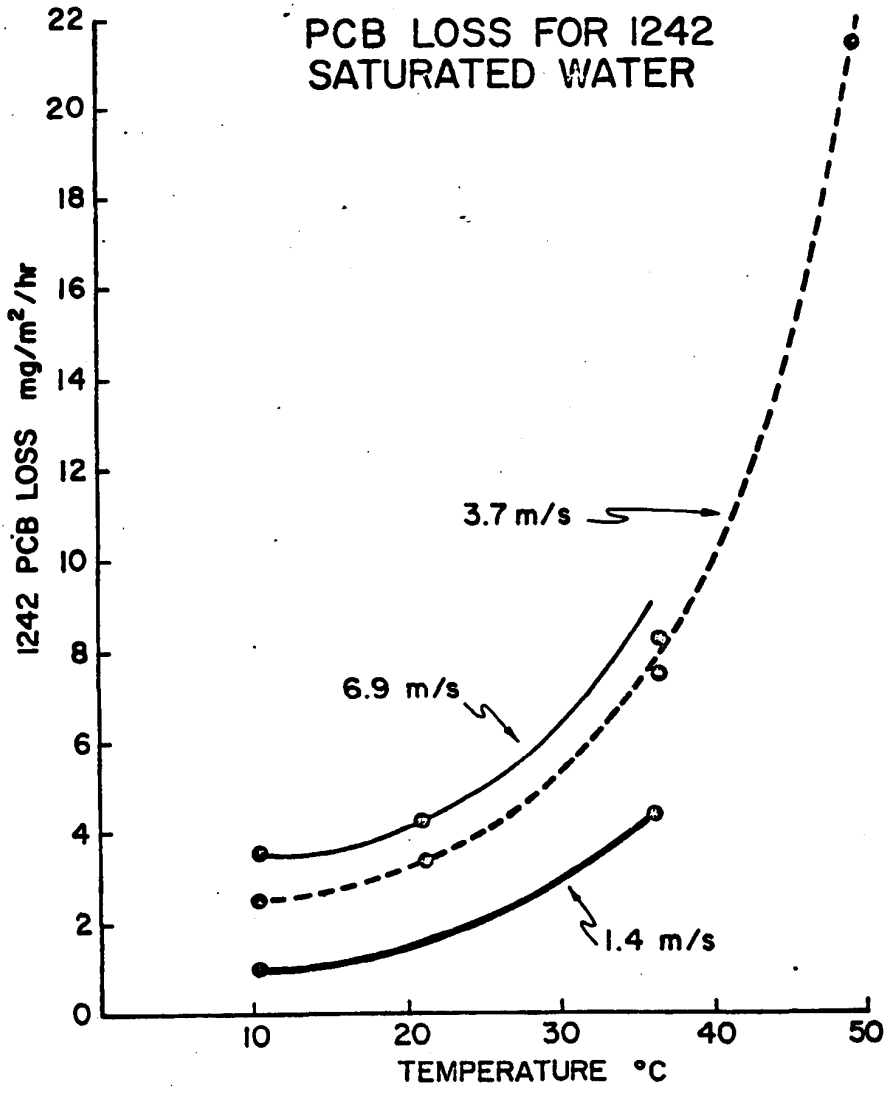
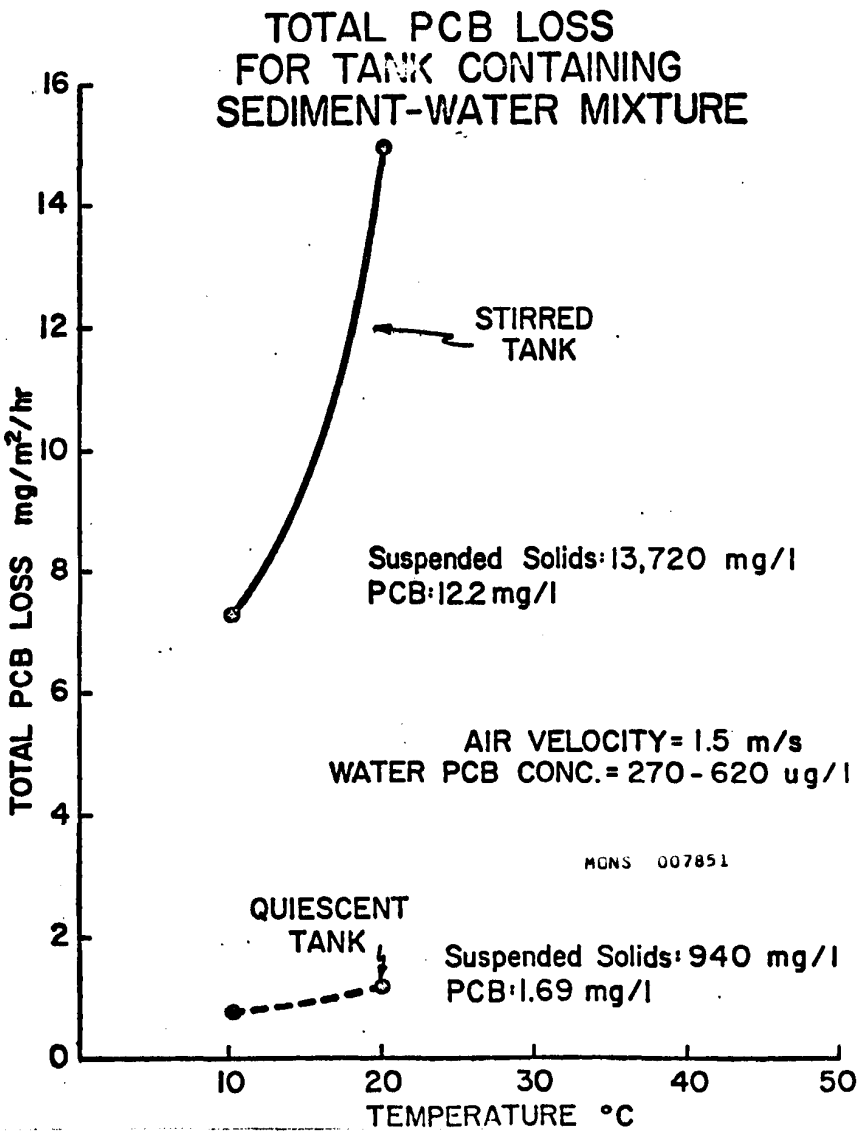


Figure 19 Ref.(16)

MONS 007850

FIGURE 20. REF. (16)



SEDIMENT TO AIR PCB LOSS

SEDIMENT PCB = 6.4 ug/g, 80% 1016
AIR VELOCITY = 1.4 m/s

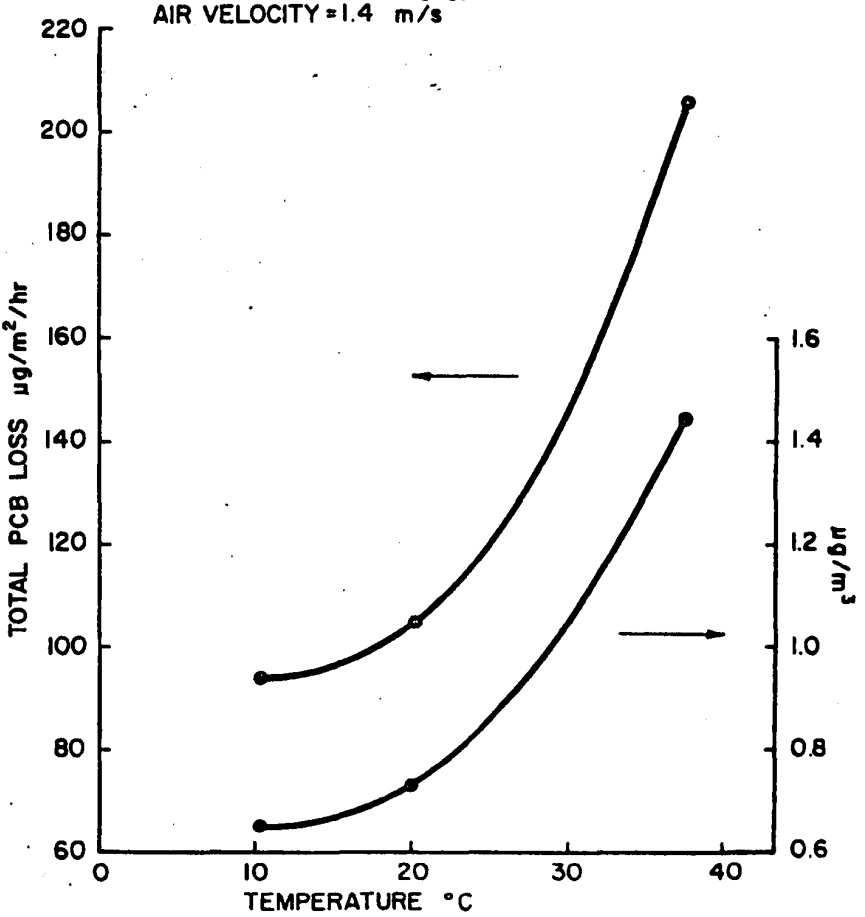
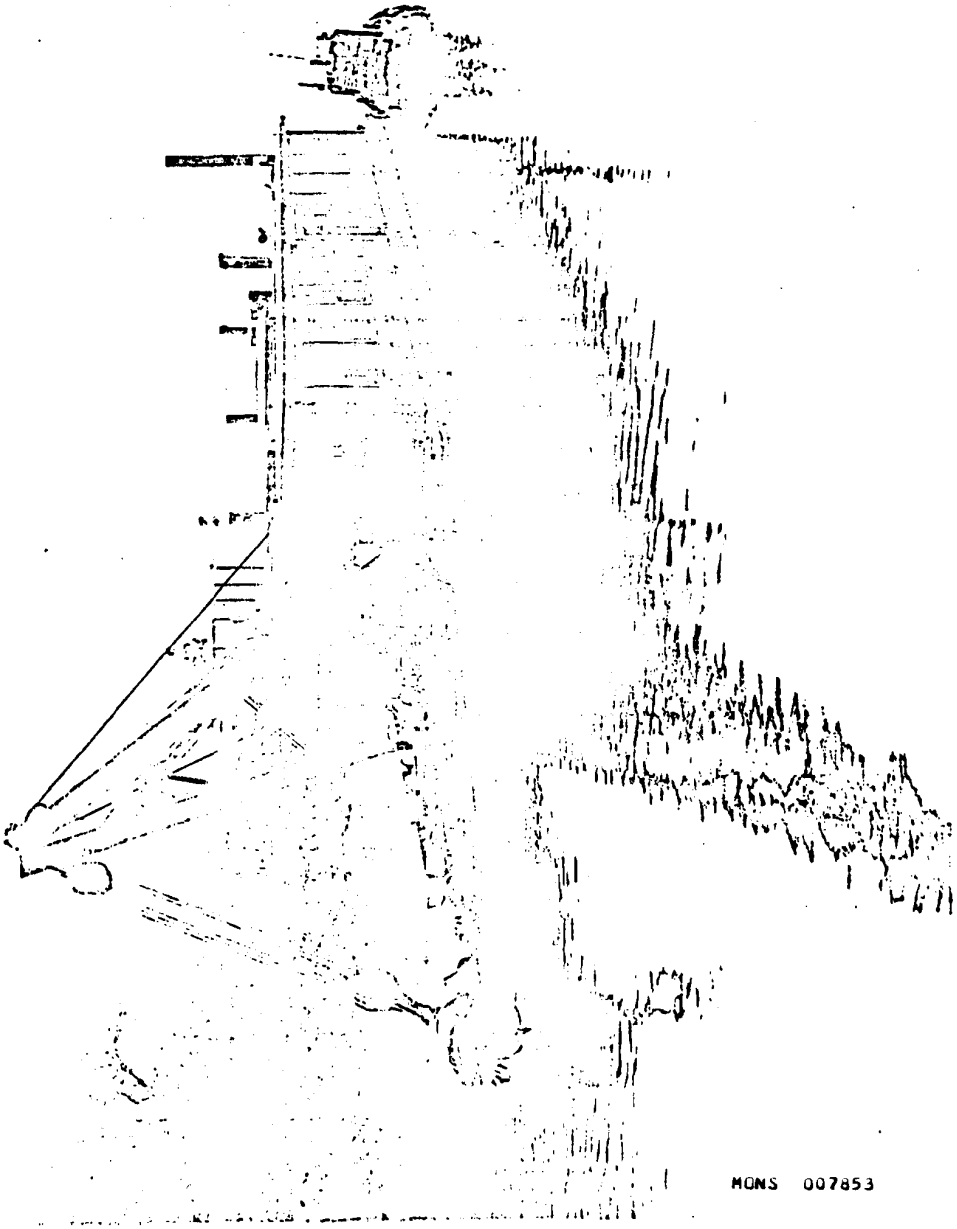


Figure 21

Ref. (16)

Figure 22. DOT Hydraulic Cutterhead Dredge.



MONS 007853

Figure 23. Scum Behind Oil Boom at Buoy 212 Site.

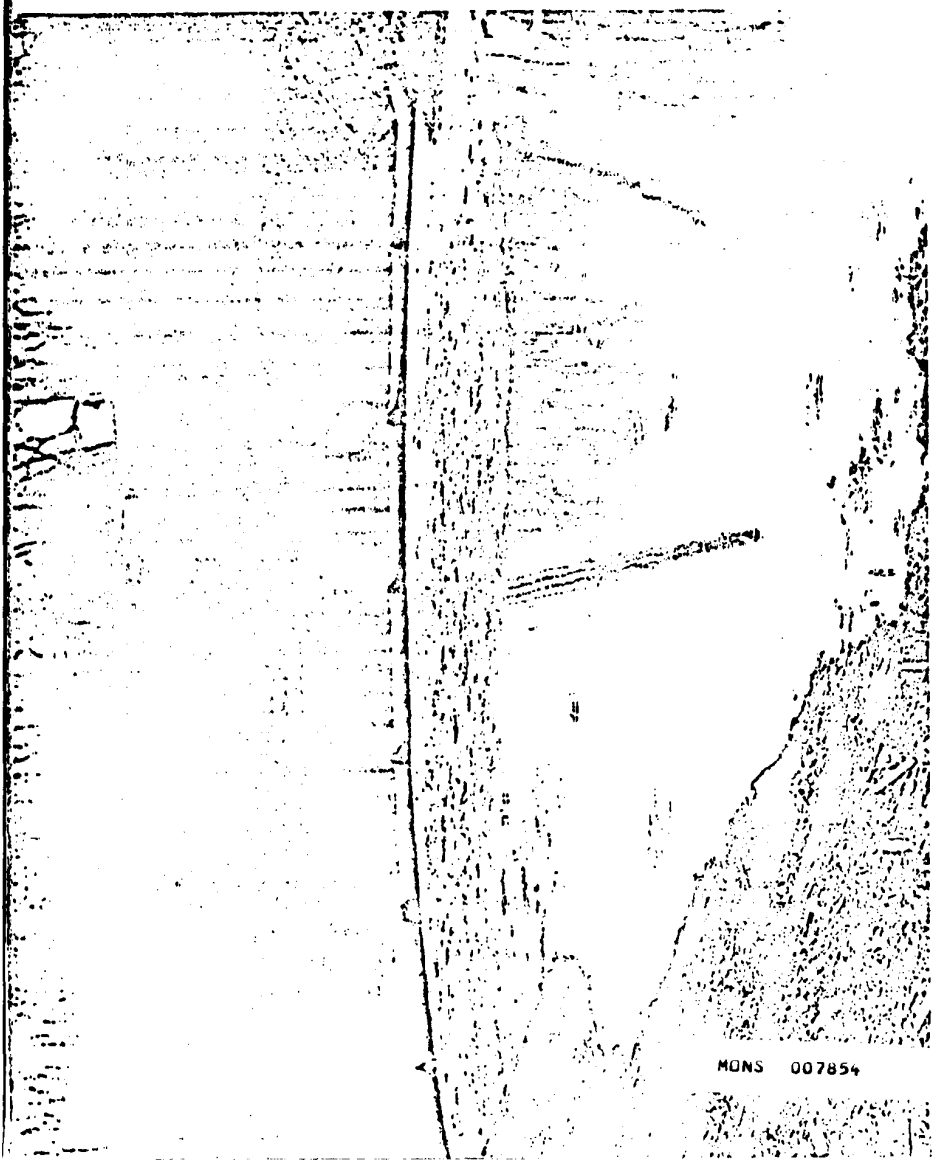


FIGURE 24.

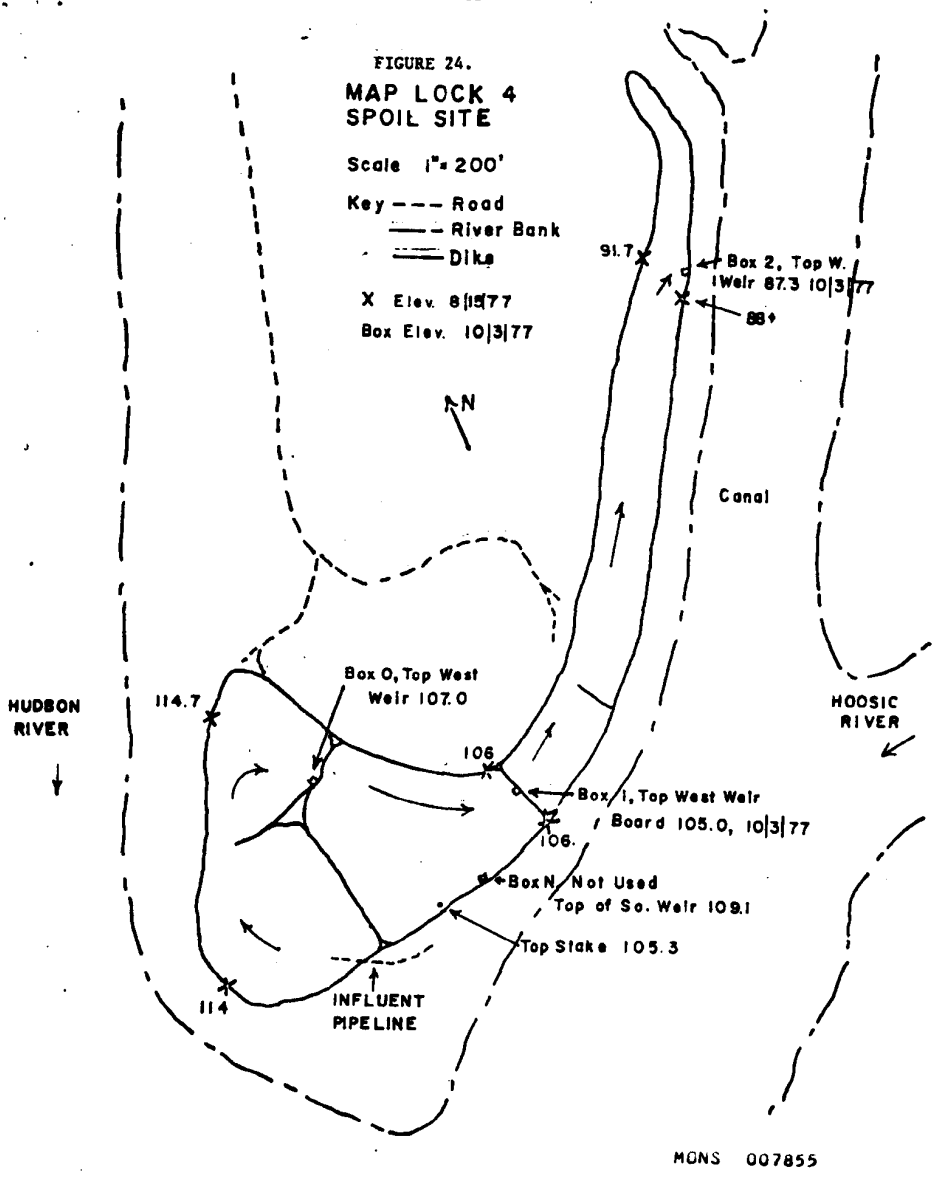

MAP LOCK 4
SPOIL SITE
Scale 1"= 200'
Key --- Road
River Bank
Dike
X Elev. 8|15|77
Box Elev. 10|3|77
N
91.7
Box 2, Top W. Weir 87.3 10|3|77
88+
Canal
HUDSON RIVER
114.7
Box O, Top West Weir 107.0
106
Box 1, Top West Weir Board 105.0, 10|3|77
106.
Box N, Not Used
Top of So. Weir 109.1
Top Stake 105.3
HOOSIC RIVER
114
INFLUENT PIPELINE
MONS 007855

Figure 25. Lower Basin of Lock 4 Site.



Figure 26. DREDGE HEAD PCB LOSS

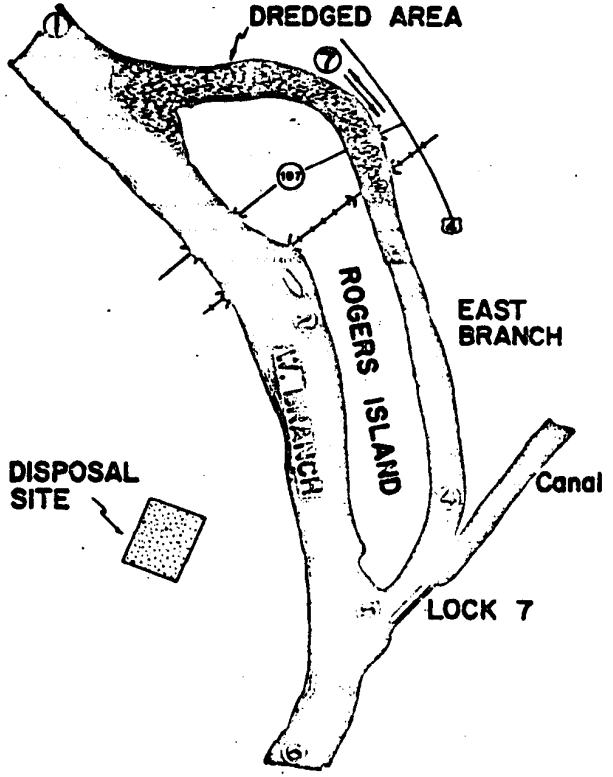


	River Section	Dredge Head
Area	149 m^2	14.9 m^2
Velocity	.198 m/s	.198 m/s
Total PCB	.1-.4 ppb	2.1 ppb
Suspended Solids	15-35 mg/l	120 mg/l
Increase in PCB*	.018 ppb	---
Increase in PCB*	43.5 g/d	---
Increase in Suspended Solids*	1.0 mg/l	---

* Due to dredge head values

FIGURE 27.

FORT EDWARD MAINTENANCE DREDGING MONITORING SITES



KEY

① UPSTREAM
② WEST CHANNEL
③ EAST CHANNEL
④ BUOY 227
⑤ LOCK 7
⑥ DOWNSTREAM
⑦ MOBIL MONITOR-DOWNSTREAM OF DREDGE

SCALE

800 400 0 800 FEET

MONS 007858

Figure 28. Dragline Bucket at Fort Edward.

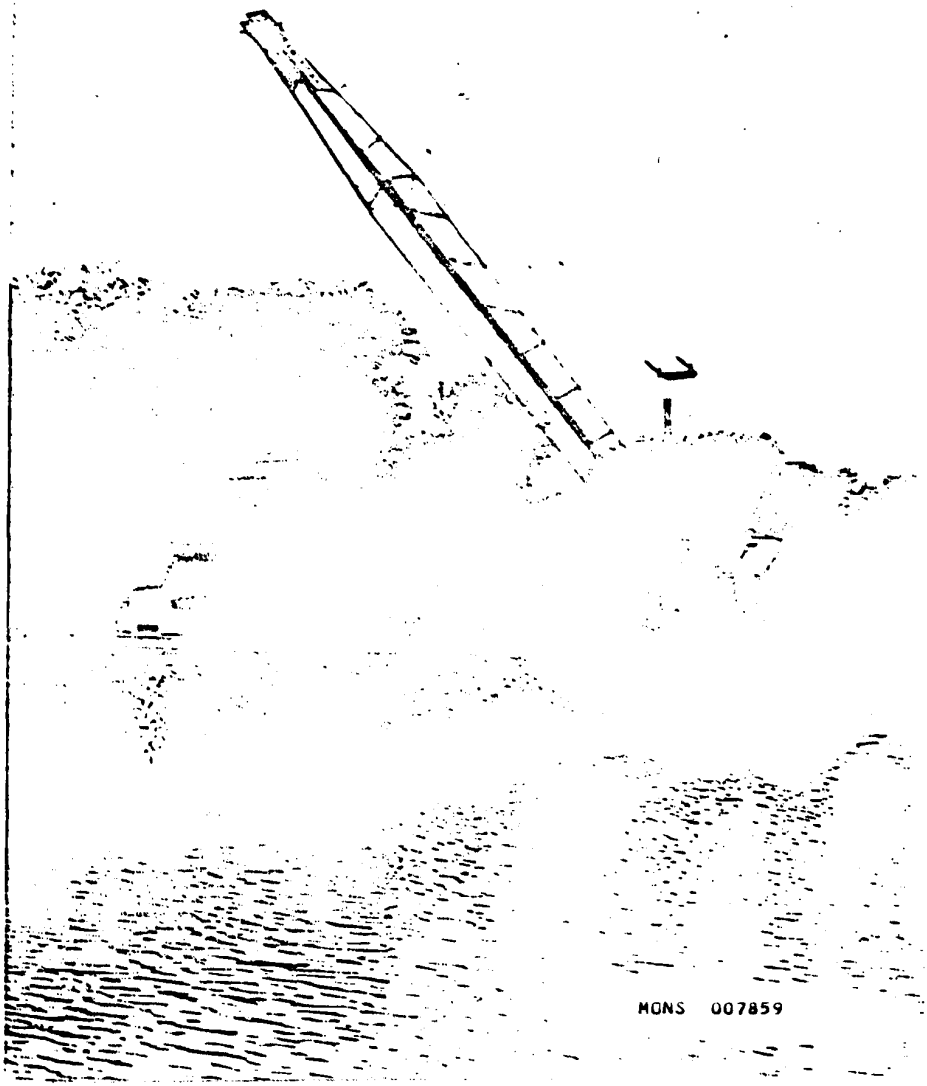


Figure 29. Scum in East Channel at Fort Edward.

