DISTRIBUTION OF PCBs IN THE THOMPSON ISLAND POOL OF THE HUDSON RIVER

FINAL REPORT OF THE HUDSON RIVER PCB RECLAMATION DEMONSTRATION PROJECT SEDIMENT SURVEY

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DISCLAIMER

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INTRODUCTION

BACKGROUND

The discharge of polychlorinated biphenyls (PCBs) to the Hudson River by two General Electric Company capacitor manufacturing facilities over a period of 30 years resulted in one of the most infamous and closely studied cases of environmental contamination in the United States. In the history of this case, man-made and natural events have served to both exacerbate and remediate the problem. The dispersion of PCB throughout 310 km (192 mi) of the river was significantly accelerated by the removal, in 1973, of a dam at Fort Edward, NY, behind which approximately 650,000 m^3 (850,000 yd^3) of sediments had been impounded (Horn *et al.*, 1979; Bopp *et al.*, 1981). Subsequent periods of high-river discharge were responsible for the massive downstream transport of PCB. High-flow events continue to transport significant quantities of resuspended PCB and sediments from the 65-km (40-mi) upper river reach to the lower river (Schroeder and Barnes, 1983).

The remedial strategy for the Hudson River basin's PCB contamination problem that has been pursued by the State of New York in cooperation with the General Electric Company, the U.S. Environmental Protection Agency (EPA), and the New York State-General Electric PCB Settlement Advisory Committee includes a series of actions which began with the 1975 reduction and 1977 elimination of the industrial PCB discharge to the river. In 1978 areas of highly contaminated river-bank sediment that were exposed following the removal of the Fort Edward Dam were stabilized from a highly erodible state. During 1977 and 1978 approximately 155,000 m^3 (200,000 yd^3) of contaminated sediment were dredged from a navigational channel in Fort Edward, NY, and placed in a clay-lined landfill (Thomas *et al.*, 1979). Several landfills in the watershed where capacitors had been dumped were also remediated. In perhaps the final phase of the remedial strategy, Congress authorized, through Section 116 of the Clean Water Act, the expenditure of 27 million dollars "to demonstrate methods for the selective removal of polychlorinated biphenyls contaminating bottom sediments of the Hudson River...".

The remedial strategy initiated in the mid-70's provided for monitoring of PCB transport and PCB levels in Hudson River biota in addition to a 1976-1977 survey to determine the distribution of PCBs in the sediments of the upper Hudson (NYSDEC, 1977). Results of monitoring from 1977-1983 have shown a marked decline in both PCB transport and PCB levels in biota (M. Brown *et al.*, 1985). It appears that natural processes have mediated the expression of the river's response to remedial actions in producing the decline.

Available data demonstrate that the recovery is far from complete. Annual transport of PCBs from the upper river to the estuary during the past six years (1981-1986) is approximately 660 kg/yr (1400 lb/yr), as indicated in Figure 1. Further, fish PCB concentrations throughout the Hudson generally exceed the U.S. Food and Drug Administration's 2 ug/g tolerance level. Prohibitions have been maintained against recreational fishing in the upper river and commercial fishing in the lower river.

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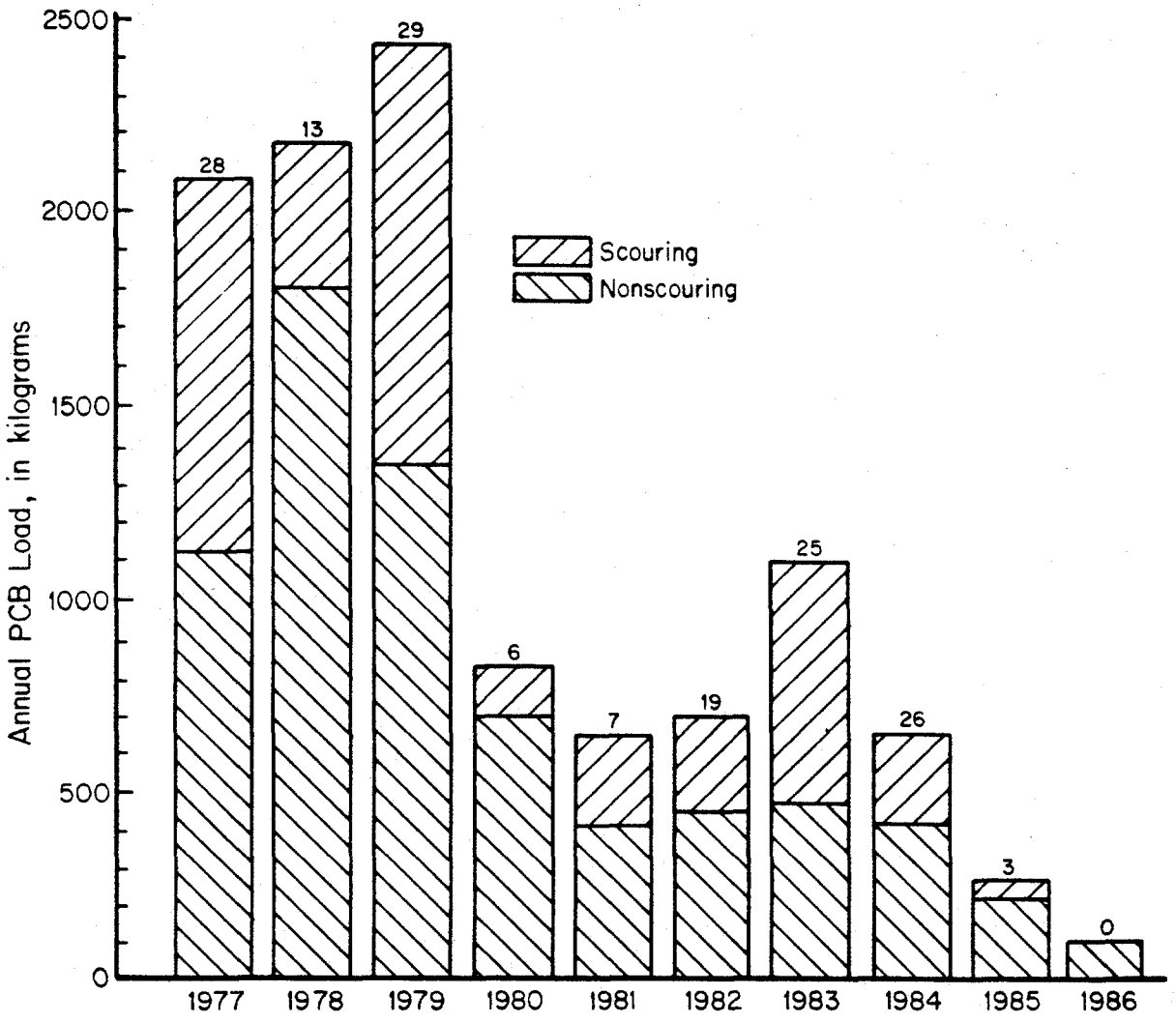

Figure 1. Annual transport of PCB in the Hudson River at Waterford, NY. Numbers above the bars indicate the number of days with flow above the estimated scour threshold of 600 m^3/s (Barnes, 1987).

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1976-1977 SEDIMENT SURVEY

During 1976 and 1977, sediment samples were collected at more than 1,000 locations in a 65-km reach of river from Fort Edward to Troy, NY. Analysis of those samples indicated that the bed of the upper river contained approximately 134,000 kg (295,000 lbs) of PCBs (Horn *et al.*, 1979). Results were used to define 40 discrete areas with average PCB concentrations generally in excess of 50 ug/g. Although these so-called hot spots constituted less than 10 percent of the total area of the sediment bed, they appeared to contain 57 percent of the total mass of PCB in the upper river (Table 1).

TABLE 1. PCB MASS AND SEDIMENT AREA ESTIMATES DERIVED FROM THE 1976-1977 SEDIMENT SURVEY

	UPPER RIVER	THOMPSON ISLAND POOL
Length (km)	65	9
PCB mass (x 10^3 kg)		
Hot spots	77	44
Total	134	54
Area (x 10^5 m^2)		
Hot spots	10.1	3.97
Total	122	13.9

Sources: Horn et al. (1979) and Tofflemire and Quinn (1979).

Twenty of the hot spots contained in an 8-km (5-mi) reach of the river bounded by the Village of Fort Edward to the north and the Thompson Island Dam to the south (Figure 2) were targeted for removal by the project. From the analysis of 100 cores and 200 grab samples collected in the 1976-1977 survey, it was estimated that this area, which is known as the Thompson Island Pool, contained 54,000 kg (119,000 lbs) of PCBs, 44,000 kg (97,000 lbs) of which were within the 20 hot-spot areas. These hot spots collectively represented 29 percent of the total area of the Thompson Island Pool (Horn *et al.*, 1979). Average PCB concentrations for individual Thompson Island Pool hot spots ranged from 38 to 380 ug/g.

An analysis of the 1977 data by Malcolm Pirnie Engineers (Malcolm Pirnie, Inc., 1978) indicated that the Thompson Island Pool hot spots contained 47,000 kg (103,000 lbs) of PCBs which is slightly higher than the estimate presented by Horn *et al.* (1979). The Malcolm Pirnie analysis, which became the working estimate subsequently used in project development, also presented an estimate of 155,000 kg (341,000 lbs) for the entire upper river, which was 21,000 kg (46,000 lbs) higher than that presented by Horn *et al.* (1979).

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PROJECT AREA

In the conventional mile point (MP) system for the Hudson, which increases northward from MP-0 at the Battery, the Thompson Island Pool runs from MP-188.5 to MP-194.6 (Figure 2). A navigational channel with a minimum depth of 12 ft is maintained throughout all but the southernmost portion of the Thompson Island Pool. The southern end is paralleled to the east by a canal. Thompson Island Pool hot-spot areas were generally delineated in nearshore areas and coves containing fine-grained sediment. With two exceptions, delineated hot spots did not extend into the navigational channel, which is generally characterized by coarse, gravelly sediments.

In 1983 an analysis of the Hudson River's PCB contamination was undertaken by NUS, an EPA consultant, to determine eligibility for funding under the 1979 Comprehensive Environmental Response, Compensation and Liability Act (Superfund). PCB data from 50 cores and 12 grab samples collected in 1983 from the Thompson Island Pool and the re-examination of the 1976-1977 sediment data highlighted the sampling problem posed by the heterogeneity of sediment types and PCB concentrations in the Thompson Island Pool (NUS, 1984). Results of the NUS analysis indicated that within short distances sediment PCB concentrations are highly variable. Further, the analysis raised the suspicion that as a result of the heterogeneity of the river bed and the low resolution of previous sampling surveys, the mass of PCBs in certain hot spots may have been substantially overestimated; whereas, other areas containing significant quantities of PCBs may have gone unidentified. NUS (1984) proposed the use of a 100-ft sampling grid imposed on previously defined hot-spot areas to confirm the existence of continuous, highly contaminated areas.

The NUS report also noted the possibility that high-flow events since 1977 may have significantly altered the locations of hot-spot sediment. However, estimates of annual PCB transport from the upper river for water years 1977-1984 (Figure 1) imply a less than 10 percent net change in the PCB mass estimated to be contained in upper-river sediments.

The scope of the Hudson River PCB Reclamation Demonstration Project (EPA, 1982) originally included a high-resolution sediment survey of the Thompson Island Pool to accommodate the development of plans and specifications for dredging. However, because doubts had been raised regarding the original definition of hot spots and their persistence, the objectives of the resurvey were modified to include the preliminary objective of confirming the existence of highly contaminated areas of sediment in the Thompson Island Pool.

SURVEY OBJECTIVES

The principal objective of the 1984 sediment survey was the specification of areas of contaminated sediment in the Thompson Island Pool to be removed by the Demonstration Project. Specifications were to be based not only upon the concentration of PCBs contained in the sediment but the availability of contaminated sediments for downstream transport.

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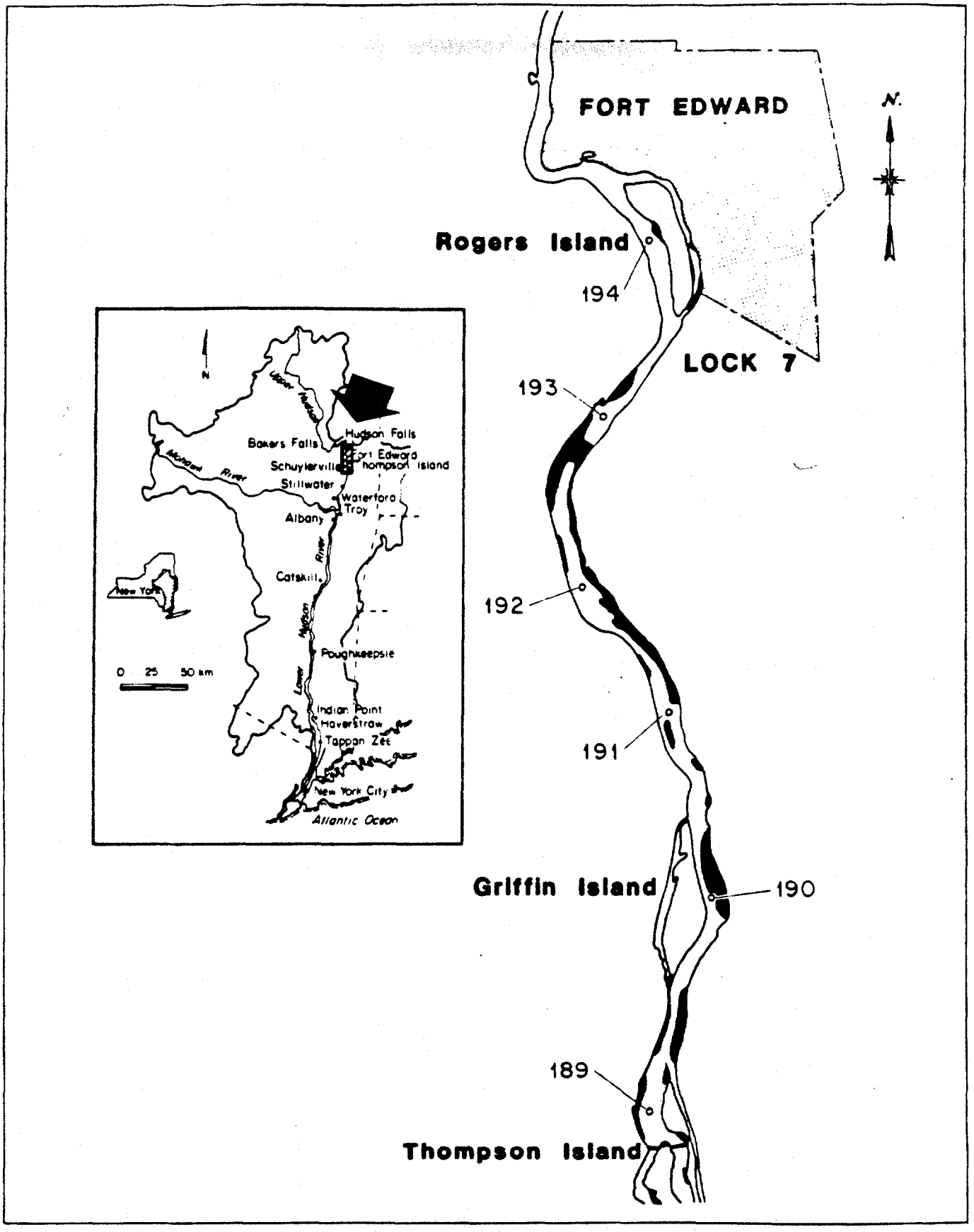

Figure 2. Thompson Island Pool and PCB hot spots as delineated by the 1976-1977 sediment survey.

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Corollary objectives included:

1. the preliminary confirmation of the persistence of the highly contaminated hot spots;
2. the assessment of sediment erodibility;
3. the assessment of errors associated with the quantification of contaminant masses in river sediments;
4. the characterization of sediment contamination by metals in the project area; and
5. the assessment of the departure of sediment PCB composition from Aroclor mixtures with respect to hypotheses of PCB biodegradation and contaminant availability.

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METHODS

SAMPLING STRATEGY

Specification contaminated sediments to be removed by dredging involved both the determination of PCB mass and contaminated sediment volume as well as the assessment of the relative availability of PCBs in a specified area for resuspension and transport. The first step toward this objective was the redefinition, through sampling and analysis, of the distribution of PCB concentrations in the Thompson Island Pool. Although the primary focus was on areas of fine-grained and modern sediment, which appear to have the highest PCB concentrations (Tofflemire and Quinn, 1979), the concentration and availability of PCB in remaining areas was also of interest.

Areas to be sampled and the level of sampling intensity were predetermined based upon an evaluation of available data for the Thompson Island Pool. Those data included: PCB and texture data from approximately 65 cores and 220 grab samples which were collected during 1976-1977 and summarized by Tofflemire and Quinn (1979); sediment-texture and sediment-probing data collected during 1980 at approximately 180 locations by Gahagan and Bryant (1981; 1982); high-resolution bathymetric soundings collected during 1982 by Raytheon Ocean Services; and sediment PCB data for 50 cores and 12 grab samples collected during 1983 reported by NUS (1984). Data were evaluated through the development of large maps (scale 1 in = 200 ft) of the Thompson Island Pool depicting bathymetric contours with 5-ft (1.5-m) intervals and the locations and PCB concentrations of previous samples having verifiable positioning data. These maps have been reduced for inclusion in Appendix A.

A 125-ft (38-m) triangular sampling grid was imposed on previously defined hot-spot areas and areas with PCB concentrations in excess of 50 ppm as determined by the 1983 sampling. The 125-ft (38-m) triangular grid produces fewer samples per unit area and has a smaller maximum distance within the grid to a sampling location than the 100-ft (30-m) grid recommended by NUS (1984). The triangular grid was superimposed on an area so as to generally include areas of transitional bathymetry within the grid. Additional locations were distributed in other than hot-spot areas based upon the results of past surveys and the apparent potential of any unsampled area to be depositional based upon bathymetry and location in the river. Altogether, 1260 locations were designated for sampling.

SAMPLE COLLECTION

Between August 27, 1984 and November 19, 1984, sediment samples were collected by Normandeau Associates, Inc. (NAI) Bedford, NH at 1037 locations in the Thompson Island Pool. To navigate to preassigned sampling locations and to determine positions of sampled locations, a microwave positioning system consisting of two moveable, shore-based transmitters and a boat-based receiver were used in association with 99 surveyed shore-control stations. Positioning of the boat within 5 m of assigned stations was required. The required accuracy for the actual sampled locations was within 2 m. The nominal precision of the equipment was within 1 m.

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At all locations, the sediment was probed with a 3/8-in (0.95-cm) diameter steel rod, and the depth to refusal was noted. Collection of a core was attempted when probe penetration was greater than 1 ft (0.3 m). Where probe penetration was less than 1 ft (0.3 m), a grab sample was attempted using a Shipek sampler. Sediment cores were collected at 586 locations during late summer and autumn, 1984. At all but eight of these stations, cores were collected using a B-6 pneumatic Vibracorer obtained from Ocean Surveys, Inc. The other cores were collected with either a hand corer or B-4 pneumatic Vibracorer. Grab samples were collected at 607 locations where cores could not be collected. At 80 locations sample collection was precluded by the presence of bedrock or very coarse material, as indicated by bottom probing. During February 1-4, 1985, DEC staff collected cores through the ice at 21 locations that had been inaccessible to the sampling vessel. These cores were collected by driving a 3-in (7.6-cm) diameter plastic core liner into the sediments with a rubber mallet.

On November 15, 984 ten sediment cores were collected from a 90-ft (27-m) transect at MP-192.7 using the B-6 Vibracore. Sediments along this east-west transect ranged from fine sands at the shallow western end to gravel at the eastern end which extended into the navigational channel. A core was also collected from the cove on the east side of the river at MP-188.5 which is immediately upstream of the Thompson Island Dam. This core was collected by driving a 2-in (5.1-cm) diameter plastic tube into the sediments with multiple light blows with a rubber mallet. Core recovery using the rubber mallet was greater than 90 percent over a depth of 3 ft (0.9 m). Core recovery, accomplished by pushing an identical tube into this fine-grained sediment, was approximately 50 percent.

SAMPLE ANALYSES

Sample Processing

All samples were transported from the field to the New York State Department of Health's (NYSDOH) inorganic chemistry laboratory in Albany for processing. The protocol for core sectioning was based upon: (a) the resolution required to assess the presence of highly contaminated strata without excessive dilution by cleaner material potentially residing above or below those strata; (b) precision of potential dredging methods; and, (c) economy of sample analysis. Overall, 1304 samples resulted from the sectioning of 407 cores. During sample processing, Vibracore samples were halved lengthwise by cutting the plastic core liner and separating the sediment into both halves of the liner using spackling knives. Half of each Vibracore was forwarded to the Lamont-Doherty Geological Observatory, Palisades, NY for archival storage.

In addition to sample processing, NYSDOH was responsible for description of sediment texture based upon visual inspection, recording lengths of cores and core sections, analysis of percent dry solids and estimation of specific weight (also known as dry density or unit dry weight) of sediment. Percent dry solids was determined by weight loss of a sediment aliquot dried at 100 C on a drying dish. To assess specific weight, sediment was carefully transferred to a 20-mL beaker. Sediment in the beaker was occasionally gently tamped to remove noticeable air pockets. Specific weight was estimated as the

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product of wet weight per unit volume of the 20-mL beaker and the percent dry solids. Most of the sediment samples classified as gravel were not analyzed to determine percent dry solids and specific weight due to difficulty in representatively subsampling the sample containers and approximating *in situ* compaction in the beaker.

PCB Analyses

PCB concentrations in sediment samples were determined either by mass spectrometry (mass-spec) or gas chromatography (GC). Mass-spec was used primarily as a screening tool to classify sediment PCB concentrations into four ranges: less than 10 ug/g, 10-50 ug/g, 50-100 ug/g and greater than 100 ug/g. The principal objective of the screening method was to minimize the number of samples with low PCB concentrations to be submitted for the more costly GC analyses. This accommodated the analysis of a greater total number of samples, and dedicated the use of the GC method for definition of more highly contaminated areas.

For mass-spec analyses, 5 g of air-dried sediment sample were shaken with 10 mL methylene chloride for 30 minutes. After centrifugation, a 1-mL aliquot of supernatant was transferred to a mini-vial. A Trace Atmospheric Gas Analyzer (TAGA) 3000 quadrupole mass spectrometer (2-560 a.m.u.) with an atmospheric pressure chemical ionization source was used for analysis. A 2-uL aliquot of the extract was placed on a direct insertion probe, and the methylene chloride was evaporated by a carrier gas. PCB was then flash vaporized by passage of a current through the probe. Because software of the mass spectrometer limits specific ion monitoring to eight masses, two such desorptions were required to monitor the two most abundant isotopic masses of each of the eight PCB isomer groups, mono- through octa-chorobiphenyl. The entire screening method was standardized using reference Hudson River sediment samples that had been analyzed by Dr. Brian Bush, NYSDOH, Albany, NY.

Samples for PCB analysis by gas chromatography were analyzed by Versar, Inc., Springfield, VA. A 10-g aliquot of wet sediment was air dried to determine the percent of dry solids. A separate 10-g aliquot was transferred to a 250-mL Erlenmeyer flask and sequentially extracted with 350 mL acetone/hexane (1:1) while shaking for 30 minutes. The extracts were combined and concen- trated to 10 mL in a Kuderna-Danish concentrator. Activated Florisil and reactive copper were employed in cleanup. Following a final concentration step, the extract was injected into the chromatograph.

The electron capture (^{63}Ni) gas chromatography system consisted of a 1.8-m x 2-mm ID glass column or a 1.8-m x 1-mm ID glass column with 3% OV-1 on 100/120 Gas Chrom Q. Temperature was ramped 180-210 C. The carrier gas was 5% methane in argon, and the flow rate was 50 mL/min. PCB concentrations reported by Versar were quantitated as Aroclor 1242, Aroclor 1254, and Aroclor 1260 using the method of Webb and McCall (1973). In addition to PCB, Versar also determined the concentration of volatile solids through combustion of a 5-10 g aliquot at 550 C.

Thirty-eight samples derived from cores collected at MP-188.5 and the 10-core transect at MP-192.6 were analyzed by capillary column GC methods

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(Bush *et al.*, 1975) at NYSDOH. Three to 5 gram aliquots of these samples were transferred to 20-mL scintillation vials and sequentially extracted with two 10-mL aliquots of acetone followed by two 10-mL aliquots of nanograde hexane. Samples were shaken for 1 minute during each extraction. Extracts were combined in a 125-mL separatory funnel to which were added 50 mL distilled water. Following phase separation, the acetone/water mixture was transferred to a 125-mL beaker. An additional 50 mL of distilled water were added to the funnel. Following separation, the water phase was added to the beaker and the hexane phase transferred to a 50-mL Erlenmeyer flask. The water phase was returned to the funnel and extracted with 5 mL hexane. This hexane extract was combined with the others in the Erlenmeyer flask. The extract was evaporated to approximately 2 mL in a Kuderna-Danish concentrator. The extract was cleaned with mercury followed by Florisil. A Hewlett-Packard 5840A gas chromatograph, equipped with a 50 m x 0.25 mm soda-glass column coated with Apiezon L, and an electron capture detector, was used for PCB analysis.

Metals Analyses

Selected samples were submitted to NYSDOH for determination of metals concentrations. The series of metals and the number of samples analyzed are provided in Table 2. Samples were submitted for metals analyses based upon the results of PCB analyses. The primary objective of the metals analyses was to characterize materials that would be dredged. Samples were thus biased towards areas having elevated PCB concentrations. The analytical methods have been described by Brown and Werner (1984). Pertinent features of the method include sample drying, grinding and sieving; digestion by concentrated nitric acid; and atomic absorption spectrophotometry of digestate.

QUALITY CONTROL

Sampling

Sampling, sample processing and analytical quality control procedures employed in the sediment survey were described in the Project's quality assurance plan (Brown and Werner, 1984). The quality control procedures related to sampling were directed toward either one of two objectives: assuring that the positions of sampled locations reported by the sampling contractor were accurate with respect to project maps; and assessing the smallscale spatial variations in PCB distribution, where smallscale is considered to be less than the 125-ft (38-m) distance between sampling stations in the triangular sampling grid. Much of the survey control for the Thompson Island Pool was provided by a survey conducted by Norman Porter during 1981. In that survey, baseline points were located along a road running parallel to the western shore of the pool. The maps used by the project (1 in = 200 ft scale) were developed by NAI during 1977 from aerial photographs taken during 1976. In 1984, DEC surveyors from the Division of Lands and Forests located 99 positions along the shores of the pool to be used as stations for the microwave transponders. The positions included those used by Raytheon in their 1982 bathymetric survey of the pool and those predetermined as necessary to maintain the optimal geometry for use of the microwave positioning system. Station coordinates for intended sampling stations supplied by DEC were translated into ranges from two or more transponder positions by NAI staff for use by field staff. As indicated earlier, tolerances for reaching a preassigned station (< 5 m) were wider than that

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TABLE 2. ANALYSIS OF SEDIMENT METALS BY NYSDOH

Metal	Detection Limit (µg/g)	Number of Samples
Arsenic	1	79
Cadmium	4	159
Copper	10	79
Chromium	20	79
Hexavalent Chromium	4	79
Lead	20	217
Mercury	0.08	79
Nickel	10	79
Selenium	1	79
Silver	4	79
Thallium	2	79

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desired for accuracy of the actual sampling position (< 2 m). The only quality assurance procedure applied to the positioning data was the recalculation of station positions for all cases where the reported sampling location was more than 25 ft (7.6 m) from the preassigned location. Less than five percent of all stations required correction of positions. All positions with the exception of six grab-sample stations (stations 29, 32, 487, 1132, 1192 and 1205) and one core-sample station (station 264) are considered valid. Analytical results for samples collected at those stations were included in river-wide statistical analyses but were excluded from calculations of PCB masses in discrete areas of the river.

To assess small-scale spatial variability in PCB distributions, four sampling locations were clustered around a central point each approximately 10 ft north, south, east and west of the central point. A total of 19 clusters of five samples each were sampled. Twelve of those clusters were on the corners of approximately 125-ft (38-m) per side triangles within the triangular sampling grid in three areas of the river. In addition, a 90-ft (27-m) transect oriented generally east-west and perpendicular to river flow was sampled at 10-ft (3-m) intervals. The ten cores from this transect were sectioned with a much higher resolution than routinely used in the survey.

Analytical QC

Data available to assess the quality of results of PCB analyses performed by Versar include the results of duplicate analyses and spiked (Aroclor 1242) sample recoveries from Versar's internal quality assurance program. In addition, blind samples were submitted to Versar in duplicate. The blind duplicates were submitted and analyzed in different batches, whereas each duplicate pair in Versar's internal quality assurance program was analyzed in the same batch. The duplicate samples analyzed as part of Versar's internal quality assurance program are referred to as known duplicates.

Figure 3 presents the frequency distribution of the percent differences between 34 pairs of known duplicates and 41 pairs of blind duplicates. Percent difference was calculated as the average of two values: the absolute difference between two results divided by the higher result and the difference divided by the lower result. It should be noted that this is a more critical method of analyzing results of duplicate analyses than the commonly employed method of dividing the absolute difference of the two results by the higher result. The results of 19 duplicate pairs analyzed by Versar, for which one or both results were reported as less than the detection limit, were excluded from this analysis. The average of the distribution presented in Figure 3a is 27.2 percent. (If the results of the 19 omitted pairs were included as zero, the mean would be reduced to 17.5 percent.) The results of 41 pairs of blind duplicate samples for which both results were reported as greater than the detection limit are summarized in Figure 3b. The mean of this distribution is 52.1 percent. Excluding the single extremely high value of 410 percent from this distribution, the mean is reduced to 42.2 percent.

The frequency distribution of 59 results from the Versar chemical recovery program presented in Figure 4 appears to be normally distributed. The mean of this sample distribution is 86.3. This is significantly ($p < .01$) less than 100

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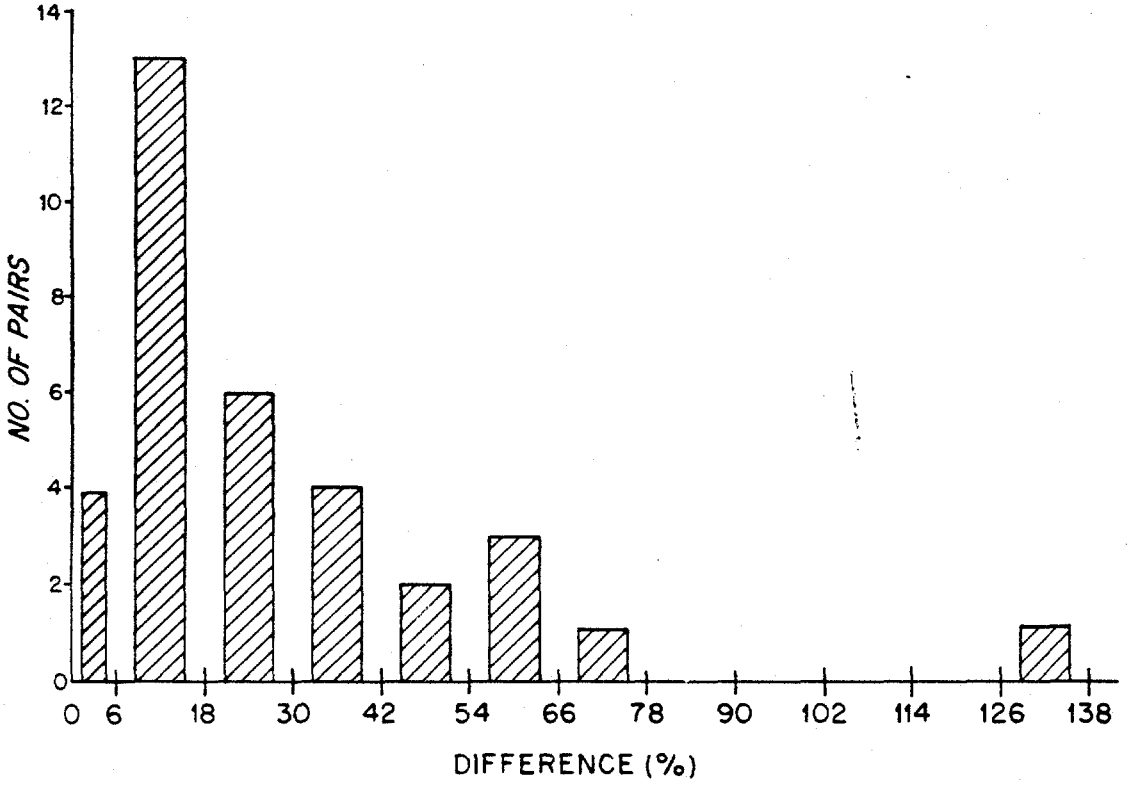
(a)



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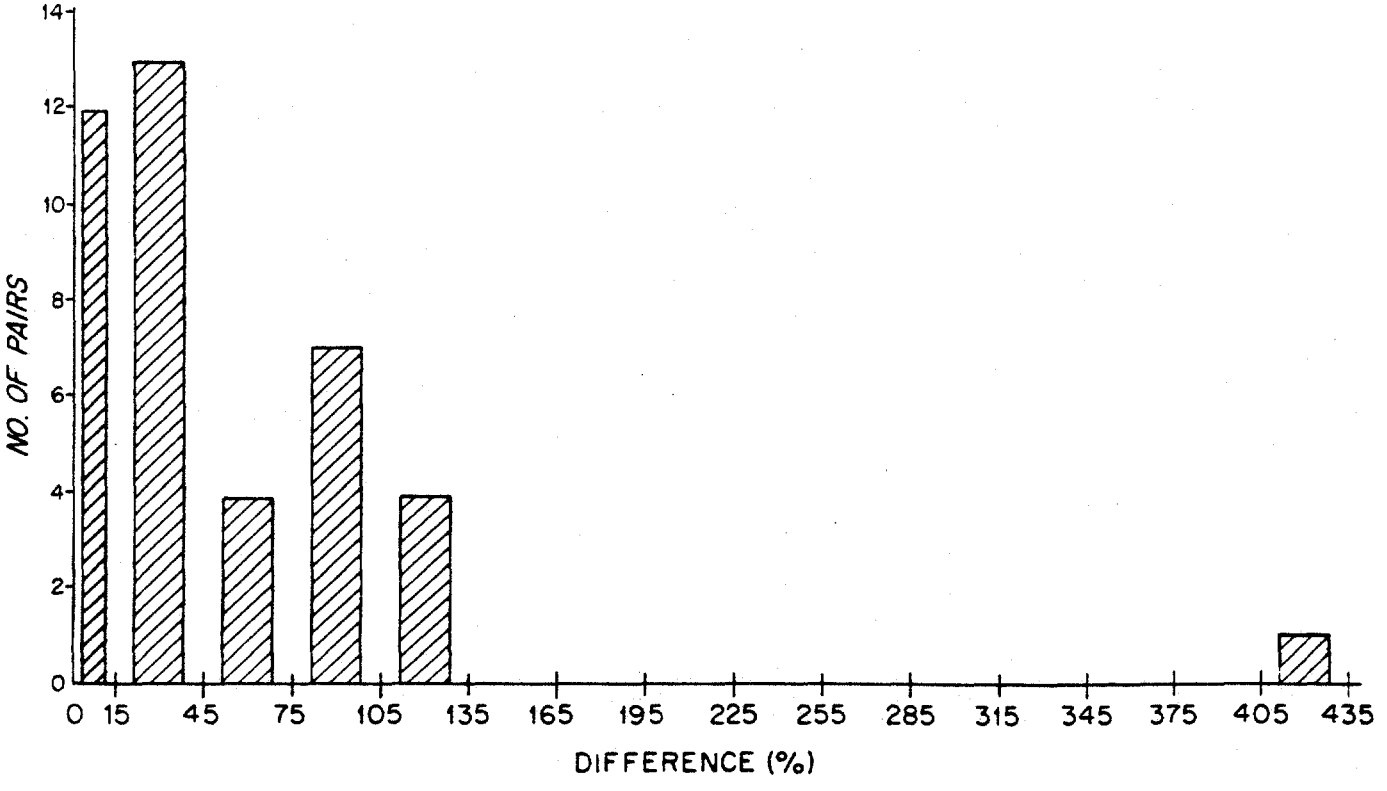

Figure 3. Frequency distribution of difference of known (a) and blind (b) duplicate analysis.

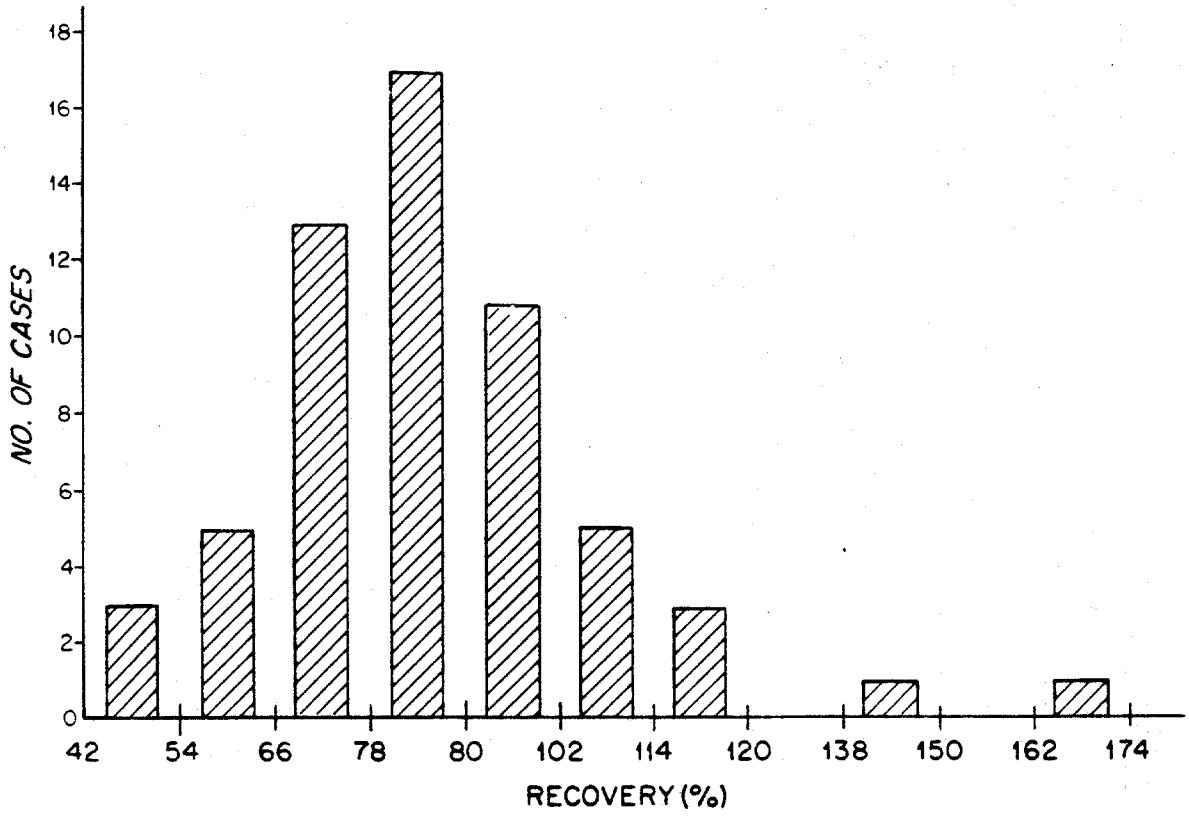

Figure 4. Frequency distribution of chemical recovery program results.

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percent which would indicate perfect accuracy and suggests the presence of an underestimating bias. The apparent cause of this will be illustrated in the following section.

In addition to those analytical QA programs described previously, three sediment samples were split between Versar and Erco, Cambridge, MA. Versar reported concentrations of 22, 13 and 7 ug/g as the sum of Aroclor 1242 and Aroclor 1254 concentrations. Erco reported respective concentrations of 26, 17 and 16 ug/g quantified as Aroclor 1248.

Recalculation of Aroclor 1242 PCB Concentrations

At the request of the principal investigator, Versar calculated PCB concentrations using the mass analyses of Aroclor 1242, Aroclor 1254 and Aroclor 1260 reported by Webb and McCall (1973). The essential results of Webb and McCall's (1973) work were tables listing the weight percent of a given Aroclor associated with packed column chromatogram peaks identified by retention time relative to that of pp'-DDE. These tables enable the analyst to determine peak-specific response factors for standards and hence environmental concentrations of PCB associated with individual peaks which are generally sequenced by the degree of chlorination. As shown by Bopp (1979) and Bopp *et al.* (1982) this type of information can provide valuable insight into the environmental behavior of PCB. Further, due to a recent report of *in situ* alteration of PCB composition that was attributed to anaerobic dechlorination (J. Brown *et al.* 1985) it was desirable to have as much information as could be extracted from packed column chromatograms available to address such alterations.

Due to differences between the chromatography columns used by Webb and McCall (1973) and Versar, the relative retention times of PCB peaks also differed. A subjective assessment by Versar of correspondence between Versar's chromatogram peaks to those reported by Webb and McCall (1973) was required for each batch.

The DEC principal investigator checked Versar's assessment of peak correspondence for all batches by examining peaks in Versar's standard Aroclor 1242 chromatogram corresponding to Webb and McCall's (1973) peaks with retention times of 0.47, 0.54, 0.58, 0.70, and 0.78 relative to pp'-DDE. Checking the correspondence of earlier peaks was difficult due to the low quality of chromatogram copies. Versar's assessment of correspondence was disputed for only one batch, and agreement was subsequently reached and corrections made. Assessing correspondence between Webb and McCall (1973) and Versar peaks for Aroclor standards is relatively easy compared to assessing correspondence between chromatogram peaks for standards and sediment samples.

Upon examination of sample chromatograms, it became apparent that, in most cases, sample peaks were assigned subjectively rather than strictly using the relative retention times developed from interpretation of Aroclor standards. DDE was used as an internal standard in the analysis of all samples and Aroclor standards. However differences in columns and GC operating conditions between Versar and Webb and McCall (1973) resulted in a lack of strict correspondence between relative retention times. This problem in addition to

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presence of peaks apparently missed by the peak integrator resulted in a high frequency of certain peaks not being quantitated. Table 3 presents the Webb and McCall (1973) relative retention times (RRT) and weight percent data for Aroclor 1242 and Aroclor 1254 peaks in addition to the relative frequency of peak identification by Versar in the Hudson River sediment samples. The relative frequency of peak detection varied from 2.2 percent for peak RRT-.16 to 79 percent for peak RRT-.37. There appears to be a positive correlation between detection frequency and the weight percent of Aroclor 1242.

In the quantitation of Aroclor 1242 PCB by Versar, only peaks corresponding to Webb and McCall's (1973) RRT-.21 through RRT-.84 were considered, which account for 89 percent of the PCB in Aroclor 1242. Total Aroclor 1242 concentrations reported by Versar were not adjusted for the unconsidered peak area. Hence, complete recovery of Aroclor 1242 additions would appear as 89 percent which is close to the 86.3 percent average previously reported. This highlights the problem associated with omitting peaks from calculations using the Webb and McCall (1973) analyses without correcting for the mass of PCB associated with ignored peaks. Estimation of the magnitude of possible error associated with this system is fairly straightforward. Failure to identify peaks that were targeted for identification in the quantitation methods would produce underestimating errors in the calculation of total PCB. Such occurrences are summarized in Table 3. It is clear from the inspection of chromatograph records that a considerable amount of the total peak area of chromatograms was not factored into the calculation of total PCB. There is very little that can be done by way of recalculation to correct for some of the early peaks which were overlooked. However, much of the overlooked peak area appears to be in the Aroclor 1242 region of the chromatograms.

Areas of peaks that were identified among the targeted peaks (Table 3) were reported by Versar on magnetic tape along with records for standards and other pertinent information regarding samples and standards such as extracted sample weight, dilution volumes, injected volumes, and mass of standard injected. This accommodated the recalculation of Aroclor 1242 PCB using several peaks that were consistently identified. Peaks RRT-.28, RRT-.47 and RRT-.58 were selected for use. These peaks in addition to being consistently identified, also correspond to those used by O'Brien and Gere (1978) to quantitate Aroclor 1016 in Hudson River sediment samples. The correspondence between the peaks used by O'Brien and Gere for Aroclor 1016 and those in the Versar chromatogram for Aroclor 1242 can be seen in Figure 5. It should be noted that the Versar chromatogram presented in this figure was produced using a column having a 1-mm ID instead of the 2-mm ID column routinely used. Chromatograms from the 2-mm column were considerably more difficult to interpret. Recalculation essentially involved development of three total Aroclor 1242 response factors from standards using three peaks, applying those response factors to the three sample peaks and taking the average of the three Aroclor 1242 concentrations. Some independent support for this method as being reliable for the quantitation of total PCB in sediments from the upper Hudson River comes from Bopp (1984; 1985). In addressing departure of sample PCB composition from that of Aroclor 1242, Bopp has employed the use of peak RRT-.47 alone in estimating total PCB concentration.

Recalculated Aroclor 1242 PCB concentrations were highly correlated (r^2 = .80) with Versar results and were on the average 40 percent higher than the

TABLE 3. RELATIVE RETENTION TIMES AND MASS-SPEC ANALYSES REPORTED BY WEBB AND McCALL (1973) AND RELATIVE FREQUENCY OF IDENTIFICATION BY VERSAR, INC.

Peak RRT	Aroclor Composition		Relative Frequency of Identification in Sediment Samples*
	Aroclor 1242 (weight percent)	Aroclor 1254 (weight percent)	
.11	1.1		3.3
.16	2.9		2.2
.21	11.3		78
.28	11.3		52
.32	11.0		46
.37	11.5		79
.40	11.1		70
.47	8.8	6.2	77
.54	6.8	2.9	72
.58	5.6	1.4	77
.70	10.3	13.2	78
.78	3.6	-	68
.84	2.7	17.3	18
.98	1.5	7.5	2.6
1.04	2.3	13.6	2.9
1.25	1.6	15.0	76
1.46	1.0	10.4	77

* 1166 sediment analyses.

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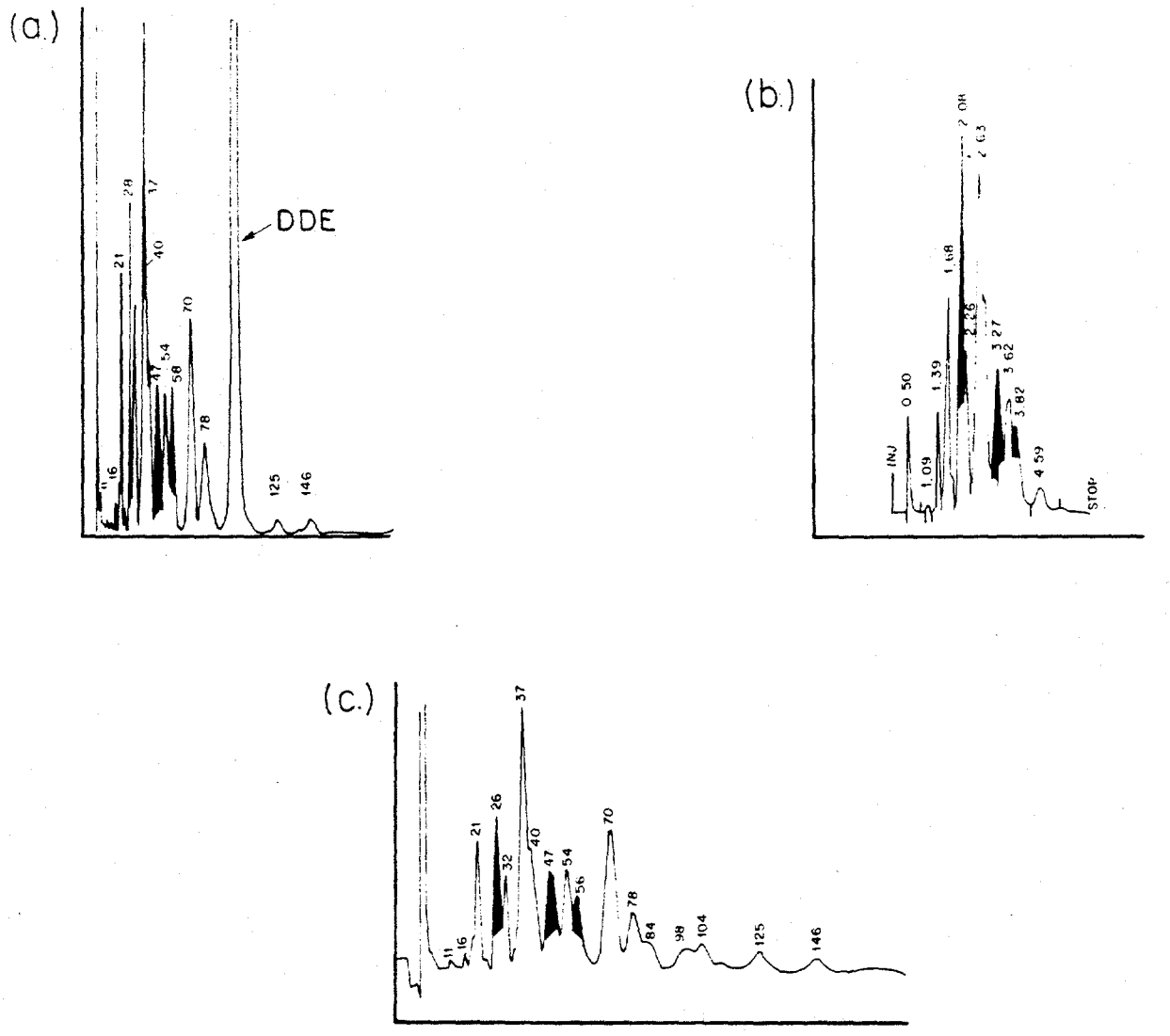

Figure 5. Correspondence among chromatograms of Aroclor 1242 by Versar, Inc. (a), Aroclor 1016 by O'Brien and Gere (1978) (b), and Aroclor 1242 by Webb and McCall (1973) (c), (relative retention times shown for (a) and (c)). The shaded peaks were used in the recalculation of the Versar data to quantitate Aroclor 1242 masses. The same peaks were used by O'Brien and Gere.

Versar results. The sum of the recalculated Aroclor 1242 concentration and the PCB concentrations reported as Aroclor 1254 and Aroclor 1260 by Versar was employed as the total PCB concentration in this analysis.

Interpretation of Mass-Spec Screen Results

In screening sediment sample extracts using a mass spectrometer, the analyst was requested to classify PCB concentrations into four ranges: less than 10 ug/g; 10-50 ug/g; 50-100 ug/g and greater than 100 ug/g. The decision to send a sample for GC analysis was largely based upon the screening result. In general, samples producing higher screen results tended to be sent for analysis by GC. Nearly all of the samples with PCB concentrations reported as either 50-100 ug/g or greater than 100 ug/g were subsequently analyzed by GC. At the other extreme, most samples that were reported as having PCB concentrations less than 10 ug/g were not sent for GC analysis. A comparison of results of samples analyzed by both methods is presented in Table 4. As evident by the size of the standard deviations relative to means, the distribution of GC results within each mass spec concentration category appears to have a lognormal rather than normal distribution. For results reported as less than 10 ug/g, the average was actually higher than the upper limit for the range. Median values fall within the mass spec concentration ranges. For the calculation of quantities of PCB discussed in a later section of the report, the means of these distributions will be employed.

The sample screening protocol tended to withhold lower sections of cores from GC analyses if screening indicated a concentration less than 10 ug/g. The depth integration of PCB concentrations in core sections used in the calculation of PCB masses required the assignment of PCB concentrations to samples that were only screened. For sections having screen results of less than 10 ug/g the average of 15 ug/g was assigned to only the uppermost section of consecutive sections near the bottom of the core having a screen concentration of less than 10 ug/g. Lower sections were assigned a concentration of zero unless PCB had been quantitated by GC or screening produced a concentration greater than 10 ug/g in a deeper section of the same core.

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Table 4. COMPARISON OF RESULTS OF MASS-SPEC AND GC ANALYSES OF SPLIT SAMPLES.*

Mass-Spec Result Category	n	GC Result Distribution Mean	Standard Deviation
< 10 ug/g	61	15.0	39.1
10 - 50 ug/g	347	30.8	42.6
50 - 100 ug/g	67	134.6	144.
> 100 ug/g	22	518.	1397.

*GC results are recalculated total PCB

RESULTS

SAMPLE COLLECTION

The number and length of cores collected were generally in line with the expectations for the program. However, several alterations of the original design for sample collection were made to ensure success. The most notable change was due to the failure of the B-4 Vibracore to penetrate sediments composed of sands and gravels. Hand-coring was found to be even less effective than the B-4 Vibracore. Early in the program a B-6 Vibracore was leased as an alternative. Nearly all of the cores were collected with this unit. The B-6 unit, weighs 148 kg (325 lbs), which is approximately three times the weight of the B-4 unit. However, even the B-6 was of limited effectiveness in coring sediments composed of gravel. Most (56 percent) of the grab samples had textures described as gravel. A histogram of core lengths is presented in Figure 6. The average length of core collected by the survey was 80 cm (31.1 in). The average core subsection length analyzed was 25 cm (9.9 in). The respective standard deviations of core length and section length distributions are 34 cm (13.2 in) and 9.9 cm (3.9 in).

The 3/8-in (0.1-cm) diameter steel rod used for sediment probing was more narrow than the pipe originally intended to assess whether a site could be cored. The thin steel rod was easier to handle than a steel pipe particularly in deep waters. However, the rod could penetrate gravel sediments relatively easily. Therefore, the correlation between the ability to collect a sediment core and rod penetration was poor. The obvious exception being cases where neither the rod nor a sampling device could penetrate a hard surface.

There was only one area of significant size that was targeted for sampling but not sampled. This was the cove on the east side of the river immediately upstream of the Thompson Island Dam (MP-188.5), formerly designated as hot spot 20. This was one of the last areas sampled by the consultant. Only the outer portion of the cove was sampled. Fortunately, a number of investigators have collected cores from this area since the 1977 survey. Data from those samples were included in the assessment of PCB concentration and PCB mass in this area.

SEDIMENT TEXTURE DISTRIBUTION

Most of the area of the Thompson Island Pool is composed of sediments with texture ranging from sand to gravel. Fine-grained sediment is found in near-shore and back-water areas such as coves and inactive channels along certain islands. Some deepwater areas, particularly near the Moses Kill (MP-189), contain fine-grained sediment. A generalized map of sediment texture developed from the sediment sampling is presented in Figures 7a and b. It should be noted there are many local discontinuities in sediment texture within the areas delineated in Figures 7a and b.

DISTRIBUTION OF PCB CONCENTRATIONS IN THE THOMPSON ISLAND POOL

Tofflemire and Quinn (1979) noted that PCB concentrations in sediment samples from the upper Hudson appear to be lognormally distributed. This appears to be the case for samples collected during 1984 in the Thompson Island

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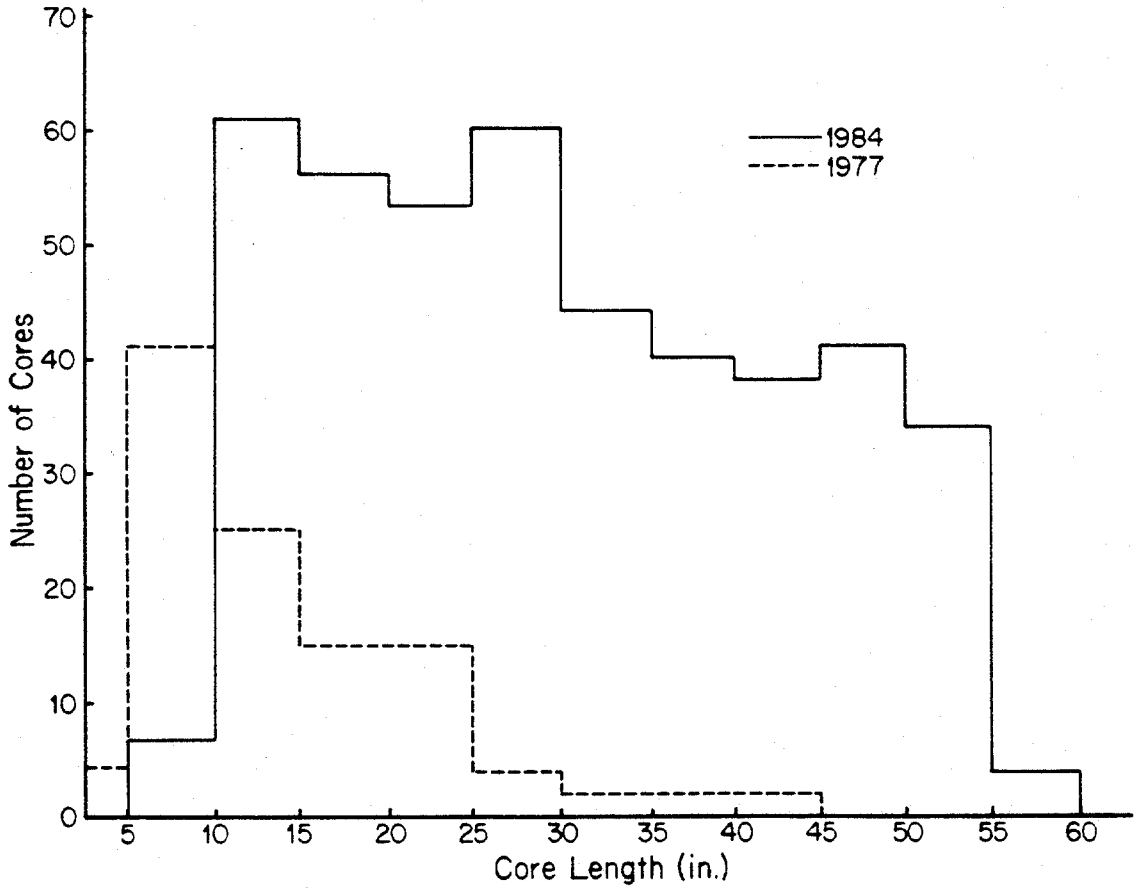

Figure 6. Distribution of core lengths for the 1977 and 1984 surveys.

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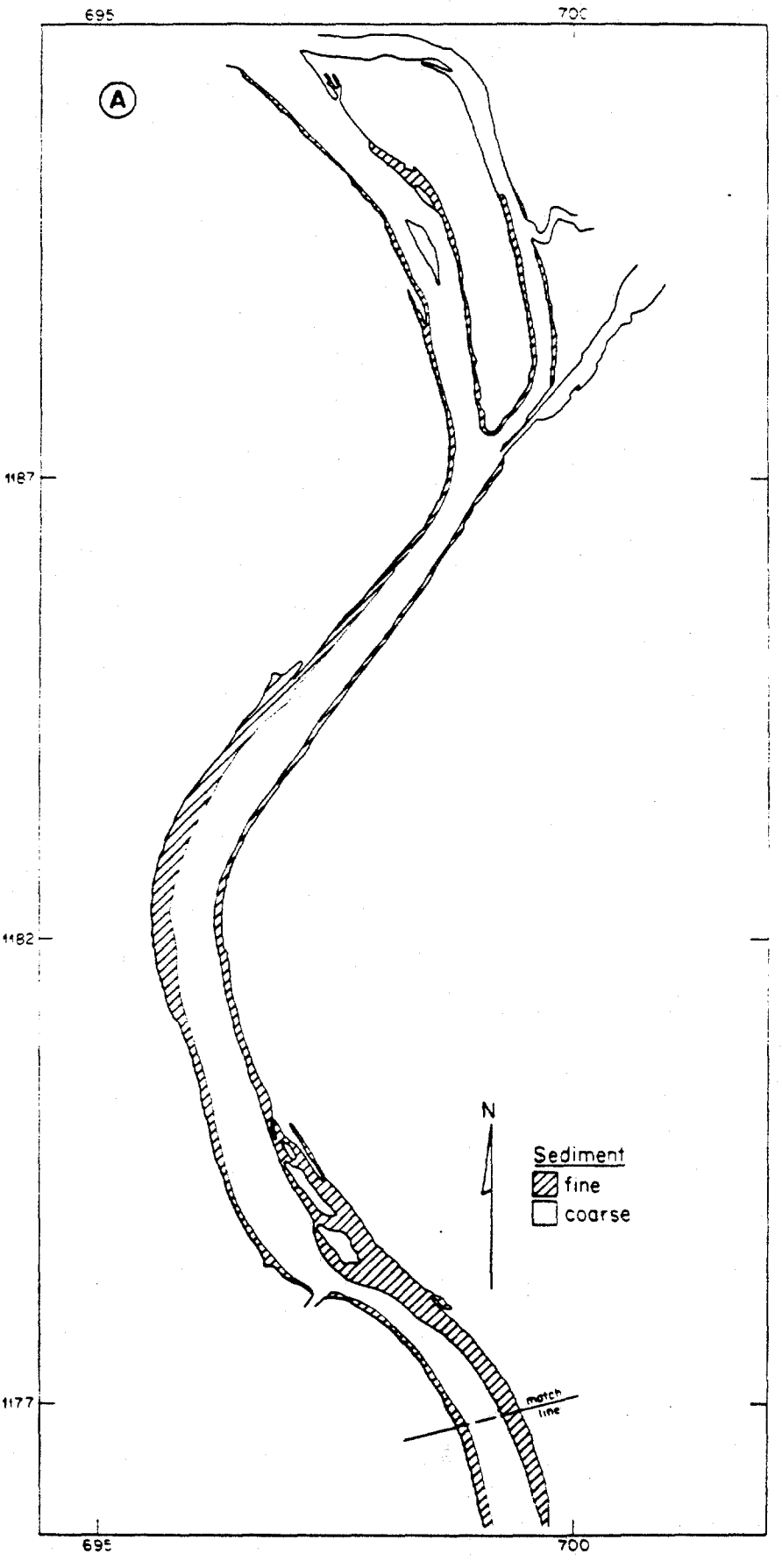

Figure 7a. Distribution of coarse-and fine-grained sediment in the northern reach of the Thompson Island Pool.

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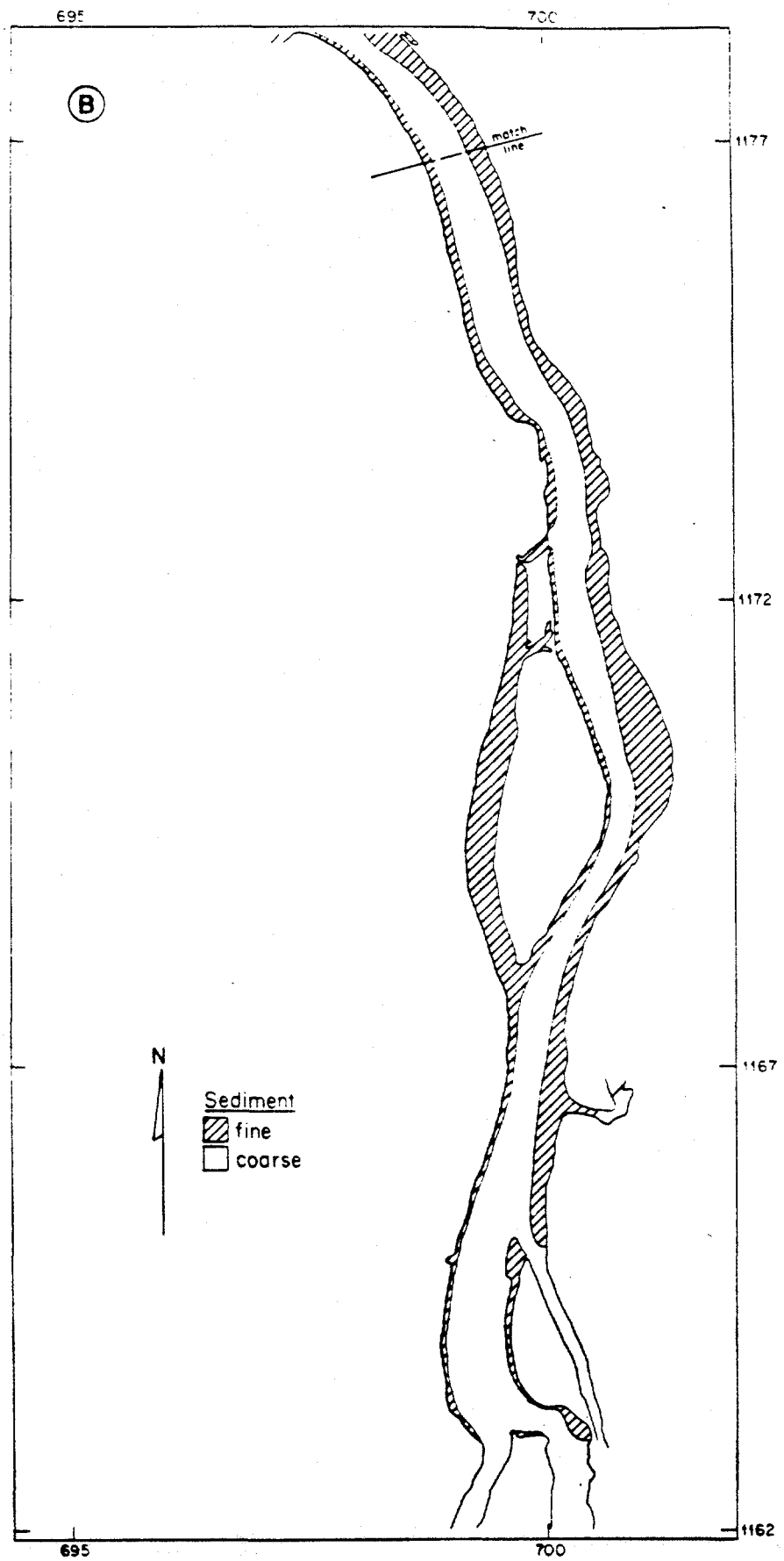

Figure 7b. Distribution of coarse- and fine-grained sediment in the southern reach of the Thompson Island Pool.

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Pool. The median, average and logarithmic mean of the GC results are 15, 63 and 25 ug/g. The highest concentration was 6,600 ug/g in a 15-cm (6-in) core section from the east channel at Rogers Island.

Sampling biases limit the use of the relative-frequency distribution of sample PCB concentrations in depicting the general contamination of the Thompson Island Pool. Several sampling biases associated with this survey and previous surveys can be readily identified. The 125-ft triangular sampling grid was applied only to areas where fine-grained sediment was expected. Thus, areas having high PCB concentrations were probably sampled more intensively than areas having comparatively low PCB concentrations. A related suspected bias associated with both the 1976 and 1984 sediment surveys involves the apparent relationship between the number of subsamples produced at a cored location and the sediment texture at that location. Areas of fine-grained sediment yield longer cores and proportionately more samples for PCB analysis than areas of coarse sediment. Core sectioning protocols used by both surveys generally produced more subsamples from longer cores than from shorter cores. Gravel-textured sediments were noted in approximately 60 percent of the grab samples and only approximately 25 percent of the core samples.

Previous work in the Thompson Island Pool (Tofflemire and Quinn, 1979; Bopp *et al.*, 1984; Bopp *et al.*, 1985) has shown that in areas of the Thompson Island Pool where fine-grained sediment is depositing at a relatively constant annual rate there are vertical gradients in PCB concentration. In those areas PCB is first detectable in strata deposited in the late 1940's to early 1950's. PCB concentrations increase generally from mid-1950's strata to a peak in the early 1970's strata and decline again towards the sediment surface. This pattern of total PCB concentration is evident in a core collected from a cove at MP-188.5 and in some of the cores collected along the transect at MP-192.7. Concentrations of PCB and ^{137}Cs in these cores are presented in Figure 8. The bathymetry of the MP-192.7 transect and corresponding sample positions are presented in Figure 9. Along the transect, PCB contamination appears to be restricted to the upper 23 cm (9 in) of sediment. In some cores the contamination is significantly more shallow. In the fine-grained sediment in the cove at MP-188.5, PCB concentrations appear to be detectable to a sediment depth of 71 cm (28 in).

The results of the analysis of the core from Station 4 of the MP-192.7 transect indicate that if the core was sectioned using the 25-cm (9.9-in) average section length, the maximum measured PCB concentration for the core would be reduced from 82 ug/g to 28 ug/g. Similarly the maximum concentration in the core from Station 6 would have been reduced from 24 ug/g to 7 ug/g.

Tofflemire and Quinn (1979) presented the relative frequency distribution of core-sample PCB concentrations for various reaches of the upper Hudson River. Their table for the Thompson Island Pool is reproduced in Table 5. The results of the 1984 survey are summarized in Table 6. The total number of core subsamples varies with sediment depth by a factor of approximately 15 for the 1976 survey (Table 5); whereas, the number of subsamples varies by a factor of approximately three for the 1984 survey. Thus the potential sampling bias appears to be greater for the 1976 survey than the 1984 survey.

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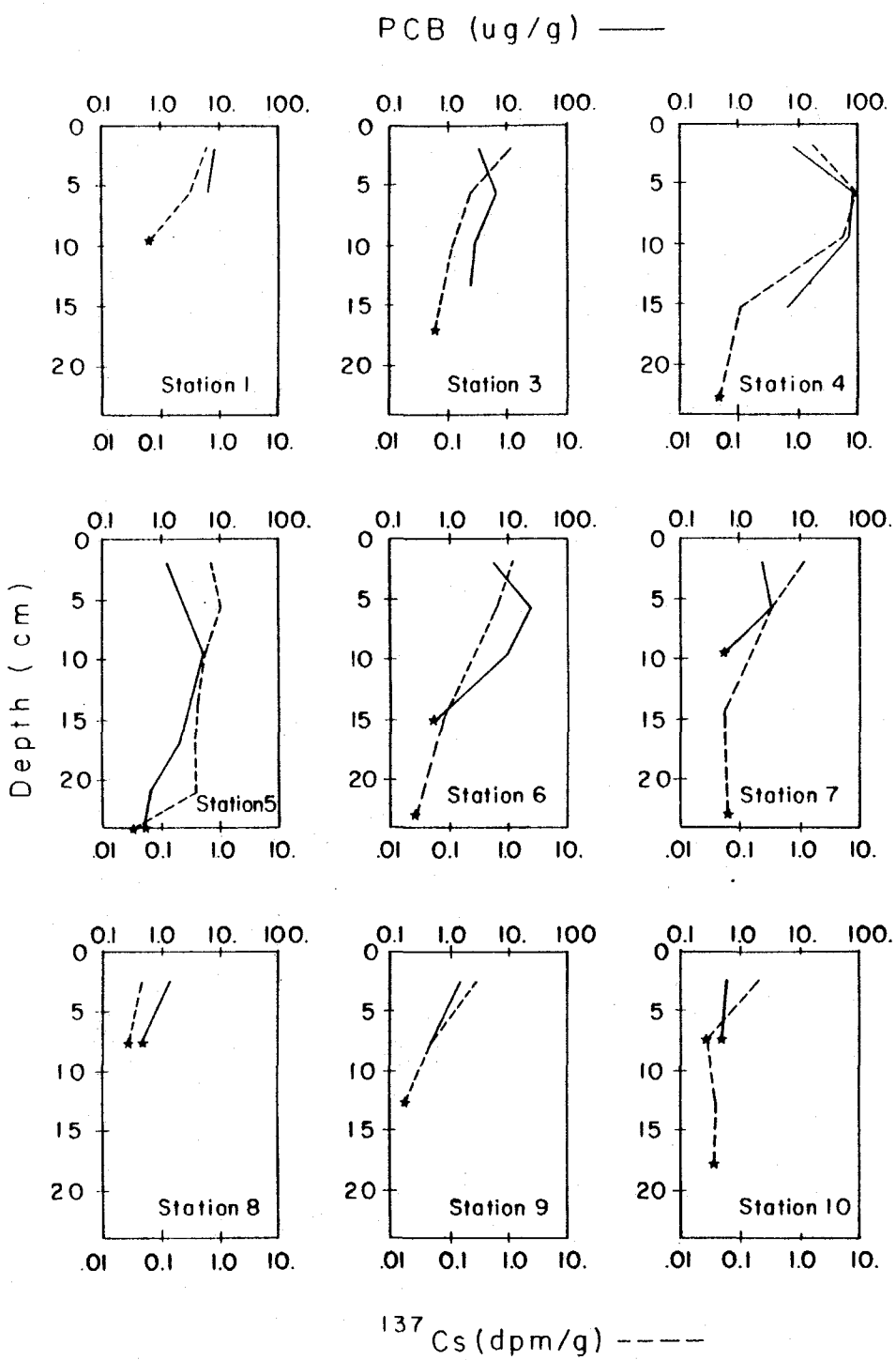

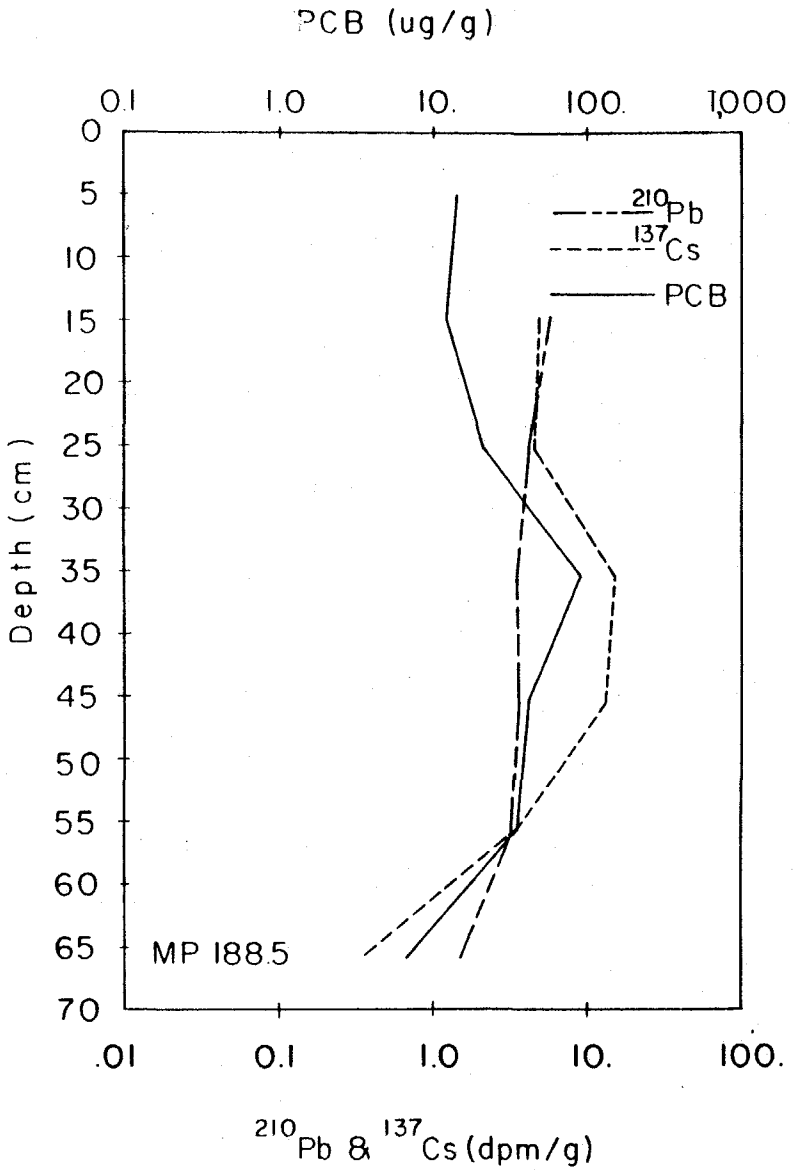

Figure 8. Concentrations of PCB, ^{137}Cs and ^{210}Pb in sediment cores collected at stations 1 through 10 of a transect at MP-192.7 and a single core collected at MP-188.5.

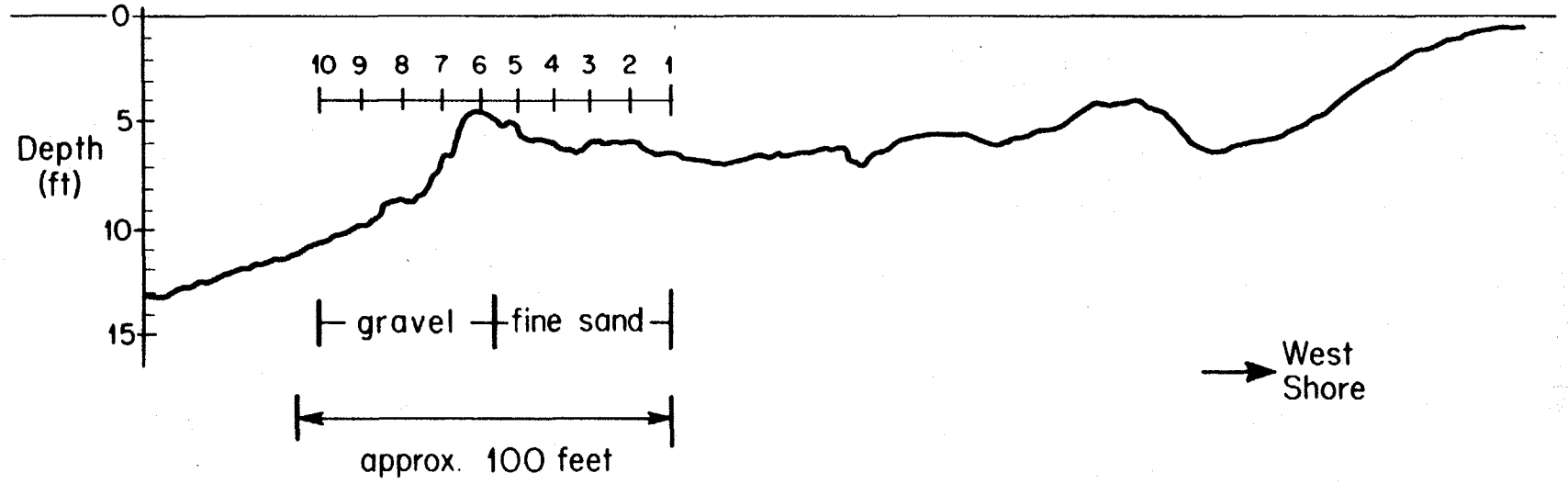

Figure 9. Bathymetry of the MP-192.7 transect.

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Table 5. RELATIVE FREQUENCY DISTRIBUTION (PERCENT) OF PCB CONCENTRATION OF 1976-1977 CORE SAMPLES (REACHES 9 AND 8 FROM FT. EDWARD TO THE THOMPSON ISLAND DAM)

PCB CONCENTRATION (µg/g)	CORE SECTION MIDPOINT (in)							
	0-1.5	1.5-3	3-6	0-6	6-9	9-12	12-18	18+
< 5	6.9	7.02	37.86	19.83	38.10	44.44	77.78	85.71
5 - 25	39.08	19.30	15.53	24.70	20.63	29.63	0	14.29
25 - 50	14.94	15.79	10.68	13.36	7.94	0	0	0
50 - 100	19.54	31.58	9.71	18.22	7.94	11.11	0	0
100 - 500	18.39	22.81	22.33	21.05	19.05	11.11	22.22	0
500+	1.15	3.51	3.88	2.83	6.35	3.70	0	0
Number of Samples	87	57	103	247	63	27	9	7

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TABLE 6. RELATIVE FREQUENCY DISTRIBUTION (PERCENT) OF PCB CONCENTRATIONS IN 1984 CORE SAMPLES.

PCB* CONCENTRATION (ug/g)	CORE SECTION MIDPOINT (in) 0-6	6-12	12-18	18-24	24-30	30-40
< 3	16.3	42.3	61.5	73.7	76.4	90.4
3 - 13.4	15.2	10.0	9.10	3.2	2.36	0
13.4 - 18.8**	29.5	23.2	9.09	8.97	17.32	6.78
18.8 - 53.1	16.9	10.0	8.23	5.77	0	2.26
53.1 - 106.	8.6	6.82	4.76	4.49	3.15	0.56
106 - 595	12.9	5.45	6.49	3.85	0.79	0
595 - 1190	0.57	1.82	0.43	0	0	0
1190 - 10,000	0	0.45	0.43	0	0	0
Number of Samples	349	220	231	156	127	177

* the concentration ranges presented are an artifact of the lognormal histogram generator program used for the analysis and Versar's 3 ug/g detection limit.

** this interval contains results of mass spectrometer screen results reported as < 10 ug/g. See earlier text regarding GC-mass spec result comparisons for additional information.

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In comparing Tables 5 and 6, it also appears that the relative frequency of high PCB concentrations in near-surface core sections is greater for the 1976 survey than for the 1984 survey. Differences in core-sectioning resolution, core-sampling success in areas of coarse sediment and PCB analytical methods probably all contribute to the apparent difference in frequency of high PCB concentrations.

PCB CONCENTRATIONS IN THE FORMER HOT SPOTS

Figure 10 contains maps presenting the distribution of PCB concentrations in the subsample from each sample location containing the highest PCB concentration. The selected concentration ranges correspond to those used for screening by the mass spectrometer. Also presented on these maps are the boundaries of the previously defined 20 hot spots.

Data presented in the maps in Figure 10 indicate that in some areas general agreement exists between the recently observed occurrences of PCB concentrations in excess of 50 ug/g and the earlier defined areas. However, in some locations disagreement is apparent between the areal extent of the highly contaminated sediment (i.e. > 50 ug/g) evident from the 1984 sample data and the earlier hot-spot definitions.

Hot spots 1-4 were delineated in the east and west channel of the Hudson River near Rogers Island. The area of hot spot 1 yielded no samples in 1984 having PCB concentrations greater than 50 ug/g. Review of the 1978 data and analysis show that only a single core had been collected from this area. This contained a maximum PCB concentration of 95 ug/g and an average PCB concentration of 63 ug/g over 38 cm (15 in). This hot spot was previously considered to be of minor significance. MPI (1978) estimated hot spot 1 to contain approximately 0.3 percent of the PCB mass in the Thompson Island Pool hot spots. Hot spots 2, 3 and 4 were previously identified in the east channel of the Hudson at Rogers Island. This reach was dredged during 1978 subsequent to the hot spot definition. Dredging was estimated to have removed 200,000 yd^3 from the area (Thomas *et al.*, 1979). Single cores from hot spots 2 and 3 were used to calculate PCB mass estimates in 1978. The 1978 PCB mass estimate for hot spot 4 was made without sampling data by applying an average PCB concentration of 50 ug/g to the area. It is clear that PCB contamination persists in the east channel of Rogers Island. Fine-grained sediments lining the west shoreline of this channel yielded the sample with the highest measured PCB concentration in the survey: a 15-cm (6-in) core section having a total PCB concentration of 6,600 ug/g.

Figure 10b presents the reach of river which includes hot spots 5 and 6. These two hot spots were estimated to contain approximately 12 percent of the hot-spot PCB mass in the Thompson Island Pool. The existence of continuous, highly contaminated sediment in hot spot 5 is not apparent. Reevaluation of earlier data from this area indicates that it was perhaps erroneous to have included the channel within hot spot 5. Two of the four grab samples and both cores collected in 1977 from the channel within the hot-spot boundaries had PCB concentrations less than 50 ug/g. The single core collected by NUS (1984) in hot spot 5 contained an average PCB concentration in excess of 50 ug/g. This core, as well as 1977 and 1984 cores having PCB concentrations in excess of 50 ug/g, were located near the western shore. The textures of most of the

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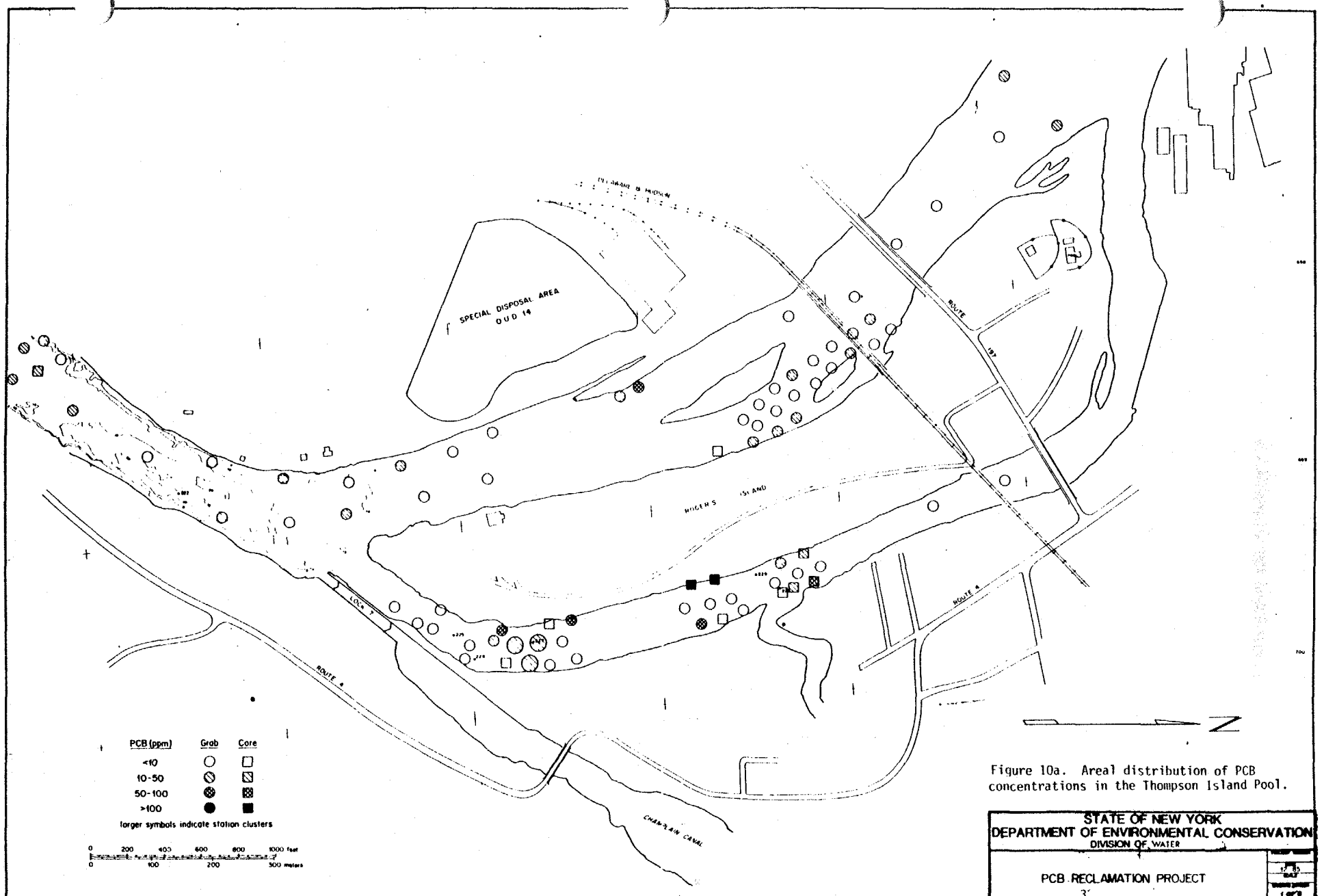

Figure 10a. Areal distribution of PCB concentrations in the Thompson Island Pool.

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PCB RECLAMATION PROJECT

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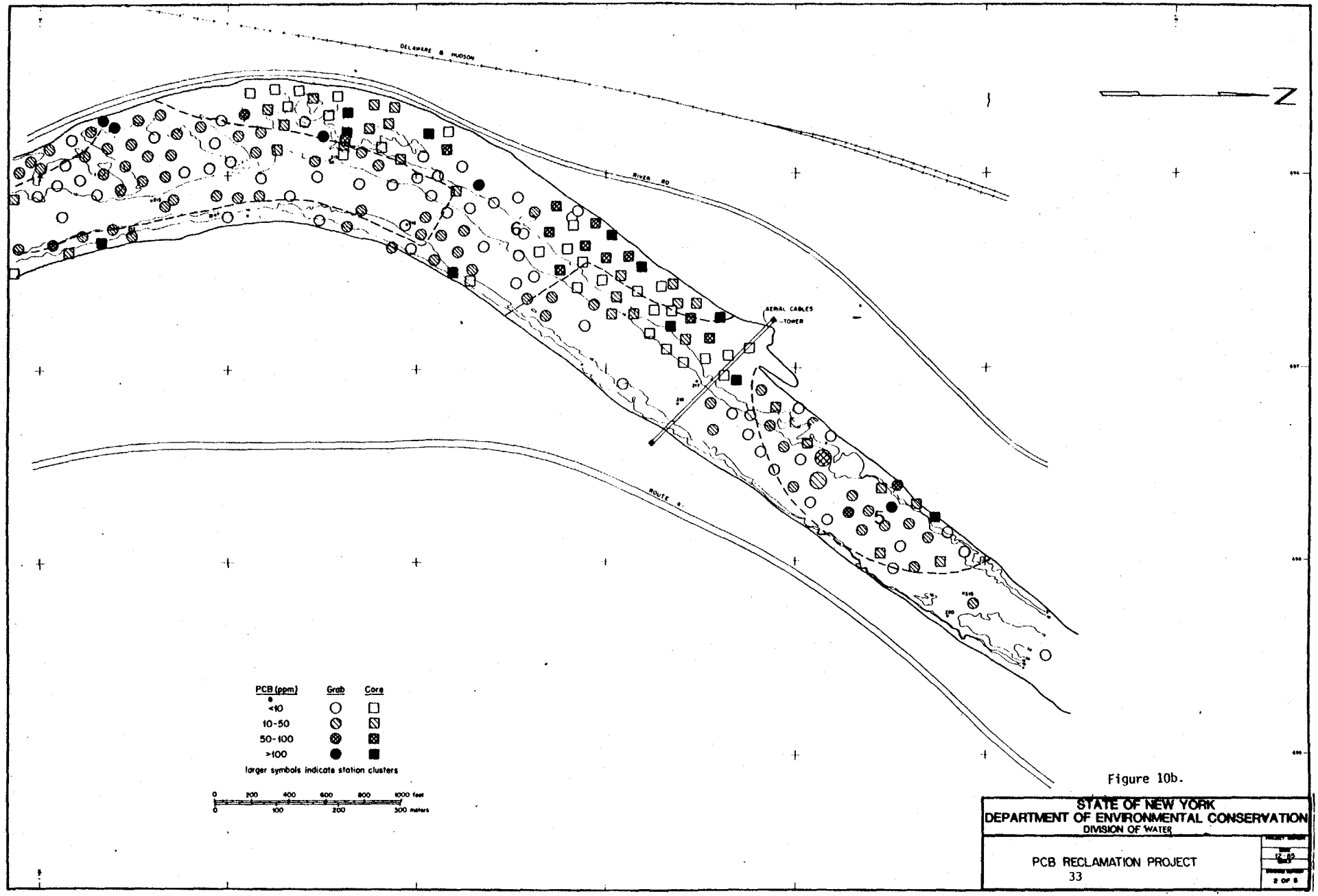

Figure 10b.

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DIVISION OF WATER

PCB RECLAMATION PROJECT
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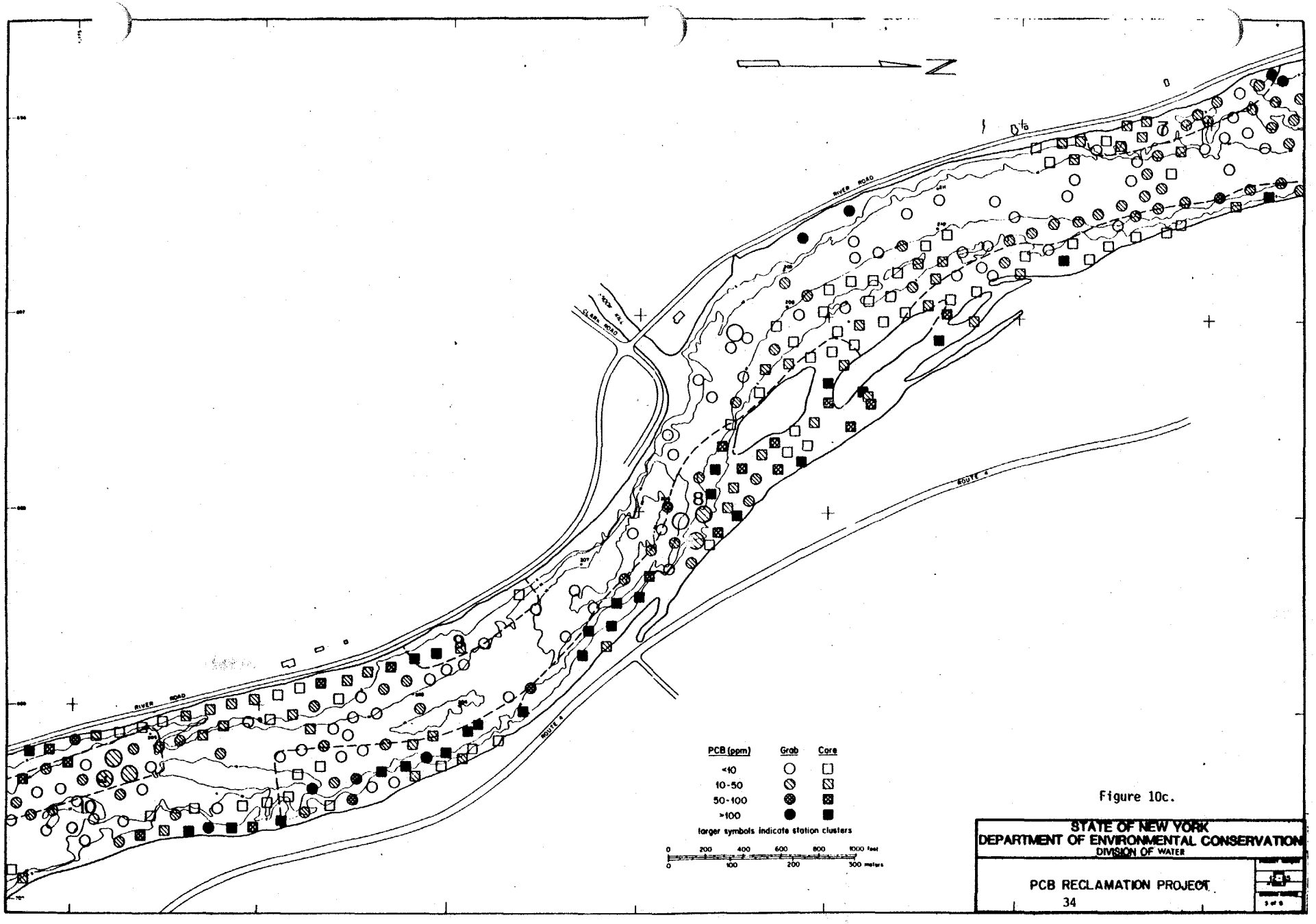

Figure 10c.

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DIVISION OF WATER

PCB RECLAMATION PROJECT

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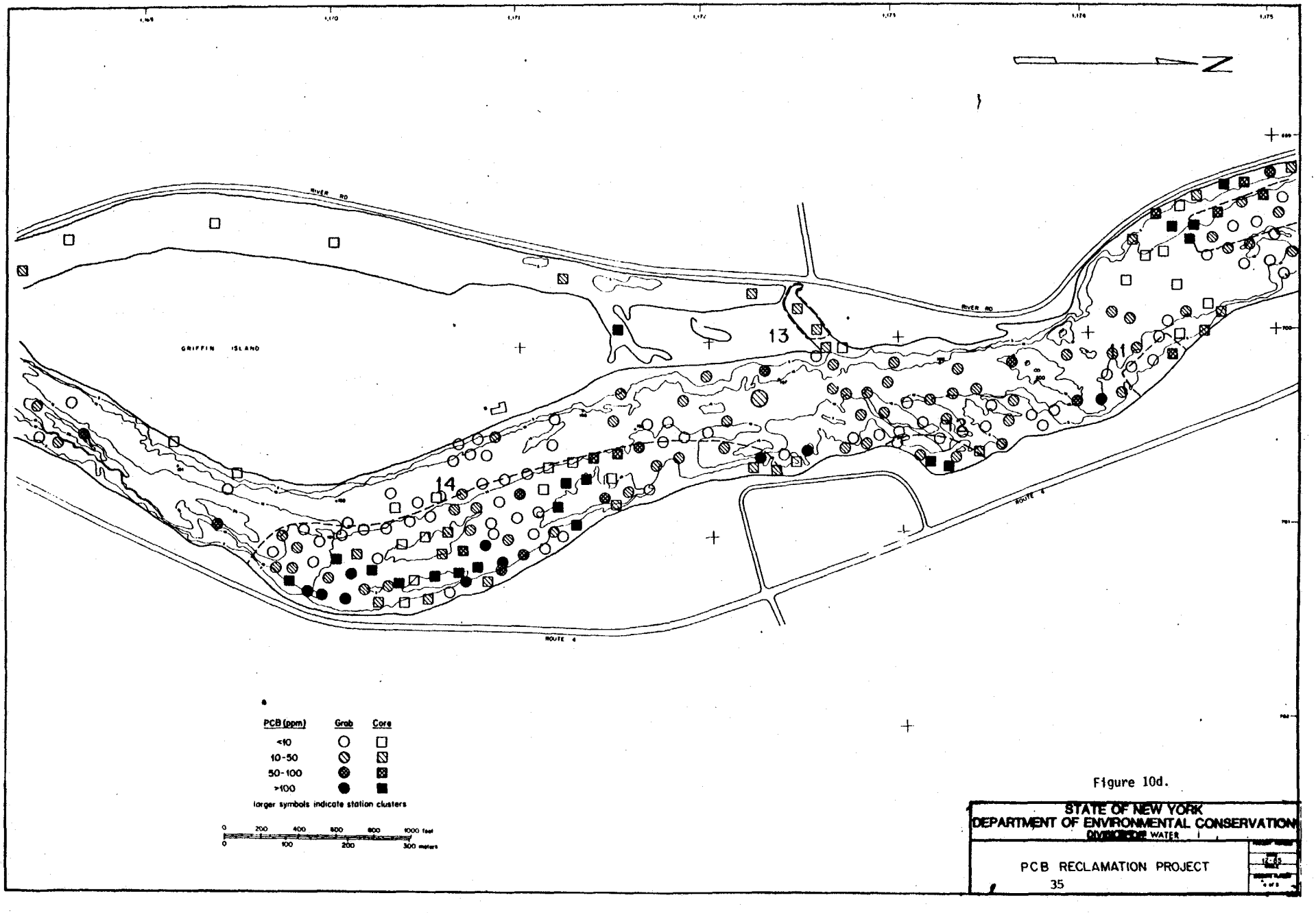

Figure 10d.

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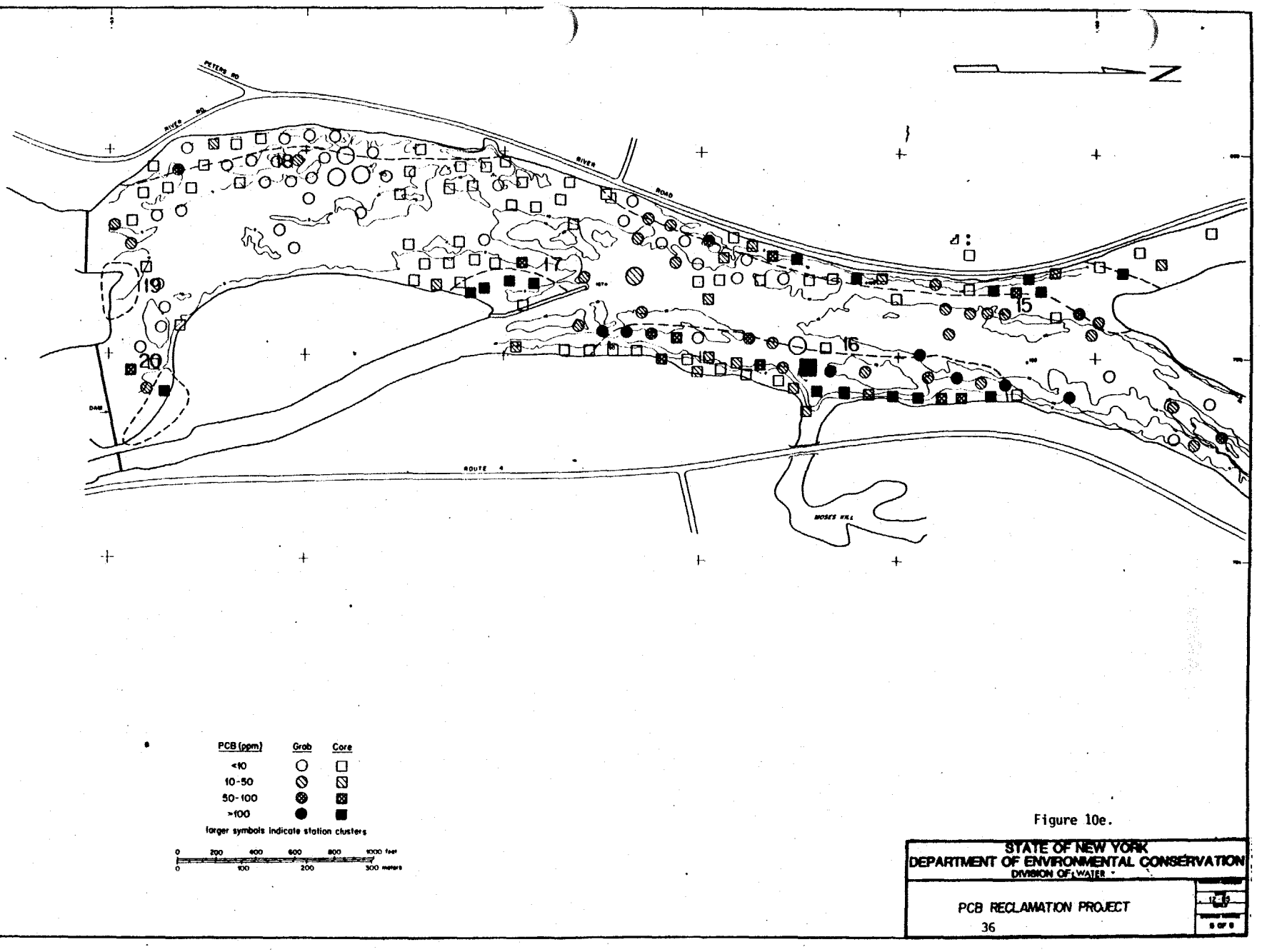

Figure 10e.

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samples collected in hot spot 5 were coarse sand and gravel with the exception of fine sand and wood chips associated with one highly contaminated core sample. Discontinuities in the presence of fine-grained sediment through this area appear to be largely responsible for the lack of a significant area of highly contaminated sediment. It is also noteworthy that this area had been used for sediment dumping by the New York State Department of Transportation (NYSDOT). Subsequent to the 1977 sampling, sediments from this area were pumped into a landfill site adjacent to the river.

As in the reevaluation of hot spot 5, it appears that inclusion of the channel area in hot spot 6 may have been unwarranted. Four of the seven samples collected in 1977 from the channel contained maximum PCB concentrations less than 50 ug/g. However, it does appear that there is a significant area of fine- grained sediment along the western shore that contains PCB concentrations in excess of 50 ug/g.

Hot spots 7, 8 and 9 and a portion of 10 are presented in Figure 10c. The existence of highly contaminated sediment throughout the area known as hot spot 7 is not apparent. However, a comparison with previous data for this area, including one core collected by NUS in 1983, containing an average PCB concentration of 3.3 ug/g, does not suggest any major change in PCB concentrations. The highest PCB concentration previously measured in the five samples from this area was 66 ug/g; the average concentration that was reported for the contaminated volume in this reach was 39 ug/g (Malcolm Pirnie, 1978). The mass of PCB in this hot spot was estimated to be less than 1 percent of the total for hot spots 1-20. Although the persistence of similar concentrations in this hot spot has been confirmed, it is doubtful that a significant volume of sediment with an average PCB concentration exceeding 50 ug/g exists in the area.

The results confirm the presence of an extensive, continuous area of highly contaminated sediment throughout most of the area previously defined as hot spot 8 and extending somewhat downstream of its earlier boundaries. The shortest core section reflected in Figure 10c had a length of 10 cm (4 in) and contained a PCB concentration of 370 ug/g. Core sections of 30 cm (1 ft) or longer with PCB concentrations in excess of 100 ug/g were frequently encountered in this area. One of the three cores collected in 1983 from this area by NUS contained a maximum PCB concentration of 11.3 ug/g. The two others contained concentrations of 307 and 110 ug/g in 23-cm (9-in) core sections. Those observations conform well with the results of the 1984 sampling. Hot spot 8 was previously estimated to contain 18 percent of the Thompson Island Pool hot-spot PCB mass.

The 1984 survey collected four cores from hot spot 9. Two of those cores contained PCB concentrations in excess of 100 ug/g. The average PCB concentration reported by MPI (1978) for this hot spot based upon 1 core and 2 grab samples was 38 ug/g. Hot spot 9 was also previously considered to be of minor importance since it appeared to contain approximately 0.5 percent of the pool's hot-spot PCB burden. The results for hot spot 10 (Figures 10c and 10d) are in good agreement with samples collected in 1976-1977 and with those collected by NUS during 1983. Earlier results indicated that PCB concentrations generally increased to well above 100 ug/g toward the southern limit of the delineated area. The average PCB concentration previously

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reported for this hot spot was 78 ug/g in the contaminated volume (Malcolm Pirnie, 1978). New results show the area containing PCB concentrations in excess of 50 ug/g extends toward the western shore in a previously unsampled area.

Hot spot 11 (Figure 10d) was earlier estimated to contain less than 0.3 percent of the total Thompson Island Pool hot spot PCBs. The average PCB concentration reported for contaminated sediments in this area was 39 ug/g (Malcolm Pirnie, 1978). Data currently available from the 1984 survey show this area to be comparatively insignificant in terms of PCB mass. However, it should be noted that the higher PCB concentrations reported in the 1977 survey were for samples collected closer to shore than the 1984 samples.

Results of the 1984 survey for hot spot 12 (Figure 10d) are in close agreement with data from the 1977 survey and the single core sample collected by NUS toward the western perimeter of the hot spot. PCB concentrations generally increase eastward in this area as sediment texture varies from gravel along the western limit to fine sand and mud along the eastern shore.

The average PCB concentration that had been reported by Malcolm Pirnie (1978) for contaminated sediments in hot spot 13 was 89 ug/g. Sediments in this inlet are fine-grained sands and mud. PCB concentrations in the 0-36 cm (0-14 in) and 0-46 cm (0-18 in) sections of both cores collected by the 1984 survey were 12 and 15 ug/g respectively.

Hot spot 14 was one of the most significant areas with respect to the earlier estimate of total hot-spot PCB mass (i.e. 33 percent). The results of the 1984 survey (Figure 10d) confirm the persistence of highly contaminated sediment throughout the length of the delineated area. The highly contaminated sediment in this area has generally been characterized as fine sand. Along the western perimeter of the southern half of the area, the gravelly sediments generally contain PCB concentrations less than 10 ug/g.

Hot spots 15 and 16 (Figure 10e), situated respectively on the west and east sides of the river in the region of the Moses Kill (MP-189.2), were previously estimated to contain a combined total of 24 percent of the hot-spot PCB mass in the Thompson Island Pool. It is clear that highly contaminated sediments persist in both of these areas. The results are in good agreement with the data from previous surveys of both areas. Toward the southern limits of both areas, sediment texture is increasingly coarse and PCB concentrations generally lower.

Hot spot 17 as delineated in Figure 10e is an area of fine-grained sediment located on the downstream side of a concrete seawall. The 1984 survey results demonstrate that highly contaminated sediments persist in this area with concentrations generally increasing towards the eastern shore.

The 1984 survey results do not indicate any area of highly contaminated sediment within hot spot 18 (Figure 10e). Hot spot 18 had been assumed to contain approximately 5 percent of the hot spot PCB in the Thompson Island Pool with an average PCB concentration of 94 ug/g in contaminated sediment (Malcolm Pirnie, 1978). Our results agree closely with those from eight samples collected in this area by NUS in 1983. It is difficult to ascertain whether the

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discrepancy is due to changes in the river bed or an improper interpretation of 1977 data and subsequent hot spot delineation.

The area designated as hot spot 19 was not sampled because the water depths were too shallow to accommodate the sampling vessel. Samples collected near the perimeter of this hot spot contained less than 10 ug/g PCB. The core collected from this area during the 1976 survey contained an average PCB concentration of 83 ug/g over its length of 5 in (13 cm). Hot spot 19 was previously estimated to contain 0.4 percent of the hot-spot PCB mass in the Thompson Island Pool.

The 1984 survey collected only one core from the cove identified as hot spot 20. The results of analysis of this core are presented in Figure 8. During the past several years, core samples have been collected in the area of hot spot 20 by several investigators, including a 1981 EPA survey (Johnson, 1981), the survey by NUS (1984) in 1983, and by Dr. John Brown, General Electric Company and Dr. Richard Bopp, Columbia University on separate occasions during 1984. With the exception of the NUS sample which contained a PCB concentration slightly exceeding 50 ug/g, PCB concentrations in other samples have approached or exceeded 1,000 ug/g. Work by Dr. Bopp *et al.* (1985), in addition to our own, suggests that fine-grained sediment accumulates in this area at a relatively constant rate in the range of 1-2 cm/year. Through the years, this area has served reliably as a source of highly contaminated sediment for various investigations.

The MPI (1978) analysis indicated that hot spots 8, 14 and 16 collectively accounted for 72 percent of the hot-spot PCB mass of the Thompson Island Pool. The 1984 survey confirmed the persistence of highly contaminated sediment within the boundaries of those hot spots.

The presentation of analytical results for the 1984 Thompson Island Pool sediment survey confirms the persistence of highly contaminated (> 50 ug/g) sediment within most of the hot spots. The confirmed hot spot areas were earlier estimated to contain more than 90 percent of the total hot-spot PCB mass in the Thompson Island Pool (MPI, 1978). Overall, no major change in the distribution of PCBs in the bed of the Thompson Island Pool between 1977 and 1984 is evident. The 1977 delineation of the Thompson Island Pool hot spots appears to be generally correct in the most highly contaminated areas. The quantity of PCB in hot spots 1-3 and 5 may have been affected by dredging operations subsequent to the 1976 survey. Collectively these areas accounted for approximately 4 percent of the 1978 hot-spot PCB mass estimate for the Thompson Island Pool.

Direct quantitative comparison of PCB concentrations between surveys is difficult. Sample PCB concentrations derived from core sections can be misleading, because, as discussed previously, they are a function of section length and position within the contaminated layer among other factors. Tofflemire and Quinn (1979), Bopp *et al.* (1985) and this survey have examined the distribution of PCB and ^{137}Cs in finely sectioned cores. Results clearly show that PCB concentrations can vary by a factor of 10 or more toward the sediment surface from maximum PCB concentrations which tend to be found toward the middle of post-1950's sediment strata. Cores and resulting core sections produced by the 1984 survey were generally longer than those

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generated by the 1976 survey. In addition, the equipment used in 1984 was better able to core coarse sediment than the equipment used in 1976. Thus, there is probably a greater bias towards fine-textured sediment in the 1976 data set than in the 1984 data.

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ESTIMATION OF PCB QUANTITIES AND SELECTION OF AREAS FOR RECLAMATION

OVERVIEW

The calculation of PCB mass in the Thompson Island Pool required vertical and horizontal integration of measured PCB concentrations. Integration of sample PCB concentrations, reported as the PCB mass per unit dry weight of sediment, required knowledge of the dry weight mass of sediment per unit volume of the river bed. This latter concentration is referred to as the specific weight of sediment. Integration also practically required use of assumptions or relationships regarding the distribution of PCB between sampled positions. This applies to both horizontal and vertical aspects of the integration. Although it was possible at core-sample locations to develop, through direct measurement, a continuous-depth profile of PCB concentrations, use of data from grab-sample locations for vertical integration required assumptions regarding the depth distribution of PCB.

Additional required assumptions involved the quantitative use of the mass-spec screen data and the assessment of specific weight of gravel sediments. The specific weight of gravel sediments was not routinely determined due to problems with approximation of *in situ* compaction by the analytical method.

VERTICAL INTEGRATION

To integrate PCB concentrations, samples that were analyzed by mass-spec and not by GC were assigned the mean of GC-determined concentrations in split samples reported for the particular mass-spec result range. These averages are presented in Table 4. As a result of the analytical protocol, only 4 samples analyzed by mass-spec having reported PCB concentrations greater than 100 ug/g were not analyzed by GC. A total of 896 samples having concentrations less than 10 ug/g by mass-spec analysis were not subsequently analyzed by GC. Errors associated with the use of a single concentration for each of the mass-spec concentration ranges are assessed in a following section using sensitivity analysis.

As noted previously, most of the sediment samples having a gravel texture could not be analyzed by the method used to estimate specific weight. Problems involved subsampling biases and the ability to assume that sediment compaction was comparable between the natural situation and the small beaker used by the method. However, 44 such samples were analyzed. The results for those samples appeared to be normally distributed. The respective mean and standard deviation of specific weight results for the 44 samples are 1.30 and 0.247 g/cm^3. A value of 1.3 g/cm^3 was subsequently used for gravel sediment samples that were not analyzed. The sensitivity of PCB mass estimates to this assumption is assessed in a later section. Overall, the results of specific volume analysis of 1,133 samples appeared to be normally distributed. The respective mean and standard deviation of the sample distribution are 1.096 and 0.417 g/cm^3.

The assumptions previously described permit the vertical integration of PCB concentrations in sediment cores to yield a unit-area PCB mass estimate at a

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sample location. For sediment cores the unit-area PCB mass is calculated as the sum of the products of PCB concentration, specific weight and section length of individual core sections. However, to estimate unit-area PCB mass at a grab-sample location, assumptions related to the distribution of PCB below the surface are required.

The textures of 362 grab samples were described as gravel, and the textures of 158 other grab samples were described as fine sand. To address the problem of PCB distribution below grab samples, data from 250 cores with uniform sediment texture over their length described as either gravel (67 cores), fine sand (141 cores) or fine sand and wood chips (42 cores) were analyzed. PCB concentrations in these cores were integrated through the uppermost 1 cm (0.4 in) of sediment by employing the measured PCB concentration and specific weight in the uppermost section of the core without correction. PCB concentrations were also integrated through the entire length of the core. We refer to the ratio of the PCB mass in the entire core to that in the uppermost 1 cm (0.4 in) as the equivalent PCB penetration depth. The respective average equivalent PCB penetration depths for fine sand, fine sand and wood chips, and gravel sediments are 41.7, 45.5 and 31.0. Respective standard deviations for fine sand, fine sand and wood chips, and gravel sediment are 38.8, 28.3 and 22.3. Values of 43 and 31 were used for fine sand and gravel respectively in the calculation of unit-area PCB mass concentration at a grab-sample location. The unit-area PCB mass at a grab-sample location was calculated as the product of PCB concentration in the grab sample, specific weight, a height of 1 cm and either of the constants 43 and 31 depending upon sediment texture. The sensitivity of the final calculated PCB mass estimates to the values of these constants is assessed in a later section.

PCB mass at each sampled location was integrated to 0.5-, 1.0- and 1.5-m (20-, 39- and 59-in) sediment depths. The distribution of unit-area PCB mass integrated to 1.5-m (59-in) depth at sampling locations is presented in Figures 11a through 11e. The average of unit-area PCB masses (integrated to 1.5 m) calculated for all sampled locations is 14.0 g/m^2. As suggested by Figure 12 the distribution of unit-area PCB masses appears to be lognormal. At sixty-three sample locations, for which GC analysis indicated less than detectable quantities, zero was used for the unit-area PCB mass. These data were excluded from the data set for logarithimic analyses but were included in later PCB mass calculations. The antilog of the log mean of the distribution presented in Figure 13 is 7.8 g/m^2. Respective coefficients of variation for the arithmetic and log distributions are 3.2 and 0.50.

HORIZONTAL INTEGRATION

In the geostatistical literature there are a number of methods available to integrate point data over a surface. Some of the more sophisticated methods have been developed for estimating ore reserves. The reliable estimation of ore grade is crucial to the economic analysis of mining operations. These methods are essentially a series of differing strategies to cope with the uncertainty of what lies between sampled points. They include area-weighted averaging, linear and curvilinear interpolation, and least squares fitting of planes and

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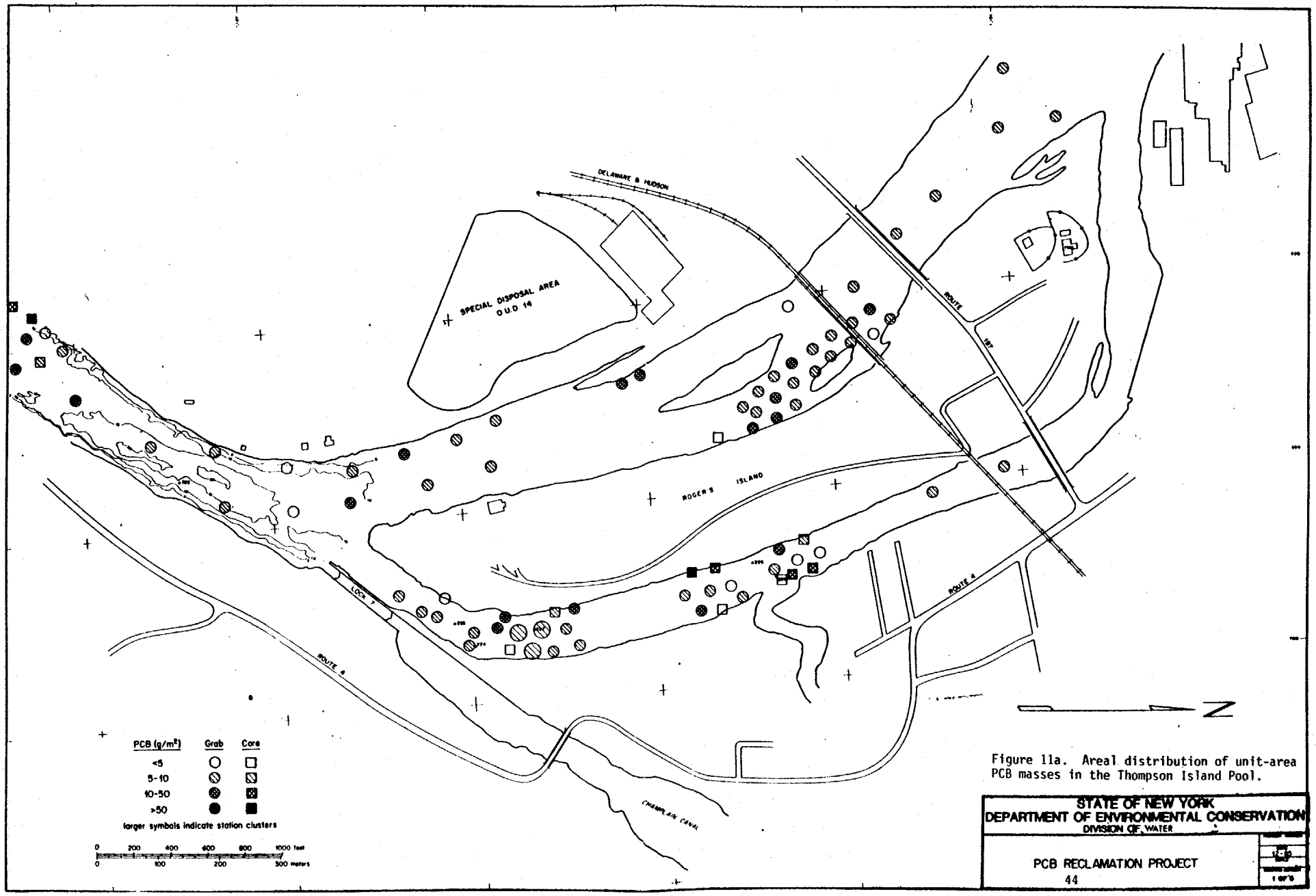

Figure 11a. Areal distribution of unit-area PCB masses in the Thompson Island Pool.

STATE OF NEW YORK
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DIVISION OF WATER

PCB RECLAMATION PROJECT
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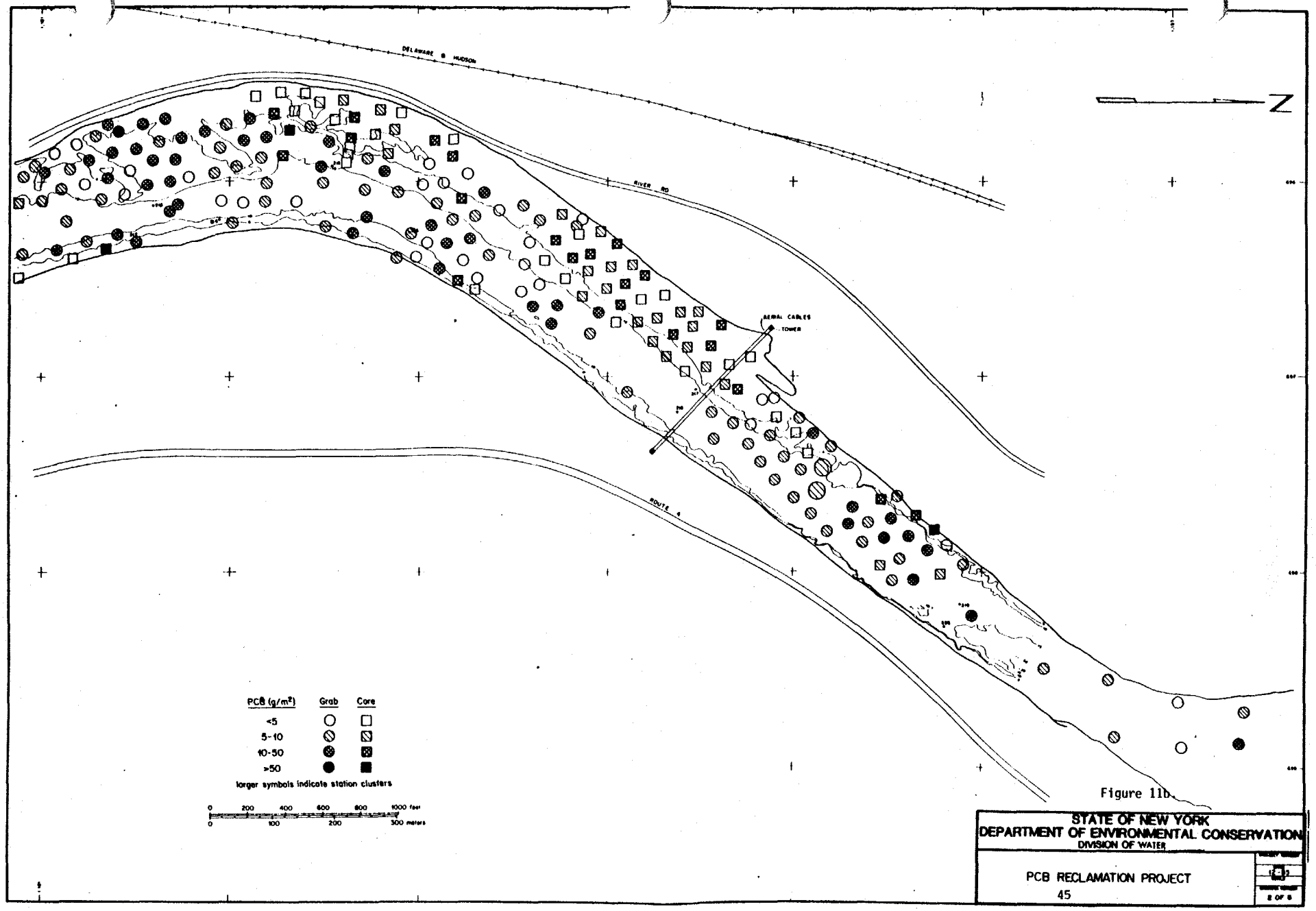

Figure 11b.

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DIVISION OF WATER

PCB RECLAMATION PROJECT
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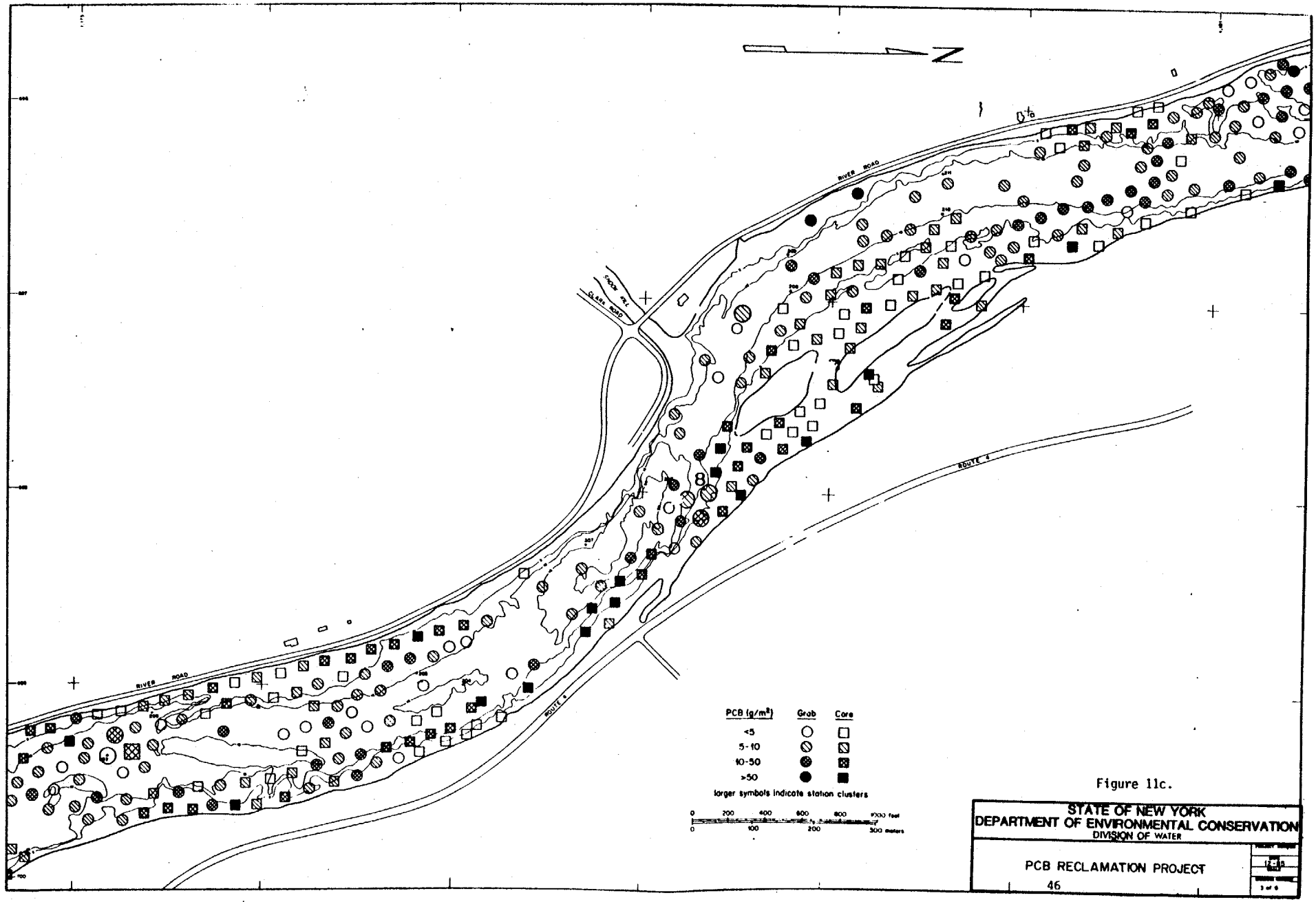

Figure 11c.

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DIVISION OF WATER

PCB RECLAMATION PROJECT

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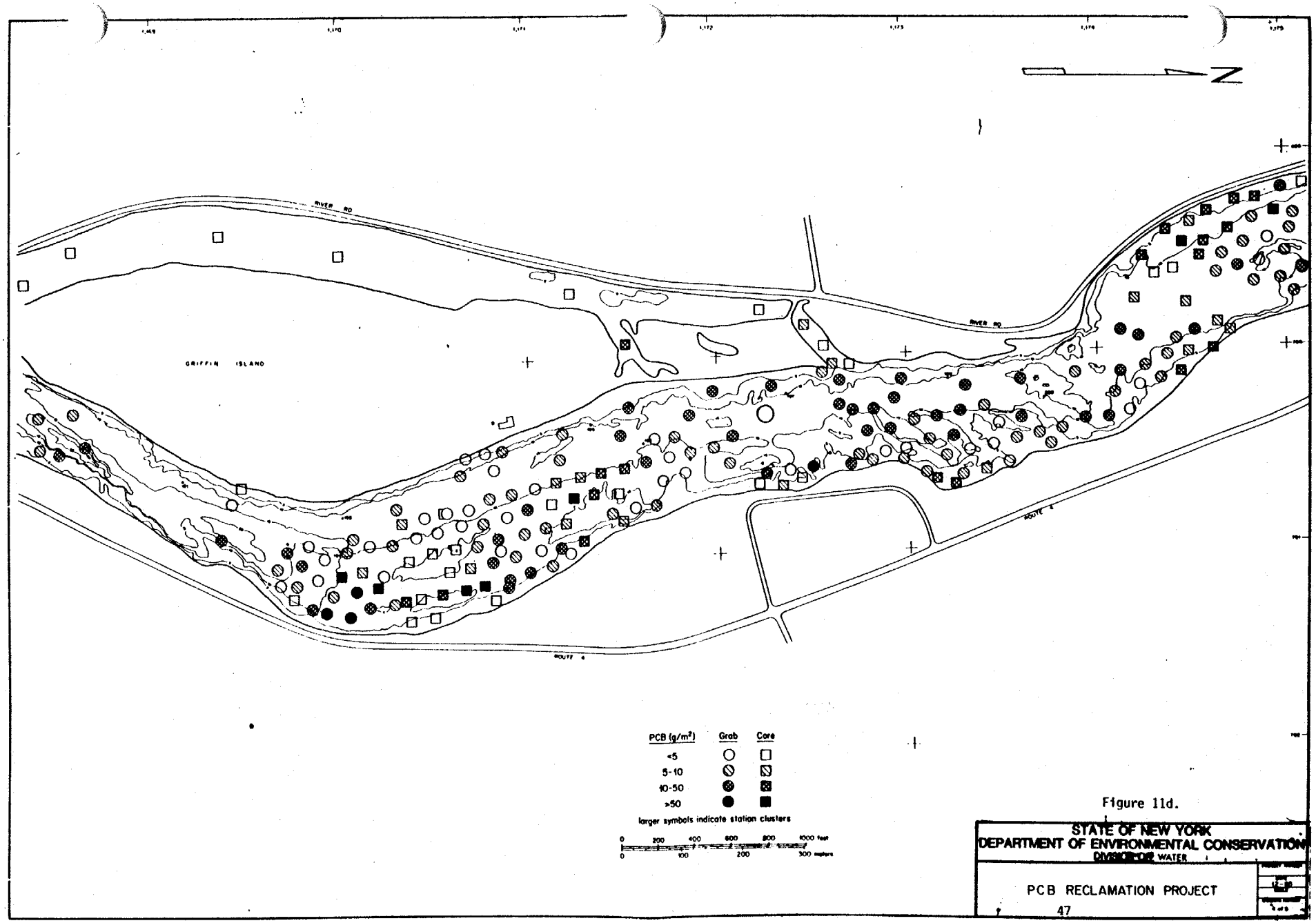

Figure 11d.

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DIVISION OF WATER

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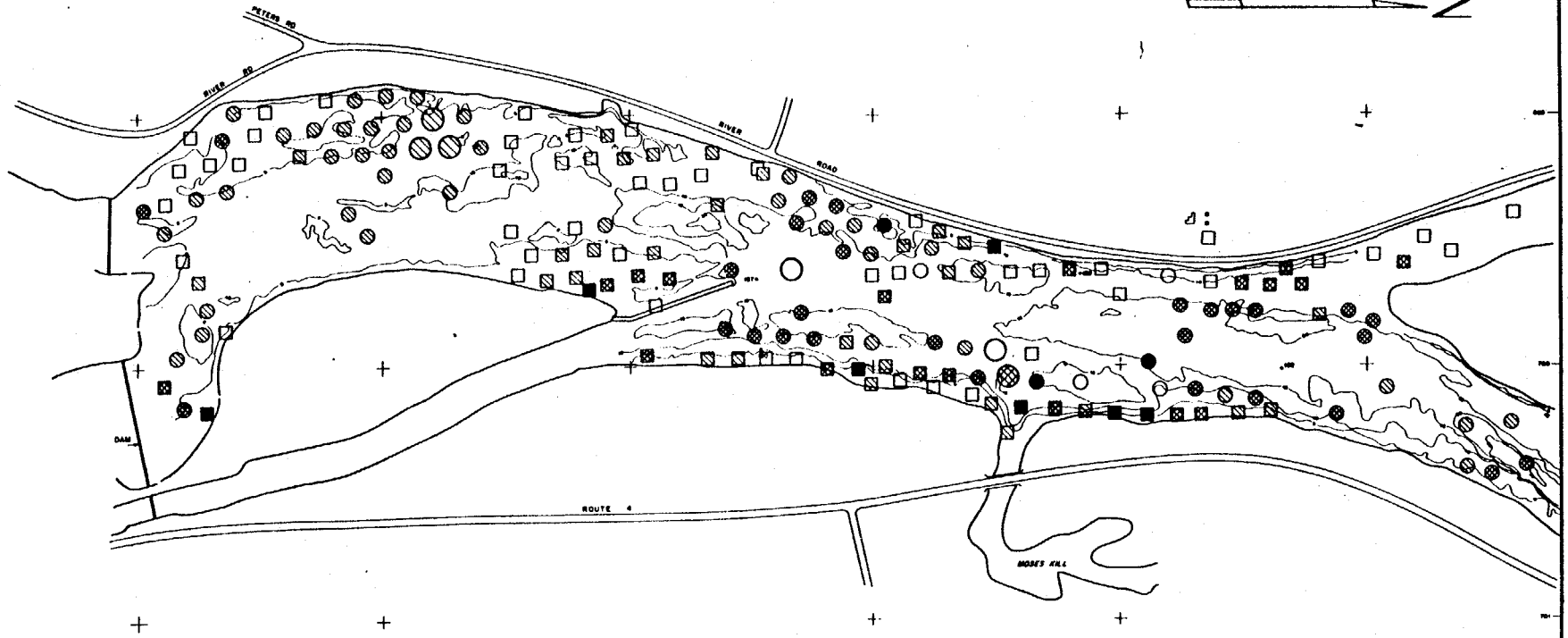

PCB (g/m²)	Grab	Core
<5	○	□
5-10	⊘	▨
10-50	⊗	▩
>50	●	■

larger symbols indicate station clusters

0 200 400 600 800 1000 feet
0 100 200 300 meters

Figure 11e.

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DIVISION OF WATER

PCB RECLAMATION PROJECT
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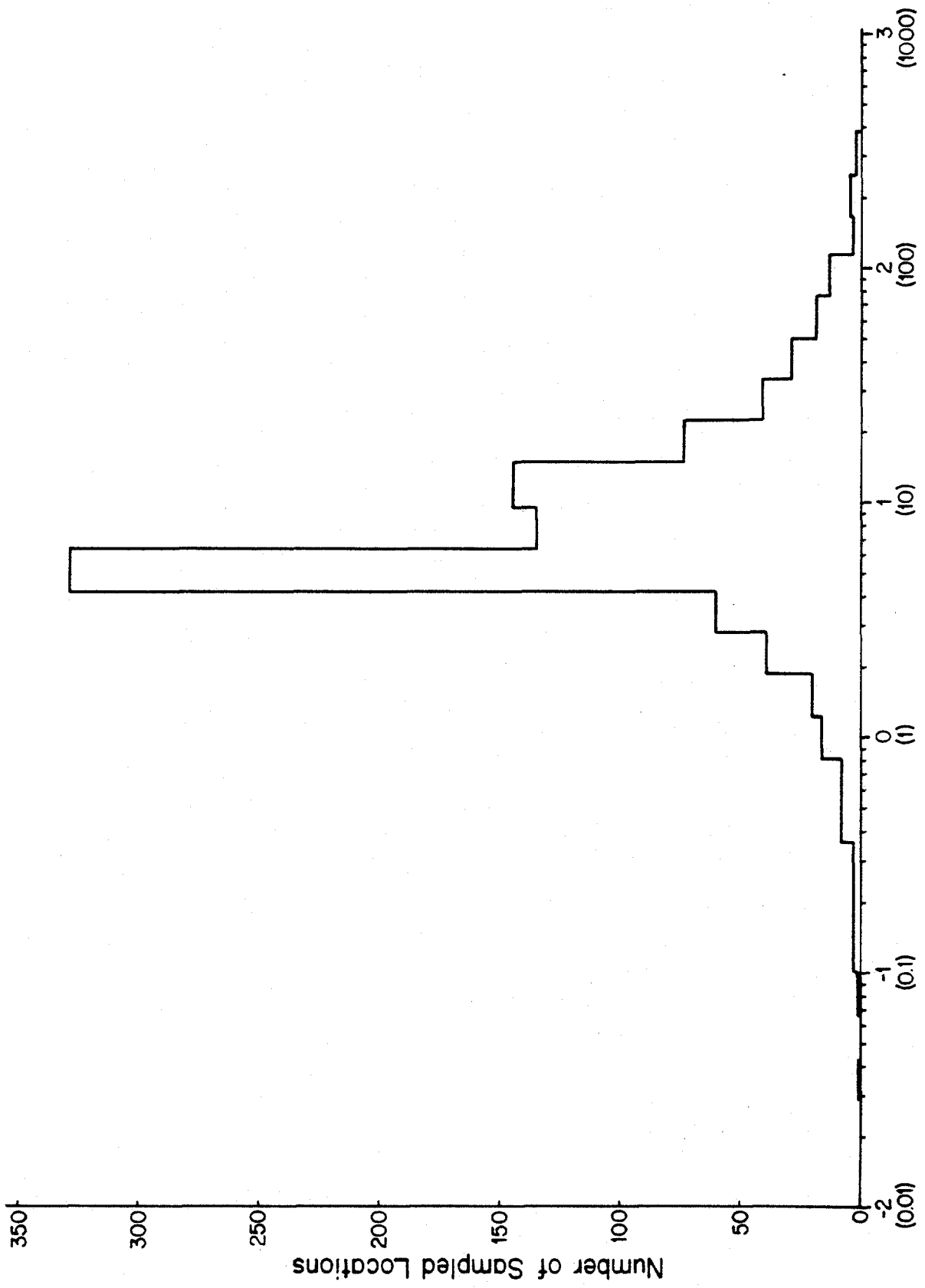

Figure 12. Frequency distribution of the logarithms of unit-area PCB masses.

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curved surfaces to data. The appropriateness of a given technique can be assessed by appraising the level of knowledge regarding spatial variability of a constituent concentration and the factors contributing to that variability in relation to sampling resolution.

One means of appraising spatial variability is through the development of a variogram which plots the variance between pairs of samples as a function of distance between pairs. A general variogram shows that as distance between two samples increases the difference between those samples increases to a point where there is little correlation between samples. The distance between samples over which the slope of the relationship between variance and sample distance is positive is referred to as the range of correlation or correlation distance. As a rule of thumb, a sampling grid spacing of two thirds of the range of correlation is sufficient to ensure correlation between sampling points and the utility of an interpolating and error estimating technique such as kriging.

To develop variograms, the unit-area PCB masses at the 20 nearest neighboring points to each of 1014 sampled locations were used as a data set. The absolute value of difference between arithmetic unit-area PCB masses and the absolute value of the differences between logarithms of the unit-area PCB masses were calculated for each of the pairs of samples. The resulting deviations were then grouped into 100, 5-ft (1.5-m) distance interval classes for analysis. The number of unique pairs within each distance class is presented in Figure 13a. The 125-ft (38-m) triangular sampling grid and the approximately 10-ft (3.0 m) interval high resolution quality assurance sampling are reflected in this figure with peaks in the region of 10-, 125-, and 250-ft (3-, 38- and 76-m) distances. There are relatively few pairs of samples separated by 20-100 ft (6.1 - 30 m). Respective averages of the absolute values of deviations and deviation of logarithms of unit-area PCB masses in each distance class are plotted in Figure 13b and 13c. The log of the average of absolute values of deviations is plotted in Figure 13d. Curves were plotted by eye. A variety of plots are presented due to an apparent quirk in the data for intervals near the 50-ft (15-m) distance. There were relatively few data in the distance intervals near 50 ft (15 m) (Figure 13a). Examination of data in this region indicates that the sample pairs differ by less than 5 g/m^2 (Figure 13b) and by a factor of approximately 10 (Figure 13c).

The respective unweighted means in Figures 13b and 13c are 7.3 g/m^2 and 0.53 g/m^2. The latter implies an average difference of a factor of 3.4. If the interval averages had been weighted for the number of sample pairs in each interval, the overall average would have implied a difference factor of slightly less than three.

Figure 13d, the log transform of Figure 13b, appears to conform best to the general variogram. Based upon the curves drawn through the data in Figures 13b and 13d, the correlation distance would appear to be approximately 90 ft. However, if one considers the subjective way in which the curves were drawn, other conclusions could be reached. Correlation distances of less than 60 ft could be reasoned from Figures 13b and 13d. A correlation of less than 30 ft could be reasoned from the data in Figure 13c. After considering how few sample locations had neighboring sample locations within 90 ft (27.4 m) and how obscure the relationship is between distance and variance within the apparent correlation distance, we selected averaging of unit-area PCB masses in discrete areas as the method of horizontal integration.

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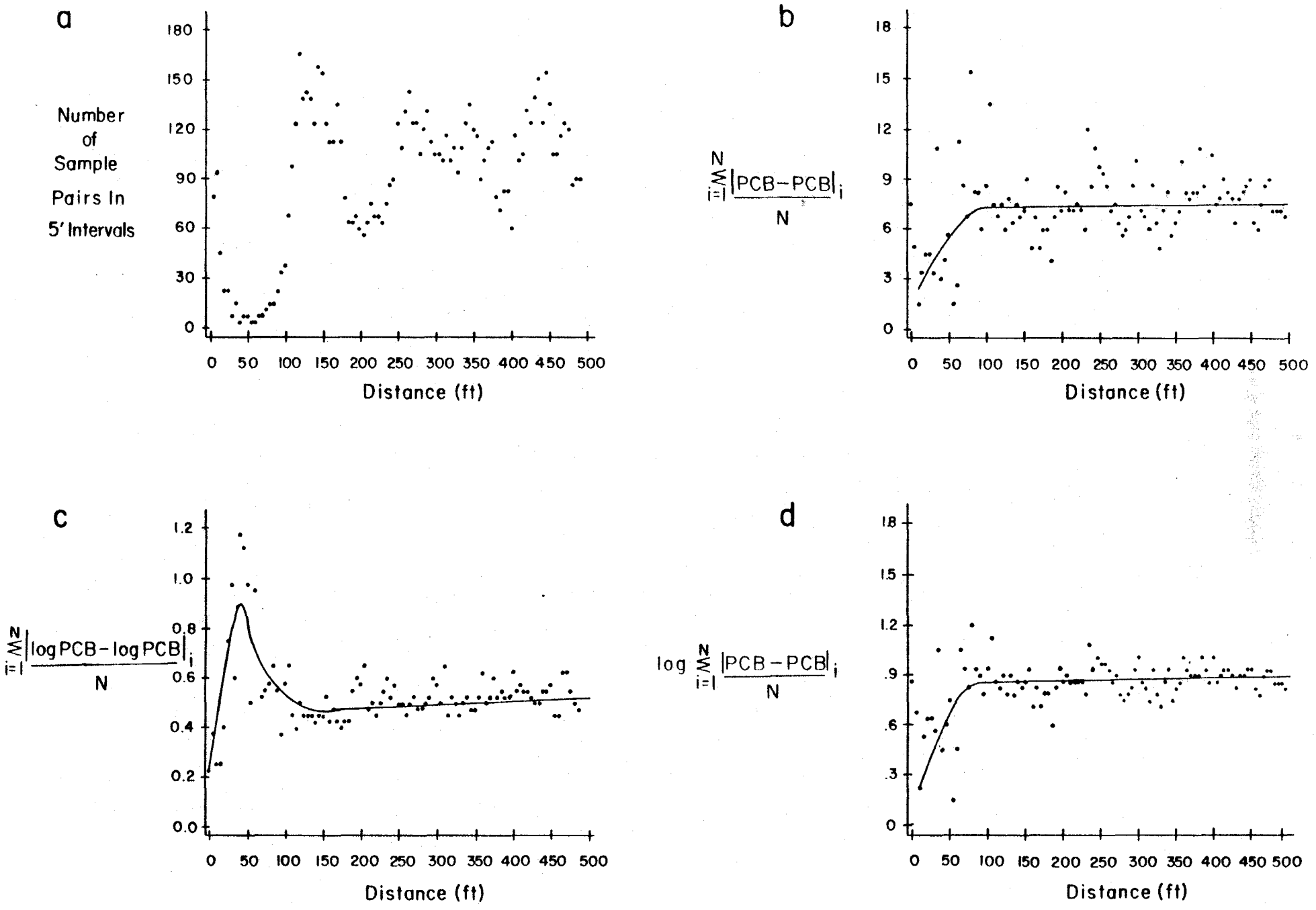

Figure 13. Variograms of unit-area PCB masses in the Thompson Island Pool.

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The river surface was divided into convex polygons. Unit-area PCB masses derived from integration of sediment depths of 0.5, 1.0 and 1.5 m (20, 39 and 59 in) were averaged using all sample locations within a given polygon. Polygons were defined on maps (1 in = 200 ft scale) which presented sample locations and unit-area PCB mass at sample locations and which were overlying bathymetric maps of the river. In defining the size and shape of polygons, unit-area PCB masses, bathymetry, sediment textures, and sample density were considered in relation to dredging design flexibility. Planimetering software used for integration required the polygons to be convex. In some cases this required that areas of relatively continuous sediment texture be subdivided. Areas with high-density quality-control sampling clusters which generally are within the correlation distance were enclosed in relatively small polygons to avoid bias. At the other extreme, the navigational channel which was not sampled intensively and which is generally characterized by coarse sediments with low PCB concentrations was included in rather large polygons. A core sample from the east channel at Rogers Island, an area that was not intensively sampled, yielded an extraordinarily high unit-area PCB mass (1200 g/m^2) and was enclosed in a polygon of limited area.

The river was divided into 109 polygons in the first calculation by the fourth author and subsequently into 138 polygons by the principal investigator. Both delineations employed the same subjective guidelines to interpret data and define polygons. The total PCB estimates for the Thompson Island Pool differed by less than 1 percent between the two sets of polygons. The estimates for the 138 polygons have become the working estimates for design of the Demonstration Project. Calculation of PCB quantities in polygons involved the interactive use of a video display terminal, a large digitizing pad and the Sperry 1100 at the State University of New York.

A map showing the 138 polygons is presented in Figure 14. Table 7 presents the corresponding calculated quantities of PCB in polygons. The total mass of PCB in the Thompson Island Pool calculated in this fashion is 23.2 tonnes based upon depth integration to 1.5 m (59 in). Essentially all (99.91 percent) appears to be above 1.0 m (39 in). Integration to 0.5-m (20-in) depth produces an estimate of 21.9 tonnes or 95 percent of the total.

DESIGNATION OF AREAS FOR RECLAMATION

The reclamation strategy for PCB in the Thompson Island Pool is based upon consideration of PCB concentration, availability of PCB for downstream transport and removal cost. It is beyond current project resources to remove the entire 23.2 tonnes of PCB from the pool and basing removal priorities only upon PCB concentration in a given area could compromise the effectiveness of the project in reducing downstream PCB transport since the current loss rate of PCB from a given area may not be directly proportional to PCB concentration. For planning purposes, a targeted volume of 225,000 m^3 (294,000 yd^3) sediment was considered. The costs of dredging, transporting and chemical landfilling of this volume appears to be generally within the means of the project according to project engineering staff.

Polygons were ranked initially by average PCB concentration. For the purposes of ranking, average PCB concentrations in polygons were estimated by calculating the ratio of the 0-0.5 m (0-20 in) integrated PCB mass to the mass

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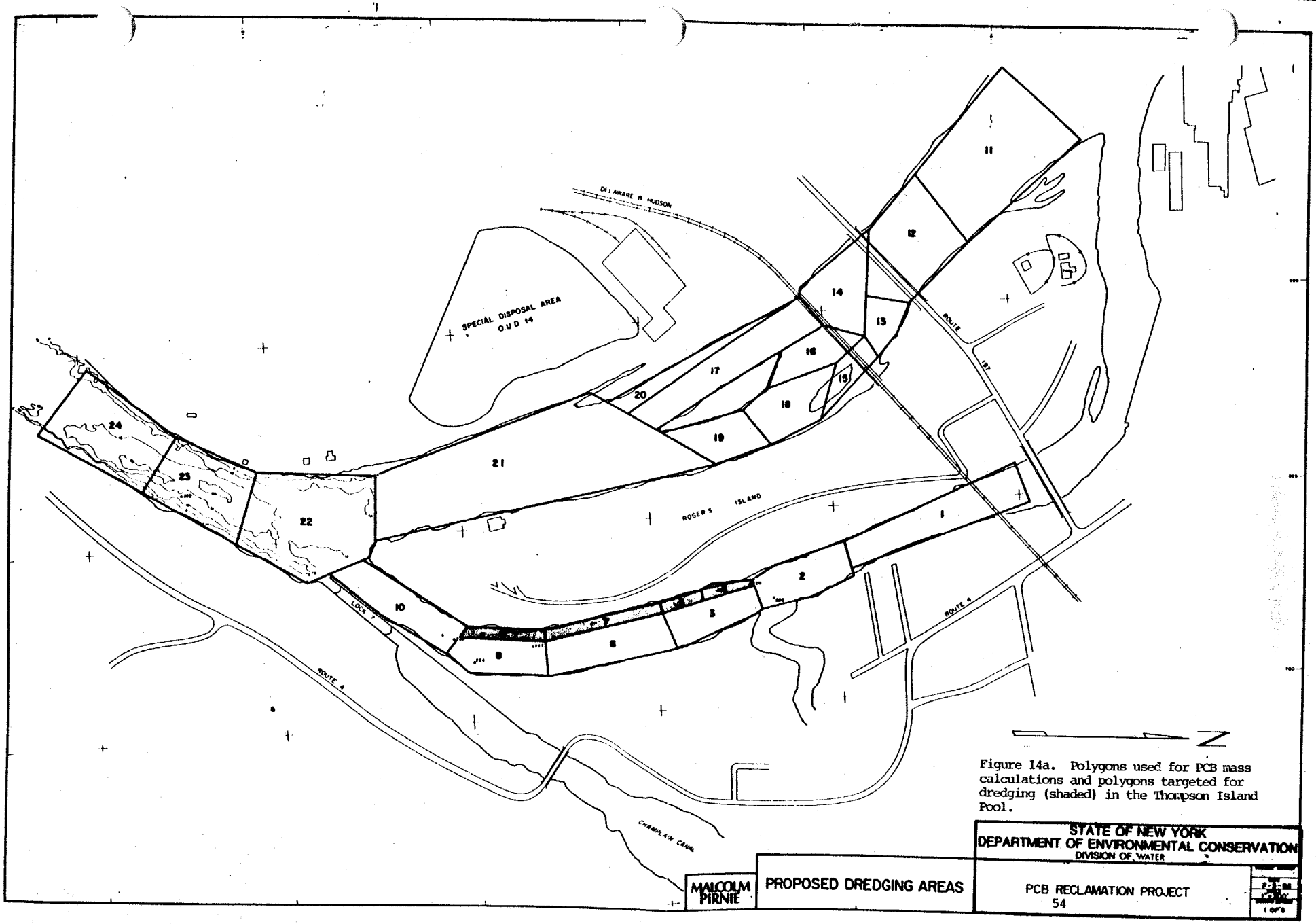

Figure 14a. Polygons used for PCB mass calculations and polygons targeted for dredging (shaded) in the Thompson Island Pool.

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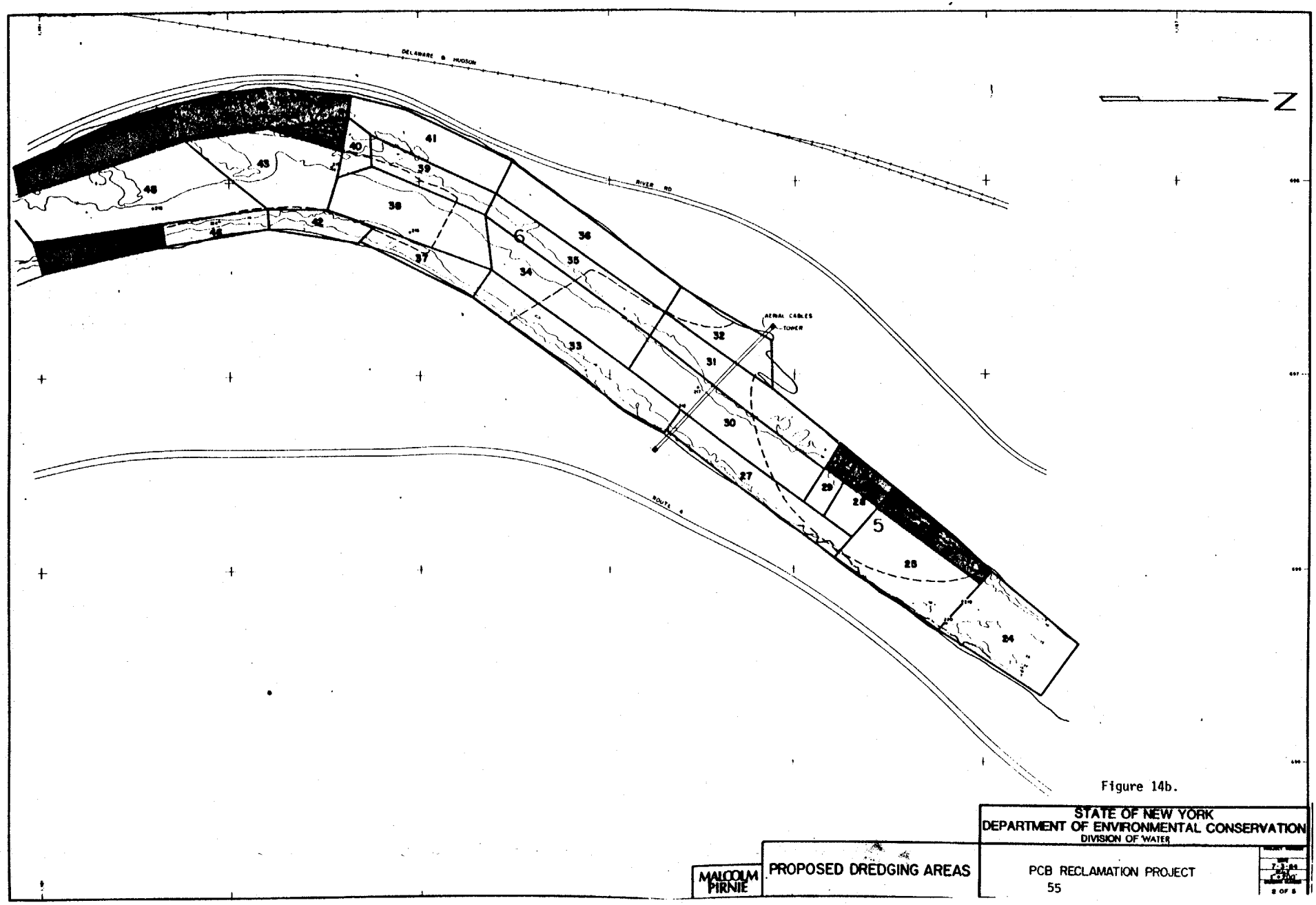

Figure 14b.

MALCOLM PIRNIE	PROPOSED DREDGING AREAS	STATE OF NEW YORK DEPARTMENT OF ENVIRONMENTAL CONSERVATION DIVISION OF WATER	
		PCB RECLAMATION PROJECT 55	

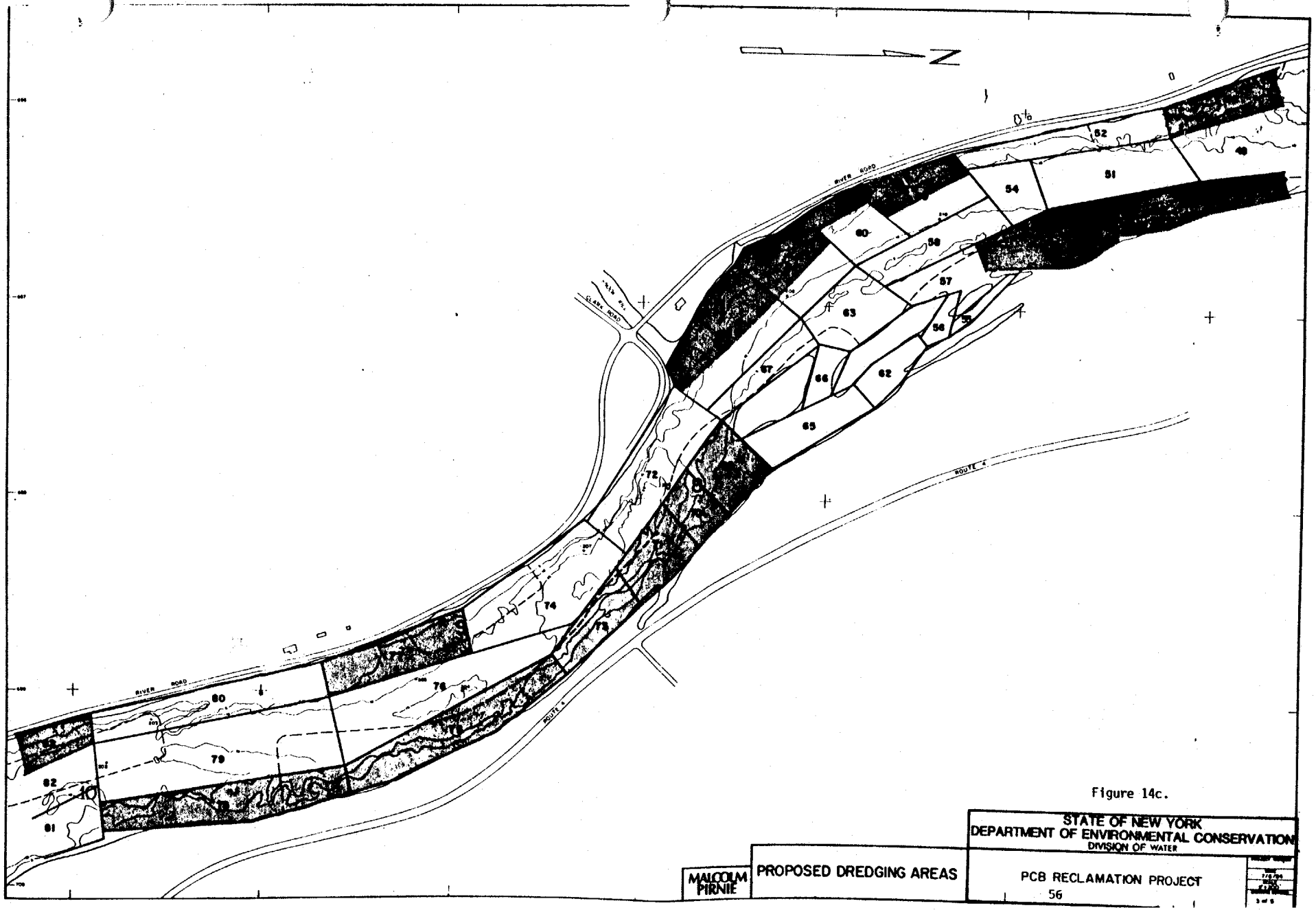

Figure 14c.

MALCOLM PIRNIE	PROPOSED DREDGING AREAS	STATE OF NEW YORK DEPARTMENT OF ENVIRONMENTAL CONSERVATION DIVISION OF WATER PCB RECLAMATION PROJECT 56

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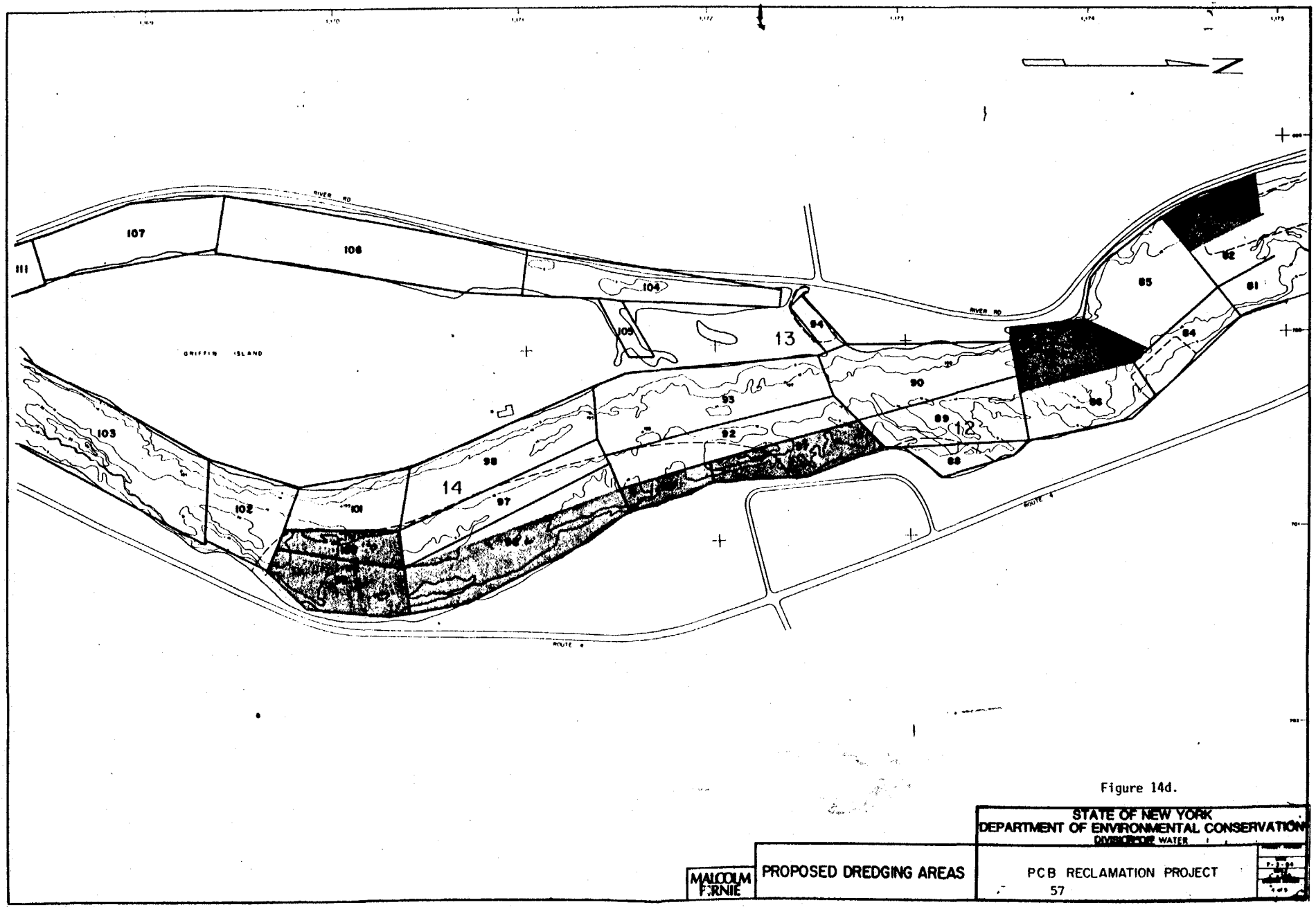

Figure 14d.

MALCOLM PIRNIE	PROPOSED DREDGING AREAS	STATE OF NEW YORK DEPARTMENT OF ENVIRONMENTAL CONSERVATION DIVISION OF WATER PCB RECLAMATION PROJECT 57

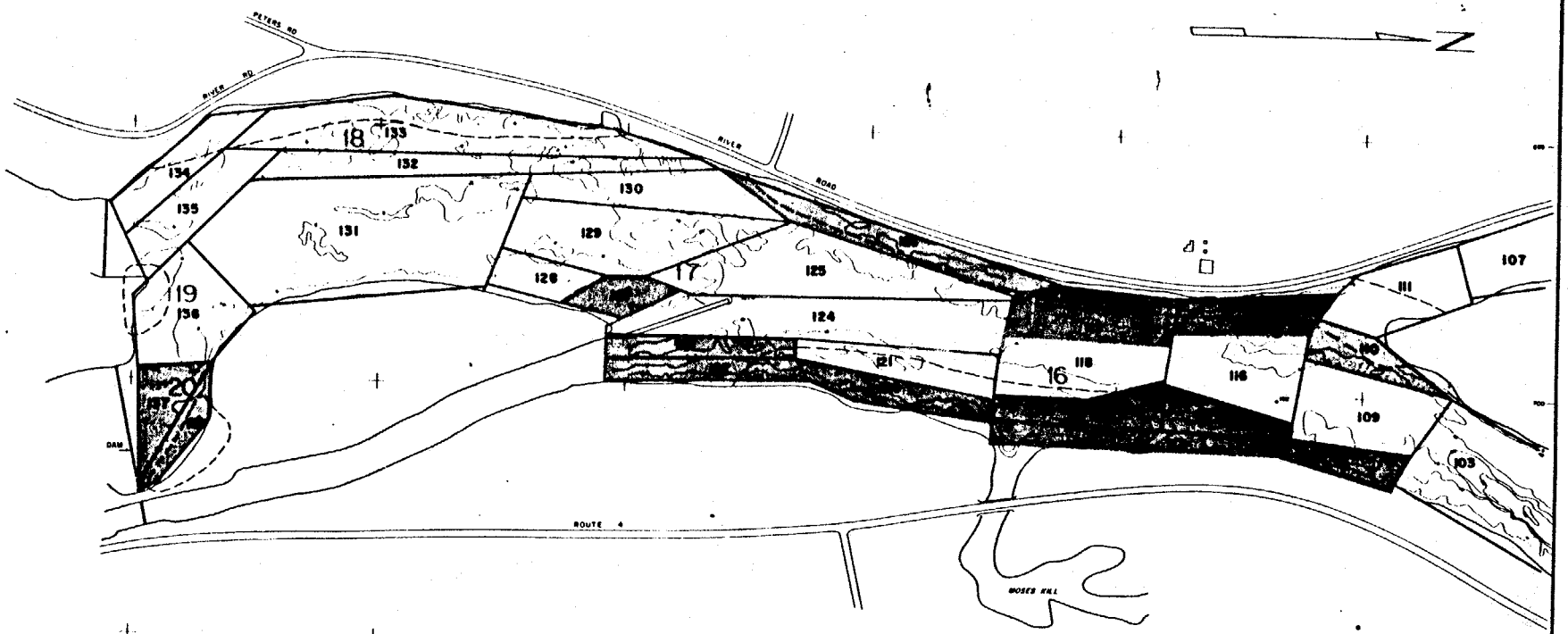

Figure 14

MALCOLM PIRNIE	PROPOSED DREDGING AREAS	STATE OF NEW YORK DEPARTMENT OF ENVIRONMENTAL CONSERVATION DIVISION OF WATER PCB RECLAMATION PROJECT 58	7-1-84

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TABLE 7. DEPTH INTEGRATED PCB MASS IN POLYGONS

Polygon Number	Area (m^2)	Depth Integrated PCB Mass (kg) 0-0.5	0-1.0m	Avg. PCB* conc. (ug/g)	PCB** Erodibility (g/m^2)	Est. PCB Loss at 100 year flood (kg)
1	16854	116	112	14	.57	9.6
2	9528	77	77	16	.70	6.7
3	8048	85	85	21	1.05	8.5
4	1602	64	80	80	5.34	8.6
5	1414	1723	1723	2437	1.82	2.6
6	11856	65	65	11	.55	6.5
7	3925	37	37	19	.77	3.0
8	8148	70	70	17	.79	6.5
9	2445	87	87	71	2.51	6.1
10	11679	58	58	10	.48	5.6
11	34652	260	260	15	.75	26.0
12	19240	114	114	12	.59	11.4
13	4363	55	55	25	.98	4.3
14	11032	66	66	12	.59	6.6
15	4245	20	20	9	.47	2.0
16	7033	42	42	12	.59	4.2
17	16558	10	10	1	.06	1.0
18	10306	86	86	17	.74	7.6
19	8165	48	48	12	.63	5.1
20	5530	125	125	45	1.59	8.8
21	62049	447	447	14	.72	44.7
22	30295	138	138	9	1.18	35.9
23	16904	105	105	12	1.37	23.1
24	20712	189	189	18	1.73	35.9
25	20133	155	155	15	1.78	35.8
26	7480	121	146	32	1.96	14.6
27	14378	85	85	12	.00	.0
28	7016	149	149	43	5.32	37.3
29	4344	36	36	17	2.02	8.8
30	22338	134	134	12	1.68	37.5
31	17432	98	102	11	1.54	26.9
32	10808	128	134	24	2.54	27.5
33	20269	145	145	14	1.45	29.4
34	18899	103	103	11	1.20	22.7
35	13794	90	106	13	.95	13.1
36	17565	247	157	28	1.56	27.5
37	8029	53	53	13	.96	7.7
38	21232	193	193	18	1.36	28.8
39	8502	94	94	22	1.34	11.4
40	15117	123	148	16	1.57	23.7
41	3075	14	15	9	.97	3.0
42	5972	49	49	17	1.13	6.8
43	20412	175	175	17	1.08	22.0
44	3202	115	124	72	1.51	4.8
45	15956	89	95	11	.72	11.6
46	5832	32	32	11	.76	4.4
47	9027	475	585	105	2.43	21.9
48	36478	258	258	14	1.08	39.6
49	17837	258	258	29	1.92	34.3

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TABLE 7. (continued)

Polygon Number	Area (m^2)	Depth PCB Mass (kg) 0-0.5	Integrated 0-1.0m	Avg. PCB* conc. (ug/g)	PCB** Erodibility (g/m^2)	Est. PCB Loss at 100 year flood (kg)
50	9800	84	84	17	2.06	20.2
51	18249	147	159	16	.90	16.5
52	12975	91	113	14	.61	8.0
53	17369	222	302	26	.94	16.3
54	7499	45	45	12	.71	5.3
55	2117	12	12	11	.00	.0
56	2685	23	23	17	.00	.0
57	8109	48	48	12	.06	.5
58	12334	68	68	11	.06	.7
59	14292	85	85	12	.06	.8
60	7300	51	51	14	1.05	7.7
61	4486	502	502	224	11.84	53.1
62	5607	107	154	38	.00	.0
63	13036	81	88	12	.93	12.1
64	15310	454	454	59	3.46	53.0
65	11396	151	172	26	.00	.0
66	3815	34	34	18	.00	.0
67	7993	59	64	15	.80	6.4
68	24707	107	107	9	.64	15.9
69	10393	187	322	36	1.43	14.9
70	6560	54	54	17	.81	5.3
71	10986	141	144	26	1.56	17.2
72	22824	191	191	17	1.02	23.4
73	8811	475	535	108	5.50	48.5
74	26740	155	155	12	.66	17.6
75	22303	381	406	34	1.20	26.8
76	27760	147	147	11	.41	11.4
77	15281	282	305	37	1.27	19.4
78	22245	334	363	30	.53	11.7
79	40084	296	340	15	.27	11.0
80	19631	116	154	12	.23	4.5
81	10697	81	81	15	.00	.0
82	12759	76	76	12	.00	.0
83	14645	343	392	47	.00	.0
84	11221	92	116	16	.47	5.3
85	24795	190	200	15	.50	12.5
86	16227	186	186	23	.64	10.4
87	15448	265	265	34	1.20	18.5
88	6158	75	77	24	2.25	13.9
89	17849	130	130	15	1.48	26.3
90	25826	257	257	20	2.02	52.2
91	12902	170	170	26	2.43	31.4
92	20640	199	222	19	1.44	29.6
93	35526	339	339	19	1.93	68.4
94	2842	14	15	10	.00	.0
95	5842	31	31	11	.00	.0
96	34094	613	634	36	1.56	53.0
97	17282	79	79	9	.42	7.3
98	26732	128	128	10	.41	11.1

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TABLE 7. (continued)

Polygon Number	Area (m^2)	Depth PCB Integrated Mass (kg) 0-0.5	0-1.0m	Avg. PCB* conc. (ug/g)	PCB** Erodibility (g/m^2)	Est. PCB Loss at 100 year flood (kg)
99	16362	466	485	57	18.49	302.5
100	8759	38	38	9	2.95	25.9
101	14341	86	86	12	5.24	75.1
102	16788	178	178	21	15.68	263.2
103	43523	483	483	22	4.31	187.8
104	17082	58	62	7	.00	.0
105	3593	69	128	39	.00	.0
106	40788	32	36	2	.00	.0
107	24554	16	17	1	.00	.0
108	5304	156	156	59	.00	.0
109	13914	127	127	18	.00	.0
110	6536	111	111	34	.00	.0
111	11948	50	51	8	.00	.0
112	9437	375	445	79	.00	.0
113	6267	110	110	35	.00	.0
114	4429	348	348	157	.00	.0
115	3266	196	209	120	.00	.0
116	14295	206	206	29	.00	.0
117	8039	138	174	34	.00	.0
118	12819	44	44	7	.00	.0
119	12311	95	95	15	.00	.0
120	7611	156	191	41	.00	.0
121	9455	57	57	12	.00	.0
122	6142	38	38	12	.14	.9
123	6723	146	146	43	.31	2.1
124	25901	182	196	14	.16	4.0
125	24486	212	216	17	.18	4.5
126	12179	268	272	44	.00	.0
127	5902	156	180	53	.48	2.8
128	5714	30	30	10	.00	.0
129	19990	113	113	11	.00	.0
130	12414	49	49	8	.00	.0
131	48723	279	279	11	.00	.0
132	13270	81	81	12	.00	.0
133	26459	133	133	10	.00	.0
134	8151	63	63	16	.00	.0
135	10266	58	58	11	.00	.0
136	14580	67	67	9	.00	.0
137	6281	103	122	33	.00	.0
138	4528	569	575	251	.00	.0

of sediment in the polygon in the upper half meter, assuming a specific weight of 1 g/cm^3. A single polygon, polygon No. 5, which has an area of 1.4 x 10^3 m^2 (1.7 x 10^3 yd^2), contains an average PCB concentration of greater than 1000 ug/g. Six polygons with a collective area of 3.5 x 10^4 m^2 (4.2 x 10^4 yd^2) have average PCB concentrations between 100 and 1,000 ug/g. Eight polygons with a collective area of 6.0 x 10^4 m^2 (7.2 x 10^4 yd^2) have average PCB concentrations between 50 and 100 ug/g, and 27 polygons with a collective area of 3.2 10^5 m^2 (3.8 x 10^5 yd^2) have PCB concentrations between 25 and 50 ug/g.

The optimal PCB mass reclamation curves for 0.5- and 1.0-m (19- and 39-in) excavation depths resulting from PCB concentration ranking are presented in Figure 15. Based upon these curves, a volume of 225,000 m^3 (294,000 yd^3) from 1-m (39-in) excavation could yield 9.5 tonnes PCB. A 0.5-m (19-in) excavation could yield 12 tonnes PCB or 52 percent of the total which includes all of the polygons with an average PCB concentration of greater than 25 ug/g in the upper 0.5 m of sediment. To remove polygons based solely upon their PCB concentration ranking would require a considerable amount of "hopscotching" among polygons and would suggest a greater degree of discontinuity of sediment contamination than is probably warranted.

In establishing dredging priorities, particularly for polygons having average PCB concentrations below the 50 ug/g regulatory limit, it also seems prudent to explicitly address availability of PCB in a given polygon for downstream transport. A component of the sediment survey was the assessment of the erodibility of sediments in the Thompson Island Pool. This analysis which was conducted by researchers at the Rensselaer Polytechnic Institute was intended to provide a means to explicitly consider sediment erodibility in selecting areas for dredging. The analysis is described in detail in Appendix B of this report. In brief, the results of a simulation of sediment transport using the HEC-6 model were used to rank polygons based upon PCB erodibility.

A one-dimensional representation of the Thompson Island Pool was used in the HEC-6 simulation. Model calibration involved averaging of channel geometry and sediment characteristics at 32 cross-sections. The most upstream cross section was at MP-193.64 which is just downstream of Rogers Island and Lock 7. The most downstream section was near the Thompson Island Dam. Changes in river bed elevation were predicted for several events including selected recent spring runoff events, and events with expected frequencies of 1 in 10 years and 1 in 100 years. The results are summarized in Table 8. The 100-year event results were selected for use in ranking the 138 polygons based upon erodibility. The average of results of two consecutive model sections were assigned to polygons between those sections. The 21 polygons upstream of MP-193.46 were assigned an elevation change of -0.1 ft. For some areas where sediment deposition is indicated, zero values were assigned to polygons since elevation changes were used for calculating PCB erosion. Zero values were also assigned to polygons 55, 56, 62, 65, 66, 94, 104-107 and 111 based upon their isolation from the main channel of the Hudson River, although they were within reaches having predicted negative bed elevation changes. PCB in polygons was depth integrated to 100-year erosion heights. Thus estimated, the total erodible PCB mass during the 100-year event is 2.4 tonnes or approximately 10 percent of the quantity contained in the pool. Considering the inherent limitations of the one-dimensional sediment transport model, we decided that the

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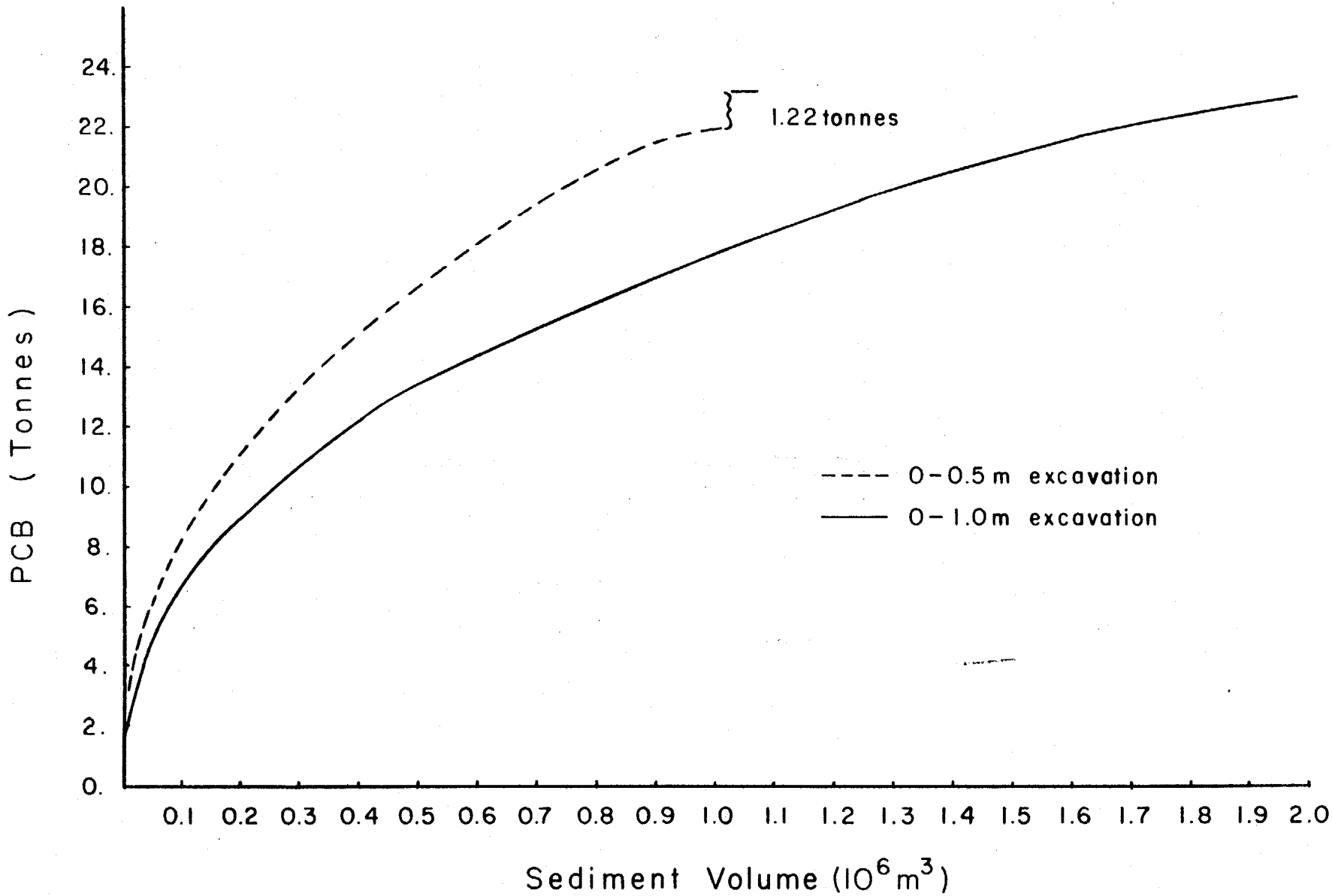

Figure 15. PCB mass reclamation curves for 1.0-and 0.5-m excavation depths optimizing removal of PCB mass.

TABLE 8. SEDIMENT EROSION IN THE THOMPSON ISLAND POOL DURING SELECTED DISCHARGE EVENTS*

Mile-Point	Bed Elevation Change (ft.)			
	25,000 cfs	30,000 cfs	46,600 cfs**	63,700 cfs***
193.640	-0.02	-0.04	-0.06	-0.32
193.460	-0.00	0.00	-0.06	-0.20
193.330	-0.01	0.00	-0.06	-0.17
193.190	-0.02	0.00	-0.15	-0.33
192.980	-0.01	0.00	-0.10	-0.22
192.780	-0.02	-0.01	0.03	-0.18
192.540	-0.03	-0.02	0.04	-0.13
192.500	-0.03	-0.03	-0.04	-0.15
192.370	-0.02	0.00	-0.07	-0.16
192.320	-0.02	0.00	-0.14	-0.31
192.070	0.01	-0.01	0.04	0.06
191.920	-0.02	-0.03	0.01	-0.10
191.580	-0.04	-0.05	0.00	-0.19
191.490	-0.06	-0.03	-0.11	-0.06
191.240	-0.04	-0.02	-0.02	-0.10
191.070	0.02	0.01	0.05	0.03
190.890	-0.00	-0.01	0.02	-0.02
190.700	-0.05	-0.01	-0.07	-0.12
190.540	-0.03	-0.01	-0.13	-0.30
190.370	-0.02	-0.02	0.04	-0.16
190.210	0.01	-0.02	0.04	-0.01
190.080	-0.02	-0.03	0.03	-0.16
189.930	-0.09	-0.02	-0.03	-1.42
189.780	0.00	-0.01	0.03	-1.29
189.530	0.04	0.00	0.04	0.49
189.460	0.10	0.06	0.06	0.53
189.320	0.00	0.00	0.02	0.24
189.060	-0.03	0.00	-0.04	-0.05
188.890	-0.01	-0.03	0.01	0.01
188.750	0.01	0.00	0.00	0.04
188.610	0.03	0.06	0.02	0.01
188.500	0.00	0.00	0.00	0.00

* Data produced from simulations using HEC-6 model by Zimmie et al (1985).
** 10-year flood.
*** 100-year flood.

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results of this type of calculation procedure seem better employed in a relative sense rather than an absolute sense. That is, the sediment transport model and subsequent PCB erosion calculations can be reasonably used to indicate whether one area is more susceptible to erosion than another. However, the accuracy of any PCB erosion estimate is uncertain.

Polygons were ranked based upon the estimated mass of PCB per unit area that would be eroded during the 100-year runoff event. Polygons in areas where no erosion was predicted were ranked based upon average PCB concentrations. Unit-area PCB losses for each polygon are presented in Table 7. Figure 16 presents the PCB reclamation curves for 0.5- and 1.0-m excavation depths based upon a ranking of PCB erodibility. PCB mass presented in this figure is the total mass of PCB to 0.5 and 1.0 m (19 and 39 in). These curves essentially reflect the removal sequence that would be followed if the reclamation strategy was to be based solely upon predicted PCB erosion during the 100-year flood. The ranking of apparently non-erodible areas based upon PCB concentration is evident in the region of 1.5×10^6 m^3 (2.1×10^6 yd^3) sediment along the 1-m (39 in) excavation curve and 7.5×10^5 m^3 (11×10^5 yd^3), along the 0.5-m (19 in) excavation curve. The curves presented in Figure 16 appear to be more linear in the 0 - 2.25×10^5 m^3 (0-3.2×10^5 yd^3) sediment range than the curves in Figure 15.

According to the ranking reflected in to Figure 16, a 1-m (39-in) excavation of 2.25×10^5 m^3 (2.94×10^5 yd^3) sediment could yield 4.4 tonnes of PCB. A 0.5-m (19-in) excavation could yield 8.2 tonnes of PCB and 67 percent of the PCB subject to erosion during the 100-year flood. However, such a strategy would leave behind areas of highly contaminated sediment. A reclamation strategy entirely based upon the analysis reflected in Figure 16 would probably place an undue level of confidence in the accuracy of the sediment transport model and would neglect other mechanisms of sediment disturbance and resuspension that could affect the long-term stability of those deposits. The inability to predict or evaluate the long-term fate of PCB in any given area with a high degree of certainty requires a limitation of importance of the estimated PCB erodibility in final specification. Clearly, areas with both high PCB concentration and high predicted PCB erosion rates would be logical choices for removal.

Polygons were categorized and prioritized by average PCB concentration and ([PCB]) erodibility (erodibility) as follows:

1) [PCB] $\geq$ 50 ug/g and erodibility > 1 g/m_;

2) [PCB] > 50 ug/g and erodibility > 1 g/m_;

3) 50 ug/g > [PCB] > 25 ug/g and erodibility > 1 g/m_;

4) 50 ug/g $\leq$ [PCB] > 25 ug/g and erodibility > 1 g/m_;
and

5) other.

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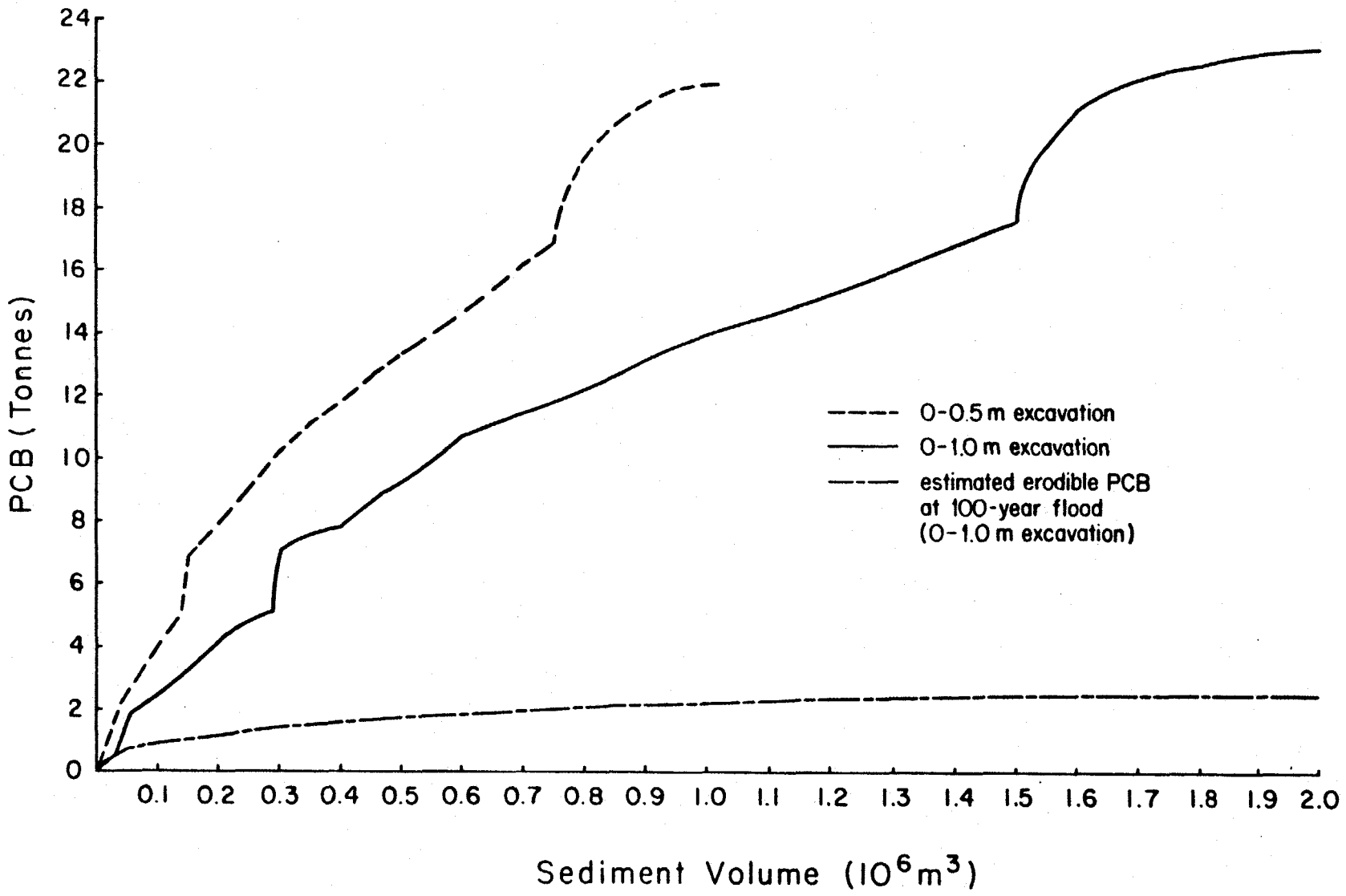

Figure 16. PCB mass reclamation curves for 1.0-and 0.5-m excavation depths optimizing removal of erodible PCB.

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On a map presenting PCB concentration and erodibility rankings for each polygon, 11 continuous areas were identified that contained varying numbers of high priority polygons. The polygons contained in each of the 11 areas and the criteria for inclusion are presented in Table 9. A perspective of the effectiveness of the removal of these 11 areas in removing total PCB and PCB estimated to be eroded during the 100-year flood is presented in Table 10. Sediment volumes presented in Table 9 are based upon a 1.0-m (19-in) excavation depth. A preliminary dredging program design that was prepared as this report was being drafted employs a 2-ft (0.6-m) excavation depth. This is only slightly deeper (4.3 in) than a 0.5-m cut. Sediment volumes summarized in Table 10 are based upon a 0.61-m (2-ft) excavation depth. It has been assumed that the additional 5 percent of the total PCB mass in the Thompson Island Pool below 0.5 m would be located within the next 0.11 m of sediment depth. As reflected by Table 10, PCB concentration was ultimately given considerably more weight than erodibility. Considering the independent reclamation curves based upon PCB concentration and PCB erodibility for a 0.61-m (2-ft) excavation depth, the theoretically achievable targets for total PCB mass and erodible PCB associated with a 2.75×10^5 m^3 (3.18×10^5 yd^3) sediment volume are 12,860 kg and 1,654 kg respectively. The total PCB would be reclaimed using erodibility prioritization alone would by 8,924 kg. The targeted amounts of 11.8 tonnes of total PCB and 0.86 tonnes of erodible PCB represent 92 and 52 percents of theoretically achievable targets, respectively. This strategy also implicitly weighed the costs of hopping among separated polygons with the dredge in establishing a limited number of continuous areas to be dredged. Inclusion of some low priority polygons, such as polygon 7 in area 1, in some areas was also based upon the apparent likelihood that they contain significantly contaminated sediment that was not reflected by sampling and analysis. These intuitive assessments were based upon knowledge of sediment texture features.

As indicated by the shaded areas in Figure 14, the final dredge design will differ slightly from the geometry of the polygons that were used for quantifying PCB mass. Also evident is the correspondence between proposed dredging areas and the previously defined hot spots 5-20 which are enclosed in dashed lines. With minor exceptions, polygons targeted for removal are in the location of previously defined hot spots.

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TABLE 9. RECOMMENDED POLYGONS AND CRITERIA FOR REMOVAL

Area	*PCB ≥ 50 ppm and Erodibility ≥ lg/m²	PCB > 25 ppm and Erodibility ≥ lg/m²	PCB ≥ 50 ppm and Erodibility < lg/m²	50 > PCB ≥ 25 ppm and Erodibility < lg/m²	Other
1 Polygons	4, 5, 9				7- contiguous w/5, 9
cum. sed (m³)***	5,460				9,390.
cum. PCB (kg)	1,890				1,930
2 Polygons		69, 71, 75		53**, 62, 65, 78	50 contiguous w/47, 53
cum. sed (m³)	17,800	61,500		118,000	70** contiguous w/69, 73
cum. PCB (kg)	1,120	1,990		2,980	135,000
					3,120
3 Polygons:	61, 64**				68** contiguous w/64
cum. sed (m³)					59** contiguous w/61
cum. PCB (kg)	19,800				58,800
	956				1,150
4 Polygons	99	91, 96**			95- contiguous w/91, 96
cum. sed (m³)					100- MP1 has included
cum. PCB (kg)					contiguous w/99
	16,400	29,300(91) 63,400(91, 96)			69,200(95) 78,000(95,100)
	484	654(91) 1,290(91, 96)			1,320(+95) 1,360(+95, 100)
5 Polygons			108, 112, 114	113, 120, 123	122- contiguous w/123
cum. sed (m³)					115
cum. PCB (kg.)				43,000	49,200
				1,610	1,640
6 Polygon			127		
sed (m³)			5,900		
PCB (kg)			180		
7 Polygon			138		
sed (m³)			4,530		
PCB (kg)			575		

Area	*PCB ≥ 50 ppm and Erodibility ≥ 1g/m²	PCB > 25 ppm and Erodibility ≥ 1g/m²	PCB ≥ 50 ppm and Erodibility < 1g/m²	50 > PCB ≥ 25 ppm and Erodibility < 1g/m²	Other
8 Polygons	44	49			45- contiguous w/44, 49
cum. sed (m^3)	3,200	21,000			37,000
cum. PCB (kg)	124	382			477
9 Polygons		26, 28			29** contiguous w/26, 28
cum. sed (m^3)		14,500			18,842
cum. PCB (kg)		295			331
10 Polygon				110, 117, 126	119 contiguous w/117, 126
cum. sed (m^3)				26,800	39,100
cum. PCB (kg)				557	652
11 Polygon				83	
sed (m^2)				14,600	
PCB (kg)				392	

* - PCB concentration in upper 0.5 m of sediment
** - Portion of Polygon likely to be excluded in later design
*** - Cummulative volume in area from left to right in table based upon 1-m excavation. For 2-ft. excavation multiply by 0.61.

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TABLE 10. RESULTS OF THE POLYGON SELECTION PROCESS

	Polygon Categories						
PCB (µg/g):	≥ 50	≥ 50	25-50	25-50	< 25	≥ 25	-
Erodibility (g/m²):	≥ 1	< 1	≥ 1	< 1	-	-	≥ 1 g/m²
Total No. of polygons	9	6	12	15	96	42	50
No. of selected polygons	9	6	8	11	11	34	17
Total PCB (kg)	4,574	1,914	3,080	2,897	10,696	12,464	12,031
Selected PCB (kg)	4,574	1,914	2,228	2,387	701	11,103	6,802
Total volume ($10^3 m^3$)	38	20	108	90	951	256	468
Selected volume ($10^3 m^3$)	38	20	75	72	69	206	113
Erodible PCB* (kg)	501	2.8	304	34	1,575	842	2,023
Selected erodible PCB (kg)	501	2.8	230	30	92	764	731

*Predicted losses for the 100-year flood event.

PCB MASS ESTIMATION ERRORS
ERRORS ASSOCIATED WITH ESTIMATING THE PCB MASS IN THE THOMPSON ISLAND POOL

DIFFERENCE BETWEEN 1978 AND CURRENT PCB MASS ESTIMATES

The current estimate of 23 tonnes of PCB in the Thompson Island Pool differs considerably from the 1978 estimate (MPI, 1978) of 61 tonnes. The net PCB transport during the water years 1978-1984 from the Fort Edward - Schuylerville reach of the Hudson which includes the Thompson Island Pool was assessed from water monitoring records provided by the United States Geological Survey (Barnes, 1987). The 5.8 tonnes of PCB exported downstream from this area during this period indicates that net PCB transport explains only a minor portion of the difference between estimates. In addition there appears to be general agreement between the 1978 delineation of the hot spots and the current distribution of elevated sample PCB concentrations. There is no evidence that a substantial change in the river bed occurred between samplings.

The factors responsible for differences in PCB estimates can be revealed through examination of the errors associated with calculation methods and assumptions of both surveys.

SENSITIVITY ANALYSIS OF CURRENT PCB MASS CALCULATIONS

As described previously, the vertical and horizontal integration of PCB concentrations involved the use of several constants. To apply data from the mass-spec screen method, which were reported in concentration ranges, average GC results for samples analyzed by both methods were used as constants. The effective depth to which grab sample PCB concentrations were applied, was estimated through statistical analysis of sediment cores having similar texture. Another linear constant used in the calculations was the specific weight of gravel sediments. This constant was derived as the average of specific weight measurements for a subset of the gravel-textured samples.

Sensitivity analyses were performed for all the above-mentioned constants by essentially repeating the calculations for the 138 polygons while varying the value of a single constant. Table 11 presents the results of the sensitivity analyses of constants used in PCB mass calculations. As suggested by this table the potential for error to be introduced by these constants is greater for areas of gravel sediment which were more difficult to core than areas of fine-grained sediment. Areas of gravel sediment tended to yield grab samples which required the assumption of an effective contamination depth. They also tended to be analyzed only by mass-spec and produce concentrations less than 10 ug/g, therefore requiring the use of a constant concentration. Most of the gravel sediment samples could not be reliably analyzed for specific volume by our method, so an assumption of a constant specific weight was also required. At the other extreme, areas of fine-grained sediment tended to yield core samples which contained higher PCB concentrations and were hence analyzed more frequently by GC than were gravel sediments. In addition, fine-grained sediment samples could also be routinely analyzed to determine specific weight. Hence, estimates of PCB mass in areas of fine-grained contaminated sediment

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TABLE 11. RESULTS OF SENSITIVITY ANALYSES FOR CONSTANTS USED IN THE CALCULATION OF PCB MASS

Constant	Value used in Calculations	Sensitivity of Thompson Island Pool PCB mass estimate
PCB concentration for mass-spec result category:		
< 10 ug/g	15.0 ug/g	388 kg/ ug/g
10 - 50 ug/g	30.8 ug/g	94.6 kg/ ug/g
50 - 100 ug/g	135 ug/g	7.85 kg/ ug/g
> 100 ug/g	518 ug/g	2.80 kg/ ug/g
Specific weight of gravel	1.3 g/cm^3	450 kg/ 0.1 g/cm^3
Equivalent depth of PCB penetration applied to grab sample PCB concentrations:		
fine sand sediments	43 cm	120 kg/ cm
gravel sediments	31 cm	208 kg/ cm

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are considerably less sensitive to errors associated with the use of constants than areas of coarse sediment with low PCB concentrations.

Comparison of 1977 and 1984 Sediment Surveys Methods

The scope of the 1976-1977 sediment survey included approximately 40 miles (65-km) of the upper Hudson River; whereas, the 1984 survey was specifically focused on the 5-mile (8-km) length of the Thompson Island Pool. Sampling and analytical methods for both surveys are summarized in Table 12. Although total sample numbers were comparable between surveys, the 1976-1977 survey collected samples at approximately 300 Thompson Island Pool locations, in contrast to the 1,000 locations sampled during the 1984 survey. In addition to the larger number of samples, the 1984 samples were qualitatively better samples. The proportion of the 1984 samples that were cores was greater than that for the 1976-1977 survey, and these cores were on the average three times longer than the 1976-1977 cores.

Analytical methods differed between surveys. The most significant differences appear to be the use of an Aroclor 1221 standard for the analysis of PCB in 1976-1977 samples and the use of a laboratory method for analysis of specific weight of sediment by the 1984 survey. The methods used for the determination in PCBs in 1984 samples appear to be more precise than the 1977 methods.

The effects of method differences on PCB mass estimates can be systematically addressed. In presenting estimates of PCB contamination, MPI (1978) acknowledged the intention to err on the side of overestimation in making calculation assumptions. One of the critical assumptions required by MPI was the depth of the contaminated layer. Because of the large number of grab samples relative to sediment cores and the short lengths of cores collected by the 1977 survey MPI (1978), an assumption regarding the depth of a contaminated sediment layer was necessary . The average of grab sample PCB concentrations and depth-weighted core sample PCB concentrations was applied to an assumed contaminated layer depth of 24 in (61-cm). This assumption was acknowledged to be conservative by the authors of the 1978 estimate since they noted that "the depth of contamination did not exceed 24 in" in the Thompson Island Pool. The methods used in 1984 did not require the assumption of a contaminated depth at 407 out of 1014 locations. At grab sampled locations effective depth assumptions of 31 and 43 cm (12 and 17 in) were made for respective gravel and fine-sand sediment. PCB mass in the 138 polygons was recalculated by applying average grab sample and core sample PCB concentrations to a 24-in (61-cm) sediment layer in the same manner as the 1978 estimate. The resulting PCB mass was 34.7 tonne or 1.5 times the current 23.1 tonne estimate. Since the 1984 cores were considerably longer than the 1977 cores and constituted a greater proportion of the total number of samples, a factor of 1.5 may well underestimate the difference in estimates due to the assumption of a constant contaminated layer thickness.

MPI (1978) assumed a constant specific weight of 1.042 g/cm^3. In the interpretation of the 1984 data, we employed specific weight as measured in the laboratory with the exception of gravel sediment samples for which an assumed value of 1.3 g/cm^3 was used. This constant was the average of results of analyses of 40 gravel samples. Application of the 1978 constant in our

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Table 12. COMPARISON OF THE METHODS AND RESULTS OF THE 1977 AND 1984 SURVEYS OF THE THOMPSON ISLAND POOL

	1977	1984
SAMPLING		
Number of Grab Samples	209 (233*)	607
Number of Cores	104 (88*)	407
Average Length of Cores (in.)	10.5 (includes 1-84 core)	31.5
Length of Core Sections (in.)	2-6	Avg.: 9.8
SAMPLE OF ANALYSIS		
No. Analyses by GC-EC	586	954
No. Screened by Mass Spec	-	1,125
Aroclors quantified	1221, 1016, 1254	1242, 1254, 1260
Percent total PCB as A 1016 or A 1242	75	92 **
Average Percent Recovery	80 (A 1016)	86 (A 1242)
Results of Duplicate Analyses	Avg. Dupl. Ratio for A 1016: 3.25	Avg. Percent Dev. A 1242: 27% within batches; 58% between batches.
Specific weight estimated by lab. measurements	No	Yes

* Number reported by Tofflemire and Quinn (1979) in parentheses disagrees with the numbers derived from examination of computer files of 1977 data.

** Number is based upon results quantitated by Versar Inc. using the Webb and Mcall (1973) analysis of Aroclors.

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calculations increased the 1984 estimate by a factor of 1.2. The increase is apparently attributable to the high water-holding capacity and low dry-weight density of fine-grained organic sediments which have the highest PCB concentrations and specific weights less than 1.0 g/cm^3.

Another difference between surveys that appears to have contributed to the difference between PCB mass estimates is the use of Aroclor standards. The 1977 survey employed Aroclor 1221 as a standard in addition to Aroclor 1016 and Aroclor 1254. As part of the 1984 survey, Aroclor 1242, Aroclor 1254 and Aroclor 1260 were used as standards. Aroclor 1221 appears to have been used in minor quantities at the General Electric manufacturing facilities. Some samples of upper Hudson River sediments appear to be enriched in certain PCB compounds relative to Aroclor 1016 and Aroclor 1242 which appear to have been the mixtures predominantly used at the plants (Brown *et al.*, 1985). In particular, the enriched concentrations of 2-monochlorobiphenyl and 2,2'-dichlorobiphenyl relative to Aroclor 1242 have been attributed to dechlorination (Brown *et al.*, 1985). Both of these compounds are major constituents of Aroclor 1221. Notably, 4-monochlorobiphenyl which is a significant component of Aroclor 1221 is at relatively low concentrations. The use of Aroclor 1221 in the interpretation of certain Hudson River sediment chromatograms is very appealing. The methods we employed for analysis resulted in the reporting of early eluting chromatogram peaks RRT-.11, RRT-.16 and RRT-.21. With the exception of RRT-.21, the frequency of PCB quantitation using these peaks was very low relative to later peaks as indicated previously (Table 3). A review of the analytical methods used by O'Brien and Gere (1978) shows that standard Aroclor 1221 generally produced two peaks in their chromatograms. A single peak was used for quantitation assuming its area to be proportional to the total mass of PCB injected. However, this peak was not specified. Based upon examination of the O'Brien & Gere chromatogram for Aroclor 1221 it would appear reasonable to assume that the peak contained the same components and possibly others as contained by Webb and McCalls (1973) RRT-.21.

Peak RRT-.21 was identified in 77 percent of the 1984 samples submitted for GC analysis. However peak RRT-.28, the earliest peak used to quantitate Aroclor 1242, was identified in only 52 percent of the samples. According to Webb and McCall (1973) peak RRT-.28 accounts for 11 percent of the PCB mass in Aroclor 1242 and contains di- and trichlorobiphenyls in a respective mass ratio of 1:3. To shed some light on the difference in PCB mass estimates that is attributable to the quantitation of Aroclor 1221 in the 1977 survey, the results of capillary column PCB analyses were summarized by isomer group. The summary for Thompson Island Pool sediment samples, Aroclor 1221, and Aroclor 1242 is presented in Table 13. Assuming monochlorobiphenyls constitute 1 percent of the PCB in Aroclor 1242, and 6.5 percent of the PCB in the Thompson Island Pool and the peaks used for quantitation of 1242 did not contain monochlorobiphenyls, it can be estimated that the 5.5 percent of total PCBs, or 85 percent of the monochlorobiphenyls, was overlooked by the 1984 survey. Considering 1) the difference between levels of dichlorobiphenyls in Aroclor 1242 (16 percent) and in river sediment (21.7 percent); 2) only a portion (25%) of one (RRT-.28) of the three peaks used to calculate Aroclor 1242 is associated with dichlorobiphenyls; and 3) peak RRT-.28 was identified in only 52 percent of the samples, we estimated that approximately 5.7 of the total PCB or 25 percent of the dichlorobiphenyls were overlooked by the method. The estimated total of 11.2 percent of the total PCB

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TABLE 13. COMPOSITON OF PCB IN THOMPSON ISLAND POOL SEDIMENT AND IN AROCLORS.

PCB Isomer Group	Sediment (%)	Aroclor 1221* (%)	Aroclor 1242* (%)
monochlorobiphenyl	6.5	51	1
dichlorobiphenyl	21.7	32	16
trichlorobiphenyl	23.5	4	49
tetrachlorobiphenyl	29.1	2	8
pentachlorobiphenyl	10.0	0.5	1
hexachlorobiphenyl	4.2		0.1
heptachlorobiphenyl	3.5		

*Data from Shiu and Mackay (1986)

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overlooked by the use of Aroclor 1242 is in general agreement with the average of 14 percent of total PCB reported as Aroclor 1221 for grab samples collected by the 1976-1977 sediment survey (Tofflemire *et al*, 1979). The average 14 percent of total PCB reported as Aroclor 1221 in the 1976-1977 survey suggests that the 1976-1977 results would be higher than the 1984 results by 16 percent due to the quantitation of Aroclor 1221 in the former survey.

The combined effect of all of the differences in depth integration, specific weight assumptions, and Aroclor 1221 quantitation is multiplicative. Thus, adjusting the current estimate by 2.09 times (i.e. product of 1.5, 1.2, and 1.16) produces an estimate of 48,400 kg. This amount accounts for 90 percent of the earlier estimate of 54,000 kg.

We thus conclude that most of the difference between 1977 and 1984 PCB mass estimates was due to differences in calculation methods and assumptions. PCB transport from the Ft. Edward to Schuylerville reach during water years 1978 through 1984 is estimated to be 5.8 tonnes based upon USGS monitoring data. Taking this into consideration we can account for virtually 100 percent of the 1978 estimate.

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OTHER CONTAMINANTS OF HUDSON RIVER SEDIMENT

In the course of assessing the extent of PCB contamination of upper Hudson River sediment, the distribution of other contaminants has also been documented (Tofflemire and Quinn, 1979; PSG, 1986). Consistently detectable are the heavy metals. Sediment samples have also been analyzed for priority pollutants, the availability or leachability of heavy metals and organic compounds as determined by a weak acid extraction procedure, a source of organic compounds, Appendix VIII compounds, total dibenzofurans and dioxins, and 2,3,7,8 tetrachlorinated isomers of dibenzofuran and dioxin.

METALS ANALYSIS

Selected core, grab and sieved samples collected during the 1976-1977 sediment survey were submitted to NYSDOH for metals analyses (Tofflemire and Quinn, 1979). Lead levels were consistently elevated above background levels. Both lead and cadmium concentrations were positively correlated to sediment-PCB concentrations.

Sediment samples collected during the 1984 sediment survey and submitted to NYSDOH for metal analyses were tested as follows: 79 for a series of nine metals, 159 for cadmium and 217 for lead. The results are summarized in Table 14. Samples selected for analysis were from areas with high PCB concentrations.

The levels of lead, cadmium and chromium can be attributed to discharges from a pigment manufacturer in Glens Falls. Lead, cadmium and chromium deposition appears to coincide with PCB deposition, particularly in fine-sand sediment. The codepositional pattern is well illustrated by the results of analysis of a core of fine-sand sediment (Figure 17). In deeper (approx. 20 in) sections of the core, levels of mercury and zinc are higher than background concentrations.

The amount of lead in Thompson Island Pool sediments was estimated. Lead concentrations were integrated using the same methods employed in the PCB quantitation. For sample locations where lead levels were not measured, a multiple linear regression describing lead as a function of PCB concentration and percent dry solids was used to generate corresponding lead concentrations. The regression used was:

$$\log C_{Pb} = 0.258 \log C_{PCB} - .015\ PDS + 2.73 \qquad (r^2 = 0.61)$$

where: C_{Pb} is the concentration of lead (ug/g);
C_{PCB} is the concentration of PCB (ug/g); and
PDS is the percent dry solids concentration.

Values for percent dry solids were not determined as extensively as PCB values. Where percent dry solids data were not available, a gravel-weighted average of 0.71 was used. Two sets of data consisting of 44 percent dry solid measurements of gravel samples and 1155 percent dry solid measurements of nongravel samples were used to arrive at the 0.71 value. The two sets were equally weighted.

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TABLE 14. SUMMARY OF 1984 METALS ANALYSIS

Metal	No. of Non-Detections	No. of Detections	Detection Limit (µg/g)	Mean* (µg/g)	Std. Dev.	Correlation w/PCB** r^2
Arsenic	4	76	1	6.38	3.05	.005(40)
Cadmium	79	80	4	21.6	20.7	.49(65)
Chromium	8	71	20	475	474	.19(40)
Hexavalent Cr	79	0	4	--	--	--
Copper	1	78	10	53.2	47.4	.18(40)
Lead	11	206	20	217	250	.46(116)
Mercury	20	59	0.08	1.96	2.76	.15(36)
Nickel	4	75	10	28.8	16.3	.024(39)
Selenium	79	0	1	--	--	--
Silver	79	0	4	--	--	--
Thallium	79	0	2	--	--	--

* Mean and standard deviation of detectable concentrations.

** Correlations are based upon logarithms of PCBs and metals concentrations. Number of paired observations used to calculate r^2 are presented in parentheses.

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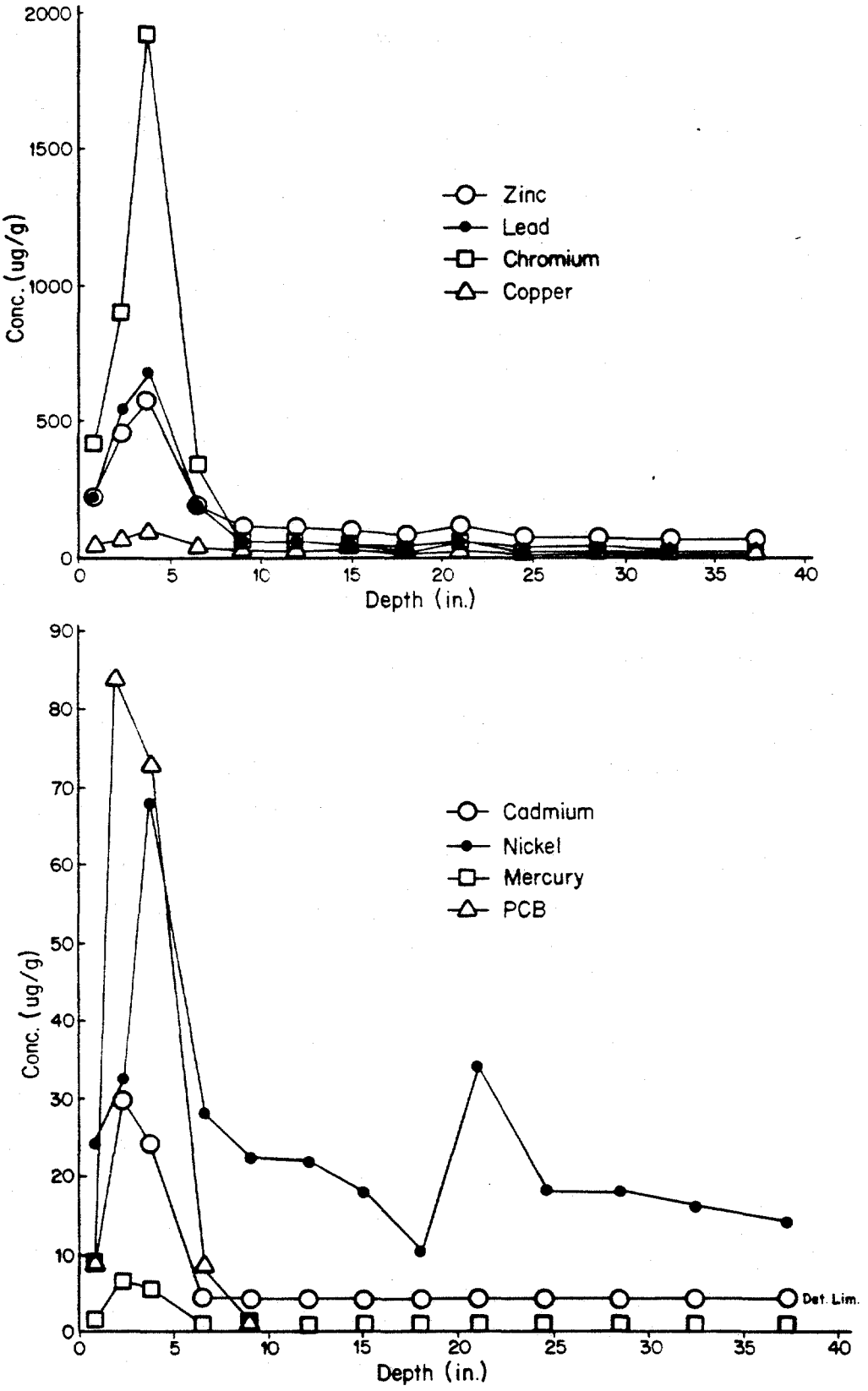

Figure 17. Distribution of metals and PCB concentrations in a core of fine-sand sediment from the MP - 192.7 transect.

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TABLE 15. RESULTS OF INORGANIC ANALYSES OF SIX HUDSON RIVER SEDIMENT SAMPLES COLLECTED IN 1986

Parameter*	Concentration (µg/g) 1	2	3	4	5	6
Aluminum	18,400	15,500	7,360	11,400	5,600	4,450
Antimony	9.0	11	7.1	8.9	5.5	ND**(5.0)
Barium	171	187	86	137	83	55
Beryllium	.74	.54	.40	.39	.41	.28
Cadmium	30	47	6.3	35	3.3	.5*
Calcium	3,260	3,310	2,460	3,850	6,970	1,390
Chromium	699	508	150	375	54	7.0
Cobalt	11	7.6	4.7	5.6	4.0	3.7
Copper	88	71	81	71	34	12
Iron	20,200	16,500	8,930	13,300	10,900	8,490
Lead	644	784	259	618	107	123
Magnesium	3,720	3,160	1,980	2,240	2,900	1,740
Nickel	29	21	17	17	11	8.0
Selenium	ND(1.0)	1.0	ND(0.5)	3.1	ND(0.5)	ND(0.5)
Tin	15	13	17	16	9.9	3.3
Vanadium	73	58	23	45	16	9.1
Zinc	599	411	165	290	78	33

* Levels of arsenic, manganese, mercury, potassium and sodium were also measured; however, poor recovery of internal standards precluded Versar, Inc. from obtaining reportable data for these samples. Levels of silver and thallium were not detectable at 1.0 ug/g.

** ND denotes that the parameter was not detected at the detection limit in parenthesis.

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TABLE 16. RESULTS OF INORGANIC ANALYSES OF SEDIMENT SAMPLES COLLECTED IN 1987

Parameter*	Concentration (µg/g) 1	2	3	4	5	6
Aluminum	2,900	3,700	2,600	2,100	3,000	2,000
Arsenic	2.0	2.0	1.4	1.2	1.8	1.8
Barium	35	46	42	26	41	24
Beryllium	0.1	0.2	0.1	ND (0.1)	0.2	0.1
Cadmium	5.4	5.4	4.2	16	1.3	ND (0.5)
Calcium	700	1,000	1,200	950	8,900	1,500
Chromium	110	100	74	64	18	24
Cobalt	2	3	3	2	3	2
Copper	26	34	18	18	16	33
Cyanide (Total)	4.1	5.8	5.2	6.1	ND (1)	1.8
Iron	3,500	5,100	3,900	3,100	6,900	3,800
Lead	130	130	78	87	34	68
Magnesium	760	1,100	860	590	3,400	900
Manganese	31	44	27	25	94	25
Mercury	0.90	0.67	0.57	0.36	0.18	0.24
Nickel	5	7	6	ND*(4)	6	5
Sodium	ND (50)	ND (50)	ND (50)	ND (50)	60	ND (50)
Strontium	3	5	5	6	24	6
Sulfide (Total)	ND (0.5)	ND (0.5)	ND (0.5)	4.9	0.6	ND (0.5)
Vanadium	12	13	12	9	9	8
Zinc	100	110	75	64	43	35

* Samples were also analyzed for antimony, fluoride, osmium, potassium, selenium, silver, thallium and tin, none of which were detected at the following respective reporting limits 5, 0.5, 50, 500, 0.4, 0.5, 0.8 and 6 ug/g.

** ND denotes that the parameter was not detected at the detection limit in parenthesis.

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TABLE 17. RESULTS OF 1984 EP TOXICITY ANALYSIS OF SELECTED SAMPLES FROM THE THOMPSON ISLAND POOL BY VERSAR, INC.

Station No.	Position Northing (ft)	Position Easting (ft)	Analyzed Core Length (in)	PCB (ug/g)	EP Toxicity Results (mg/ℓ) Ar	Ba	Cd	Cr	Pb	Hg	Se	Ag
210	1167109	700189	27	184.	<.01	<1.0	<0.1	<0.5	<0.5	<0.002	<0.005	<0.5
603	1176639	699350	24	118.	<.01	<1.0	<0.1	<0.5	<0.5	<0.002	<0.005	<0.5
235	1167733	699666	25	108.	<.01	<1.0	0.106	<0.5	<0.5	<0.002	<0.005	<0.5
328	1170742	701142	17	273.	<.01	<1.0	<0.1	<0.5	<0.5	<0.002	<0.005	<0.5
360	1171330	700693	17.5	71.	<.01	<1.0	<0.1	<0.5	<0.5	<0.002	<0.005	<0.5
500	1174585	699458	18.	133.	<.01	<1.0	0.138	<0.5	<0.5	<0.002	<0.005	<0.5
640	1177383	699035	29	230.	<.01	<1.0	<0.1	<0.5	<0.5	<0.002	<0.005	<0.5
651	1177730	698619	21	250.	<.01	<1.0	<0.1	<0.5	<0.5	<0.002	<0.005	<0.5
655	1177880	698476	26	169	<.01	<1.0	<0.1	<0.5	<0.5	<0.002	<0.005	<0.5
EP Toxicity Maximum					5.0	100.	1.0	5.0	5.0	0.2	1.0	5.0

As with PCB, lead concentrations were integrated to 0.5-, 1.0- and 1.5-m depths. In light of the correlation of PCB with lead and the PCB integration showing more than 99 percent of the PCB contained in the upper 1.0 m of sediment, anthropogenic lead was estimated taking the difference between total lead in the upper 1 m of sediment and two times the mass of total lead between 1-m and 1.5-m sediment depths.

It appears that 170,000 lbs (76 tonnes) of lead from anthropogenic sources are contained in the upper 1 m of sediment in the Thompson Island Pool. The total cadmium quantity, 10,000 lbs (4 tonnes), was estimated based on the total mass of lead and the proportional relationship determined by comparing measured levels of lead and cadmium:

$$C_{Cd} = (.0585)\ C_{Pb} \qquad (r^2 = 0.65)$$

where: C_{Cd} is the concentration of cadmium (ug/g); and,
C_{Pb} is the concentration of lead (ug/g).

Additional sampling (six hand cores) of areas designated as hotspots 3 (samples 5 & 6), 8 (samples 3 & 4), and 20 (samples 1 & 2) was conducted in August, 1986 and again in July, 1987. The results of the 1986 sampling were summarized and included in the project's NYCRR Part 373 permit application. Each core was homogenized and submitted to Versar, Inc. as an individual sample. The results of the 1986 inorganic analysis are summarized in Table 15. This effort was repeated in 1987, where hotspot 20 is represented by samples 1 and 2, hotspot 8 by samples 3 and 4 and hotspot 3 by samples 5 and 6 (Table 16). The values for cadmium, chromium, copper, lead, and nickel determined in 1986 were within the concentration range of the 1984 results. The 1987 values for the same parameters were consistently lower. The confirmation of this difference would require a more intense sampling survey and analysis of cores as sections as opposed to homogenized composites.

EXTRACTION PROCEDURE TOXICITY

Nine, dry, archived sediment samples collected during the 1984 sediment survey were submitted to Versar, Inc. for Extraction Procedure (EP) Toxicity testing. These samples were selected to portray highest contaminant concentration based on PCB concentration. Samples were composites of consecutive upper sections of cores. Measured PCB concentrations of individual core sections were depth-weighted to develop the corresponding PCB concentrations presented with the results of the EP Toxicity test in Table 17. Metals concentrations in all samples were less than maximum allowable levels set for the EP Toxicity test. Concentrations of arsenic, barium, cadmium, chromium, lead and mercury in the extract were determined.

Aliquots of the six sediment samples collected in 1986 from hot spots 3, 8, and 20 were submitted to Versar, Inc. for EP Toxicity testing for the metals only. All six extracts had less than detectable levels of the eight metals. Core lengths, PCB levels of homogenized core samples and detection limits are listed in Table 18.

Six sediment samples collected in 1987 were submitted to Enseco for EP Toxicity testing. Analyses were restricted to organic compounds. All samples

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TABLE 18. RESULTS OF 1986 EP TOXICITY ANALYSIS OF SELECTED SAMPLES FROM THE THOMPSON ISLAND POOL BY VERSAR, INC.

Sample No.	Hot Spot No.	Analyzed Core Length (in)	PCB (ug/g)	EP Toxicity Results (mg/ℓ) Ar	Ba	Cd	Cr	Pb	Hg	Se	Ag
1	20	21	332	<.01	<2.0	<0.1	<0.05	<0.5	<0.002	<0.005	<0.5
2	20	14	560	<.01	<2.0	<0.1	<0.05	<0.5	<0.002	<0.005	<0.5
3	8	10.5	36	<.01	<2.0	<0.1	<0.05	<0.5	<0.002	<0.005	<0.5
4	8	17	325	<.01	<2.0	<0.1	<0.05	<0.5	<0.002	<0.005	<0.5
5	3	21	505	<.01	<2.0	<0.1	<0.05	<0.5	<0.002	<0.005	<0.5
6	3	8.5	ND(0.04)*	<.01	<2.0	<0.1	<0.05	<0.5	<0.002	<0.005	<0.5
EP Toxicity Maximum				5.0	100.	1.0	5.0	5.0	0.2	1.0	5.0

* Not detected at a detection limit of 0.04 ug/g

had levels less than the detection limits (Table 19). (Core lengths and PCB levels of homogenized core samples are listed in Table 20.)

DIBENZOFURANS AND DIOXINS

Four sections from two cores, from MP-188.5 and MP-191.1 collected by Dr. Richard Bopp of Columbia University, were analyzed by NYSDOH for dioxin and dibenzofuran. As such analyses are both time-consuming and costly, archived samples were selected on the basis of PCB concentration and contaminant loading chronology to provide a maximum amount of information. ^{137}Cs analysis revealed that some samples represent modern sediment, while others portray contaminant concentrations corresponding with the period of maximum industrial discharge. Results are listed in Table 20. Sections 8-12 cm and 24-28 cm of the core from MP-188.5 yielded the highest levels of the total tetra-chlorodibenzofuran (TCDF), total tetrachlorodibenzo-p-dioxin (TCDD) and the 2,3,7,8 isomers of both TCDF and TCDD.

As part of the 1987 collection, sediment samples from hotspots 20 (samples 1 and 2), 8 (samples 3 and 4) and 3 (samples 5 and 6) were submitted to Enseco, Cambridge, Ma, for total TCDD, TCDF and PCB analyses. These results are summarized in Table 21.

Based on two 1983 values and two 1987 values the average amount of TCDF per PCB concentration in sediments in the project area is 1.8 pg/ug. The total mass of TCDF in Thompson Island Pool sediments, assuming a 1.8 pg/u8g (ppm) level of contamination, is approximately 42 g. The total PCB mass reclaimed and transferred to the containment facility will proportionally determine the mass of TCDF transferred.

The introduction of TCDF and TCDD into the environment can be attributed to a number of processes: deposition of residual from coal and wood combustion, discharges from facilities whose processes result in the pyrolysis of chlorophenols (used in the wood industry as preservatives), or the discharge of compounds containing TCDF and TCDD as trace contaminants. Chlorophenols have been shown to contain trace amounts of dioxins, and industrial PCB mixtures are known to contain trace amounts of TCDFs.

Levels of dioxin can most likely be attributed to the practice of ash dumping in the river in the vicinity of Ft. Edward. The amounts of TCDF in upper river sediments are within expected ranges in relationship to the quantities of PCB discharged.

The amount of TCDFs present in Aroclor mixtures reported in the literature varies. The level reported by Morita *et al.* (1977) for total TCDF in Aroclor 1242 is 2.3 ppm (pg/g TCDF / ug/g A1242) (Figure 18). As illustrated by the difference in TCDF to PCB ratios in upper and lower river samples, upper Hudson River sediments do not appear to be a predominate source of TCDD or TCDF to the lower river.

PRIORITY POLLUTANTS

The six sediment samples collected in 1986 were submitted to Versar, Inc. for volatile organic, semivolatile organic and pesticide analyses. These results

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TABLE 19. DETECTION LIMITS AND MAXIMUM ALLOWABLE CONCENTRATIONS OF EP TOXICITY ORGANIC PARAMETERS

Parameter	Detection Limit (ug/ℓ)	EP Tox. Max. Conc. (ug/ℓ)
alpha-BHC	0.05	
beta-BHC	0.05	
delta-BHC	0.05	
gamma-BHC (Lindane)	0.05	400
Heptachlor	0.05	
Aldrin	0.05	
Heptachlor Epoxide	0.05	
Endosulfan I	0.05	
Dieldrin	0.10	
4,4'-DDE	0.10	
Endrin	0.10	20
Endosulfan II	0.10	
4,4'-DDD	0.10	
Endosulfan Sulfate	0.10	
4,4'-DDT	0.10	
Endrin Aldehyde	0.10	
Methoxychlor	0.50	10,000
Chlordane	0.50	
Toxaphene	1.0	500
Aroclor-1016	0.50	
Aroclor-1221	0.50	
Aroclor-1232	0.50	
Aroclor-1242	0.50	
Aroclor-1248	0.50	
Aroclor-1254	0.50	
Aroclor-1260	0.50	
2,4-D	10,000	10,000
Silvex	1,000	1,000

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Table 20. RESULTS OF TCDD, TCDF AND PCB ANALYSES OF SEDIMENTS COLLECTED IN 1983 FROM THE UPPER HUDSON RIVER

Sample - Milepoint	188.5	188.5	188.5	191.1
Sediment Stratum (cm)	0-2	8-12	24-28	0-2
2,3,7,8 TCDD (dioxin) (ng/g-dry wt.)*	***	0.029	0.083	<0.005
Total Tetrachlorodibenzodioxins*	***	0.056	0.135	<0.005
2,3,7,8 TCDF (dibenzofuran) (ng/g-dry wt.)*	***	0.041	0.069	<0.005
Total Tetrachlorodibenzofuran (ng/g dry wt.)*	***	0.731	0.598	<0.005
Total PCB (µg/g - dry wt.)**	77.	620.	500.	29.

*Determined by NYSDOH.

**Determined by Dr. Richard Bopp, Lamont-Doherty Geological Observatory of Columbia University.

***Poor recovery of internal standards precluded NYSDOH from obtaining reportable data for this sample.

NOTE: 1 ng/g = 1 part per billion (ppb)
1 µg/g = 1 part per billion (ppm)
.001 ng/g = .001 ppb = 1 part per trillion (ppt)

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Table 21. RESULTS OF 1987 TCDD, TCDF AND PCB ANALYSES OF HOT SPOT 20 (SAMPLES 1 AND 2), HOT SPOT 8 (SAMPLES 3 AND 4) AND HOT SPOT 3 (SAMPLES 5 AND 6)

Parameter	Sample 1	2	3	4	5	6
Total TCDF (ng/g)	ND(0.02)*	ND(0.018)	0.17	0.10	ND(0.012)	ND(0.014)
Total TCDD (ng/g)	ND(0.012)	ND(0.017)	ND(0.015)	ND(.058)	ND(.013)	ND(.027)
Total PCB (µg/g)	17	21	55	54	14	12
Core length (in)	26.5	25	17	13	15.5	18

*Not detected at the detection limit in parenthesis.

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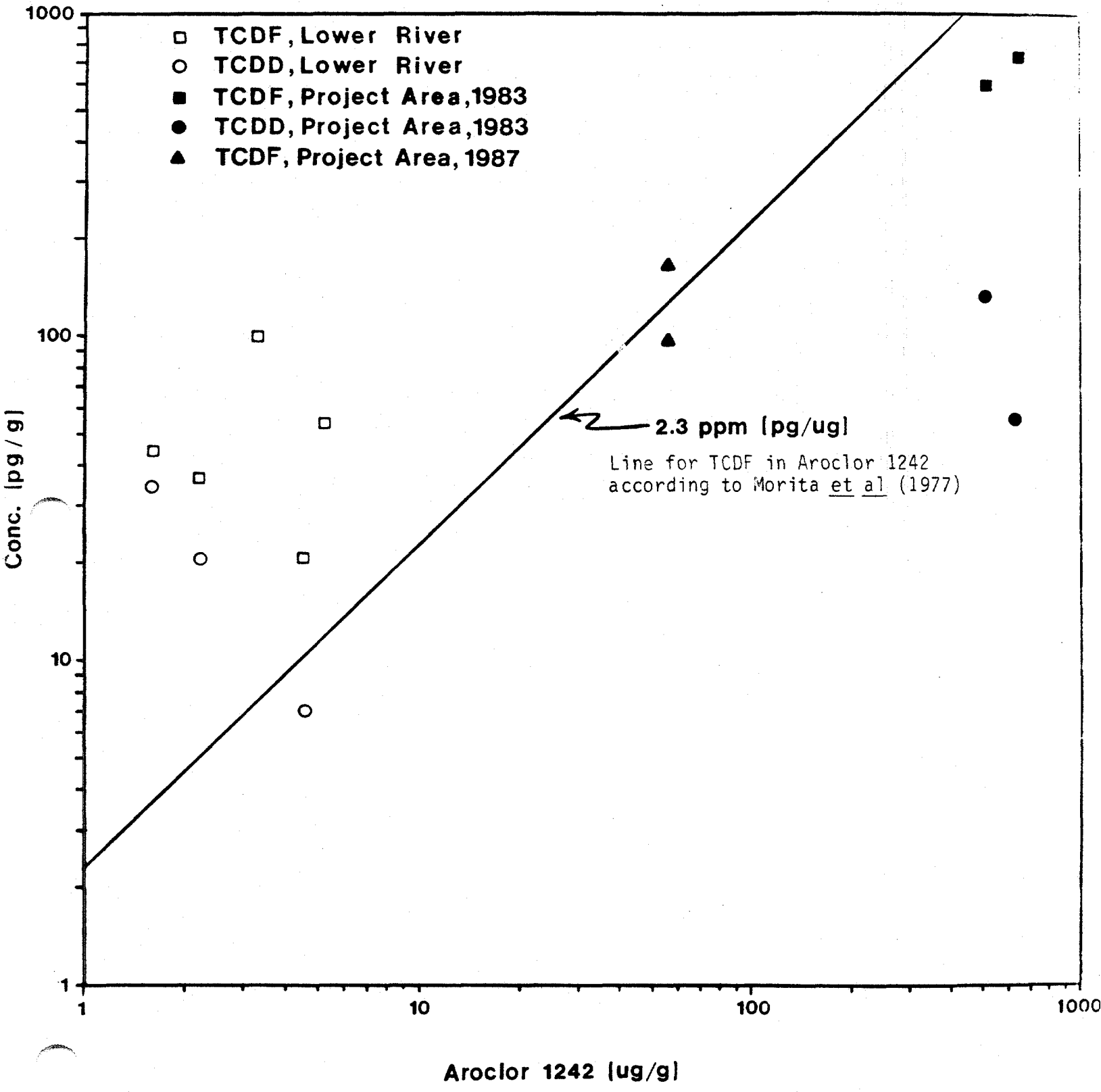

Figure 18. Comparison of TCDD, TCDF and Aroclor 1242 concentrations in samples from the lower river and the project area. (Sources of data for Lower River sediments: TCDF and TCDD - Petty et al. (1983). PCB - Bopp (pers. comm.).)

were summarized and submitted as a portion of project's Part 373 permit application (PSG, 1986). No volatile organics, semivolatile organics or pesticides were detected in the six samples.

In 1987 sediment samples were collected from those areas sampled in 1986, hotspots 3, 8 and 20, and submitted to Enseco for analyses of Appendix VIII compounds, which are used under Part 261 of the Resource Conservation and Recovery Act to determine if a waste is toxic. The following groups of constitutents were included in the analysis: organochlorine pesticides, organophosphate pesticides, volatile organics, semivolatile organics and herbicides. Three substances were detected in at least two of the six samples (Table 22). The presence of acetone is most likely a result of laboratory contamination. Di(2-ethylhexyl) phthalate (DEHP) is utilized in plastic manufacturing to enhance flexibility. Consumer products such as imitation leather, rainwear and flooring may contain up to 40% by weight DEHP. DEHP is also used in the production of electrical capacitors as a dielectric fluid. 2,4,5-T (2,4,5-trichlorophenoxyacetic acid) was widely used in the control of woody plants and broad-leafed weeds along highways and utilities rights of way. Its use is now restricted.

Of the non-PCB contaminants, the metals, in particular lead and cadmium, are the most consistently detectable. However, as indicated by EP Toxicity testing, they are not available for leaching. Quantities of TCDD and TCDF are within expected trace contaminant ranges. Other contaminants, such as volatile organics, semivolatile organics and pesticides, are either not present or are present in apparently insignificant quantities.

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TABLE 22. RESULTS OF APPENDIX VIII ANALYSIS OF SIX HUDSON RIVER SEDIMENT SAMPLES COLLECTED IN 1987

Parameter	Concentration (mg/g) 1	2	3	4	5	6
Volatile organics						
Acetone	440	ND (25)*	340	1,600	1,500	500
Semivolatile organics						
Di (2-ethylhexyl) phthalate	ND(1600)	3,700	ND(1600)	ND(1600)	ND(1300)	4,500
Herbicides						
2,4,5-T	2.2	ND (1.7)	1.7	ND (1.7)	ND (1.7)	ND (1.7)

* ND is not detected at the detection limit in parenthesis.

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APPENDIX A

Maps of the Thompson Island Pool with locations and PCB Data for Pre-1984 sediment samples.

The data format for core samples presented on the maps is:

a(b-c)

where a is the depth-weighted average PCB concentration (mg/kg) through the top b inches of core of total length c also in inches.