

Appendix I

Details of Data Treatment for Sediment Core Analyses

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ABBREVIATIONS

2,3,7,8-TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
COPC	chemical of potential concern
Cs-137	cesium-137
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
g/cm ³	grams per cubic centimeter
g/kg	grams per kilogram
HMW	high molecular weight
KFI	known full inventory
kg/m ³	kilograms per cubic meter
LMW	low molecular weight
LPR	Lower Passaic River
m	meter
MPA	mass per unit area
ng/kg	nanograms per kilogram
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
RI	remedial investigation
RM	river mile

1 Sediment Data Treatments

The following sections describe how sediment data were handled for several analyses used in the Remedial Investigation (RI) report. Sections 1.1, 1.2, and 1.3 describe the selection of cores for: 1) analyses of peak contaminant concentrations in buried sediment (used in Section 10 of the RI report); 2) analysis of where sediments below the depth sampled can be presumed to be clean (termed subsurface zeroing and used in mapping for Appendix J); and 3) analysis of the mass of contaminant in the sediments (used in Section 6.3 of the RI report). The core selection methodology and resulting cores used in the analysis differs for each. Section 1.4 describes the methodology for estimating contaminant mass in the sediments from the cores chosen for this analysis. Section 1.5 provides information on the sedimentation rates used in Section 10.

1.1 Selection of Peak Analysis Cores

Peak contaminant concentrations in the sediment column are used in Section 10 Figures 10-4 and 10-10 through 10-14. To perform analyses involving peak concentrations, the first step was to identify suitable cores. Only cores where the concentration peak was clearly identified in the vertical sediment column were considered suitable for use in peak concentration analyses. To identify these cores, a set of criteria were developed to maximize use of available data and ensure that cores that likely captured peak concentrations in the sediment column were selected. Criteria were based on 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) concentrations because it is the primary human health risk driver (see Section 8 of the RI report) in the Lower Passaic River (LPR), and it is not impacted by external sources (see Section 10 of the RI report).

The core selection criteria are as follows:

1. Include cores from studies where the full sediment inventory was sampled (see Table 1). These cores are referred to as known full inventory (KFI) and are indicated by KFI on the plot panels in Figure 1. These cores were also required to meet the following criteria:
 - a. Total of all gaps between segments with measured concentrations is less than 0.1 foot.
 - b. Core has a surface segment.¹

These criteria ensured the core did not have large missing segments either on the surface or subsurface where a maximum concentration may exist.

2. The remaining cores that did not fall into the KFI category were required to meet the following criteria to be considered for inclusion in peak concentration analyses:
 - a. Total of all gaps between segments is less than 0.1 foot.

¹ Cores were required to have a surface segment to ensure that they did not have an unmeasured peak at the surface.

- b. Core is at least 2.5 feet deep.
- c. Core contains a minimum of three segments.
- d. The core must meet at least one of three additional requirements:
 - i. Maximum concentration is not in the bottom segment.
 - ii. Maximum concentration is greater than 10,000 nanograms per kilogram (ng/kg).
 - iii. Concentration in the bottom segment is less than or equal to 30 ng/kg.

The minimum gap length criterion (a) ensured the core did not have large missing segments. The length criterion (b) removed short cores that likely did not reach refusal. The minimum number of segments criterion (c) ensured the profile had adequate resolution to determine a peak.

The three additional requirements (d) were designed to further enhance core selection. The first criterion (d.i) selected for cores where the maximum concentration was not measured in the final segment. These profiles typically implied that the peak was captured in a shallower segment. Cores with peak concentration in the bottom segment could suggest an unmeasured peak below the last measured segment. Despite potentially not measuring the true peak, cores with very high concentrations measured in the final segment were considered valuable for inclusion in peak analyses. Therefore, the second criterion (d.ii) was developed to include cores with concentrations greater than 10,000 ng/kg. The third criterion (d.iii) was developed because segments with very low concentrations typically suggested that deeper sediment also had low concentrations; thus, the peak was likely captured in a shallower segment. Eighty-eight percent of cores longer than 2.5 feet, with concentrations less than or equal to 30 ng/kg at or above the 2.5-foot segment, exhibited peaks shallower than 2.5 feet.²

3. After cores were categorized using the above criteria, the core profiles (Figures 1 and 2) were examined. Professional judgment was applied to include additional cores with identifiable concentration peaks or exclude cores without clear peaks. Table 2 lists these professional judgment cores and the reasoning for including or excluding them. Professional judgment is also indicated on the profiles in Figures 1 and 2.

1.2 Selection of Cores for Subsurface Zeroing

To map subsurface concentrations for contaminant fate and transport modeling as described in Appendix J, it was necessary to identify locations where concentrations could be assumed as negligible below the last measured segment. Only cores that sampled to native material or were judged to be deep enough to have captured the entire chemical inventory were considered suitable

² A sensitivity analysis was performed to evaluate the impact of using 50 ng/kg or 10 ng/kg for this criterion. Using 50 ng/kg did not make a large difference, so the 30 ng/kg criterion was used because it is more conservative. The criterion of 10 ng/kg excluded cores where it looked reasonable to assume there was no contamination below the bottom slice based on the core profiles.

for assuming concentrations of zero below the last measured segment. To identify these cores, a set of criteria were developed to maximize use of available data and ensure that unmeasured sediment beneath the core likely has low concentrations. Similar to the peak concentration analysis described above, concentration criteria were based on 2,3,7,8-TCDD concentrations.

The criteria used to identify cores for subsurface zeroing were as follows:

1. The core penetrated to refusal (see Table 3 for list of these cores), or
2. The core met the following criteria:
 - a. It recovered at least 2.5 feet of sediment.
 - b. Data were available for a minimum of three segments.
 - c. The bottom segment had a 2,3,7,8-TCDD concentration less than or equal to 30 ng/kg.

The length criterion (a) removed short cores that may not have penetrated to clean sediment. The minimum number of segments criterion (b) ensured the profile had adequate resolution to determine a profile. The third criterion (c) was developed because segments with such low concentrations typically indicated that deeper sediment has comparable or even lower concentrations. As a check of criterion (c), core profiles longer than 2.5 feet were identified. Out of these cores, a subset containing concentrations less than or equal to 10, 30, and 50 ng/kg in the core segment ending at 2.5 feet were examined. Figure 3 shows the distribution of maximum concentrations below 2.5 feet for these cores. Of the cores with concentrations less than or equal to 30 ng/kg in the top 2.5 feet, 88% exhibited peaks within the 2.5-foot segment, suggesting that the 30 ng/kg criterion is reasonable.³ Figure 4 shows profiles for cores where a concentration of zero was assumed below the last segment. Figure 5 shows profiles for cores where this assumption was not made.

3. After cores were categorized using the above criteria, the core profiles (Figures 4 and 5) were examined. Professional judgment was applied to include additional cores suitable for assuming concentrations of zero below the last measured segment or exclude cores where this assumption could not be made. Table 4 lists these professional judgment cores and the reasoning for including or excluding them. Professional judgment is also indicated on the profiles in Figures 4 and 5.

³ A sensitivity analysis was performed to evaluate the impact on core profiles selected using 50 ng/kg or 10 ng/kg for this criterion. Using 50 ng/kg did not make a large difference in the number of cores selected, so the 30 ng/kg criteria was used because it is more conservative. The criteria of 10 ng/kg was not used because it excluded cores where it looked reasonable to assume there was no contamination below the bottom slice (based on the core profiles).

1.3 Selection of Cores for Estimating Contaminant Mass in Sediments

To estimate contaminant mass per unit area (MPA) in support of analyzing trends in contaminant inventory in Section 6 of the RI report, cores that likely captured the full contaminant inventory were identified. Criteria were developed to maximize the use of available data while ensuring that the selected cores provided reasonable estimates of inventory. Similar to the two core selection analyses described above, criteria were based on 2,3,7,8-TCDD concentrations.

The core selection criteria are as follows:

1. Include cores from studies where the full sediment inventory was sampled (see Table 5). These cores are referred to as KFI and are indicated by KFI on the plot panels in Figure 6. These cores were also required to meet the following criteria:
 - a. Total of all gaps between segments is less than 0.1 foot.
 - b. Core has a surface segment.

These criteria ensured the core did not have large missing segments where a maximum concentration or significant mass inventory may exist.

2. The remaining cores that did not fall into the KFI category were required to meet the following criteria to be considered for inclusion in MPA analyses:
 - a. Total of all gaps between segments is less than 0.1 foot.
 - b. Core has surface segment.
 - c. Core is at least 2.5 feet deep.
 - d. Core contains a minimum of three segments.
 - e. The core must meet at least one of three additional requirements:
 - i. Concentration in the bottom segment is less than or equal to 50% of the peak concentration.
 - ii. Maximum concentration is greater than 10,000 ng/kg.
 - iii. Concentration in the bottom segment is less than or equal to 30 ng/kg.

The minimum gap length (a) and surface segment (b) criteria ensured the core did not have large missing segments. The length criterion (c) removed short cores that likely did not reach refusal. The minimum number of segments criterion (d) ensured the profile had adequate resolution to assess the profile.

The three additional requirements (e) were designed to further enhance core selection. The first criterion (e.i) selected for cores where the deepest segment had concentrations that were less than or equal to 50% of the peak concentration. These profiles suggest that a significant portion

of the mass inventory was captured by the core. The second criterion (e.ii) was developed to include cores with concentrations greater than 10,000 ng/kg. This criterion selected for cores with sufficiently high concentrations regardless of whether the core captured full inventory, on the basis that even a lower bound estimate for high inventory cores is helpful to assessing the overall contaminant inventory of the river. The third criterion (e.iii) was developed because segments with very low concentrations typically suggest that deeper sediment is unlikely to add a significant amount of mass to the total inventory estimate. Eighty-eight percent of cores longer than 2.5 feet, with concentrations less than or equal to 30 ng/kg at or above the 2.5-foot segment, exhibited peaks shallower than 2.5 feet.⁴

3. After cores were categorized using the above criteria, the core profiles (Figures 6 and 7) were then examined. Professional judgment was applied to include or exclude additional cores based on their suitability for representing the mass inventory for 2,3,7,8-TCDD. Table 6 lists these professional judgment cores and the reasoning for including or excluding them. Professional judgment is also indicated on the profiles in Figures 6 and 7.

1.3.1 *Application to Other COPCs*

The MPA analysis was performed for five additional chemicals of potential concern (COPCs): total polychlorinated biphenyls (PCBs)⁵, sum of 4,4'-DDx⁶, mercury, high-molecular-weight (HMW) polycyclic aromatic hydrocarbons (PAHs), and low-molecular weight (LMW) PAHs. For the summed COPCs (total PCBs, sum of 4,4'-DDx, HMW PAHs, and LMW PAHs), segments with incomplete totals were excluded from MPA calculations. The cores identified as suitable for MPA analyses based on 2,3,7,8-TCDD in Section 1.3 were further examined to assess the completeness of the profile for estimating contaminant mass inventory in other COPCs. Cores were assessed with the following criteria:

1. The core was included if the COPC was measured in all the segments for which 2,3,7,8-TCDD was measured.
2. COPC core profiles were visually examined to determine if: 1) the core had additional gaps compared to the 2,3,7,8-TCDD core; 2) the core had a shorter maximum depth compared to the 2,3,7,8-TCDD core; or 3) the core was missing a surface segment. Professional judgment was

⁴ A sensitivity analysis was performed to evaluate the impact of using 50 ng/kg or 10 ng/kg for this criterion. Using 50 ng/kg did not make a large difference, so the 30 ng/kg criterion was used because it is more conservative. The criterion of 10 ng/kg excluded cores where it looked reasonable to assume there was no contamination below the bottom slice based on the core profiles.

⁵ The PCB homolog sum was used for total PCBs. The PCB Aroclor sum was substituted for samples where PCB homolog sums were not reported or incomplete.

⁶ Historical data from 1995 to 1999 are available for the sum of 4,4'-DDx but not total DDx. The sum of 4,4'-DDx is defined as the sum of three isomers: 4,4'-dichlorodiphenyldichloroethane (DDD), 4,4'-dichlorodiphenyldichloroethylene (DDE), and 4,4'-dichlorodiphenyltrichloroethane (DDT). To allow the use of the historical data, the sum of 4,4'-DDx is used rather than total DDx (total DDx also includes isomers 2,4'-DDD, 2,4'-DDE, and 2,4'-DDT). A comparison of total DDx and 4,4'-DDx for the post-2005 data is presented in Figure 8 and indicates that 4,4'-DDx is well correlated to total DDx and comprises most of the total DDx.

applied to include or exclude these cores. Tables 7 through 11 list these professional judgment cores and the reasoning for including or excluding them. Figures 9 through 18 show the core profiles that were included or excluded from the MPA analysis.

1.4 Sediment Mass Inventory

Contaminant MPA is a measure of the contaminant mass inventory in the sediments at a given location. MPA was calculated using the contaminant concentration in the sediment (on a dry-weight basis) together with the dry bulk density of the sediments. MPA values for each core were calculated (in grams per square meter) using the following formula:

Equation 1

$$MPA = \sum_{i=1}^n [C]_i \cdot \rho_{BD} \cdot L$$

where:

- n = number of segments in the core
- $[C]_i$ = contaminant concentration in segment i (grams per kilogram [g/kg], dry weight)
- ρ_{BD} = dry bulk density (kilograms per cubic meter [kg/m³]) of sediments in segment i
- L = length of section i (meter [m])

Dry bulk density was calculated for samples with available measurements of percent moisture and specific gravity⁷ using the following equation:

⁷ Specific gravity was from measured data.

Equation 2

$$\rho_{BD} = \frac{SG(1 - M_p)}{1 + M_p(SG - 1)}$$

where:

ρ_{BD}	=	dry bulk density (grams per cubic centimeter [g/cm ³])
SG	=	specific gravity
M_p	=	percent moisture in decimal fraction form

Samples that reported moisture content instead of percent moisture had moisture content converted to percent moisture with the following equation:

Equation 3

$$M_p = \frac{M_c}{1 + M_c}$$

where:

M_p	=	percent moisture in decimal fraction form
M_c	=	moisture content in decimal fraction form

The studies with available dry bulk density are listed in Table 12. Samples without available dry bulk density were assigned the arithmetic average of all calculated dry bulk density samples (0.848 g/cm³).

Prior to MPA calculation, concentrations in gaps less than or equal to 1 foot were estimated by taking the arithmetic average of the two segments immediately adjacent to the gap (i.e., the segments above and below the gap). The core selection process previously described in Section 1.3 generally rejects cores with large gaps; however, some cores with large gaps may have been included by professional judgment.⁸ Given the increased uncertainty of gaps greater than 1 foot, MPA within the gap was assumed to be zero, rather than interpolated between measured segments. For cores that lacked a surface segment, the MPA within this missing segment was assumed to be zero.

⁸ Number of cores with gaps greater than 1 foot that were included by professional judgement for the various contaminants are: 17 2,3,7,8-TCDD cores, 17 total PCB cores, 18 total 4,4'-DDx cores, 16 mercury cores, 12 HMW PAH cores, and 16 LMW PAH cores.

Duplicate measurements in a segment were averaged. Additional segments that overlapped a continuous profile were removed.

1.4.1 Interpolation

To estimate regional mass inventory, the MPA estimates for each sampling location were interpolated using Thiessen polygons throughout the river. The interpolated areas spanned from river mile (RM) -6 to RM 17.4, covering Newark Bay and the LPR. Samples from the LPR tributaries were not used. To respect the different geomorphic characteristics of the study area, cores were grouped and interpolated separately in different regional groupings.

Within the LPR, the interpolation groupings developed for surface concentration mapping were used; see Figures 3-1a to 3-1p in Section 3 of Appendix J.

Each of the interpolated MPA values was multiplied by the area of influence from the Thiessen polygon to calculate the contaminant mass for that polygon. Large-scale estimates of contaminant inventory (as in Section 6.3 of the RI report) were generated by summing contaminant masses across polygons.

1.5 Sedimentation Rates

The sedimentation rates plotted in Figures 10-4 and 10-10 through 10-14 are listed in Table 13. Sedimentation rates for samples collected in 1995 were from Erickson et al. (2007). The calculation of sedimentation rates for the samples collected during the 2008 Low Resolution Coring program can be found in AECOM (2010). For the remaining samples, cesium-137 (Cs-137) data were used to calculate the sedimentation rate, as described below.

The period of maximum atmospheric deposition of Cs-137 occurred in 1963. Thus, in a location with consistent deposition of similar sediments, the depth of the maximum Cs-137 activity represents the depth of sediments deposited in 1963. The average sedimentation rate since that time can thus be calculated for these locations as follows:

Equation 4

$$\text{Sedimentation Rate} = \frac{\text{Depth of 1963 peak}}{\text{Sampling year} - 1963}$$

It should be noted that the calculated average historical sedimentation rates are not necessarily representative of current or future deposition rates.

Only Cs-137 profiles with a well-defined peak were considered for the analyses in Section 10 of the RI report. Profiles and discussions of the Cs-137 data have been presented in Section 4 of the RI report. The selected cores and calculated sedimentation rates can be found in Table 13.

2 References

- AECOM, 2010. *Draft Low Resolution Coring Characterization Summary*. Lower Passaic River Study Area RI/FS. Prepared for Cooperating Parties Group. February 2010.
- Erickson, M.J., C.R. Barnes, M.R. Henderson, R. Romagnoli, and C. Firstenberg, 2007. "Geomorphology-based interpretation of sedimentation rates from radiodating, lower Passaic River, New Jersey, USA." *Integr Environ Assess Manag* 3(2):166-92.