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ENGINEERING ANALYSIS

HUDSON RIVER PCBs REASSESSMENT FS

APPENDIX E

ENGINEERING ANALYSIS

E.1 TECHNICAL MEMORANDUM: REMOVAL PRODUCTIVITY and EQUIPMENT REQUIREMENTS (Mechanical Dredges)

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NOVEMBER 2000

REMOVAL PRODUCTIVITY and EQUIPMENT REQUIREMENTS
(Mechanical Dredges)

In order to establish a set of preliminary equipment requirements to accomplish removal of Upper Hudson River targeted sediments by mechanical dredges, an analysis was conducted combining information from the project's GIS database, plans of proposed dredging areas, and vendor information. The analysis was based on the use of excavators outfitted with suitable auxiliaries designed to minimize sediment resuspension and to direct accurate removal of targeted sediments.

Bathymetric data was available from a survey conducted in 1991 and 1992 (Rogers Flood, 1993); also, see Feasibility Study Chapter 4. The survey information, in final form, consisted of maps illustrating one foot depth contours in River Sections 1 and 2 (see FS Plate 3). When expanded by computer, the bathymetric maps provided a useful basis for identifying the access problems that mechanical dredging equipment would encounter along the Upper Hudson. The mapped contours were used to establish the configuration of the mechanical dredges to be incorporated in the alternative-specific analysis provided in this FS. The process of selecting removal equipment, at this conceptual stage, was interpreted from the river bathymetry data and the layout of the proposed removal areas. Various dredging contractors were contatced to obtain information on appropriate and available removal equipment for the Upper Hudson River conditions. In the event that the selected remedy includes dredging, final specification of dredging methods and equipment will be made during design and implementation. Various factors that entered into the equipment evaluation process are as follows:

- Large capacity dredging equipment may not be able to access a significant portion of targeted near-shore sediments;
- Target sediments tend to be in deposits that range from 1 to 4.5 feet in thickness suggesting that larger scale equipment would not function efficiently;
- Limiting removal work to only a single low-capacity unit that can work in both shallow and deeper river segments would impact project productivity;
- To date environmental buckets have been fabricated in a limited range of capacities;
- Environmental buckets, due to the added features, may be heavier (bucket weight/cubic yard capacity) than comparable conventional buckets;
- Hopper and deck barges cannot be fully loaded at numerous work locations due to draft limitations;
- Handling and processing capacities at transfer stations may be constrained by wharf limitations, available land area, and rail capacity.

Given the complex interaction between these factors described above, an optimal dredging strategy can not be generated for this FS. However, it is possible, by applying technical judgement, to identify equipment type, number of units, and other elements of a mechanical removal scenario. Given the above listed factors, it has been decided that two different capacity dredging units will be selected to accomplish all removal work. The characteristics of the lower capacity unit are as follows:

- Excavator fitted with a two-cubic-yard environmental bucket;
- Draft of excavator plus working platform less than three feet;
- Effective working reach of 30 feet in three feet of water;
- Unconstrained operating cycle less than one minute; and
- Proposed operating cycle of three minutes.

Characteristics of the higher capacity unit are as follows:

- Excavator fitted with four-cubic-yard bucket;
- Draft of excavator plus working platform less than five feet;
- Effective working reach of 30 feet in five feet of water;
- Unconstrained operating cycle less than one minute; and
- Proposed operating cycle of two minutes.

The in-situ volume of targeted sediments that would be removed by each of the dredging packages was determined by overlaying maps of proposed dredging areas on maps illustrating river bathymetry using the project GIS database. Then the following procedure was followed to estimate work areas and removal volumes applicable to each of the equipment packages:

- A line offset 30 feet from the mapped shoreline was drawn in all areas to be remediated; This line represents the removal limit of the dredge equipment based on an effective working reach of 30 ft.
- The post-dredge five foot contour was located;
- The 30 foot offset of the shoreline was compared to the location of the post-dredge five foot contour; if the 30 foot offset extended outboard of the post-dredge five foot contour, the larger capacity equipment package could be used to remove targeted sediments outboard of the mapped shoreline;.
- In areas where the 30 foot offset did not extend beyond the post-dredge five foot contour, the lower capacity system would be used to complete removal work not accessible to the larger system;
- It was assumed that all targeted sediment in the non-navigable river section (Lock 6 pool) will be removed with lower capacity equipment due to constraints associated with mobilizing equipment in this section;
- In River Section 3, it was assumed that the lower capacity dredge will remove targeted sediments where water depths range from zero to six feet and that the larger system will be used to remove material where water depths exceed six feet.

Using the above guidelines, target sediment removal volumes were determined for both the larger and lower capacity dredging systems. These are shown in the following table for the two removal alternatives:

Proposed Volumes to be Removed from the Upper Hudson River

Alternative	**Volume by Lower Capacity System (cy)**	**Volume by Higher Capacity System (cy)**	**Total Volume Removed (cy)**
REM-0/0/3	2,642,266	1,180,794	3,823,060
REM-3/10/Select	2,028,988	622,742	2,651,730

To meet alternative-specific construction durations (five years for REM-3/10/Select and seven years for REM-0/0/3) removal productivity for each dredge type was estimated. On the basis of the productivity estimate it then becomes possible to estimate the number of dredges that would be needed to complete the work. Computation of the removal productivity has been based on the following:

- Dredge equipment would operate 12 to 14 hours/day (actual dredging);
- Dredging operations would be conducted 6 days/week;
- The dredging season would be 30 weeks;
- An overlap of 15% per cut was assumed between bites;
- The larger dredge system will make a horizontal, 1.5-ft cut; and
- The lower capacity ("smaller") dredge system will make a horizontal, 1-ft cut;
- Each bucket load will consist of 80 percent sediment and 20 percent entrained water;
- The density of the in-situ sediments is 1.4 tons/cy;
- Removal with the larger system will be by means of a four-cubic-yard environmental bucket operating on a two minute cycle; and
- Removal with lower capacity system will be by means of two-cubic-yard environmental bucket operating on a three minute cycle.

Based on the above factors, the following removal rates have been computed for each of the equipment packages. It should be noted that the following tabulation provides removal rates in terms of in-situ sediment volume removed.

Dredge Productivity

Nominal Bucket Capacity	**Operating Cycle**	***In-situ* Sediment Removal Rate**
four cubic yards	two minute cycle	82 cubic yards per hour
two cubic yards	three minute cycle	27 cubic yards per hour

Knowing the hourly productivity of each equipment package, and the daily and seasonal operating patterns, it is possible to estimate the number of dredges that would be needed to accomplish the targeted removal work in the specified number of construction seasons. Results of this analysis are summarized in the following table. It should be noted that equipment quantities presented below are averages. During actual removal operations it is possible that the number will vary according to the contractor's dredging plan.

Equipment Requirements

Alternative	Volume by 4-cy dredge (tpd)	Volume by 2-cy dredge (tpd)	Number of 4-cy Dredges	Number of 2-cy Dredges
REM-0/0/3	2,936	1,312	2	3
REM-3/10/Select	3,156	969	2	2

Targeted sediments are placed into barges for transport to either a northern or southern transfer facility. In general, it has been assumed that sediment removed by the larger equipment package would be placed into hopper barges loaded to a maximum of 1,000 tons. These barges will be towed to a southern transfer facility located south of Lock 5, potentially in the vicinity of the Albany area, for processing and disposal. Sediments removed by the lower productivity equipment will be placed onto deck barges that will be loaded to a maximum of 200 tons. The deck barges will, in general, be towed to the northern transfer facility, adjacent to the TI Pool, for processing prior to final disposal.

For purposes of this analysis, it was assumed that the northern transfer facility will be utilized to its maximum processing capacity of 1,460 tpd of in-situ sediment (based on an output of 1,600 tons per day of stabilized sediment). However, to fully utilize the estimated capacity of the northern facility, 158 tpd of sediment slated to be removed by the larger equipment package will need to be towed to the northern facility under the REM-0/0/3 alternative and 501 tpd under the REM-3/10/Select alternative.

In-river transit time to the southern transfer facility was estimated to be, on average, 9 hours and unloading of hopper barges to be 6 hours. The total turn around time for a hopper barge was estimated to be 24 hours. It was concluded that three sets of hopper barges would be required so that one barge can be loaded at the work site while the second is being unloaded at the transfer facility and a third is in transit. Based on the total amount of sediment plus entrained water being removed each day, the number of hoppers required could then be determined.

For alternative REM-0/0/3, the larger dredges remove approximately 2,936 tpd of in-situ sediment and each dredge removes 1,785 tpd of sediment plus entrained water (working 12.5 hrs/day). Since two larger machines are required for this alternative (producing 3,570 tpd of sediment plus water), 4 hopper barges will be loaded daily and 12 hoppers total are required. For REM- 3/10/Select, 3,156 tpd of sediment is removed (by the larger dredges) and each dredge removes 1,999 tpd of sediment plus entrained water (working 14 hrs/day). Since two dredges are also required for this alternative (producing 3,998 tpd of sediment plus water), 4 hopper barges will be loaded per day with 12 hoppers total required. Tow boats are assumed to work 24 hours per day so that four are required for each alternative to transport the hopper barges.

Material removed by the lower-capacity system (two-cubic-yard) will be barged to the northern transfer facility in 200-ton loads. Travel time to the northern transfer facility was estimated to be one hour on average. Time to unload the 200 tons barge loads was estimated at 3 to 4 hours. This implies a total turn around time per barge of about 6 hours. Since one small dredge will load approximately 2.5 barges per day, it was assumed that a minimum of two barges are required per dredge. This is to ensure that the equipment will not experience down time while waiting for the return of a barge. For alternative REM-0/0/3, 1,312 tpd of sediment is removed by the smaller machines and each unit removes about 571 tons sediment plus entrained water per day (working 11 hrs/day). Since three dredges are required for this alternative (producing 1,142 tons of sediment plus water), 9 deck barges are loaded per day and a total of six such barges are required (two per dredge) to avoid down time. An additional deck barge is required to transport dredged materials from the deep equipment (approximately 158 tpd) to the northern facility to ensure it is utilized to its maximum capacity.

For alternative REM-3/10/Select, 969 tpd of shallow sediment is removed and each small dredge removes 495 tons sediment plus entrained water (working 13 hrs/day). Since two dredges are required (producing 1,238 tons of sediment plus water), 6 barges are loaded per day and a total of four barges are required to avoid down time. Three additional deck barges are required to transport dredged materials from the deep equipment (approximately 501 tpd) to the northern facility to ensure it is utilized at its maximum capacity. Tow boats are assumed to operate 24 hours per day so that 3 are required for REM-0/0/3 and 2 for REM-3/10/Select.

The following table summarizes the removal equipment required per alternative.

Removal Alternative Equipment List

Alternative	**Dredges**	**Barges[1]**	**Tow Boats**	**Work Boats [2]**
REM-0/0/3	2 (4-cy) dredges 3 (2-cy) dredges	12 hopper 8 deck	4 large 3 small	1
REM-3/10/Select	2 (4-cy) dredges 2 (2-cy) dredges	12 hopper 7 deck	4 large 3 small	1

Notes:
(1) Deep dredge material being transported to the northern transfer facility to help maximize its capacity was assumed to be barged in deck barges
(2) One work boat has been assumed to aid in dredge and barge repositioning

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ENGINEERING ANALYSIS

E.2 TECHNICAL MEMORANDUM: AREAS CAPPED FOR THE CAPPING ALTERNATIVES-CONCEPT DEVELOPMENT

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AREAS CAPPED FOR THE CAPPING ALTERNATIVES- CONCEPT DEVELOPMENT

Quantities estimated for the capping alternatives include area capped and volume of sediment removed. The assumptions used in estimating the area capped are described in this section.

Areas to be capped were delineated using the following assumptions:

C Target sediments in areas with 0 to 6 feet water depth will be removed to 1.5 feet below the sediment surface then capped. The exception to the capping specification in 0 to 6 feet water depth areas are: (1) if all contamination is removed when 1.5 feet of sediment is removed, there will be no capping in these areas, and (2) if the bottom of contamination is at 2 feet, the entire thickness of contaminated sediments will be removed with no capping.

C Target sediments in areas with 6 to 12 feet water depth will be capped; except where the bottom of contamination is at 2 feet or less, then the entire thickness of contaminated sediments will be removed with no capping.

C Target sediments in the navigation channel (defined as areas with >12 feet water depth) will be removed to the bottom of contamination. Areas with water depth greater than 12 feet but are not in the navigation channel (e.g., the river section east of Rogers Island) will be capped with no sediment removal.

C For the section of the river between Thompson Island Dam and Lock 6, all sediments in target areas will be removed, i.e., there will be no capping in this section.

C In target areas below Lock 5, it is assumed that the entire thickness of contaminated sediments will be removed with no capping. This is based on the assumption that the mobilization of capping material and equipment is likely not cost effective to cap relatively small volumes of contaminated sediments in this river section.

Results of the computational effort are displayed in the following table (Table 1). The table provides estimates of capped areas by river section and, within each section, by water depth for each target criteria.

Table 1: Estimates of Capped Areas for the Capping Scenarios

River Section	Area Capped by Water Depth (Acres)											
	Full-Section				>3 g/m^2				>10 g/m^2			
	0-6'	6-12'	>12'	Total	0-6'	6-12'	>12'	Total	0-6'	6-12'	>12'	>12'
1	108.8	64.3	1.2	174.3	103.1	52.4	-	155.5	88.6	40.7	-	129.3
2	30.6	23.0	-	53.6	30.6	22.7	-	53.3	29.5	22.2	-	51.7
3	-	-	-	-	-	-	-	-	-	-	-	-
Total	139.4	87.3	1.2	227.9	133.7	75.1	-	208.8	118.1	62.9	-	182.0

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ENGINEERING ANALYSIS

E.3 TECHNICAL MEMORANDUM: VOLUME REMOVED FOR THE CAPPING ALTERNATIVES- CONCEPT DEVELOPMENT

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VOLUME REMOVED FOR THE CAPPING ALTERNATIVES- CONCEPT DEVELOPMENT

Quantities estimated for the capping alternatives include area capped and volume of sediment removed. The assumptions used in estimating the volume removed are described in this section.

Volume removed for the capping scenarios were estimated using the following assumptions:

- Sediments are removed to accommodate the cap without changing the hydraulic characteristics of the river in shallow areas (defined as areas with water depth less than 6 feet).

- Target sediments in areas with 0 to 6 feet water depth will be removed to 1.5 feet then capped.

- If the bottom of contamination is at 2 feet, the entire thickness of contaminated sediments will be removed with no capping.

- In target areas with 6 to 12 feet water depth, where the bottom of contamination is at 2 feet or less, then the entire thickness of contaminated sediments will be removed with no capping. Where the bottom of contamination is more than 2 feet below the sediment surface, there will be no sediment removal.

- Target sediments in the navigation channel (defined as areas with >12 feet water depth) will be removed to the bottom of contamination. Areas with water depth greater than 12 feet but are not in the navigation channel (e.g., the river section east of Rogers Island) will be capped with no sediment removal.

- For the section of the river between Thompson Island Dam and Lock 6, all sediments in target areas will be removed.

- All target sediments below Northumberland Dam will be removed, i.e., no capping will be implemented below Northumberland Dam.

The methods used to compute the volume of sediments removed for the capping scenarios are as described previously for the removal scenarios in Appendix B. Results of the computational effort are displayed in the following table (Table 1). The table provides estimates of volume removed for the capping scenarios by river section and, within each section, by water depth for each target criteria.

TABLE 1: Estimates of Volume Removed for the Capping Scenarios

River Section	Volume Removed by Water Depth (Cubic Yards)											
	Full-Section				>3 g/m^2				>10 g/m^2			
	0-6'	6-12'	>12'	Total	0-6'	6-12'	>12'	Total	0-6'	6-12'	>12'	Total
1	525,469	340,045	554,194	1,419,708	378,587	173,536	297,049	849,172	262,757	7,148	122,578	392,483
2	395,898	263,940	325,500	985,338	276,953	49,948	144,405	471,306	188,012	13,218	90,750	291,980
3	-	-	-	-	468,813	78,144	24,120	571,076	361,181	71,052	10,925	443,158
Total	921,367	603,985	879,694	2,405,046	1,124,353	301,628	465,574	1,891,554	811,950	91,418	224,253	1,127,621

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ENGINEERING ANALYSIS

E.4 TECHNICAL MEMORANDUM: CAPPING WITH DREDGING-PRODUCTIVITY and EQUIPMENT REQUIREMENTS
(Mechanical Dredges)

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NOVEMBER 2000

CAPPING WITH SELECT REMOVAL PRODUCTIVITY and EQUIPMENT REQUIREMENTS
(Mechanical Dredges)

In-situ capping is one concept being considered for remediation of contaminated sediments in the Upper Hudson River. The capping with select removal concept involves capping in water depths 0 to 6 ft and 6 to 12 ft where the depth of contamination is greater than 2 ft. In areas where the depth of contamination is 2 ft or less, removal will occur with mechanical dredging equipment. All areas requiring remediation in the channel (water depth > 12 ft) will be dredged using mechanical equipment to the depth of contamination. In areas located in water depths 0 to 6 ft where capping occurs, 1.5 ft of contaminated material will be mechanically removed so that the river shoreline location and water depths following remediation are approximately the same as the existing conditions.

In order to establish a set of preliminary equipment requirements to accomplish select removal of Upper Hudson River targeted sediments by mechanical dredges, an analysis was conducted combining information from the project GIS database, plans of proposed dredging areas overlaid on plans of proposed capping areas, and vendor information. The analysis was based on the use of excavators outfitted with suitable auxiliary equipment designed to minimize sediment resuspension and to direct accurate removal of targeted sediments.

Bathymetric data was available from a survey conducted in 1991 and 1992 (Roger Flood, 1993); also, see Feasibility Study Chapter 4. The survey information, in final form, consisted of maps illustrating one foot depth contours in River Sections 1 and 2 (see FS Plate 3). When expanded by computer, the bathymetric maps provided a useful basis for identifying the access problems that mechanical dredging equipment would encounter along the Upper Hudson. The mapped contours were used to establish the configuration of the mechanical dredges that would be incorporated in the alternative-specific analysis provided in this FS. The process of selecting removal equipment, at this conceptual stage, was interpreted from the river bathymetry data and the layout of the proposed removal areas. Various dredging contractors were contacted to obtain information on appropriate and available removal equipment for the Upper Hudson River conditions. In the event that the selected remedy includes dredging, final specification of dredging methods and equipment will be made during design and implementation. Various factors that entered into the equipment evaluation process are as follows:

- Large capacity dredging equipment may not be able to access a significant portion of targeted near-shore sediments requiring select removal to allow for cap placement;
- Target sediments requiring select removal tend to be in deposits that range from 1 to 3 feet in thickness suggesting that larger scale equipment would not function efficiently;
- Limiting removal work to only a single low-capacity unit that can work in both shallow and deeper river segments would impact project productivity;
- To date environmental buckets have been fabricated in a limited range of capacities;
- Environmental buckets, due to the added features, may be heavier (bucket weight/cubic

yard capacity) than comparable conventional buckets;

- Hopper and deck barges cannot be fully loaded at numerous work locations due to draft limitations;
- Handling and processing capacities at transfer stations may be constrained by wharf limitations, available land area, and rail capacity.

Given the complex interaction between these factors described above, an optimal dredging strategy can not be generated for this FS. However, it is possible, by applying technical judgement, to identify equipment type, number of units, and other elements of a mechanical removal scenario. Given the above listed factors, it has been decided that two different capacity dredging units will be selected to accomplish all select removal work. The characteristics of the lower capacity unit are as follows:

- Excavator fitted with a two-cubic-yard environmental bucket;
- Draft of excavator plus working platform less than three feet;
- Effective working reach of 30 feet in three feet of water;
- Unconstrained operating cycle less than one minute; and
- Proposed operating cycle of three minutes.

Characteristics of the higher capacity unit are as follows:

- Excavator fitted with four-cubic-yard bucket;
- Draft of excavator plus working platform less than five feet;
- Effective working reach of 30 feet in five feet of water;
- Unconstrained operating cycle less than one minute; and
- Proposed operating cycle of two minutes.

The in-situ volume of targeted sediments that would be removed by each of the dredging packages for this alternative was determined by overlaying maps of proposed select dredging areas with proposed capping areas on maps illustrating river bathymetry using the project GIS database. The following assumptions were made to estimate work areas and removal volumes applicable to each of the equipment packages:

- The Larger Capacity Dredge System will be used in water depths 6-12' and >12' (channel) to remove sediments requiring select removal for this alternative;

- The Smaller Capacity Dredge System will be used in water depths 0-6' to remove contaminated material in all areas requiring select removal for this alternative;

- It was assumed that all targeted sediment in the non-navigable river section (Lock 6 pool) will be removed with lower capacity equipment due to constraints associated with mobilizing equipment in this section.

Using the above guidelines, target sediment removal volumes were determined for both the larger and lower capacity dredging systems. These are shown in the following table for the capping with select removal alternative:

Proposed Volumes to be Removed from the Upper Hudson River

Alternative	**Volume Deep (cy)**	**Volume Shallow (cy)**	**Total Volume Removed (cy)**
CAP/SR-3/10/Select	825,003	907,818	1,732,820

To meet alternative-specific construction durations (five years for CAP/SR-3/10/Select), the removal productivity for each dredge type was estimated. On the basis of the productivity estimate it then becomes possible to estimate the number of dredges that would be needed to complete the work. Computation of the removal productivity has been based on the following:

- Dredge Equipment will operate 13 to 14 hrs/day (actual dredging);
- Dredging will be conducted for 6 days/week;
- The dredge season will be for 30 weeks;
- An overlap of 15 percent per cut was assumed between bites;
- The larger dredge system will make a horizontal, 1.5-ft cut; and
- The lower capacity ("smaller") dredge system will make a horizontal, 1-ft cut;
- Each bucket load will consist of 80 percent sediment and 20 percent entrained water;
- The density of the in-situ sediments is 1.4 tons/cy;
- Removal with the larger system will be by means of a four-cubic-yard environmental bucket operating on a two minute cycle; and
- Removal with lower capacity system will be by means of two-cubic-yard environmental bucket operating on a three minute cycle.

Based on the above factors, the following removal rates have been computed for each of the equipment packages. It should be noted that the following tabulation provides removal rates in terms of in-situ sediment volume removed.

Dredge Productivity

Nominal Bucket Capacity	**Operating Cycle**	***In-situ* Sediment Removal Rate**
four cubic yards	two minute cycle	82 cubic yards per hour
two cubic yards	three minute cycle	27 cubic yards per hour

Knowing the hourly productivity of each equipment package, and the daily and seasonal operating patterns, it is possible to estimate the number of dredges that would be needed to accomplish the targeted removal work in the specified number of construction seasons. Results of this analysis are summarized in the following table. It should be noted that equipment quantities presented below are averages. During actual removal operations it is possible that the number will vary according to the contractor's dredging plan.

Capping with Select Removal Productivity Equipment Requirements

Alternative	Volume by 4-cy Dredge (tpd)	Volume by 2-cy Dredge (tpd)	Number of 4-cy Dredges	Number of 2-cy Dredges
CAP/SR-3/10/Select	1,283	1,412	1	3

Targeted sediments are placed into barges for transport to either a northern or southern transfer facility. In general, it has been assumed that sediment removed by the larger equipment package would be placed into hopper barges loaded to a maximum of 1,000 tons. These barges will be towed to a southern transfer facility located south of Lock 5, potentially in the vicinity of the Albany area, for processing and disposal. Sediments removed by the lower productivity equipment will be placed onto deck barges that will be loaded to a maximum of 200 tons. The deck barges will, in general, be towed to the northern transfer facility, adjacent to the TI Pool, for processing prior to final disposal.

For purposes of this analysis, it was assumed that the northern transfer facility will be utilized to its maximum processing capacity of 1,460 tpd of in-situ sediment (based on an output of 1,600 tons per day of stabilized sediment). However, to fully utilize the estimated capacity of the northern facility, 58 tpd of sediment slated to be removed by the larger equipment package will need to be towed to the northern facility under the CAP/SR-3/10/Select alternative.

In-river transit time to the southern transfer facility was estimated to be, on average, 9 hours and unloading of hopper barges to be 6 hours. The total turn around time for a hopper barge was estimated to be 24 hours. It was concluded that three sets of hopper barges would be required so that one barge can be loaded at the work site while the second is being unloaded at the transfer facility and a third is in transit. Based on the total amount of sediment plus entrained water being removed each day, the number of hoppers required could then be determined.

For CAP/SR-3/10/Select, 1,283 tpd of sediment is removed by the larger dredges and each large dredge removes 1,714 tpd of sediment plus entrained water (working 12 hrs/day). Since one dredge is required for this alternative, 2 hopper barges will be loaded per day with 6 hoppers total required. Tow boats are assumed to work 24 hours per day so that 2 are required for this alternative to transport the hopper barges.

Material removed by the lower-capacity system (two-cubic-yard) will be barged to the northern transfer facility in 200-ton loads. Travel time to the northern transfer facility was estimated to be one hour on average. Time to unload the 200 tons barge loads was estimated at 3-4 hours. This implies a total turn around time per barge of about 6 hours. Since one small dredge will load approximately 2.5 barges per day, it was assumed that a minimum of two barges are required per dredge. This is to ensure that the equipment will not experience down time while waiting for the return of a barge. For alternative CAP/SR-3/10/Select, 1,412 tpd of sediment is removed from the smaller dredges and each small dredge removes 619 tons sediment plus entrained water per day (working 13 hrs/day). Since three shallow dredges are required for this alternative (producing 1,857 tons of sediment plus entrained water), 10 barges are loaded per day and a total of seven barges are required for this alternative (two per dredge) to ensure no down time. Tow boats are assumed to work 24 hours per day so that 3 will be required for the CAP/SR-3/10/Select alternative.

The following table summarizes the removal equipment required for the CAP/SR-3/10/Select Alternative.

Capping with Select Removal Alternative Equipment List

Alternative	**Dredges**	**Barges**[1]	**Transport Tugs**	**Work Boats** [2]
CAP/SR-3/10/Select	1 (4-cy) dredges 3 (2-cy) dredges	6 hopper 7 deck	5 3	1

Notes:
(1) Any Deep dredge material being transported to the northern transfer facility to help maximize its capacity was assumed to be barged in deck barges
(2) One work boat was assumed for this alternative to aid in dredge barge repositioning

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E.5 TECHNICAL MEMORANDUM: APPLICABILITY OF TURBIDITY BARRIERS for REMEDIATION

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APPLICABILITY OF TURBIDITY BARRIERS
TO REMEDIATION OF THE UPPER HUDSON RIVER

1.0 Introduction

Various types of turbidity barriers have been used to limit downstream migration of sediments that may be re-suspended during dredging operations. This memorandum first provides an overview of a range of turbidity barrier types. While some specialty systems may have applicability to remediation of the Upper Hudson, the remainder of the memorandum focuses on the use of non-structural systems such as silt curtains.

2.0 Overview of Turbidity Barriers

Barriers can be placed into two categories for convenience, structural and non-structural types. Structural barriers are typically employed as permanent features for in-situ containment; however, they have lately been increasing used on a temporary basis to control movement of contaminated sediments. Non-structural barriers are normally employed for the duration of a dredging project and then removed. The use of a non-structural system allows the barrier to be re-located to new dredge areas as a dredging project progresses through various stages. Portable modular systems may be used to improve re-locatability over structural systems while allowing greater hydrodynamic control and stability than non-structural barriers.

2.1 Structural Barriers

Structural barriers such as sheet piling are particularly suitable for situations where the containment area needs to be de-watered so that dry excavation work can be performed. While these systems provide considerable structural capacity, they can also be relatively expensive, and usually require significant equipment and manpower resources to install.

Sheet piling consists of a series of steel sections that interlock with one another. Piles are driven in panels to approximately the same depth. It is not anticipated that turbidity barriers comprised of structural sheeting will have general applicability to conditions in the upper Hudson. Based on acoustical surveying conducted in the river, it appears that relatively shallow rock is present at the site and could impede pile driving at many locations.

2.2 Non-Structural Barriers

Non-structural containment barriers include oil booms, silt curtains, and silt screens. Oil booms are utilized in situations where the dredged sediments could potentially release oily residues. Silt curtains are constructed of impervious materials that block or deflect the passage of water and sediments. Silt screens are similar to silt curtains, however these barriers allow water to flow through while impeding the passage of a fraction of the suspended load.

The advantage of using non-structural barriers is that they can easily be re-located to new work areas after dredging at a specific location has been completed. Conditions which limit applicability include strong river currents, high winds and areas where rising and falling tidal waters are present. Silt curtains are not viewed as appropriate in situations where the river current is greater than approximately 1.5 feet/second, and where the depth of the river exceeds 21 feet. However, it should be noted that if the silt curtain is set up in a configuration that is closely parallel to river flow, the curtain could function effectively in currents approaching 3 feet per second.

Typically, a silt curtain and silt screen is suspended by a flotation unit at the water surface, and held in a vertical position by a ballast chain within the lower hem of the skirt. Anchors attached to the barrier also serve to hold it in place.

2.3 Other Portable Systems

Similar to sheet piles, other available commercial products such as the Portadam™ and Aqua-Barrier™ systems are also used for construction site dewatering and containment, diversion of water flow, erosion control, and flood control. These systems are low-cost alternatives to building earthen dams or using sheet piles, and are relatively easy to set-up. These systems are generally limited to situations with a maximum water depth of up to ten feet.

The Portadam™ system utilizes a freestanding steel support structure in conjunction with an impervious fabric membrane. The support members transfer fluid loading to an approximately vertical downward load, allowing for installation on a solid impenetrable foundation. This structure free-stands on the existing bed, which eliminates the need for pile-driving equipment, cross bracing or anchorage. The membrane is placed on the outer section of the support structure, and is rolled out all the way down to the level of the bed. Hydraulic loading on the membrane assists in the sealing and stability of the entire structure. Once installed, the work area enclosed by the structure can be de-watered.

The Aqua-Barrier™ and GeoCHEM Water Structures™ systems utilize water-filled vinyl polyester-reinforced tubes to provide mass for stability, and they can be coupled together to form a barrier of any length. Punctures in the material may be easily patched with repair kits. They are lightweight, easy to transport, and re-usable. While these systems are not as sturdy as the

Portadam™ system, they can be used in cold weather conditions, and are reasonably resistant to sunlight exposure.

These systems may potentially be applicable to conditions with the Hudson River, particularly for those phases of work that involve removal of sediments in shallow embayments and secondary channels.

3.0 Deployment of Non-Structural Turbidity Barriers

3.1 Components

Components of a non-structural barrier system includes the fabric which forms the barrier itself, a floatation system to suspend the barrier in the water column, and an anchoring system to hold the barrier in place.

3.1.1 Fabrics

In general, there are two types of fabrics available. The first is a woven polypropylene design that allows water to flow through while retaining all or a portion of suspended solids. This type of fabric is generally light, and is designated with an EOS – U.S. standard sieve rating. Generally, a higher rating means that the material will allow a smaller fraction of suspended material to pass through. The second class of fabrics are generally heavier and more sturdy than the fabric described above, and consist of either a laminated or vinyl-coated polyester fabric, which prevents both water and all suspended solids from passing through the barrier. Generally, these impervious barriers are referred to as silt curtains, while the woven polypropylene designs are usually termed silt screens to reflect the difference in the functionality of the two products. The term silt curtain will be used here to refer to both silt screens and silt curtains.

Silt curtain sections are usually available in 50- or 100-foot lengths, and can be joined together a number of different ways, depending on the design selected. A typical connection between barrier sections would be through the use of rope lacing or nylon ties, but some situations may require inserting the ends of two adjoining barrier sections into a PVC pipe to provide a more effective seal. This latter system requires assembly in the field, and would not lend itself to furling of the curtain prior to deployment. As a result, set-up and removal operations would be more time-consuming and tedious.

3.1.2 Flotation System

Silt curtains are suspended from the water surface by a flotation pocket which may be heat-sealed onto the top section of the curtain. The actual flotation device is inserted inside this pocket and may consist of a cylindrical-shaped piece of material such as Styrofoam or polyethylene. The diameter of the flotation device varies depending on the buoyancy required, but in most cases is generally between 6 and 12 inches. For example, a larger section of curtain generally requires a greater degree of flotation in order to be able to support the additional weight, and consequently, the diameter of the flotation pocket would need to be proportionally larger.

3.1.3 Anchoring System

It is essential that the curtain be immobilized as much as possible, so that wind and river currents do not impact its performance. A ballast chain, typically 1/4 inch or 5/16 inch in diameter is placed inside a heat sealed pocket at the bottom of the curtain, which helps to keep the curtain in a vertical position. Anchors are also typically used to limit lateral movement of the barrier. Each anchor is usually attached to a 12 inch – 24 inch diameter mooring buoy, which in turn is attached to the top of the curtain. This arrangement minimizes the risk of submerging the barrier's flotation system under heavy loads. Anchors are placed approximately 50 to 100 feet apart, although site-specific conditions (*e.g.*, high river currents, river-bottom conditions) may require decreasing this spacing.

Some anchor types that are commonly used include mushroom anchors, danforth anchors and concrete blocks. Mushroom anchors consist of a cast iron bowl at the end of a shank. This type of anchor is usually employed in areas with sandy bottoms. The anchor will sink gradually, but once it is fully embedded, it has substantial holding power. Danforth anchors are lightweight and consist of two long, narrow flukes that pivot at the end of a long shank. The flukes engage quickly, and the anchor buries itself completely under heavy loads. Concrete blocks are simply what their name implies, and they vary in size depending on the degree of anchorage required.

3.2 Installation and Removal

Ideally, the barrier should be set up as parallel to the river flow direction as possible in order to minimize the amount of pressure that is forced onto the barrier by the river current. This would typically involve anchoring each end of the barrier to two points on the shoreline, resulting in an arc-shaped configuration. In addition, a deflector curtain may also be installed upstream of the contained area in order to reduce the river current pressure on the silt curtain. Each section of the barrier is joined together on the shore, and furled in preparation for placement in the water. Depending on conditions such as wind, current velocity, and the total length of the barrier which is to be deployed, a small boat with a three person crew may be sufficient for installation. In other situations, a crane may be required to hoist successive portions of the furled barrier while a boat pulls the barrier in place. The installation of the anchor system is coordinated with the placement of the barrier in the water.

Once the curtain is in place and properly anchored, it is unfurled. Some systems are designed to allow the depth of the curtain skirt to be adjusted up or down as required. The flotation segment is typically equipped with lines which run down to the bottom of the skirt. These lines can be pulled to lift the curtain to the desired depth. In very shallow areas, a staked barrier may be used. Some manufacturers do not recommend extending the skirt all the way to the river bottom since silt may build up on the bottom inside of the curtain and cause submersion. However, in practice, this type of installation has been used frequently and successfully for maximum possible containment of suspended sediments.

Figure 1 illustrates the cross-section of a typical silt curtain installation in a watercourse.

The removal procedure is essentially the opposite of installation. Special care must be taken during the installation and removal process so that the curtain fabric is not damaged by rocks or boulders present on the shoreline and the river bottom, or by the equipment that is utilized to install the barrier.

4.0 Example Projects Using Silt Curtains

The following subsections briefly discuss projects that involved the use of silt curtains and where, in most cases, PCB contamination was present in the sediments. These discussions focus on the experience encountered with the usage of silt curtains at these sites. The last sub-section presents details that are applicable to the Hudson River project.

4.1 Domestic Projects

4.1.1 **<u>Cherry Farm (Tonawanda, NY)</u>** – In this project, a turbidity curtain was placed adjacent to a weed bed where river velocities were less than two feet per second. It was essential that the curtains could withstand the river current velocity, as well as potential wave action, so that sediment re-suspension would be confined to the dredge area. In addition, an oil boom was deployed around the immediate dredging area to contain accidental releases from the dredging equipment. Dredging was performed using a hydraulic cutterhead because the sediments were found to be too hard-packed for conventional clamshell/mechanical dredging. Turbidity outside the curtain area was monitored and found to be within acceptable criteria.

4.1.2 **Ford Outfall (River Raisin, Monroe, MI)** – In this project, inner and outer silt curtains were installed over a one-week period. Concrete blocks were used as anchors. Prior to installation, a schedule was developed with commercial ship-traffic representatives for removal and redeployment of the silt curtain during a two-week shutdown period to allow commercial ship traffic to reach the port of Monroe. The proposed location of the upstream wing of the outer curtain intruded on a section of the river which was needed by commercial vessels for maneuvering into a nearby turning basin. Additionally, the silt curtain manufacturer was also concerned with the effects of propeller-wash forces and possible physical contact from passing vessels on the silt curtains or the anchoring system. Based on subsequent sediment sampling analysis, it was determined that the southern limit of the dredging area could be moved in order to allow for a wider shipping channel. However, in one instance, a ship gained unauthorized entry into the shipping channel and passed close enough to the perimeter of the outer silt curtain to cause damage to the curtain fabric. As a result, the dredging operation was discontinued temporarily while a dive crew was sent to repair the curtain. The project delay was reduced by the use of a temporary silt curtain patch, which allowed dredging to resume until the appropriate patching materials and equipment arrived.

4.1.3 **Grasse River Project 1, (Massena, NY)** - This pilot study also employed a containment system consisting of an inner and an outer turbidity curtain. This project experienced minor delays because of a redesign in the silt curtain anchoring system. This was necessary because minimal penetration (only a few inches) was achieved upon several attempts to plant the anchors to full depth. The helical screw anchors which were called for were designed to hold forces up to 20,000 pounds provided that ample penetration into the river substrate is achieved. Because attempts to properly anchor this system design failed, it was decided that the original helical screw anchoring system would be replaced with large blocks of concrete. The redesign resulted in a minimal delay to the project. An additional curtain was used to isolate a portion of the dredge area within the primary (inner) curtain. Total suspended solids (TSS) readings taken within the work area were as high as 250 mg/L, but levels outside the curtains were maintained below a specified action level of 25 mg/L above background. However, it was estimated that between approximately 5 and 30 pounds of soluble PCBs were released from the containment system during removal operations.

4.2 International Projects

4.2.1 **Welland Reef (Canada)** – This project involved the removal of mill scale material using an Amphibex, which is a combination mechanical-hydraulic suction dredge. This equipment was considered capable of completing the dredging without causing significant impact on downstream water quality. However, as a precaution, silt curtains were utilized to minimize the impact of possible sediment re-suspension. Overall, turbidity levels were found to be low throughout most of the dredging activities, but on several occasions turbidity levels downstream from the silt curtain exceeded acceptable criteria because of high river flows that caused problems with the silt curtains. This issue was resolved by cleaning or weighing down the silt curtain and temporarily halting dredging until downstream turbidity levels were reduced to acceptable levels.

4.2.2 **Lake Jarnsjon (Sweden)** – The dredging equipment that was selected for this project was also specifically designed to limit sediment re-suspension. However, based on investigations, and theoretical calculations of suspension, transport, and settling of the sediments, it was decided that the eastern portion of the lake should be dredged within a protective silt curtain barrier, and positioned in such a way that the most heavily contaminated sediments in the lake were enclosed. Total suspended solids were monitored, and in most instances, the concentrations outside the confined area were lower than those measured inside. However, the TSS concentrations measured within the enclosed area were generally low, indicating that the dredging equipment performed very well in limiting sediment re-suspension.

5.0 Applicability of Silt Curtains to the Remediation of the Upper Hudson River

The following example examines the use of silt curtains in the Upper Hudson River assuming the use of mechanical dredging equipment. It is important to note that removal utilizing hydraulic dredging equipment would require a different approach.

5.1 Possible Deployment Configuration

According to data obtained from the 1998 Data Summary Report for the 1996-1997 Thompson Island Pool Studies prepared by O'Brien and Gere Engineers, Inc., flow velocities in the Hudson river north of the Thompson Island Dam were found to range between 0.2 and 1.5 ft/sec. This data shows that silt curtains can be used effectively in these areas. In addition, near-shore flow velocities are expected to be relatively low, suggesting that silt curtains would be particularly feasible for use along the river shoreline.

A typical in-river set-up for a two-silt curtain array is shown in Figure 2. The silt curtains are installed in arc-shaped configurations that parallel the direction of river flow.

The area enclosed by each silt curtain is proposed to be approximately 2 acres. Based on this enclosed area, a typical barrier set-up is estimated to have a length of approximately 1,000 feet.

In order to allow barges to enter and exit the enclosed work area, a modified installations will be required. One possibility is to have two overlapping sections that are fastened with connectors to allow for rapid uncoupling. The entrance should be configured on the upstream side, so that the river flow will assist in reducing the amount of suspended sediments that are released each time that a barge enters or exits the work area. The entrance may also be left open by securing each end of the silt curtain to pilings. Another possibility is to use pilings to secure two sections of the barrier, and to place a third section of the barrier between to act as a gate. These two configurations are illustrated in Figure 2. Another configuration involves placing a structural barrier upstream of the silt curtain to divert the river flow from the area. A piling is attached to the upstream end of the silt curtain, leaving sufficient room for barges to enter and exit the dredge zone. According to manufacturers, no significant additional costs are expected using the first two arrangements.

5.2 Cost Estimates

5.2.1 Materials

Assuming that five mechanical dredging operations are being conducted simultaneously, it will be necessary to have one set of barriers at each location. Assuming that one spare set is always available, and all sets must be fully replaced each year, 12 sets of barriers will be required for each construction season. Therefore, over the five-year duration of the project, a total of 60 silt curtains will be needed. Table 1 shows the costs associated with the silt curtains material provided by various manufacturers. Price quotes are based on an order of at least 2000 linear feet of material, and may vary depending on the total quantity ordered.

Manufacturer	Product	EOS-US Std. Sieve	Price/ linear foot[1]
R.H Moore & Associates	Type II	N/A	$8.80
American Engineering Fabrics	Type II – AEF 650W	100	$15.00
American Boom & Barrier Company	Type Mark II	N/A	$11.35
	Type PC-2	70	$12.20
Indian Valley Industries	Carthage 6% fabric	70	$9.50
Brockton Equipment/ Spilldam Inc.	Siltdam Type II	70	$10.81

[1] Based on a 10 ft deep section of curtain, and at least 2000 total linear feet

The highest quote given is $15 per linear foot for the Type II – AEF 650W turbidity barrier which is manufactured by American Engineering Fabrics. Note that this product has a higher EOS US Standard Sieve rating, which is reflected in the higher cost of this particular fabric. In addition to the silt curtain material itself, an anchoring system will also be required. Brockton Equipment/ Spilldam Inc. offer anchor and anchor buoy sets for approximately $140 per set. Marker light buoys are also available for approximately $92 each. Assuming that all equipment is purchased at the current (year 2000) rates, the total material cost is as follows, assuming an average barrier length of 1,000 feet as discussed previously:

Silt curtain costs:

1000 ft of material @ $15/foot = $15,000

$15,000 * 60 silt curtains = $900,000

Anchors and marker buoys:

Anchors and marker buoys are typically spaced at 50 ft and 100 ft intervals, respectively. Therefore, for a 1,000-foot section of curtain, 21 anchors and 11 marker buoys will be required. Ten sets in total will be required: Five sets for the active dredge sites, and another five sets that will be available for installation in subsequent dredge areas. Therefore a total of 210 anchors and 110 marker buoys will be required for the entire project:

Anchors: $140 * 210 = $29,400
Markers: $92 * 110 = $10,120

Therefore, the total cost of the materials including a 35% contingency is:

($900,000 +$ 29,400 + $10,120) * 135% = $1,268,352

5.2.2 Labor & Equipment Considerations

Labor and installation associated with the silt curtains also need to be factored into the final cost. The amount of labor required is dependent on river conditions at each location. For example, areas that have higher currents or winds will make installation of the barriers more difficult, unless additional equipment and manpower is used. In these cases, a barge with a crane may be needed to help place the curtain in the water, an additional barge may be needed to hold the curtain in place, and a tug may be required to position everything. Other areas may require only a small boat to deploy the curtain. Installation at a given location typically requires 1 to 3 full days and is dependent on the equipment used, weather conditions, and river conditions at the dredge site.

6.0 Conclusions

The use of silt curtains to control sediment re-suspension has been successfully demonstrated at several remedial dredging projects. For removal activities in the shoal areas outside the Hudson River navigation channel the use of silt curtains presents a potentially effective means to reduce downstream transport of re-suspended sediments. River current velocities are at or below the practical operational limits of silt curtains, and river geometry appears favorable to use of barriers along most near-shore areas.

Figure 1 - Turbidity Barrier Configuration (Section)

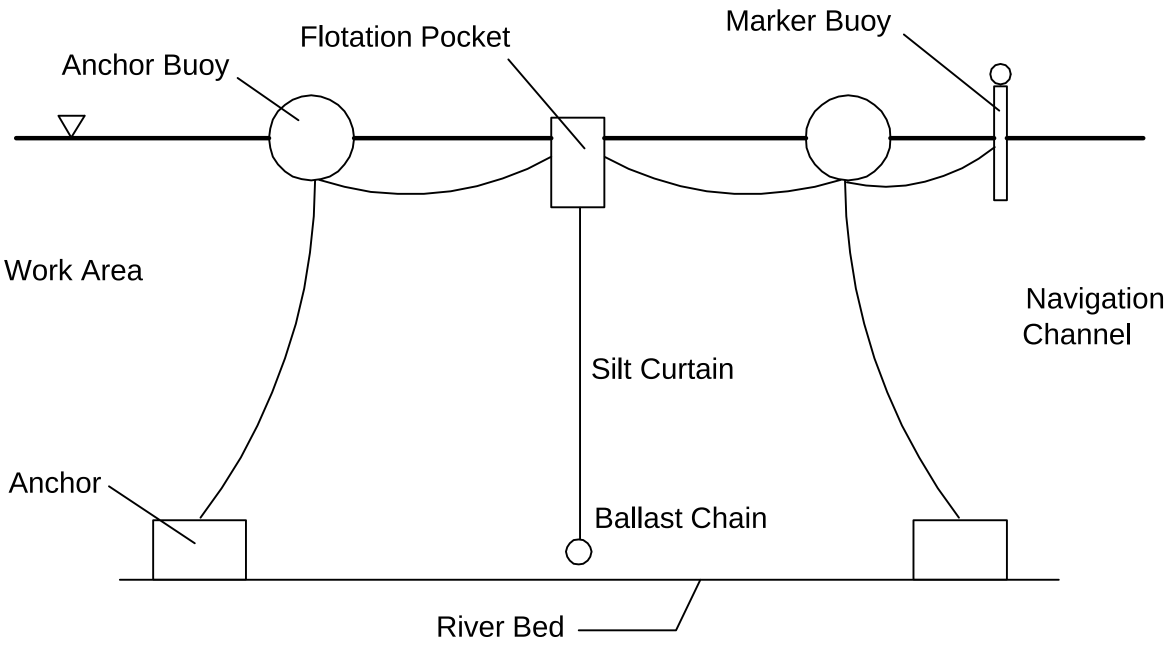
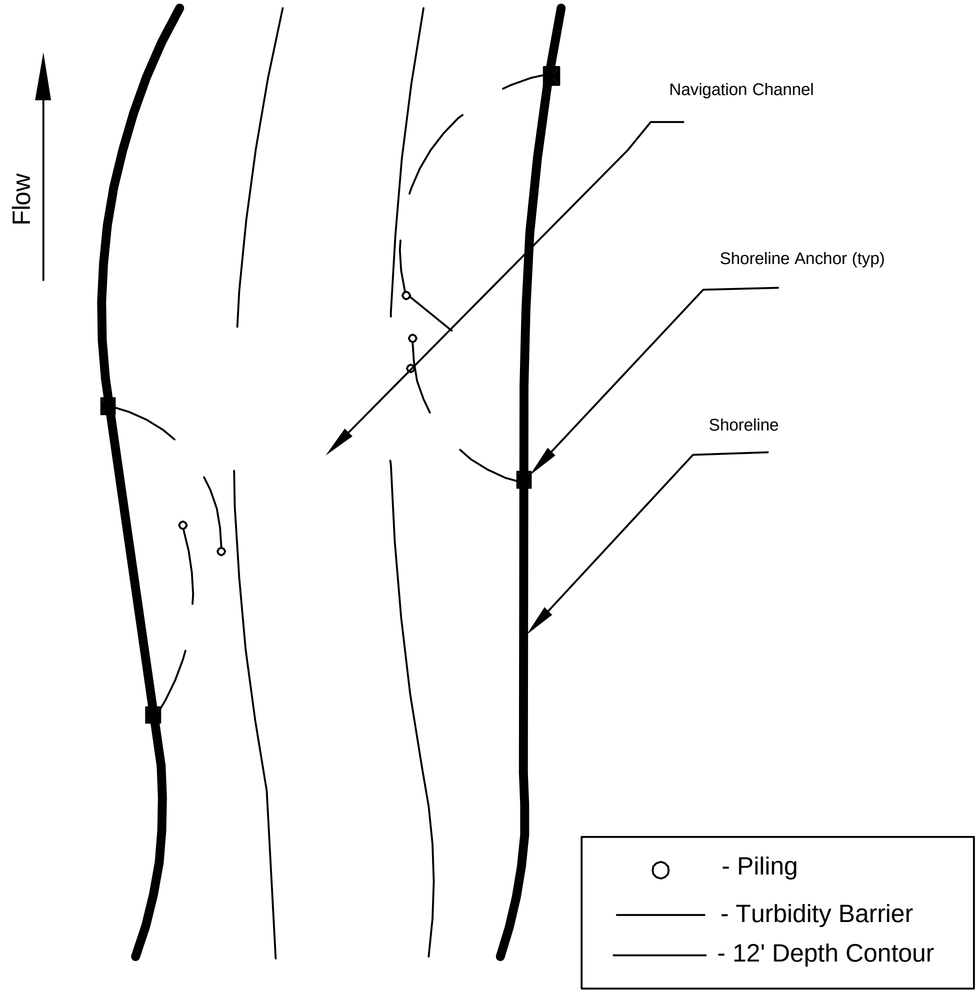


Figure 2 - Turbidity Barrier Configuration
Typical River Section



HUDSON RIVER PCBs REASSESSMENT FS

APPENDIX E

ENGINEERING ANALYSIS

E.6 TECHNICAL MEMORANDUM: SEMI-QUANTITATIVE ASSESSMENT OF WATER QUALITY IMPACTS ASSOCIATED WITH DREDGING ACTIVITIES

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Semi-Quantitative Assessment of Water Quality Impacts Associated with Dredging Activities

This memorandum describes the application of a model for sediment resuspension and downstream transport as a result of sediment dredging. The application deals with two dredge types, a 12-in cutter-head dredge and a 4-cy enclosed bucket dredge. The development of this model is described in the attachment to this appendix. The results of this application describe the release rate of PCBs associated with the resuspended sediments and the ensuing increase in the water column PCB concentration. The analysis is considered semi-quantitative since it does not address the exact fate of the PCBs released but rather provides an upper-bound estimate of the PCB release and increase in water column concentration. The results of the analysis and their implications are summarized in Chapter 8 of the FS.

As part of the evaluation of the short-term impacts associated with sediment removal, a semi-quantitative analysis was prepared describing sediment resuspension and downstream transport of PCBs. The purpose of the model was to provide an estimate of the amount of PCB mass liberated from the sediments during dredging. This PCB mass would subsequently be available for downstream transport where it can further contaminate sediments, water and biota. The model itself is described in the attachment to this appendix. The following discussion describes the model's application to the anticipated dredging conditions as well as the estimated impacts.

The model itself consists of two components, a resuspension term representing sediment resuspension at the dredge head, and a gaussian plume transport model which describes the dispersion and settling of the particles downstream. To estimate the impacts downstream, PCB concentrations were assigned to the resuspended sediments. Based on the rate of resuspension, the flux of PCBs to the water column as well as the resulting water column concentrations were estimated. Several assumptions regarding the application of the model should be noted as follows:

- Only fine particles and their associated PCB mass were assumed to be added to the water column. Because of their larger size, larger particles quickly fall from the water column and are expected to add little PCB.
- The PCB flux to the water column was estimated as the PCB flux 10 m downstream of the dredge head. No further removal of PCBs by settling was permitted, yielding a conservative (upper-bound) estimate of possible PCB release.
- Both cutter-head and enclosed bucket dredges were examined. However, only the conventional enclosed bucket is evaluated herein. As mentioned in the attachment to this appendix, recent advances in bucket design are expected to reduce resuspension rates beyond those applied herein.
- No adjustment was made for the silt curtains, which serve to reduce downstream movement of sediment. This represents an additional conservative (*i.e.,* upper bound) assumption.
- River flow was assumed to be 3000 cfs for the entire calculation. This low value, along with the settling assumption described above, serves to maximize PCB concentrations in the water column, again a conservative assumption.
- Sediment conditions were averaged on a river-section wide basis to yield a mean value that would be typical of the average material dredged over the course of the

remediation.

- The percentage of fine-grained sediment in the dredged sediments was estimated from the volumes of cohesive and noncohesive sediments to be removed in each river section.
- PCB content on resuspended material was assumed to be identical to that of the bulk sediment removed.
- Dredge operations were assumed to extend for 30 weeks each year.
- Dredge operations (for REM alternatives) were assumed to be 14 hours per day for the environmental enclosed bucket dredge and 17 hours per day for the cutter-head dredge, as defined in the FS. Under the capping alternative, mechanical dredging hours were reduced by 35% to 9 hours to account for the lower removal volumes.
- PCB concentration increases were calculated as daily mean conditions for the period of dredge operations each year (30 weeks).
- PCB fluxes were calculated for equivalent production rates by the two dredge types. That is, the estimates were performed for a single 12-in cutter-head dredge and three 4-cy enclosed bucket dredges.

To examine the potential impacts of each alternative on the entire Upper Hudson, the impacts are semi-quantitatively evaluated for each river section. This analysis is considered semi-quantitative because it does not describe the precise fate of the resuspended PCBs but rather provides a conservative numerical estimate of the PCB release rate and ensuing water column concentration. When necessary, properties of the better documented TI Pool are applied to the calculations for the other sections. This section clearly has the most extensive data sets for estimating mean sediment properties (*e.g.*, the 1984 NYSDEC PCB survey and the 1992 USEPA side-scan sonar survey) and is to undergo the greatest level of remediation of any section. Thus, extrapolating its properties to the other sections when necessary for the calculations should not introduce significant errors.

The estimate of the percentage of fine-grained sediment (silt and clay) in the dredged material was derived from a volume-weighted average of the fine-grained content of cohesive sediments and noncohesive sediments in the areas to be dredged. As described elsewhere in Appendix E, the fraction of fine-grained sediment is 65 percent in cohesive sediments and 20 percent in noncohesive sediments. As described in the attachment, the rate of sediment resuspension varies linearly with the fine-grained sediment content of the dredged material. Thus the proportion of the two sediment types will vary the rate of sediment resuspension and PCB release. The estimates of the fraction of cohesive and noncohesive sediment for each river section under each remediation scenario is given in Table E.6-1.

The estimate of the PCB concentration in the dredged material and the associated resuspended sediment was derived on a volume-weighted basis. The PCB concentration was simply derived as the ratio of the mass of PCBs removed by the mass of sediment removed. Note that this value will be less than the average PCB concentration for the river section, since dredging will inevitably remove both contaminated and uncontaminated material. The mass of sediments removed was derived from the volume of sediments to be removed. The total volume of sediments to be removed for each scenario was estimated as part of the engineering analysis and is given in Table 6–3 of the FS. The fractions of cohesive and noncohesive volume removed were derived for the TI Pool and then applied to the river sections downstream (see Table E.6-1). The volume of each sediment type was then multiplied by its respective solids density (0.71 tons/cy cohesive and 1.16 tons/cy noncohesive) to yield the mass of each fraction. The concentration of PCBs on the dredged material was then the PCB mass to be removed divided by this volume-weighted mass of sediments. The results of this calculation are given in Table E.6-1.

In the attachment, the PCB release rate is calculated for two separate sediment concentrations for a dredged sediment consisting of 30 percent cohesive and 70 percent noncohesive sediments. The estimated values for PCB release and downstream concentration are linear in their relationship with fine-grained material and PCB concentration. Thus the values presented in Table E.6-1 can be used proportionately to estimate PCB loads and water column concentrations at conditions different from those simulated by the model. These results are presented in Tables E.6-2, E.6-3 and E.6-4. These tables correspond to the alternatives CAP-3/10/Select, REM-3/10/Select and REM-0/0/3. The results from these tables are discussed at length in Chapter 8 of the FS. In general, the analysis found that these increases in PCB load and concentration during the period of operation would be relatively minor as compared to the ongoing releases of PCBs from the sediments of the river as well as from the Hudson Falls source.

Table E.6-1
Sediment Distributions and PCB Concentrations in Dredged Materials

		Sediment Distribution		Tri+ PCB Concentration
Section	Scenario	Percent Cohesive	Percent NonCohesive	on Dredged Materials [5]
1	Hot Spot Removal	62%	38%	NC [3]
	Expanded Hot Spot Removal	37%	63%	8.4
	Full Section Removal	26%	74%	7.7
	Hot Spot Capping with Select Removal	58%	42%	NC [3]
	Expanded Hot Spot Capping with Select Remova	27%	73%	8.4
2	Hot Spot Removal [1]	62%	38%	23
	Full Section Removal [1]	26%	74%	15
	Hot Spot Capping with Select Removal [1]	58%	42%	29
3	Selected Hot Spot Removal [1]	62%	38%	13
	Expanded Hot Spot Removal [1, 2]	62%	38%	14
	Selected Hot Spot Capping with Select Removal	58%	42%	13

Notes:

1. Sediment percentages were taken from those for Section 1.
2. Percentages were taken to be the same as selected hot spot removal since there was little difference between the two scenarios in this section.
3. These concentrations were not calcualted since they were not needed for the alternatives calculations.
4. Cohesive sediments were assigned a dry solids density of 0.71 tons/cy. Noncohesive sediments were assigned a dry solids density of 1.16 tons/yd.
5. Tri+ PCB concentrations were estimated from the Total PCB data presented in Table 6-3 of the FS

Table E.6-2
Estimate of Dredging Resuspension Rates for the CAP-3/10/Select Alternative

Dredge Type	No. of Units in Operation	Production Rate Per Dredge cy/hr	Sediment Resuspension Losses Per Dredge						Tri+ PCB Concentration on Sediments [4] mg/kg	Duration [5] years	Resulting Downstream Instantaneous PCB Flux [6] mg/s	Resulting Downstream Concentration Increase [7] @3000 ng/L	Resulting Downstream PCB Load Increase [8] kg/yr	Resulting PCB Release [9] kg
			Cohesive Sediment Loss Rate [1] kg/s	Cohesive Sediment Percent Of Mass [2]	Noncohesive Sediment Loss Rate [1] kg/s	Noncohesive Sediment Percent Of Mass [2]	Mean Resuspension Rate Per Dredge kg/s	Mean Resuspension Rate Under Operation [3] kg/s						
Section 1 - Expanded Hot Spots														
4 -cy Conventional Enclosed Bucket	3	95	0.07	27%	0.022	73%	0.035	0.105	8	3	0.51	2.3	3.0	9
Section 2 - Hot Spots														
4 -cy Conventional Enclosed Bucket	3	95	0.07	58%	0.022	42%	0.050	0.150	29	1	2.6	12	16	16
Section 3 - Select Hot Spots														
4 -cy Conventional Enclosed Bucket	3	95	0.07	58%	0.022	42%	0.050	0.150	13	1	1.2	5	7	7
Summary of Impacts (Time-weighted)[11]														
4 -cy Conventional Enclosed Bucket	3	95	0.07	39%	0.022	61%	0.041	0.123	13	5	1.1	4.8	6	32

Notes:
1. This loss rate represents particles less than 74 µm (*i.e.*, silts and clays)
2. This is the precentage of mass being dredged which is cohesive or non-cohesive, as noted. The value is used to weight the loss rate term to yield a mean resuspension rate for the
3. This represents the loss rate for 1 cutter head dredge or three bucket dredges, which yield equivalent production rates.
4. This is the volume weighted average Tri+ PCB concentration in the dredge material. The value is assumed to be the concentration of Tri+ on the resuspended sediment.
5. Duration of dredging operation in the reach.
6. This is the net Tri+ PCB flux 10 m downstream of the dredge head during operation. No further settling is assumed.
7. This concentration represents a 24 hour average net concentration increase of Tri+ in the water column. This value should be added to the estimated existing Tri+ concentration generated by the river sediments. It is based on 9 hours of operation for 3 bucket dredges. This concentration assumes the river to be well mixed and ignores further settling or
8. This represents the net additional Tri+ PCB load assuming 30 weeks of operation 6 days per week.
9. This value is the sum of additional Tri+ PCB released over the entire period of dredging in the river section
10. A flow of 3000cfs was also used in River Section 3. Note that the flow corresponding to 3000cfs in River Section 1 would be about 5000cfs in Section 3, resulting in further
11. This block represents time-weighted average concentrations and loads as well as cumulative PCB release for the entire remediation period.

Table E.6-3
Estimate of Dredging Resuspension Rates for the REM-3/10/Select Alternative

Dredge Type	No. of Units in Operation	Production Rate Per Dredge cy/hr	Sediment Resuspension Losses Per Dredge						Tri+ PCB Concentration on Sediments [4] mg/kg	Duration [5] years	Resulting Downstream Instantaneous PCB Flux [6] mg/s	Resulting Downstream Concentration Increase [7] @3000 cfs ng/L	Resulting Downstream PCB Load Increase [8] @3000cfs kg/yr	Resulting PCB Release [9] kg
			Cohesive Sediment Loss Rate [1] kg/s	Cohesive Sediment Percent Of Mass [2]	Noncohesive Sediment Loss Rate [1] kg/s	Noncohesive Sediment Percent Of Mass [2]	Mean Resuspension Rate Per Dredge kg/s	Mean Resuspension Rate Under Operation [3] kg/s						
Section 1 - Expanded Hot Spots														
12 in Cutterhead	1	270	0.17	37%	0.053	63%	0.096	0.096	8	3	0.29	2.4	3.2	10
4 -cy Conventional Enclosed Bucket	3	95	0.07	37%	0.022	63%	0.040	0.119	8	3	0.58	4.0	5.3	16
Section 2 - Hot Spots														
12 in Cutterhead	1	270	0.17	62%	0.053	38%	0.126	0.126	23	1	1.1	9	12	12
4 -cy Conventional Enclosed Bucket	3	95	0.07	62%	0.022	38%	0.052	0.155	23	1	2.2	15	20	20
Section 3 - Select Hot Spots														
12 in Cutterhead	1	270	0.17	62%	0.053	38%	0.126	0.126	13	1	0.6	5	7	7
4 -cy Conventional Enclosed Bucket	3	95	0.07	62%	0.022	38%	0.052	0.155	13	1	1.2	8	11	11
Summary of Impacts (Time-weighted)[11]														
12 in Cutterhead	1	270	0.17	47%	0.053	53%	0.108	0.108	12	5	0.5	4	6	28
4 -cy Conventional Enclosed Bucket	3	95	0.07	47%	0.022	53%	0.045	0.134	12	5	1.0	7	9	47

Notes:

1. This loss rate represents particles less than 74 µm (*i.e.,* silts and clays)
2. This is the precentage of mass being dredged which is cohesive or non-cohesive, as noted. The value is used to weight the loss rate term to yield a mean resuspension rate for the river
3. This represents the loss rate for 1 cutter head dredge or three bucket dredges, which yield equivalent production rates.
4. This is the volume weighted average Tri+ PCB concentration in the dredge material. The value is assumed to be the concentration of Tri+ on the resuspended sediment.
5. Duration of dredging operation in the reach.
6. This is the net Tri+ PCB flux 10m downstream of the dredge head during operation. No further settling is assumed.
7. This concentration represents a 24 hour average net concentration increase of Tri+ in the water column. This value should be added to the estimated existing Tri+ concentration generated by the river sediments. It is based on 17 hours of operation for the cutter head and 14 hours of operation for the 3 bucket dredges. This concentration assumes the river to be
8. This represents the net additional Tri+ PCB load assuming 30 weeks of operation 6 days per week.
9. This value is the sum of additional Tri+ PCB released over the entire period of dredging in the river section
10. A flow of 3000cfs was also used in River Section 3. Note that the flow corresponding to 3000cfs in River Section 1 would be about 5000cfs in Section 3, resulting in further reduction
11. This block represents time-weighted average concentrations and loads as well as cumulative PCB release for the entire remediation period.

Table E.6-4
Estimate of Dredging Resuspension Rates for the REM-0/0/3 Alternative

Dredge Type	No. of Units in Operation	Production Rate Per Dredge cy/hr	Sediment Resuspension Losses Per Dredge						Tri+ PCB Concentration on Sediments [4] mg/kg	Duration [5] years	Resulting Downstream Instantaneous PCB Flux [6] mg/s	Resulting Downstream Concentration Increase [7] @3000 cfs ng/L	Resulting Downstream PCB Load Increase [8] kg/yr	Resulting PCB Release [9] kg
			Cohesive Sediment Loss Rate [1] kg/s	Percent Of Mass [2]	Noncohesive Sediment Loss Rate [1] kg/s	Percent Of Mass [2]	Mean Resuspension Rat Per Dredge kg/s	Mean Resuspension Rat Under Operation [3] kg/s						
Section 1 - Full Section														
12 in Cutterhead	1	270	0.17	26%	0.053	74%	0.083	0.083	8	4	0.25	2.1	2.8	11
4 -cy Conventional Enclosed Bucket	3	95	0.07	26%	0.022	74%	0.034	0.103	8	4	0.51	3.5	4.6	18
Section 2 - Full Section														
12 in Cutterhead	1	270	0.17	26%	0.053	74%	0.083	0.083	15	2	0.5	4	5	10
4 -cy Conventional Enclosed Bucket	3	95	0.07	26%	0.022	74%	0.034	0.103	15	2	0.9	7	9	17
Section 3 - Expanded Hot Spots														
12 in Cutterhead	1	270	0.17	62%	0.053	38%	0.126	0.126	14	1	0.7	5	7	7
4 -cy Conventional Enclosed Bucket	3	95	0.07	62%	0.022	38%	0.052	0.155	14	1	1.3	9	12	12
Summary of Impacts (Time-weighted)[11]														
12 in Cutterhead	1	270	0.17	31%	0.053	69%	0.089	0.089	11	7	0.4	3.1	4.1	29
4 -cy Conventional Enclosed Bucket	3	95	0.07	31%	0.022	69%	0.037	0.111	11	7	0.7	5	7	48

Notes:
1. This loss rate represents particles less than 74 µm (*i.e.,* silts and clays)
2. This is the precentage of mass being dredged which is cohesive or non-cohesive, as noted. The value is used to weight the loss rate term to yield a mean resuspension rate for the river
3. This represents the loss rate for 1 cutter head dredge or three bucket dredges, which yield equivalent production rates.
4. This is the volume weighted average Tri+ PCB concentration in the dredge material. The value is assumed to be the concentration of Tri+ on the resuspended sediment.
5. Duration of dredging operation in the reach.
6. This is the net Tri+ PCB flux 10m downstream of the dredge head during operation. No further settling is assumed.
7. This concentration represents a 24 hour average net concentration increase of Tri+ in the water column. This value should be added to the estimated existing Tri+ concentration generated by the river sediments. It is based on 17 hours of operation for the cutter head and 14 hours of operation for the 3 bucket dredges. This concentration assumes the river to be well mixed and
8. This represents the net additional Tri+ PCB load assuming 30 weeks of operation 6 days per week.
9. This value is the sum of additional Tri+ PCB released over the entire period of dredging in the river section
10. A flow of 3000cfs was also used in River Section 3. Note that the flow corresponding to 3000cfs in River Section 1 would be about 5000cfs in Section 3, resulting in further reduction of the
11. This block represents time-weighted average concentrations and loads as well as cumulative PCB release for the entire remediation period.

HUDSON RIVER PCBs REASSESSMENT FS

APPENDIX E

ENGINEERING ANALYSIS

ATTACHMENT TO E.6: PRELIMINARY ASSESSMENT OF WATER QUALITY IMPACTS ASSOCIATED WITH HUDSON RIVER PCBs SUPERFUND SITE CLEANUP ACTIVITIES

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NOVEMBER 2000

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1.0 INTRODUCTION

EPA is investigating alternative remedies for the Hudson River PCBs Superfund site. One alternative under consideration is to dredge the sediments from the river using either hydraulic or mechanical dredges. TAMS Consultants is completing a comprehensive evaluation of dredging alternatives including an evaluation of the implications of applying various dredging technologies.

1.1 Scope

The purpose of this report is to provide a preliminary evaluation of the water quality impacts that will be associated with dredging. Site conditions, operational plans, and dredge production estimates used in the preliminary evaluation are all based upon work by TAMS Consultants with support from Gahagan and Bryant and YEC, Inc.

For the purposes of this report, the term “water quality impacts” refers only to resuspension and transport of suspended sediment and associated PCB concentrations. The majority of the report focuses on sediment resuspension although a short discussion of PCB transport and partitioning is provided in Section 5.

1.2 Review of Pertinent Site Conditions

The hydraulics of the Upper Hudson are relatively complex, typical for a large river channel with widely varying water depths. Water depths in the river system range from 2 to 23 ft. Current velocities range from 0.05 to 1.5 ft/sec. Chemical and physical characteristics of the PCB contaminated sediments vary spatially in both the lateral and vertical dimensions. Sediment characteristics range from cohesive sandy-silt sediments to non-cohesive silty-sand sediments. Removal thickness is predominantly 2 to 5.5 ft in most areas.

As a result of these variations, the characteristics of the dredging operation will also vary significantly from between areas. This assessment will not attempt to consider all of these complexities, but rather focus on typical dredging scenarios. Only cohesive sediments are considered since they will result in the highest resuspension. Depending upon the dredging scenario, however, a considerable portion of the dredging will involve dredging non-cohesive sediments that will have substantially lower water quality impacts.

1.3 Existing Procedures for Estimating Sediment Resuspension from Dredging Operations

Defensible estimates of water quality impacts require three components: source term estimates, far-field transport estimates, and review of field data from comparable sites. The latter is necessitated by the large uncertainty associated with source term estimates. This section briefly summarizes the current state-of-the-science, focusing primarily on near-field models and available field data.

1.3.1 Summary of Available Field Data

Interest in sediment resuspension resulting from dredging activities primarily began in the 1970s. The early work in the US was conducted by Huston and Huston (1976), Bohlen and Tramontaro (1977), and Barnard (1978). These included limited data from a few field studies, with the most comprehensive data collected by Bohlen and Tramontaro (1977). Despite these initial US efforts, Japanese researchers seem to have conducted most comprehensive studies of sediment resuspension resulting during the 1970s. A number of papers and reports were published describing field studies including Yagi, *et al.* (1975), Koba (1976), Koiwa *et al.* (1977), Yagi, *et al.* (1977), and Nakai (1978). Although these reports seem to describe very comprehensive field studies, the reports are not in sufficient detail to utilize the data to its fullest. It is clear from these reports and papers that the studies conducted during this time were primarily focused upon navigational dredging efforts rather than remedial dredging.

Efforts in the 1980s began to focus on contaminated sediments. However, the focus was more on contaminated sediments that had migrated into the navigation channel and were impacting navigational dredging operations than dredging aimed at remediation. Japanese efforts continued as described by Koba and Shiba (1981, 1982), Koba (1985), and Kaneko, *et al.* (1984). Herbich and Brahme (1991) provide an excellent summary of research conducted by US and Japanese researchers until about 1985.

In the US, the U.S. Army Corps of Engineers and others undertook a number of field studies. Pertinent references include Raymond (1984), Hayes, McLellan, and Truitt (1988), McLellan, *et al.* (1989), and Kuo, *et al.* (1985). Still, most of these studies focused on navigational dredging rather than remediation. For example, barge overflow occurred during all of the bucket dredging operations. Only Hayes, McLellan, and Truitt (1988) describes investigations aimed primarily at remediation dredging and the bucket dredge study described there also included barge overflow. In 1989, several dredges were field tested in New Bedford Harbor to determine their suitability for dredging contaminated sediments. Sediment resuspension and PCB release data collected during the dredging operations are reported in (NED 1990).

Several field studies have also been conducted in the 1990’s and these have focused more specifically on remediation dredging. Additionally, water quality monitoring in association with actual remediation dredging operations provides some data that is worthy of consideration. These data, however, are less useful since most consist of only a few data points and usually without specific association to dredging operations.

Field studies of sediment resuspension and transport around cutterhead dredging operations were conducted in association with pilot dredging operations in Lavaca Bay, Texas during August 1998 and January 1999. First, extensive data on sediment resuspension were collected around an 18-inch dredge removing silty sediment above a clay bottom in about 20 ft of water. Then, a 12-inch dredge was monitored while removing 3 to 5 ft of silty clay sediment from a shallow mud-flat. Data from these field studies is provided in Wu and Hayes (2000).

Hayes, *et al.* (2000) describe suspended sediment and turbidity data collected in the immediate vicinity of bucket dredging operations in Boston Harbor in August 1999. Three bucket types were monitored during this study – enclosed clamshell, standard clamshell, and CableArm navigational bucket. Since all of the data were collected while dredging similar sediments under similar conditions, they provide a reasonable comparison of the bucket characteristics.

1.3.2 Near-field Models

The near-field model most often used is that proposed by Nakai (1978). The most attractive feature of Nakai's approach is its simplicity:

$$W_O = TGU\left[\left(\frac{R_O}{R_{74}}\right)Q_S\right]$$

where W_o = total quantity of turbidity generated by dredging, tons
TGU = turbidity generation unit, tons/m^3
R_{74} = fraction of particles with a diameter smaller than 74 microns
R_0 = fraction of particles with a diameter smaller than the diameter of a particle whose critical resuspension velocity equals the current velocity in the field
Q_s = in situ volume of dredged materials, m^3

The TGU term is intended to integrate site conditions and dredge type, size, and operation into a single value while the remainder of the formulation incorporates sediment properties. Nakai provided a table of TGU values for a variety of dredges and dredge sizes calculated by measuring TSS along laterals normal to flow at 30 m and 50 m downstream from the dredging operation. Only limited descriptions of the field investigations on which these values are based were provided in the paper. Pennekamp, *et al.* (1996) provide additional TGU values based upon field studies in Europe.

A few items are worthy of note. First, Nakai used turbidity to refer to suspended solids concentration rather than actual turbidity (i.e. light absorption) measurement. Secondly, the immediate focus is on the rate of solids resuspended as required for input to transport models. Nakai's original equation can be modified to give rate of resuspension:

$$w_O = TGU\left[\left(\frac{R_O}{R_{74}}\right)q_S\right]$$

where

w_0 = rate of sediment resuspension by dredging, tons/sec
q_S = in situ volume of dredged materials, m^3/sec

Nakai's approach, however, has a fundamental problem, specifically the term R_0Q_S/R_{74}. R_0Q_S represents the fraction of sediment that, if resuspended would theoretically remain in suspension forever since the ambient velocity exceeds their critical resuspension velocity; if the velocity is sufficient to resuspend the particles, they will certainly stay in suspension at that velocity. However, the $1/R_{74}$ term modifies W_0, incorrectly; as the fraction of particles smaller than 74 microns increases, W_0 decreases. Logically, more resuspension is expected from smaller particle sizes. Nakai's equation receives widespread use despite this erroneous behavior. It may be because, except in extreme situations, $R_0 < R_{74}$ so the term

$$\left(\frac{R_O Q_S}{R_{74}}\right) < Q_S$$

which tends to mask the problem. It is surprising that this problem has not been noted more widely.

The only other known source-strength models began their development with Hayes (1986). These models focus solely on cutterhead dredges and attempt to integrate dredge operation characteristics with site conditions and are based only upon field studies with predominantly fine-grained sediments. The latest models, published by Wu and Hayes (2000), are of the form:

$$\text{DM:}\quad \hat{g}_{DM}(\%) = \frac{(C_S t_C)^{0.676} V_S^{\;2.008}}{10^{3.647} L_S^{\;13.899}} \left(\frac{A_E}{d_C}\right)^{14.575} \left(\frac{Q}{D^2}\right)^{0.805}$$

$$\text{NDM:}\quad \hat{g}_{NDM}(\%) = 10^{-3.3293} \left(\frac{A_E}{L_S d_C}\right)^{13.503} \left(\frac{Q}{D^2 V_S}\right)^{0.388}$$

where

$\hat{g}$ = predicted rate of sediment suspended by the cutter and available for transport away from the dredging operation as a fraction of sediment mass dredged (percent)
C_S = in-situ sediment concentration (g/L)
t_c = thickness of cut (m)
V_S = swing velocity at the tip of the cutter (m/sec)
a = cutter rotation speed (rev/sec)
L_s = dredge stepping distance (m)
A_E = cutter surface exposed to free water (m^2)
d_C = diameter of cutter (m^2)
Q = volumetric flow rate through dredge (m^3/sec)
D = sediment inlet pipe diameter (m)

The DM and NDM designations refer to the basis used for developing the empirical models as described by Hayes *et al.* (2000). Although different, both models provide equally valid estimates for source strength. Hayes *et al.* (2000) also provides equations to calculate A_E based upon the cutter size, ladder angle, and cutting depth.

The variable $\hat{g}$ is analogous to Nakai’s TGU, although the units are different. The actual rate of sediment resuspension, g, can be calculated from $\hat{g}$ as:

$$g = m_s(\hat{g}/100)$$

where

$$m_S = 3600 C_S L_C t_C V_S$$

and

g = predicted rate of sediment suspended by the cutter and available for transport away from the dredging operation (kg/hr)
L_C = length of the cutterhead (m)

The primary drawback of this approach is that it requires some basic knowledge of the dredging operation to utilize.

Collins (1995) developed a similar model for bucket dredges. Unfortunately, the bucket dredge model is much less developed than the hydraulic dredge models.

1.3.3 Far-field Models

Many suspended sediment models have been developed that are capable of estimating suspended solids concentrations in the vicinity of the dredging operation. However, a few have been developed specifically for dredging sources. Cundy and Bohlen (1980) developed the first known model of this type. The models recommended for use here combine simplifying assumptions and characteristics of the dredge operation to allow analytical solutions to the transport equation. While these are not the most accurate transport models available, they are adequate for the planning-level reviews in this report. The far-field transport model for hydraulic cutterhead dredges was developed by Kuo, *et al.* (1985):

$$c(x,y,z) = \frac{1000g}{4px\sqrt{k_Y k_Z}} e^{-\left[\frac{u(z + wx/u)^2}{4k_Z x}\right]}$$

where

$c(x,y,z)$ = TSS concentration at any x, y, z coordinate, mg/L
k_y = lateral (y-direction) dispersion coefficient, m^2/sec
k_Z = vertical (z-direction) dispersion coefficient, m^2/sec
u = ambient velocity in x-direction , m/sec
w = settling velocity of suspended sediment particles, m/sec

A similar far-field transport model was developed by Kuo and Hayes (1991) for bucket dredging operations and is given by

$$c(x,y) = \frac{g}{uh\sqrt{4pk_Y x/u}}\, e^{-\left[\frac{uy}{4k_Y x} + \frac{wx}{hu}\right]}$$

2.0 HYDRAULIC CUTTERHEAD SOURCE STRENGTH ESTIMATES

Hydraulic cutterhead dredges are capable of dredging the Upper Hudson River and are an alternative under consideration for removing the contaminated sediments. It is assumed that a 12-inch hydraulic cutterhead dredge will be used for the project. The estimated the average production rate and flowrate of the dredge are 270 cy/hr (353 m^3/hr) and 8,000 gpm, respectively. The 600 HP dredge would use a 40-inch diameter by 42-inch long basket-type cutter.

Generally, swing speeds that result in a tangential speed at the cutter of less than 1 ft/sec are recommended to minimize turbidity generation. However, swing speed and step should be matched with the sediment thickness being removed so that the amount of sediment “attacked” by the dredge is similar to the anticipated production rate. Faster swing rates will result in excessive residuals; slower feed rates will reduce the solids concentration in the slurry. For a cut thickness of 2 ft and a forward step of 2 ft, a swing speed of about 0.5 ft/sec mathematically provides the appropriate sediment feed rate to the suction.

Based upon data collected during studies of the Upper Hudson River, the cohesive sediments to be removed are primarily sandy-silts with a density of 0.71 tons/yd^3 (58 percent solids or 844 kg/m^3). Non-cohesive sediments are primarily silty-sands with a density of 1.16 tons/yd^3 (76 percent solids or 1,379 kg/m^3). Both sediments should be free-flowing and require little cutting effort by the cutter blades; thus, their primary function will be in guiding the sediments to the suction pipe. This can be accomplished with a relatively slow rotation speed. A rotation speed that results in a tangential cutter speed of 1 ft/sec will be used for resuspension assessments. This probably represents a normal or above normal value for this size dredge and it seems practical to reduce that to 0.5 ft/sec during the actual dredging operation if possible. Many dredges of this size do not have variable cutter speeds, but that could be installed at a nominal cost for this project.

2.1 Nakai's TGU Estimates

Nakai provided TGU values for three hydraulic dredging studies removing silty sediments in his original paper. The values were 5.3, 9.9, and 22.5 kg/m^3. Nakai provided only pump horsepower as a reference to dredge size and two of the three studies used a dredge with a 4,000 HP pump; the 9.9 kg/m^3 was from a dredge with 2,500 HP. These suggest much larger dredges than the 12-inch, 600 HP dredge proposed for the Hudson River. Pennekamp, *et al.* (1996) did not provide any new TGU values. However, these three studies involved sediments consisting of 94 to 99 percent smaller than 74 mm where the Hudson River sediments are closer to 65 percent (cohesive sediments) and 20 percent (non-cohesive sediments). If Nakai's formulation is followed exactly, this discrepancy illuminates the problems with the R_{74} term described previously. To combat this problem, it seems logical to attempt to recreate Nakai's observed rate of resuspension for the projects; i.e.

$$\frac{W_0}{Q_S} = TGU\left(\frac{R_O}{R_{74}}\right)$$

Nakai did not provide values of R_0, but a conservative value of 1.0 can be used and the equation simplifies to TGU/R_{74}. The three field studies presented by Nakai yield 5.4, 10.5, and 22.8 kg/m^3. For an in situ sediment density of 0.71 tons/yd^3 (844 kg/m^3), these values represent mass loss rates of 0.64 percent, 1.24 percent, and 2.70 percent (percent values are by mass). Using a production rate of 270 cy/hr (206 m^3/hr), the mass generation rates, w_0, are 0.53 kg/sec, 1.03 kg/sec, and 2.24 kg/sec. Of these values, the middle values of 10.5 kg/m^3, 1.24 percent, and 1.03 kg/sec are associated with the smaller dredge with 2500 HP. All of these values should be rather conservative since only the fine fraction of particles (smaller than 74 microns) are subject to sediment resuspension. In cohesive Thompson Island Pool sediments, this is only about 65 percent of the total sediment mass and far less in the non-cohesive sediments.

2.2 Wu and Hayes Model Estimates

Both models presented by Wu and Hayes (2000) were used to estimate the rate of sediment resuspension for the physical and operational dredge characteristics described above and ranges of sediment removal thickness and water depths that represent the expected site conditions. The resulting estimates are shown in Table 1.

All estimates for the 40-inch cutter are less than 0.5 percent loss except for those with a 3-ft cut. The larger values for the 3-ft cut result from having a cutter diameter larger than the sediment removal thickness. It is generally accepted that more resuspension results from times when the cut thickness is less than the cutter diameter. However, the field data on which Wu and Hayes' equations are based contained only a few observations of these type cuts. Thus, it is believed that these values result from the power forms of the equations that are overly sensitive to A_E and probably do not represent reliable estimates. It should be noted that such high resuspension rates have not been observed in any field studies to date.

Table 1. Resuspension estimates from Wu and Hayes models for different sediment removal thickness and pre-dredging water depths.

Water Depth (ft)	8_{DM} (%)	8_{NDM} (%)	Water Depth (ft)	8_{DM} (%)	8_{NDM} (%)	Water Depth (ft)	8_{DM} (%)	8_{NDM} (%)
t_c = 3 ft			t_c = 4 ft			t_c = 5 ft		
40-inch cutter								
5	1.0	0.7	5	0.4	0.3	5	0.5	0.3
10	2.8	1.7	10	0.4	0.3	10	0.5	0.3
15	7.5	4.2	15	0.4	0.3	15	0.5	0.3
20	18.9	10.1	20	0.4	0.3	20	0.5	0.3
36-inch cutter								
5	0.2	0.2	5	0.1	0.1	5	0.1	0.1
10	0.6	0.4	10	0.1	0.1	10	0.1	0.1
15	1.6	1.0	15	0.1	0.1	15	0.1	0.1
20	4.0	2.4	20	0.1	0.1	20	0.1	0.1
Operating and site characteristics used to calculate the values above:								
V_S = 0.21 m/sec			Q = 0.50 m^3/sec			D = 0.30 m		
L_s = 0.46 m			C_S = 844 g/L			d_C = 0.76 m		

For comparison purposes, Table 1 also includes values for a 36-inch cutter. These values are much more reasonable with only a few values greater than 1 percent and the largest value of 4.0 percent. While this suggests that it might be reasonable to use a smaller cutter, it also verifies the expectation that the extremely high numbers for the 40-inch cutter are erroneous.

2.3 Comparable Field Data

Two field studies have gathered resuspension data near the cutter of 12-inch cutterhead dredges – the Dubuque in Calumet Harbor, IL in 1985 and the Tyro, Jr. in Lavaca Bay in 1999. Unfortunately, site conditions at neither of these represents the Upper Hudson, although Calumet Harbor is the closest. Calumet Harbor sediments were a silty loam with about 85 percent smaller than 74 microns. The Dubuque used a 3-ft diameter cutter and approximately 3 ft of sediment was removed during all passes from a depth of 27 ft. Current velocities were generally less than 0.3 ft/sec. The Lavaca Bay study involved dredging about 4 ft of silty-clay sediment from a shallow flat (1 to 5 ft deep) subject to strong tidal conditions. The cutter diameter was similar and many different operational strategies were used. A shroud covered the top of the cutter during much of the operation, but it is unclear if it had any significant impact upon sediment resuspension.

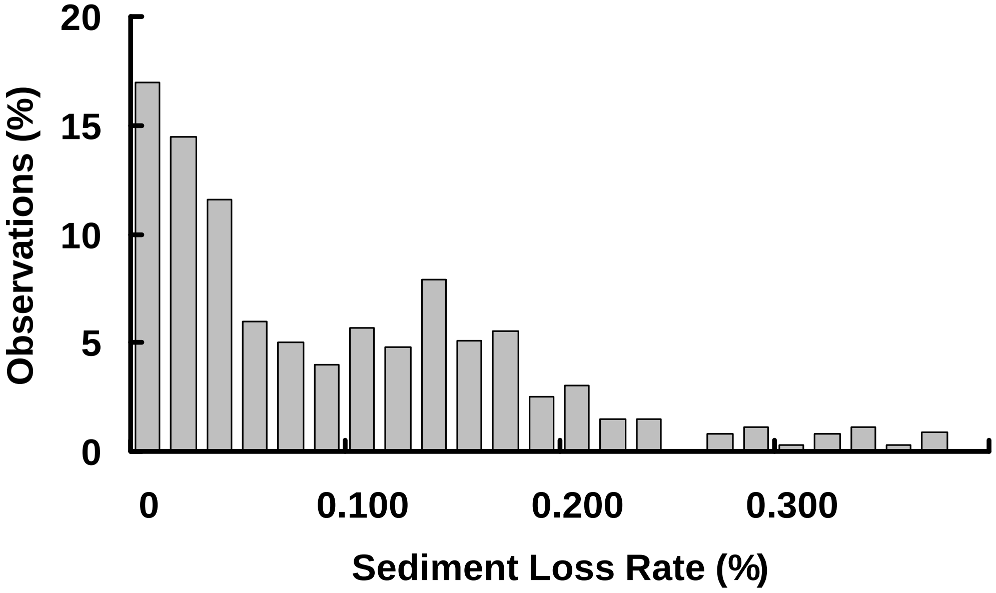

Figure 1. Histogram of observed sediment resuspension rates as percent of sediment removed.

In both cases, water samples were taken very near the cutter and analyzed for total suspended solids (TSS) concentration. Data taken simultaneously were averaged and combined with the dredge operation to calculate the mass rate of sediment resuspension. Dividing by the rate of sediment removal and multiplying the result by 100 gives the rate of sediment loss due to resuspension in percent. Figure 1 shows the observed resuspension rates during the two field studies. All observed values were below 0.4 percent with the majority less than 0.2 percent.

2.4 Summary

The field data and model results are in reasonable agreement with both suggesting sediment loss rates of less than 0.5 percent. Nakai's single observation from a much larger dredge seems to give a higher loss rate of 1.24 percent using rather conservative assumptions. Assessing these independent observations suggests that selecting a sediment loss rate of approximately the maximum observed for a 12-inch dredge during the Calumet Harbor and New Bedford operations, about 0.35 percent, should represent a reasonably conservative estimate of sediment resuspension during the dredging of the Upper Hudson. The sediment resuspension rate for a dredge production of 270 cy/hr (206 m^3/hr) in sediment with an in situ density of 0.71 tons/cy (844 kg/m^3) with a 0.35 percent loss would be approximately 0.17 kg/sec.

3.0 ENCLOSED CLAMSHELL SOURCE STRENGTH ESTIMATES

Bucket dredges are another option for removing the PCB-contaminated sediments. Mechanical dredges have several advantages including being more mobile and having less impact on vessel traffic. Three main disadvantages have been cited. First, the material must be rehandled, thereby increasing the costs. However, there may be little economic penalty for the Upper Hudson River project because the long distances to the treatment and disposal areas pose difficulties for hydraulic dredges. Second, traditional buckets result in an uneven bottom and must remove more excess uncontaminated sediments to get the contaminated layers. Fortunately, new buckets are available that dredge a flat bottom. Lastly, a perception that water quality impacts associated with bucket dredges are significantly higher than for hydraulic cutterhead dredges persists based primarily on data gathered during navigational dredging operations that allowed barge overflow (McLellan *et al.* 1989). Barge overflow is not usually allowed in environmental dredging operations. Additionally, new buckets such as the watertight clamshells, the CableArm Environmental Bucket, and the Horizontal Profile Bucket have been designed to reduce resuspension during dredging.

The enclosed clamshell bucket (referred to as a "watertight" bucket by some) is a relatively inexpensive modification to a traditional clamshell bucket and has been demonstrated to generate substantially less resuspension than the traditional bucket. Thus, it is expected that any bucket dredging operations in the Upper Hudson Project would either use a watertight clamshell dredge or a bucket that would generate even less resuspension. Considering the available draft and limited size of locking facilities on the Upper Hudson, it is assumed that a 4-cy bucket will be used in the area. Typical 4-cy bucket dredging operations operate at a cycle time of 45 to 60 seconds. However, additional restrictions such as reduced bucket fall speeds and extra care on behalf of the operator will increase the cycle time. A 2-minute cycle time is estimated to be realistic and is used in all calculations. That yields a production rate of 95 cy/hr for an 80 percent fill rate.

3.1 TGU Estimates

Nakai (1978) provided TGU values for three sizes of bucket dredges (note that Nakai's term is "grab" dredger) – 3 m^3 (3.9 yd^3), 4 m^3 (5.2 yd^3), and 5 m^3 (6.5 yd^3). Nominal production rates for these type buckets is estimated to be 190 cy/hr, 250 cy/hr, and 500 cy/hr respectively assuming an 80 percent fill rate and 1-minute cycle time. Although not specifically mentioned, these were almost certainly standard clamshell buckets. Observed TGU values were 89.0 and 84.2 for the two larger buckets working in silty clay and clay sediments; three TGU observations of 15.8, 11.9, and 17.1 kg/m^3 were provided for the smaller bucket dredging silty loam sediments.

Pennekamp *et al.* (1996) calculated a TGU value of 3 kg/m^3 for an open clamshell with a production rate of 118 cy/hr (90 m^3/hr). They also determined the TGU for a watertight clamshell with a production rate of 217 cy/hr (166 m^3/hr) to be 19 kg/m^3. They also indicated that a vertically averaged TSS concentration of 100 mg/L above background was observed during the dredging operation. Assuming a typical cycle time and fill rate suggests that it was probably a 3 m^3 (3.9 cy) bucket.

It seems that the TGU of 19 kg/m^3 observed by Pennekamp *et al.* (1996) is the most representative of a dredging operation that used a bucket size applicable to the Upper Hudson. For an in situ sediment density of 0.71 tons/yd^3 (844 kg/m^3), this represents a sediment resuspension rate of 2.2 percent and a source generation rate of 0.38 kg/sec for a 95-cy/hr (73 m^3/hr) production rate.

3.2 Comparable Field Data

Several field studies of sediment resuspension resulting from bucket dredging operations have been conducted. Kuo and Hayes summarized the best estimates of source strength from three of these studies; the results are shown in Table 2.

Table 2. Summary of estimated resuspension losses for several bucket operations (from Kuo and Hayes 1991).

Field Study Location	Resuspension Loss (%)	Original Data Source
Thames River	0.88	Bohlen *et al.* (1979)
St. Johns River	0.11	Collins (1995)
Black Rock Harbor	0.28	Collins (1995)

The most recent data were collected in Boston Harbor in August 1999 (Hayes *et al.* 2000) during the operation of a 39-cy enclosed bucket. The enclosed bucket was a conventional 26-cy bucket converted to an enclosed bucket with a 39-cy capacity. The bucket removed about 2 feet of sediment from the 38-ft bottom with an observed depth-averaged TSS concentration of 50 mg/L. Assuming that concentration occurs across a 10-m width in a current velocity of 0.17 m/sec the source strength is about 1.1 kg/sec. The dredge production was about 2,000 cy/hr. Assuming the sediment concentration was the same as in the Hudson River, the sediment lost to resuspension is 0.31 percent. The source generation rate for this loss is 0.06 kg/sec for a 95-cy/hr (73 m^3/hr) production rate.

3.3 Summary

Observed sediment resuspension rates from enclosed bucket operations range from 0.11 percent to 2.2 percent. For a bucket size applicable to a dredging operation in the Upper Hudson, this represents a range of source strengths from 0.06 kg/sec to 0.38 kg/sec. The data from Pennekamp *et al.* (1996) seem out of line with the other observations. It is expected that the Boston Harbor data are probably more representative, especially considering that the operation will be conducted in a very conservative manner. Thus, a sediment loss rate of 0.3 percent seems to be a reasonable estimate for bucket dredging operations in the Upper Hudson River. This loss rate represents a source of 0.07 kg/sec.

4.0 HORIZONTAL PROFILER DREDGE SOURCE STRENGTH ESTIMATES

A hydraulically operated dredge called the horizontal profiler conducted test-dredging operations in New Bedford Harbor during the summer of 2000. The horizontal profiler utilizes a bucket attached to a hydraulically operated arm rather than a steel cable. The rigid arm increases operational control and should reduce sediment resuspension by eliminating bottom impact. Additionally, the bucket is outfitted with relief valves to reduce hydraulic pressure inside the bucket and seals to reduce leakage. Thus, it is expected that the total resuspension rate will be considerably less than for the enclosed bucket operations described above. Unfortunately, resuspension data from the New Bedford operations are not available at the time of this writing.

In the absence of field data or any predictive methodologies, the only approach to estimating the source rate is to assume that it is some fraction of the resuspension rate for the enclosed bucket. Since the horizontal profiler is expected to use the same size bucket, *i.e.* 4-cy, and the same cycle time of 2 minutes, a direct proportion seems justifiable. A reduction of approximately 50 percent compares to a source rate of 0.15 percent or 0.035 kg/sec. This seems to be a reasonable estimate assuming the dredge is operated with care.

5.0 ASSESSMENT OF WATER QUALITY IMPACTS

Near-field source estimates represent the rate at which sediment particles are introduced into the water column. They do not, however, provide any information on the downstream water quality impacts that result from the suspended sediments being transported away from the dredging site by ambient and induced currents. Additionally, dredge operation strongly influences the initial geometry of the resuspended sediments in the water column. In turn, this geometry has considerable influence on downstream transport.

A complete evaluation of water quality impacts requires integrating a calibrated hydrodynamic model of the system with a water quality model capable of predicting changes due to advection, turbulent diffusion, and settling of the suspended particles. Such a model is beyond the scope of this evaluation. It could even be debated that such a sophisticated transport model is unwarranted in any circumstances where the source rate is so uncertain. However, some assessment of downstream water quality impacts is useful to put the source terms in context. Fortunately, steady-state models for both cutterhead and bucket dredging operations have been developed (Kuo *et al.* 1985; Kuo and Hayes 1991). These models combine source geometry and hydrodynamic simplifications with an assumption of steady-state conditions to allow analytical solutions to the transport equation. Although their application is limited, these models provide reasonable estimates of water quality impacts.

5.1 Average Source Strength Values

Sections 2 and 3 described the basis for estimating sediment resuspension rates expected during dredging of the Upper Hudson River. These rates do not consider the makeup of the sediments being dredged. Only 65 percent of "cohesive sediments" is smaller than 74 microns and realistically available for resuspension and transport. About 20 percent of the non-cohesive sediments is smaller than 74 microns. Even if the resuspension rates developed above are assumed to apply to the cohesive sediments in the Upper Hudson, resuspension from the non-cohesive sediment areas will be considerably less. It is estimated that resuspension during dredging of non-cohesive sediments will be about 31 percent (0.20/ 0.65 = 0.31) of that from cohesive sediments. The long-term average resuspension rate should take into account that 70 percent of the sediments to be dredged from the Upper Hudson are non-cohesive. Table 3 summarizes the resulting sediment resuspension rates. These rates are used in the plume modeling described below.

Table 3. Summary of estimated resuspension losses for dredging operations in the Upper Hudson River.

Dredge	Sediment Resuspension Loss (kg/sec) Cohesive Sediments (30%)	 Non-cohesive Sediments (70%)	 Average
12-inch cutterhead	0.17	0.053	0.088
4-cy enclosed bucket	0.07	0.022	0.036

5.2 TSS Plume Estimates

Depth-averaged TSS concentrations were predicted using the far-field transport equations described above using conditions and values representative of the Upper Hudson River. A water depth of 3 m is used with a steady, unidirectional current velocity of 0.12 m/sec in the downstream direction. Chapra (1997) suggests a range of 3 to 30 m/d for the settling velocity of silt particles. Since data on settling rates were not available, a median value for settling velocity of 16.5 m/d (1.9×10^{-4} m/sec) was used in the transport calculations. Chapra (1997) also shows that lateral turbulent diffusion ranges from 5 to 10^6 cm^2/sec (5×10^{-4} to 10^2 m^2/sec). A value of 10 m^2/sec was used based upon the discussion by Kuo *et al.* (1985). Additionally, Kuo *et al.* found that a vertical diffusion coefficient (k_z) of 0.0005 m^2/sec was representative for the James River. Since this is consistent with Chapra's ranges, it was also used for the Upper Hudson River.

Kuo and Hayes' (1991) far-field transport equation gives depth-averaged TSS concentrations resulting from bucket dredging operations directly. Figure 2 shows the TSS isopleths for a source rate of 0.036 kg/sec.

The far-field transport equation presented by Kuo et al (1985) for hydraulic dredging operations gives TSS concentrations at specific depths. Depth-averaged TSS concentrations were determined from TSS values calculated for depths of 0.25, 0.75, 1.25, 1.75, 2.25, and 2.75 meters. Figure 3 shows the TSS isopleths for a source rate of 0.088 kg/sec. It should be noted that this assumes that the source is at the very bottom of the river as suggested by Kuo *et al.* (1985). Since the cutter resuspends sediments in the immediate vicinity of the cutter about 1

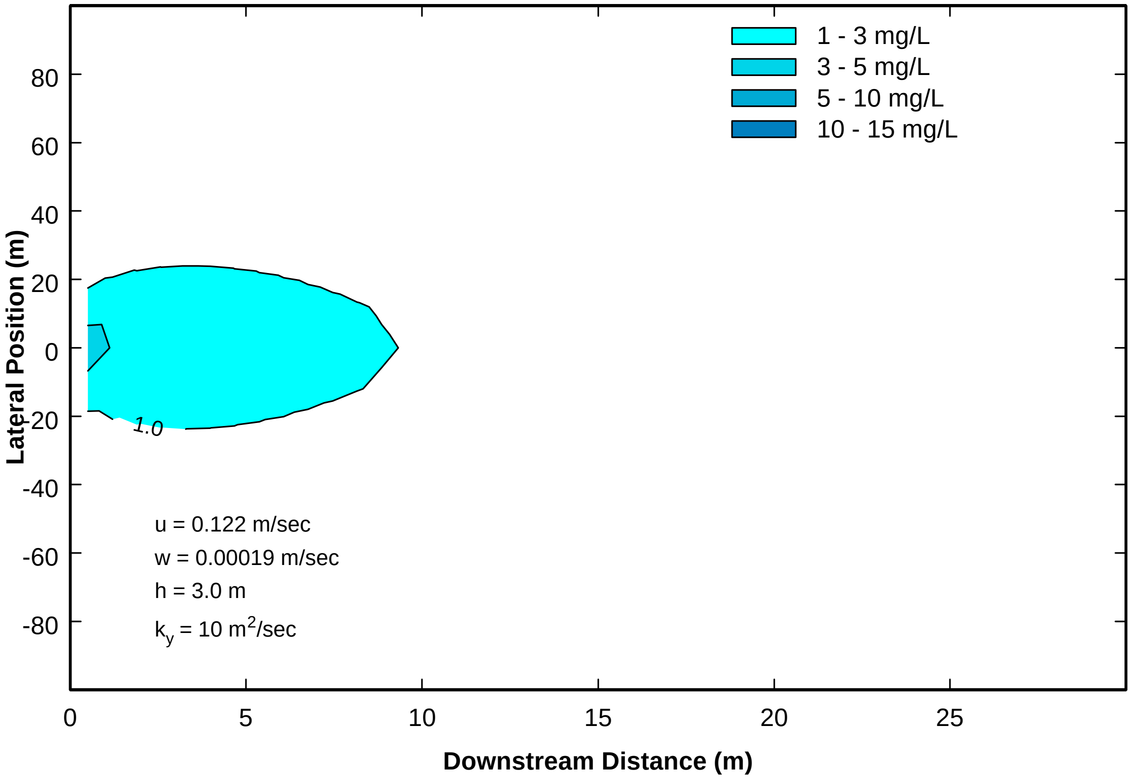

Figure 2. Depth-averaged TSS concentrations for enclosed bucket dredge operating in the Upper Hudson River.

meter or so vertically into the water column, it might be more realistic to move the source to 1 m above the bottom. This would increase the resulting TSS plume.

5.3 PCB Plume Estimates

5.3.1 Background

Solid-liquid partitioning of toxic contaminants is a complex physico-chemical process. A simple linear partitioning theory has been developed to represent the process. This is the basis for virtually all water quality models that include toxic contaminants. The basis for the concept is that the total contaminant concentration consists of both dissolved and particulate phases such that

$$C_T = C_d + C_p$$

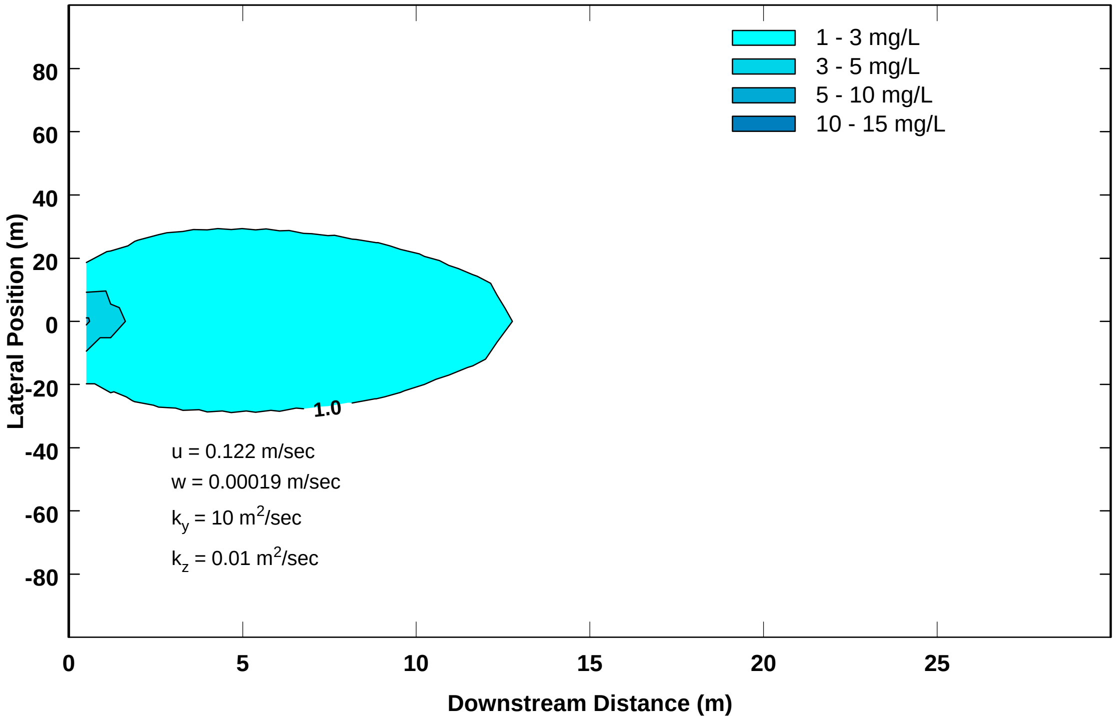

Figure 3. Depth-averaged TSS concentrations for hydraulic cutterhead dredge operating in the Upper Hudson River.

where

C_T = total contaminant concentration, mg/L
C_d = dissolved-phase contaminant concentration, mg/L
C_p = particulate-phase contaminant concentration, mg/L

And, the components are assumed to represent fixed fractions of the total concentration, *i.e.*

$$C_d = F_d C_T \qquad \text{and} \qquad C_P = F_P C_T$$

where

F_d = fraction of total contaminant concentration that is in the dissolved phase
F_P = fraction of total contaminant concentration that is in the particulate phase

These fractions are functions of the contaminant partitioning properties and the suspended solids concentration in the water. They can be calculated as:

$$F_d = \frac{1}{1 + K_d TSS} \qquad \text{and} \qquad F_P = \frac{K_d TSS}{1 + K_d TSS}$$

where

K_d = partitioning coefficient, L/kg
TSS = suspended solids concentration, mg/L

Ideally, these models would be incorporated into a transport model of the toxic constituent then solved simultaneously with the TSS transport equations that form the basis of the models presented by Kuo *et al.* (1985) and Kuo and Hayes (1991). Time limitations prevent that type of comprehensive model development. A conservative alternative is to apply the partitioning equations to TSS concentrations predicted by the applicable transport models presented previously. Particulate and dissolved concentrations tend to be higher using this approach because of the inability to consider dilution of the dissolved constituent and the effect of continually reduced bulk toxic constituent concentrations on particulate concentrations.

5.3.2 Congener Concentrations

Further transport calculations in this document consider only tri+ PCB congener concentration because of their ecological toxicity (USEPA 1998). It is estimated that the dredged material removed from the TI Pool will average between 8 and 9 mg/kg. However, based on historic sampling events, TI Pool contaminated sediments were found to average approximately 25 mg/kg. Computations will be completed for two sediment concentrations, 10 mg/kg to represent the average concentration in TI Pool dredged sediments and 25 mg/kg to represent historic analytical data.

5.3.3 Tri+ PCB Congener Transport

TSS concentrations from the TSS plume transport calculations described previously form the basis for estimating water column PCB concentrations. The partitioning coefficient (K_d) applicable to Hudson River tri+ PCB congeners is 10^5 L/kg based on analyses conducted for BZ #44 (USEPA 1997). Total tri+ PCB congener concentrations in the water column were calculated using the fundamental relationship

$$C_T = M_{PCB} TSS$$

where

M_{PCB} = mass of PCB absorbed on to the in situ sediment, mg/kg

For the two conditions described above, total tri+ PCB congener concentrations were determined as:

$$(C_T)_{avg} = 10*TSS \qquad \text{and} \qquad (C_T)_{max} = 25*TSS$$

where the resulting concentration values of C_T are in parts per trillion (ppt).

Figures 4 and 5 show predicted tri+ PCB congener water column concentrations for the average concentration of 10 ppm. Figures 6 and 7 show predicted tri+ PCB congener water column concentrations for the maximum average sediment concentration of 25 ppm.

While these estimates of total tri+ PCB congener concentrations represent cummulative concentrations, dissolved or particulate tri+ PCB congener concentrations may be of even greater interest. In particular, the dissolved water column concentrations tend to be of greater concern because of their increased bioavailability. Dissolved and particulate concentrations can be calculated as the product of F_d or F_p and the total tri+ PCB congener concentrations. F_d and F_p vary with TSS concentration as shown in Figure 8.

6.0 SUMMARY

Conservative estimates of TSS resuspension rates for enclosed bucket and hydraulic dredging operations in the Upper Hudson River were developed. These TSS source estimates were used as the drivers for simple TSS and PCB transport modeling. TSS transport model results suggest the turbidity plume during dredging operations will persist at low concentrations approximately 20 m downstream. Tri+ PCB congeners are the primary constituent of concern and exist at an average concentration of about 10 mg/kg in the TI Pool sediments and at concentrations about 25 mg/kg in cohesive sediments. The PCB plume exists in all areas of elevated TSS. However, the tri+ PCB congener concentrations are estimated to be under 20 ppt just downstream of the dredging operation. Table 4 shows estimates of the flux that leaves the dredging area, defined arbitrarily as 10 m downstream of the point of dredging.

The predicted TSS and PCB tri+ congener plumes from both dredging operations are relatively small. However, there are water quality impacts that must be considered. Additionally, applying the information presented here requires additional consideration in the construction phase of the project. Specifically, although the water quality impacts from a 12-inch hydraulic cutterhead dredge is greater than that of the 4-cy bucket dredge, the rate at which it can remove sediments is also higher. It is likely that multiple bucket dredges may need to operate simultaneously to achieve a reasonable project duration. The results of this analysis suggest that both dredge types can operate with limited water quality impacts and dredge selection should probably be based upon other factors such as cost, availability, and site conditions.

Table 4. Estimated tri+ PCB congener flux concentrations 10 m downstream from the dredging operation.*

Dredge	Plume Width (m)	Approx. Avg PCB Conc (ppt)	Estimated PCB Flux (µg/sec)
10 mg/kg sediment PCB concentration			
12-inch cutterhead	60	15	330
4-cy enclosed bucket	40	15	220
25 mg/kg sediment PCB concentration			
12-inch cutterhead	60 m	40	660
4-cy enclosed bucket	60 m	30	490

**Based upon a water depth of 3.0 m and average current velocity of 0.122 m/sec.*

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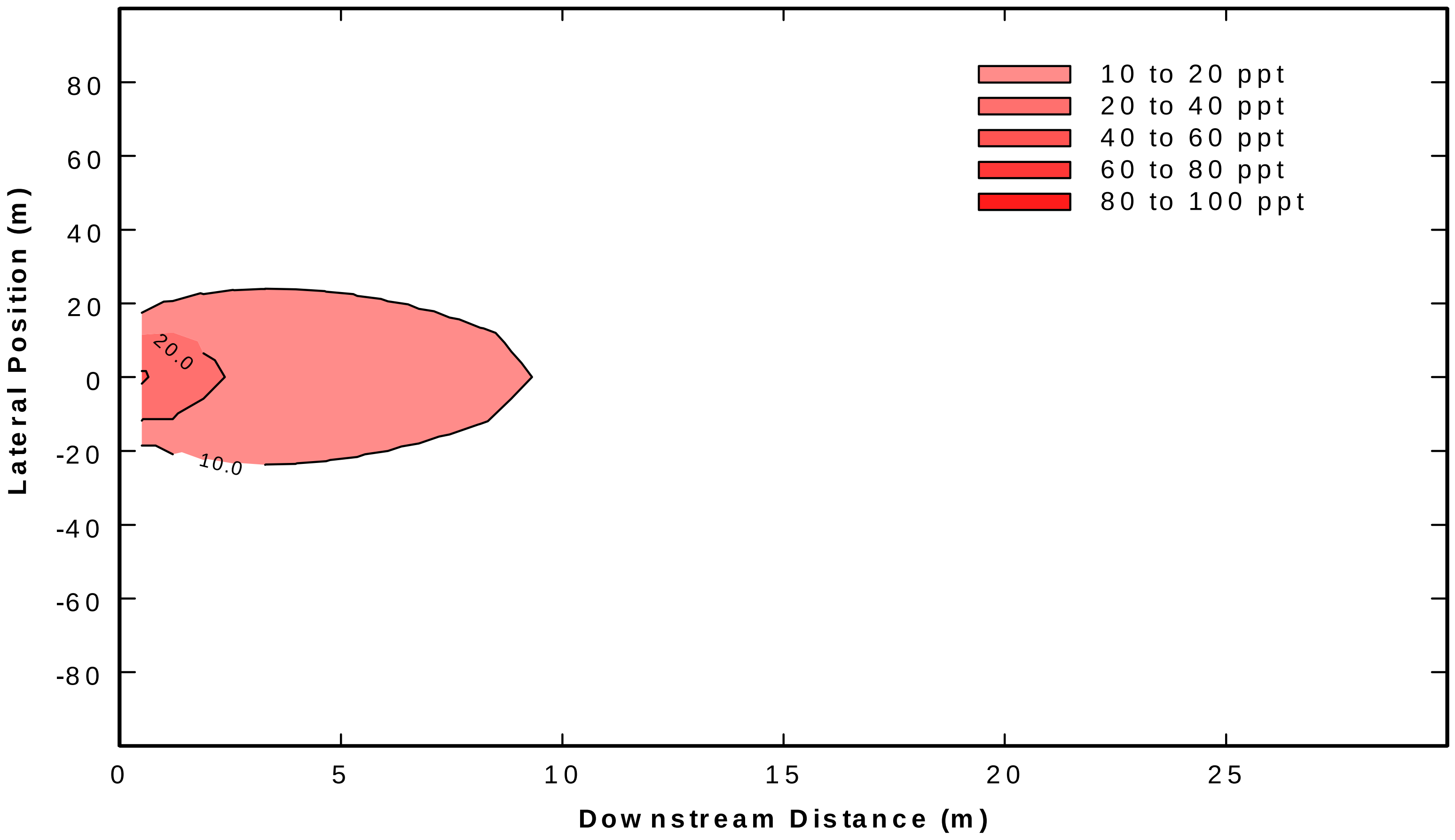

Figure 4. Estimated total tri+ PCB congener water column concentrations (ppt) during enclosed bucket dredging operations in the Upper Hudson based upon a sediment bulk Tri+ PCB concentration of 10 mg/kg.

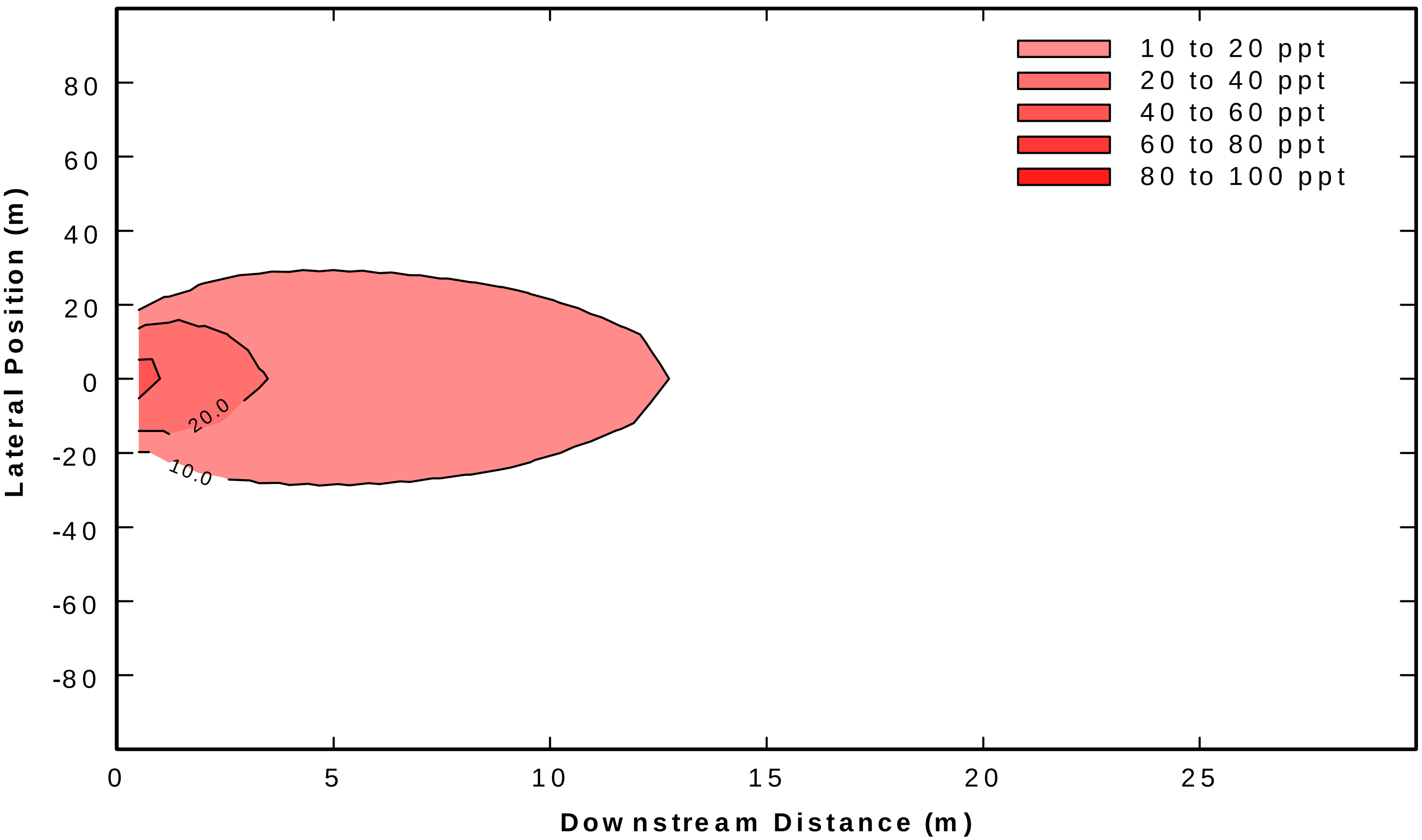

Figure 5. Estimated total tri+ PCB congener water column concentrations (ppt) during hydraulic cutterhead dredging operations in the Upper Hudson based upon a sediment bulk Tri+ PCB concentration of 10 mg/kg.

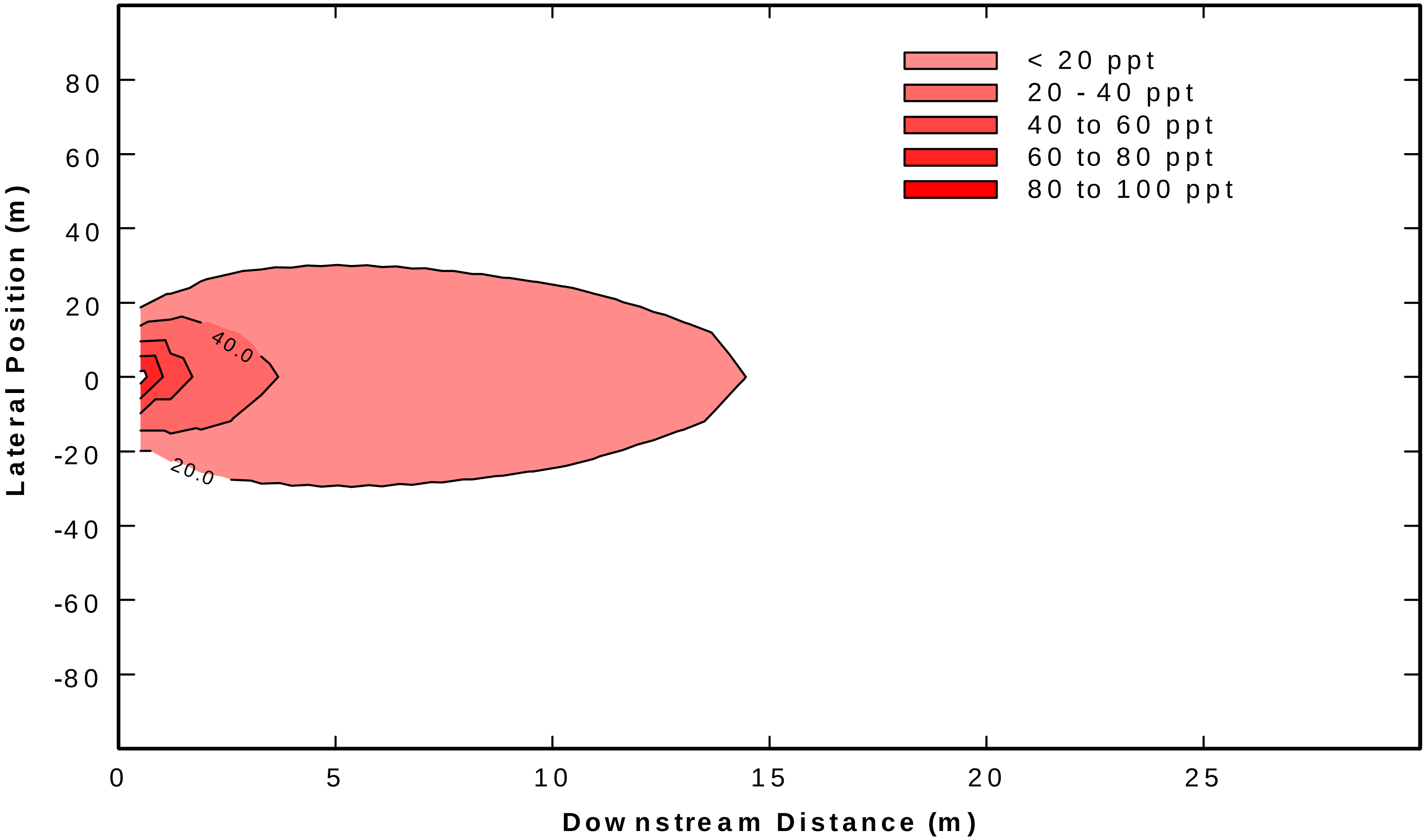

Figure 6. Estimated total tri+ PCB congener water column concentrations (ppt) during enclosed bucket dredging operations in the Upper Hudson based upon a sediment bulk Tri+ PCB concentration of 25 mg/kg.

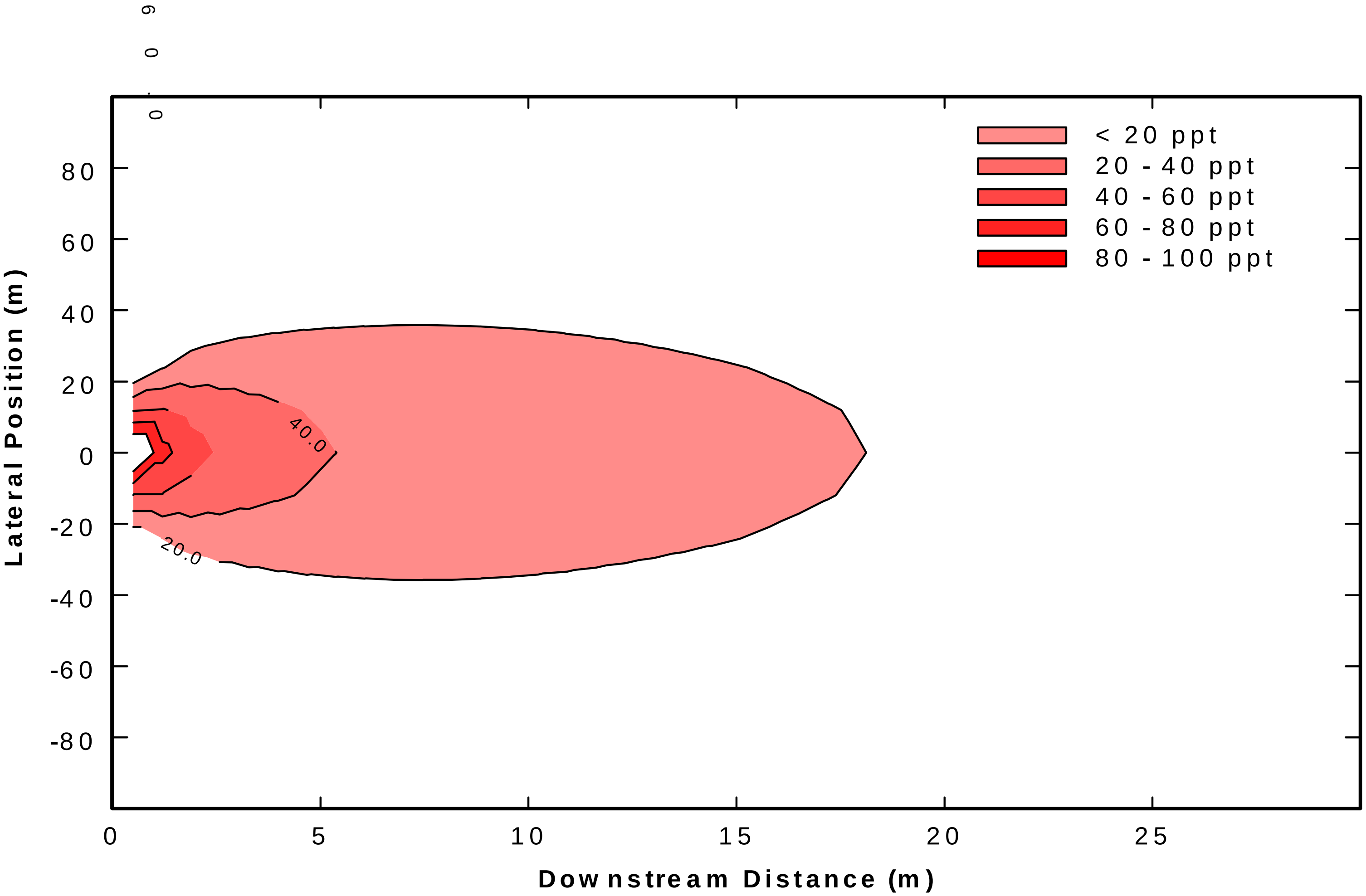

Figure 7. Estimated total tri+ PCB congener water column concentrations (ppt) during hydraulic cutterhead dredging operations in the Upper Hudson based upon a sediment bulk Tri+ PCB concentration of 25 mg/kg.

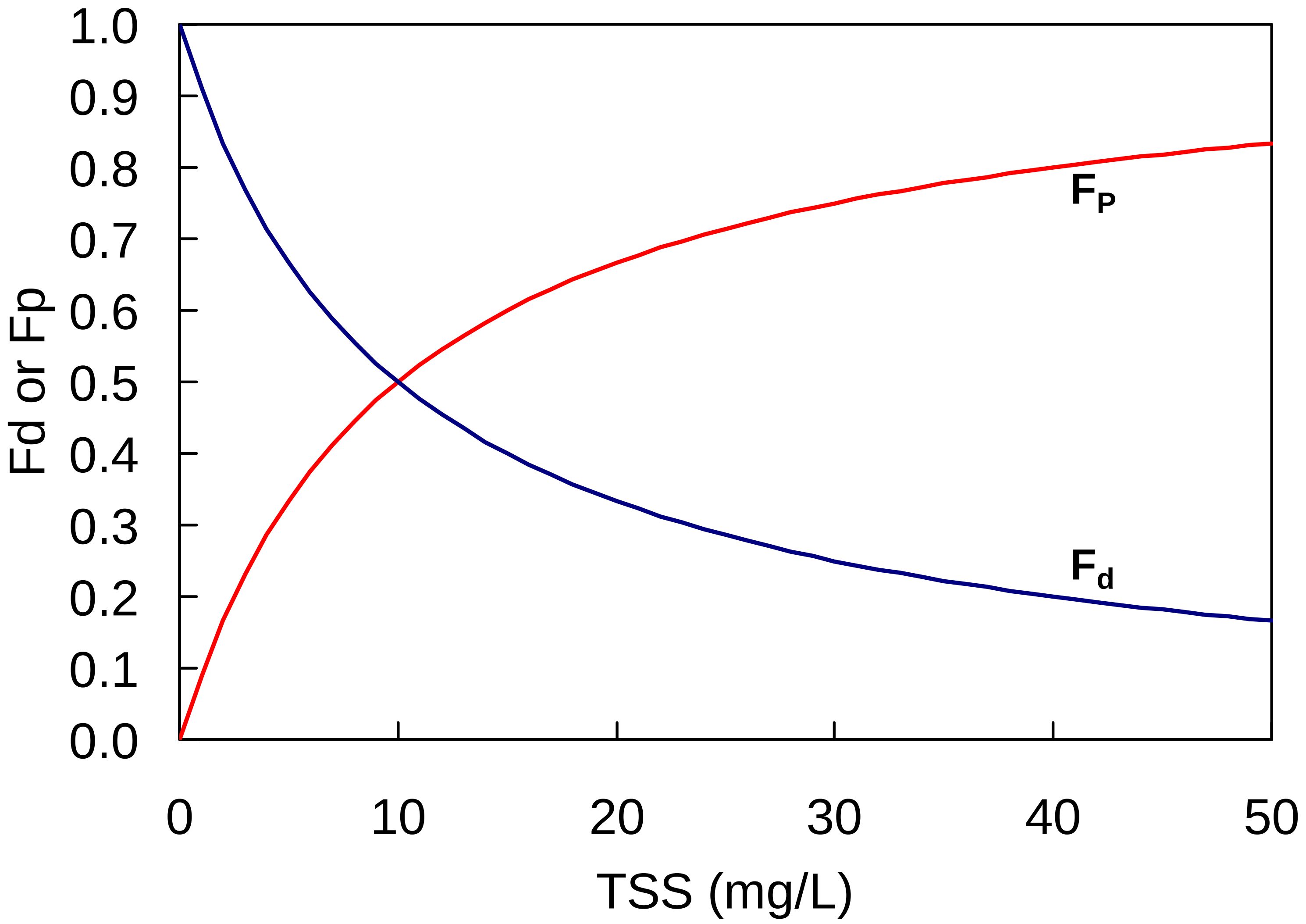

Figure 8. Variation of F_d and F_P with TSS concentration.

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APPENDIX E

ENGINEERING ANALYSIS

E.7 TECHNICAL MEMORANDUM: BACKFILL ESTIMATES CONCEPT DEVELOPMENT

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NOVEMBER 2000

BACKFILL ESTIMATES CONCEPT DEVELOPMENT

Backfilling is necessary to help prevent resuspension of PCBs into the water column and to aid in habitat replacement. Backfilling of the Hudson River will occur as a separate operation following the removal alternatives or capping with dredging alternative. Backfill material will be placed in all areas remediated except in the navigation channel (water depth >12 ft).

Backfill Estimates for the Removal Alternatives

For these alternatives, the backfill scheme will consist of the following:

- Areas with water depth >12 ft: No backfill will be placed
- Areas with water depth from 6 ft to 12 ft: Backfill will consist of 0.5 ft layer of sand followed by 0.5 ft gravel layer.
- Areas with water depth from 0 ft to 6 ft: Backfill will consist of 1 ft layer of sand in all areas except for near shore wetlands where 0.5 ft sand will be placed followed by sufficient amount of fine material to bring the area back to its initial grade (elevation).

Amounts of material required for backfill were computed per alternative per dredge area per water depth. The dredge area was broken down into surface area located in 6 ft to 12 ft water depth and surface area located in 0 ft to 6 ft water depth.

Required amounts of backfill for each removal alternative are shown in the following table:

Removal Alternative	**Total Gravel (cy)**	**Total Sand (cy)**	**Total Fine Material (cy)**
REM-3/10/Select	327,133	327,133	197,368
REM-0/0/3	612,842	612,842	245,154

An additional 15 percent of backfill was added to all volumes in the above table for purposes of bank reconstruction and habitat replacement. The total volumes of sand and gravel were altered for ecological purposes to reflect an even distribution of sand and gravel throughout the river.

Backfill material will be applied to all removal locations once removal operations are complete in the dredge area and upstream of that dredge area. Equipment required for placement of the backfill material includes:

(2) Hopper Barges (150'X42')
(2) Transport Tugs
(1) Deck Barge
(1) Telescoping conveyor
(1) Conveyor belt
(1) Bobcat

Backfill Estimates for the Capping with Dredging Alternative

For the CAP-3/10/Select alternative, the backfill scheme will consist of:

- Areas with water depth > 12 ft: No backfill will be placed.
- Areas with water depth from 6 ft to 12 ft: All capped areas at this depth will be backfilled with a mixture of sand and gravel at a thickness of 0.5 ft and dredged areas will receive backfill consisting of 6 inches sand and 6 inches gravel.
- Areas with water depth from 0 to 6 ft: 1 ft sand will be placed in all areas except critical areas and capped areas. For near shore wetland areas, 0.5 ft sand will be placed followed by sufficient fine material to bring the area back up to its initial grade and in all capped areas a mixture of sand and gravel will be placed at a thickness of 0.5 ft.

Required amounts of backfill for the CAP-3/10/Select alternative is shown in the following table:

Alternative	**Total Gravel (cy)**	**Total sand (cy)**	**Total Fine Material (cy)**	**Total (Sand + Gravel) (cy)**
CAP-3/10/Select	121,903	121,903	197,368	192,227

An additional 15 percent of backfill was added to all volumes in the above table for purposes of bank reconstruction and habitat replacement. The total volumes of sand and gravel were altered for ecological purposes to reflect an even distribution of sand and gravel throughout the river.

The same equipment as listed for the removal alternatives will be used for backfill placement for the capping alternative.

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APPENDIX E

ENGINEERING ANALYSIS

E.8 TECHNICAL MEMORANDUM: HABITAT REPLACEMENT/RIVER BANK RESTORATION CONCEPT DEVELOPMENT

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NOVEMBER 2000

HABITAT AND VEGETATION REPLACEMENT CONCEPT DEVELOPMENT

The areas requiring habitat and vegetation replacement were estimated using the following assumptions:

- After remediation, areas identified as potential wetlands will be backfilled with a mixture of sand and fine material to restore pre-remediation elevations. Following backfilling, these areas will be planted. Approximately half of the area will be planted with submerged vegetation, and the other half will be planted with emergent vegetation.

- Shallow areas (defined as areas in 0 to 6 feet water outside critical areas) will be backfilled with one foot of sand. Following backfilling, approximately one-third of the area will be planted with submerged vegetation. The remaining areas will not be planted.

RIVER BANK STABILIZATION CONCEPT DEVELOPMENT

The length of river bank requiring stabilization or reconstruction after remediation was estimated using the following assumptions:

- There are three types of proposed shoreline stabilization concepts. The types of shoreline stabilization depend on the depth of removal adjacent to the shoreline. All shoreline areas will be backfilled with approximately one foot of sand prior to bank stabilization.

- Shoreline areas where removal of sediments is to a depth less than 2 feet will be stabilized by hydroseeding above the water line.

- Shoreline areas where removal of sediments is between 2 feet and 3 feet will be stabilized through placement of a vegetation mat (approximately 20 feet wide) along the shoreline.

- Finally, shoreline areas where removal of sediments exceeds 3 feet will be stabilized by using a log type of revetment system in addition to the vegetation mat discussed previously.

The following tables present areas for habitat replacement and length of shoreline for bank stabilization by alternative.

Habitat and Vegetation Replacement

Alternative	Area with Shallow River Habitat Replacement (Acres)	Area with Emergent Wetland Habitat Replacement (Acres)
CAP/SR-3/10/Select	75.8	21.0
REM-3/10/Select	76.0	21.5
REM-0/0/3	150.6	37.0

River Bank Stabilization

Alternative	Total Shoreline Disturbed (LF)	Shoreline Adjacent to Sediment Removal Depth of <2 feet	Shoreline Adjacent to Sediment Removal Depth of 2 to 2.5 feet	Shoreline Adjacent to Sediment Removal Depth of >3 feet
CAP/SR-3/10/Select	91,955	77,764	12,481	1,710
REM-3/10/Select	91,955	17,075	46,564	28,316
REM-0/0/3	173,773	92,446	50,052	31,275

Notes:
All shoreline lengths were computed using GIS/Database software.

HUDSON RIVER PCBs REASSESSMENT FS

APPENDIX E

ENGINEERING ANALYSIS

E.9 TECHNICAL MEMORANDUM: REQUIREMENTS FOR A TRANSFER FACILITY ADJACENT TO THE THOMPSON ISLAND POOL

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NOVEMBER 2000

REQUIREMENTS FOR A TRANSFER FACILITY
ADJACENT TO THE THOMSPON ISLAND POOL

1.0 Introduction

Sites for transfer facilities require adequate land area to support the equipment and systems needed to process incoming dredged material. While a number of existing locations in the Albany area may potentially be dedicated to processing sediments removed from the Upper Hudson, there are essentially no operating industrial sites, adjacent to the TI Pool that can provide the required support. Thus, a site, that does not have an active industrial or materials handling use will need to be identified and developed for this purpose.

Principal facilities/systems that will need to be established at a transfer facility adjacent to the TI Pool area as follows:

- Barge basin and mooring facility;
- Barge dewatering and unloading systems;
- Temporary sediment storage and drainage area;
- Sediment stabilization system (mechanical dredging);
- Slurry processing facility (hydraulic dredging);
- Wastewater treatment facility
- Stabilized sediment storage area;
- Rail connection to mainline;
- Rail car storage area; and
- Rail car loading facilities.

The transfer facility's capacity for processing sediments is a function of the scale of the equipment and systems that can reasonably be placed at the site. The scale of those systems is in turn dictated by available land area, site topography, property configuration, and the orientation of the site in relationship to principal transportation modes (barge, rail, and roadway). The general implications of each of the principal systems on transfer facility capacity and, therefore, site requirements is described here.

2.0 River Front Operations (Mechanical Dredging)

Mooring and berthing facilities need to be provided for incoming barges loaded with dredged material. In the case of the northern transfer facility, either deck barges loaded with about 200 tons of cargo or hopper barges loaded with about 1,000 tons of cargo will arrive at the facility throughout the working day. Loaded hopper barges are expected to draw about eight feet of water and, therefore, a basin depth of about ten feet will be adequate to accommodate the barges (and towboats). It is possible that some barges will be loaded with more than 1,000 tons of cargo and, therefore, the basins will need to be deepened further.

Sizing the barge basin will depend on the number of barges that it is planned to unload at any one time and on the number of barges that need to be temporarily stored. It is likely that barge storage can be accommodated in-river and, therefore, the scale of mooring facility will primarily be dictated by the decision made with regard to barge unloading. The large barges that will be used as part of an active remedy will be about 150 feet in length. Thus, a wharf or dock designed to unload one barge at a time will be about 200 feet long and, for simultaneous unloading of two barges, about 400 feet long. A decision on one versus two unloading positions depends on the processing rate required at the transfer station.

Once barges arrive at the transfer facility, the barges will be tied to the dock/wharf and unloaded. For this analysis, it has been assumed that one barge will be unloaded at a time and a total of three deck barges and one hopper barge will be unloaded per day (1,600 tons/day). The following are expected durations for each principal component of dockside operations:

Barge tie-up .... 0 min

Pump-out excess water from barge at 50 gpm per pump:

- The volume of excess water is based on the dredge productivity which consists of 20 percent water/ 80 percent sediment per dredge cycle
- Assume 3 deck barges at 200 tons each and 1 hopper barge at 1,000 tons
- Volume of water to be remove from the deck barge = 6,500 gallons
- Time to pump-out one deck barge = 100 min using two pumps (1.1 hours)
- Time to pump-out 3 deck barges..195 min (3.25 hrs)
- Volume of water to be removed from hopper barge = 32,500 gallons
- Time to pump-out hopper barge (2 pumps) ....25 min (5.4 hrs)

Unload sediment from hopper and deck barge:

- Assume 4-cy clamshell used to unload the hopper and deck barges
- The cycle time of the clamshell is one minute with 75% efficiency
- Time to unload hopper barge (870 tons sediment)........................207 min (3.5 hrs)
- Time to unload three deck barges (1 @ 175 tons sediment)..........125 min (2.1 hrs)

Empty barge departs/loaded barge arrives and moored (4 barges/day) ....120 min (2 hrs)

Total time to accomplish unloading with one active berth.............................1,004 min (16.25 hrs)

Thus with one active position it will be possible to unload four barges in about 16 to 17 hours. This would suggest that the length of wharf/dock needed at the northern transfer facility (assuming 1,600 tons per day throughput) is about 200 feet. However, since it can be anticipated that barges will arrive for unloading in a somewhat random pattern, there would be value in having a second berth to allow an incoming barge to be readied for unloading while actual unloading operations occur in the adjacent berth. Thus, one concept for the transfer facility would be to construct a 400 foot long wharf/dock with only one barge being unloaded at any one time.

3.0 Rail Car Loading (Mechanical and Hydraulic Dredging)

On the assumption that the northern transfer facility is limited to exporting about 1600 tons of stabilized sediment each day, it will be necessary to establish a logistics system that integrates on-site processing operations with practices of the originating railroad. Stabilized sediment will be shipped to landfills in rail gondolas capable of carrying 100 tons of cargo. Thus, on average, 16 car loads of stabilized dredged material will depart the transfer facility each working day. It is possible that this output will be temporarily stored in the nearest yard operated by the originating railroad.

Rail car storage and loading facilities will need to be provided at the transfer facility so that on-site operations can be smoothly transitioned into those of the railroad. It would be reasonably cost effective to have one pick-up and drop-off of rail cars each day. In order to do so, it will be necessary to place about 1,000 feet (about 60' per car) of storage/loading track exclusive of any lead in and distribution lines. The dimensions of the on-site rail yard (rail storage plus materials storage), assuming loading at each of two tracks, may be approximately 500 feet by 125 feet with much of that area devoted to storage of stabilized sediments prior to load-out. Alternative geometries will be evaluated during the design phase of any particular remedy.

If rail car loading will be accomplished with two 2-yard pay loaders operating on a 1 minute cycle time, material would be loaded at a rate of four yards per minute. Thus, 1,600 tons could be loaded into gondolas in about 7 hours without accounting for loading inefficiencies, car switching activities, and other impediments to loading operations. In any event, it does not appear that rail car loading will be as significant a constraint on transfer facility throughput as will barge unloading in the event that the goal is to process and load-out 1,600 tons of stabilized sediment. It can be expected that as the targeted throughput is increased, rail operations will increase in complexity and will become a more significant in relationship to waterfront operations.

4.0 Sediment Stabilization (Mechanical Dredging)

Stabilization of mechanically dredged sediments is described in detail in Appendix E, section E.10. Principal components of the system are feed hoppers, conveyors, pug mills, and storage facilities for both stabilization agents and processed dredged material. Land area requirements for the stabilization equipment will be substantially less than for the rail yard described above; consequently, it is not expected that this particular component system of the transfer facility will importantly influence site selection.

Conveyors and pug mills (the principal active elements of the stabilization system) are available in a range of capacities and the target processing rate of 1,600 tons per day can be accomplished by commercially available equipment. In addition, it is possible to increase system throughput in several ways, including installing parallel processing trains, in order to attain a targeted processing rate *(e.g.*, 1,600 tons per day). Consequently, it is not expected that the stabilization system will be a constraint on processing stabilized sediments at the northern transfer facility.

5.0 Slurry Dewatering (Hydraulic Dredging)

The functioning of this system is described in Appendix H. Its major components are a series of screens, hydrocyclones, flocculation and settling tanks, and belt presses. In addition, a fairly substantial water treatment system must be installed, under the hydraulic dredging scenario, to process about 8,000 gpm of incoming water. A design has not been developed for either the dewatering or water treatment systems at this feasibility stage. While considerable historic experience exists with all elements of the dewatering and treatment systems, the scale of equipment needed to support hydraulic dredging operations in the Upper Hudson is substantial. Therefore, it is not possible to comment on land area requirements for erecting an integrated processing complex or on limitations that dewatering and water treatment may impose on throughput at the northern transfer facility.

HUDSON RIVER PCBs REASSESSMENT FS

APPENDIX E

ENGINEERING ANALYSIS

E.10 TECHNICAL MEMORANDUM: DREDGED SEDIMENT PROCESSING CONCEPT

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DREDGED SEDIMENT PROCESSING

1.0 Introduction

1.1 Project Background

Removal by dredging is among the alternatives being considered for remediating contaminated sediments found within the Upper Hudson. Sediments found in the river have varying physical properties that may influence both the dredging methods, sediment handling and final disposal of the dredged material.

One of the methods evaluated for removal of contaminated sediments is mechanical dredging. Based on a review of applicable mechanical dredging technologies, a system consisting of an excavator fitted with suitable auxiliary equipment appears to be a viable approach for accomplishing the required removal work.

The identified mechanical equipment is capable, under ideal conditions, of removing sediments at their *in-situ* moisture levels. However, it is expected that in actual practice, approximately 20% additional water will be captured with each removal cut of the dredge. Both the *in-situ* and entrained water will complicate the handling and disposal of sediments that have been removed from the river bed. In order to load the dredged material into rail gondolas it is expected that the railroad will require the sediments to pass a paint filter test (essentially no free water). In addition, it is possible, given the quantities being disposed, that receiving landfills may require the incoming material to be stackable without it being blended with other soils that may otherwise be available.

This memorandum addresses possible methods for improving the properties of excavated sediments to render them suitable for transportation to either disposal or beneficial use facilities.

1.2 Sediment Characteristics

The sediments of the Upper Hudson River have a range of physical properties but can be placed into two principal categories for general assessment purposes: (1) finer-grained, cohesive sediments; and (2) coarser-grained non-cohesive materials. The following tabulation provides the principal physical characteristics of sediments in each of these categories:

Properties of Hudson River Sediment

	Non-cohesive sediment	**Cohesive sediment**
Typical location	Deeper areas and channel	Shallower areas
Fine sand or coarser (%)	80	35
Silt or finer (%)	20	65
Solids (%)	76	58
In-situ Density (gm/cc)	1.82	1.45
Organic content (%)	1 to 2	3 to 4

As shown in the table above, the non-cohesive sediments are largely sand with some silt while the opposite is the case for the cohesive materials, although the cohesive portion has a relatively high sandy fraction. The organic content of the Upper Hudson sediments ranges from 1 percent to 4 percent. Therefore, physical characteristics of the sediment indicate they would drain well. The *in-situ* solids contents combined with other physical properties of the material also suggest that handling properties of the dredged sediments could be readily improved by any one of several processes including gravity draining, mechanical dewatering, and chemical stabilization.

1.3 Dredged Material Handling

The moisture content of mechanically dredged sediments will reflect both its *in-situ* condition and the water that has been entrained during dredging operations. It is expected that as much free water as possible will be withdrawn (by pumping) from incoming barges at the temporary sediment transfer and processing facilities. Since it is expected that 10 to 12 hours may be required to barge sediments to an Albany area transfer facility, considerable solids separation is likely to occur, in the barge, prior to its unloading at Albany. Removing that free water will reduce the moisture content of the dredged material and, therefore, improve its handling properties. It should be noted that it may be possible to configure transport barges so that maximum advantage can be taken of the in-river transport time to reduce the water content of the dredged material.

Due to the variability of the properties of the dredged materials, the in-barge solids separation may not sufficiently improve its handling properties, therefore, it may be necessary to further process the incoming dredged material before rail loading. Additional processing may consist of either mechanical dewatering or chemical stabilization.

2.0 Mechanical Dewatering

Mechanical dewatering technologies have been used extensively in sediment remedial projects to reduce the amount of water and to prepare the sediments for further treatment or disposal. These systems press or draw water from the feed material by applying energy.

Generally, mechanical dewatering technologies can increase the solids content up to 70% by weight.

3.0 Chemical Stabilization

Several chemical stabilization methods are available to further improve the handling properties of the sediments removed from the Hudson River. This section explores different methods that can be used to stabilize/solidify the sediment matrix (referred to collectivity as stabilization). A series of bench tests using actual sediment samples would be needed in order to select the most suitable mix of reagents.

3.1 Sorbents

Sorbents include materials that act by absorption or adsorption of drainable liquid. Since sorbents retain liquid in the matrix of the absorbing material, absorption is considered a reversible process. According to EPA regulations (40 CFR 264.314(b)) "the placement of non-containerized liquid hazardous waste or hazardous waste containing free liquids (whether or not sorbents have been added) in any landfill is prohibited." Based on this requirement, it can be assumed that sorbed free liquids are still considered free liquids. Thus, use of sorbents alone may not be considered a viable stabilization process for landfill disposal of river sediments.

Certain sorbents have a role in the stabilization of contaminated materials. For instance, activated carbon can adsorb organic contaminants that could otherwise interfere with reagents added to chemically stabilize the sediment. Other sorbents can also contribute to chemical reactions. If the stabilized matrix gains strength over time, the stabilizing reagent is considered to be involved in chemically transforming the matrix. Examples of sorbents that can chemically react with other reagents or available compounds in the soil include: zeolites, oxide/hydroxides, volcanic ash, fly ash, lime, kiln dust, rice hull ash. Unsuitable sorbents (presumably because they act by sorption alone) include vermiculite, bentonite, fine-grained sands.

USEPA regulations (40 CFR 264.314(e)) further state "sorbents to be used to treat free liquids to be disposed of in landfills must be non-biodegradable". Thus, materials such as shredded paper, sawdust, corn cob dust, etc. are not acceptable.

3.2 Binders

Binders improve handling properties by generating a cementitious reaction without necessarily reacting with the contaminant. Several additive reagents capable of accomplishing this goal have been identified. Refer to Table 1 for estimated cost and properties of selected reagents. Refer to Table 2 for chemistry information for selected reagents.

3.2.1 Inorganic Binders

3.2.1.1 Pozzolan-Portland Cement Materials

These materials create cementitious compounds (calcium-silica hydrates, calcium-alumina hydrates) upon hydration, causing a gain in strength over time. They are fine powders that require enclosed transport and storage systems to reduce dust migration and premature hydration. Several of these compounds are caustic in nature and need to be handled with care.

Limitations include interference of the contaminants (calcium sulfate, borates, carbohydrates) on setting and stability of the final product. Oil and grease can prevent bonding and decrease strength. Organic solvents and oils can impede setting and may volatilize because the hydrating reaction is exothermic. Some metals (nickel, lead, zinc) can have increased solubility at the high pH occurring during reaction.

Portland Cement

- Creates cementitious compounds (calcium silicate and aluminate hydrates) upon hydration;
- The reaction is not limited to fine grained soils;
- It provides free lime available for pozzolanic reaction;
- It provides high strength gain at low addition rates, minimizes volume increase, minimizes temperature rise;
- The more product added, the higher the strength gain;
- It is useful for reducing initial water content;
- It is most effective at temperatures above 40 degrees;

Five different types of Portland cement are available with Type I being the most widely used and lowest cost. Type II has a low-alumina content and is designed to be used in the presence of moderate sulfate concentrations. Type III is a rapid-set cement. Type IV has a low heat of hydration and a long set time. Type V is a low-alumina, sulfate resistant cement used with high sulfate concentrations.

Lime

- Lime reacts with soil via: a) hydration (good for quickly drying fine-grained soils); b) flocculation (cations adsorb to clay surfaces and exchange with calcium, increasing strength and impermeability); c) cementation (a slower reaction, limited to amount of available silica);
- It increases the optimum water content of sediment;
- Lime hydration forms calcium hydroxide, which is soluble and subject to attack by weak acids, salts, or other sulfates;

- Lime is not considered effective for coarse-grained soils;
- Adding lime to the point of achieving a soil pH of 12.4 ensures that pozzolanic reactions will occur;

  Hydrated Lime – ($Ca(OH)_2$) reacts with Class F fly ash to provide long term strength without temperature rise. It has less available lime than quicklime.
  Quick Lime – (CaO) – produces a greater temperature rise, a greater volume increase and quickens the reaction. It can burn skin or corrode equipment. It needs a silica source (*i.e.* silicates in soil, fly ash) for pozzolanic reaction. It has 25% more available lime than hydrated lime therefore less product is required than with hydrated lime, although it is initially more expensive. One part quicklime reacts with 0.32 parts water (by weight).

Fly Ash – Fly ash is a coal combustion byproduct collected from the power plant dust removal systems. It can be used to replace a portion of Portland cement to increase the cementitious compound formed, thereby adding strength. It can replace from 10 percent to 30 percent of cement. Through pozzolanic activity, the silica in the fly ash will react with the free lime from Portland cement to form similar cementitious compounds to those produced during the hydration of Portland cement. This action forms a denser, higher strength concrete with lower permeability. The permeability rate of a 70/30 Portland cement/fly ash compound was shown to have a 6 times reduction in the permeability rate compared with 100 percent Portland cement. Its fine particles also fill voids, making more homogeneous cement. It is also useful for reducing plasticity and slowing reaction speed.

Fly ash acts as a pozzolan with sources of lime such as cement kiln dust, lime kiln dust, or quicklime to produce a low strength cementitious compound. When used alone, large quantities can be added to quickly reduce a soil's moisture content; however this is a sorption process.

_ Class F Fly Ash – is a good bulking agent that does not harden by itself (pH<11). It requires the addition of lime to produce strength (reaction pH 12.5 until lime is consumed).
_ Class C Fly Ash – is self cementing due to the increased proportion of lime. It has a higher initial pH than Class F but final pH is <11.5. This material is not available in the vicinity of the Upper Hudson River.

Cement or Lime Kiln Dusts – Cement kiln dust (CKD) is a byproduct of Portland cement production and thus has a similar composition. Lime kiln dust (LKD) is the byproduct of lime production and thus has a high lime content. Both provide good strength gain at relatively low dose rate and low volume increase but with temperature and pH increase. They tend to have inconsistent lime contents. The LKD has around 30 percent available lime. CKD and LKD can be used with a source of silica (*i.e.* fly ash, soluble silicates) to form a cementitious compound upon hydration.

Soluble Silicates– increase the water demand and gelling of concrete. They flash set Portland cement to produce low-strength concrete and possibly reduce the interference from metal ions in a waste stream. They decrease the amount of cement needed and react with the available lime produced by Portland cement hydration. Alkalis may enhance reactions with amorphous silica. Silica fume can also be used, which has the advantage of more available silica, making it a very efficient pozzolanic material. In concrete with a water-cement ratio of 0.55 and higher, 1 pound of silica fume can replace 3-4 pounds of cement

Slag – (low ratio of calcium to silica) – creates cementitious compound and silicon dioxide upon hydration. The silicon dioxide then reacts with available lime to create secondary cementitious compounds. It has a reduced heat of hydration, increased setting time and increased strength when used in combination with Portland cement. However, this product is not readily available in the vicinity of the Upper Hudson River.

Fluidized Combustion Bed or Dry Scrubber Ashes - (quicklime and sulfur)- high surface area material used to achieve rapid strength gain at low addition rates. This type of ash tends to be coarser than fly ash and thus would not react as quickly.

3.2.1.2 Cement Additives

Additives can be blended into cement to improve its reaction in the presence of interfering contaminants.

Activated Carbon – increases the binder effectiveness for organics when introduced with Portland cement. It adsorbs contaminants, which then can become physically bound to the matrix produced by the cement.

Calcium Chloride – adds strength, lowers plasticity, quickens process, but is costly.

Gypsum – is used in Portland cement to retard the dissolution of tricalcium aluminate which if unimpeded tends to quickly form hydrate crystals over silicate particles, inhibiting their further hydration.

Lignin – Calcium Lignosulfonate provides dispersive characteristics, making it a useful addition to cement mixes. It reduces the amount of water required to use the product effectively.

3.2.1.3 Other Cements

Sulfur Polymer Cement (95 percent elemental sulfur, 5 percent organic modifier) – This cement is useful in treating incinerator ash and radioactive wastes. It is not compatible with wet waste, nitrate salts, organics or ion-exchange resins. It is highly resistant to alkaline and acidic environments. The reaction forms a linear polymer, which requires 24 hours to complete.

Phosphate Ceramics (trade name Ceramicrete) – is formed via hydration of magnesium oxide and monopotassium phosphate. It yields a hard, dense ceramic. It is a fairly new technology that can be used to treat inorganic waste – alkaline or acidic. Thus far, it has been demonstrated successful in the treatment of ash, salts, radioactive waste, and mercury.

3.2.2 Organic Binders

Organic binders or polymers are more expensive and more difficult to use than inorganic binders. They are typically heated and combined with waste streams to thermoplastically encapsulate the waste into a solid matrix. They are used to solidify radioactive wastes or hazardous organic compounds. They include asphalt, epoxide, unsaturated polyesters, and polyethylene.

3.3 Recent Solidification Projects/Studies

United Heckathorne, Richmond, CA - The sediment from this project was solidified with a combination of 5 percent Portland cement and 2 percent sodium silicate to achieve enough strength to make the mix stackable for landfilling. The material was mixed in holding ponds and ready for shipment the next day. The sodium silicate was added to increase the gelling and water demand of the Portland cement. Without the addition of sodium silicate, 18 percent Portland cement would have been needed to stabilize the sediments. Also considered was the use of class F fly ash, but that would have required a 45 percent addition to stabilize the sediments.

Ford Outfall, Monroe MI – The sediment from this dredging project was solidified with 12 to 13 percent Portland cement to achieve a strength of 25 psi, sufficient to support maintenance traffic on the placement lagoon.

Willow Run Creek, Ypsilanti, MI – The sediment from this dry excavation project was solidified with calciment (a mixture of lime and Portland cement) fly ash and then cement kiln dust. Reagent availability was a problem due to a construction boom at the time. The sediment was an oily sludge mixed with a backhoe with a cure time of from 3 days to 2 weeks. The strength requirement was 10 psi.

NYCDOS Marine Transfer Station, NYC and Brooklyn, NY – Powdered quicklime was used as a stabilizing agent during an evaluation program on dredged material from two DOS Marine Terminal Stations. The dredged material consisted of: 4 to 20 percent sand and 80 to 96 percent silt and clay; initial moisture content of 126 to 259 percent; organic content of 7 to 18 percent. It was determined that the addition of about 8 percent quicklime was needed to raise the pH to 12.4 (pH required for pozzolanic reaction). A moisture content reduction of 67 percent was achieved in 28 days. The greatest rate of reduction occurred immediately (around 50 percent reduction).

Given the previously mentioned beneficial properties of portland cement, its widespread use for sediment stabilization, and information obtained from various technical publications (see references). Portland cement has been selected as the stabilizing agent for the purpose of preparing a cost estimate.

3.4 Other Considerations

A number of factors can affect the selection of the reagent used for stabilization beyond its ability to reduce free liquids. These include cost, availability, handling, reaction time required, weather effects, dosage required, as well as landfill costs for increased weight. Trucking costs for obtaining stabilizing reagents can easily exceed costs of the reagents. Using pressurized tankers to deposit reagents directly into silos reduces dust migration, product hydration, and material handling. The speed of reaction can be affected by weather conditions. Sediment material storage space will most likely be at a premium, therefore reaction rate can be important. However, short reaction times are usually associated with exothermic reactions, which could lead to volatilization of contaminants. Increasing dosages of reagents can quicken reactions, however this also increases the costs of product and of landfilling. If multiple reagents are to be used and mixed on-site, there would be additional silo costs, material transport costs, and conveyance costs.

4.0 Conclusions

Preliminary data on sediment characteristics indicate that the dredged material may drain easily in a temporary storage facility and would not require mechanical dewatering or chemical stabilization. However, due to the variability in sediment properties and dredging scenarios stabilization with 8 percent cement has been included as a process in the cost analysis.

As previously stated, the selection of a reagent should be based on bench scale testing. Possible outcomes of bench-scale testing and cost optimization may include the following options:

- use of other stabilizing materials; for example, a preliminary project trade-off analysis revealed that 8 percent cement is equivalent in cost to about 18 percent fly-ash.
- use of a low cost mechanical dewatering system to dewater the entire mass, or fraction of the dredged material so that it meets shipping requirements.

Selection of the appropriate dewatering process for improving the handling properties of dredged sediment can have an important impact on project cost. For instance, if gravity drainage is found to improve the handling properties to the extent that removed sediments are acceptable for transportation and disposal to landfills, then the project cost could be substantially reduced.

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Table 1

REAGENT PROPERTIES/COST

Product	**Density**	**SG**	**Cost**	**Destination**	**Reference**
Portland Cement	90 pcf	3.15	$81/ton	Albany, NY	Dan C. Gorke Blue Circle Cement Ravena, NY 800-631-2777
Slag		2-2.5	n/a		
Sodium Silicate		2.2 (fume)	$0.397/lb	Butler, NJ	Fax Quote: PQ Corporation Valley Forge PA 610-651-4200
Silica Fume		2.2	$800/ton	Albany, NY	Phone Quote: Mark Master Builders 800-722-8899
Fly Ash Class F	75 pcf	2.25	$12/ton	Albany, NY	Leo Palmateer (Pozzoment) Blue Circle Cement 518-756-5085
Fly Ash Class C		2.2-2.6	n/a		
Quick lime	70 pcf		$93/ton	Adams, MA	Fax Quote: Karen Flank Specialty Minerals, Inc. 610-861-3575
Hydrated Lime	40 pcf		$97/ton		
Lime Kiln Dust		2.7	$30/ton	Albany, NY	Leo Palmateer (Pozzoment) Blue Circle Cement 518-756-5085
Lime Kiln Dust			$10/ton	Adams, MA	Phone Quote: Jerry Lewis Specialty Minerals, Inc. 413-743-6279
Cement Kiln Dust			$15/ton	Albany, NY	Phone Quote: Paul Minor St. Lawrence Cement 513-452-3001

Table 2
CHEMICAL PERCENTAGES OF REAGENTS (approx.)

	Portland Cement	**Slag**	**Silica Fume**	**Quicklime**	**Hydr.Lime**	**Fly Ash F**	**Fly Ash C**	**CKD**	**LKD**
Reference	*6*		*8*	*4*	*5*	*6*	*6*	*3*	*2*
Silica	22	36	99			55	40	15	4
Alumina	5.1	12				26	17	3	2.5
Lime (CaO)	63.8	39		96		9	25	42	58 (29 avail)
H.Lime ($Ca(OH)_2$)					67				
Iron	2.4	.4		0.1		7	6	2	1
Sulfur	2.4	1.4				.6	3.3	9	.5
Magnesium	2.7	11		0.8	32	2	5	1	
Avail. Alkalies	0.5					0.5	1.3		
LOI				0.1				21.4	

PORTLAND CEMENT CHEMISTRY (*Reference 1, 9*)

Initial Compound	Formula	Abbreviation	% Wt.	% wt. water bind	Heat generated	Comments
Tricalcium silicate	Ca_3SiO_5	C_3S	50	25	500kJ/kg	quick reaction, high early and final strength, resistant to sulphur attack
Dicalcium silicate	Ca_2SiO_4	C_2S	25	20	250kJ/kg	slower reaction, high final strength
Tricalcium aluminate	$Ca_3Al_2O_6$	C_3A	10	40-210	900kJ/kg	Quick reaction, high early strength, low final strength
Tetracalcium aluminoferrite	$Ca_4Al_2Fe_{10}$	C_4AF	10	37-70	300kJ/kg	low strength
Gypsum	$CaSO_4.2H_2O$		5			avoids quick set of C_3A

Main Compounds Formed:

Calcium silicate hydrate	$3CaO.2Sio_2.4H_2O$	CSH				cementitious compound responsible for strength
Calcium hydroxide	$Ca(OH)_2$	Free lime				quick hydration, soluble

Cement Reaction:	Portland Cement + Water = CSH + Free Lime (up to 20 wt.%)
Pozzolanic Reaction:	Free Lime + Silica Source (soil, flyash, sodium silicate, etc.) = CSH

Maximum water demand of Portland cement = 45% (calculated) by wt.
Water demand of Quicklime = 30%

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2. Peters Chemical Company, High Calcium Kiln Dust Typical Material Specification, www.peterschemical.com/kilndust.htm, downloaded 10/2000
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HUDSON RIVER PCBs REASSESSMENT FS

APPENDIX E

ENGINEERING ANALYSIS

E. 11 TECHNICAL MEMORANDUM: EVALUATION OF OFF-SITE LANDFILLS FOR FINAL DISPOSAL OF DREDGED SEDIMENTS

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NOVEMBER 2000

EVALUATION OF OFF-SITE LANDFILLS FOR FINAL DISPOSAL OF DREDGED SEDIMENTS

Introduction

Disposal locations for dredged sediments were evaluated in two categories: (1) facilities permitted to accept sediments containing PCB levels at or above 50 ppm and, (2) those which are permitted to accept sediments having PCB concentrations below 50 ppm. Candidate landfills were analyzed on the basis of distance from the Hudson Valley, rail access, seasonal capacity limitations, projected operating life, and published or verbally quoted disposal costs. It should be noted that this screening is for purposes of evaluating implementability and estimating costs only; not for purposes of final selection of a disposal facility.

1.0 TSCA Landfills

Landfills that can accept sediments with 50 ppm or greater PCB levels require a TSCA permit. A nationwide list of these facilities was obtained from USEPA and these were then evaluated in terms of the factors stated above.

Based on USEPA's input, it was determined that the number of candidate facilities is limited and that only one such facility exists in New York State. The closest TSCA-permitted landfill outside New York State is the Wayne disposal facility, located in Belleville, Michigan. Rail facilities are situated within 10 miles of the landfill and, therefore, disposal there would involve a final truck haul from the rail head. Trucking services would be provided by the Wayne facility but at an additional cost to the disposer. Additionally, a state hazardous waste tax must be paid when disposing at this facility. Total cost would be approximately $150/ton (including disposal, transportation from RR spur, and state tax). Operations are anticipated to continue there for the next 20 to 25 years; however, based on costs and limited rail access, this facility has been screened out as a candidate for receiving TSCA regulated sediments from the Hudson River.

TSCA-permitted facilities located farthest from the Hudson River include Chemical Waste Management in Kettleman City, Ca, Chemical Waste Management of the Northwest in Arlington, OR, Envirosafe Services Inc. of Idaho in Boise, ID, and US Ecology in Beatty, NV. These facilities are comparable in terms of tipping fees, capacity limitations, expected years of operation, and rail access to the facilities discussed below. However, all these landfills were screened out due to their distance from the Hudson River; a factor which can be expected to inflate transportation costs beyond those presented below.

The remaining TSCA-permitted facilities include Chemical Waste Management in Emmelle, AL, Waste Management Model City Facility in Model City, NY, Safety-Kleen Grassy Mountain Facility in Knolls, UT and Waste Control Specialists, LLC of Andrews, TX. Of these landfills, Waste Control Specialists in Texas is the only facility with rail service directly into the landfill while the Grassy Mountain Facility in Knolls, Utah has rail access located in proximity to their facility. The Model City Facility in NY state has no rail access and Waste Management in Emmelle, Alabama has rail connections within 10 miles of their facility. Based on this information, Waste Management of Emmelle, AL has been screened out.

The Model City Facility in NY State is retained due to its proximity to the Hudson River. In comparing the Utah facility with that in Texas, both have rail access but the Texas facility has on site rail facilities, has published a disposal cost of about $52/ton (including local taxes), and provides considerable disposal capacity. The facility in Utah published a disposal cost of about $70/ton, is somewhat farther from the Hudson River than the Texas site, but also has considerable disposal capacity. On the basis of total cost and distance from the Hudson Valley region, the Grassy Mountain Facility in Knolls, Utah has been screened out and the facility in Andrews, Texas is retained.

Thus, two candidate TSCA facilities are considered possible disposal locations for purposes of the FS: Waste Management's Model City facility in Model City, NY and Waste Control Specialists LLC in Andrews, Texas. The principal distinctions between the two is that Model City is located closest to the Hudson River and is limited to truck access. The facility in Texas is considerably farther from the Hudson River than the Model City Facility but it provides direct rail access into the landfill. In terms of disposal costs, tipping fees at Model City are about $75/ton with an additional 6% local tax while for the Texas facility tipping fees are approximately $45/ton with a $7.50/ton local tax. The remaining factor that needs to be considered in making a selection between the two facilities is transportation costs.

The Canadian Pacific RR, which serves the upper Hudson Valley region was contacted to obtain an estimate for transporting stabilized PCB-contaminated dredged material by gondola car to the Texas landfill. While obtaining a shipping cost proved difficult in this case, it was suggested that assuming a cost of about $5000 per 100 ton car load would be a reasonable approximation for a large project. On this basis the cost of rail transportation to Texas has been estimated at $50 per ton. A comparison can now be made between use of a truck accessed landfill in New York State and a rail fed facility in Texas.

The cost of trucking to Model City, NY is estimated as follows:
- daily rate of truck, driver, fuel, etc. = $700
- Model City is one day round trip from the transfer stations
- truck carries 25 tons for a unit cost of $28/ton

The total cost comparison between Model City and Texas is as follows:

- Texas = $50 to ship plus $52 to tip = $102/ton
- Model City = $28 to ship plus $79 to tip = $107/ton

While disposal costs vary somewhat between the two disposal options, given the preliminary nature of this analysis it is difficult to reach a definitive conclusion on the basis of estimated costs alone. For purposes of the analysis conducted in this FS report, however, it will be assumed that TSCA regulated material will be shipped to Texas for disposal.

2.0 Non-TSCA Landfills

Sediments with PCB levels below 50 ppm can be disposed in landfills that are not permitted pursuant to TSCA. Given that overall project costs are particularly sensitive to transportation factors, it would be logical to identify facilities in New York State for disposal of non-TSCA sediments. Unfortunately, many of the landfills within NY State are either not permitted to accept PCBs, are permitted to handle PCBs only at very low levels, or have other permit imposed limitations on accepting particular waste sources. Thus, only two New York landfills have been identified as potential candidates for disposing contaminated sediments. As a result, the evaluation of non-TSCA landfills was expanded beyond New York to include Canada, Atlantic region states, and states in the mid-West.

Results of this search produced the following candidates: BFI Waste Systems of North America, Inc. Niagara Falls Landfill (formerly CECOS) in Kenmore, NY., CINTEC in LaSalle, Quebec, Enfoui-Bec in Quebec, Franklin County Regional in Constable, NY., Horizon Environment in Grandes Piles, Quebec, two landfills in Maine, and several landfills in West Virginia, Ohio, and Michigan.

The two New York State landfills are not ideal candidates for disposal of Hudson River sediments. The Franklin County Regional Landfill is extremely limited in terms of the PCB materials they can accept for disposal. NYSDEC only permits Franklin County to accept materials with PCB concentrations in the ppb range; this level is not relevant to management of Upper Hudson sediments. BFI Waste Systems is problematic due to their capacity limitations. They have stated that they can accept 500 tons/day which translates to about 90,000 tons per construction season (May to November). Thus, this facility can manage less than half of the non-TSCA material that is expected to be generated during removal operations, assuming no other customers.

Another set of potential disposal sites were identified in Canada. CINTEC, located in LaSalle, Quebec, is not able to accept waste directly from the US, therefore, CINTEC has been screened out. Enfoui-Bec, located in Quebec along the St. Lawrence River, did not identify any problems with importing waste from the US; however, they have a remaining capacity limitation of about 300,000 tonnes and, therefore, have been eliminated from further consideration. The final Canadian facility considered was Horizon Environment, situated in Grandes Piles, Quebec. They required that an agreement be reached between Environment Canada and USEPA to use their facility. This landfill has managed about 100,000 tons of sediment from Cumberland Bay, Lake Champlain. They do not have direct rail access; however, rail service is available about 2.5 miles from their facility. The landfill appears to have adequate capacity to handle a substantial fraction of sediments from the Upper Hudson River. Disposal costs are about $50/ton and if rail were selected as the mode of transportation, they would add trucking costs from the rail line to the landfill.

In addition to the above Canadian disposal facilities, landfills located in the US mid-West and Atlantic Region were also investigated as alternatives to manage the non-TSCA material that would be generated by a removal alternative. This search has produced several possibilities in Maine, West Virginia, Ohio, and Michigan.

Maine:

1) Waste Management - Norridgewock. No specific information has yet been obtained for this facility.

2) Sawyers Environmental- Hampden. Can accept less-than-50 ppm PCB material. Rail line near site but no direct line into site. Expect to close in 15 years. No capacity limitations in terms of the amount of material they can receive in any one given period. Have permit that may open three million cubic yards of additional capacity but they are presently in litigation with the locality.

Ohio:

It was determined from conversations with DEP, that MSW facilities in the state can accept less-than 50-ppm PCBs but the landfill operator must establish appropriate operating and handling procedures. A list of disposal facilities throughout the state was obtained and several were contacted.

West Virginia:

The State environmental agency indicated that as long as PCB concentrations fall below the hazardous waste limit, landfills in this jurisdiction can potentially accept sediments from the Upper Hudson River. A list of possible landfills throughout the state was obtained for future evaluation.

1) Northwestern Facility - Parkersburg, WV. This landfill can accept less-than-50 ppm PCB material and is capable of accepting 30,000 tons per month. They have enough capacity to foresee future operation for the next 30 years at current usage rates. Costs for disposal were quoted at $34.05/ton, however, no rail access exists at this landfill.

2) Meadowfill Landfill - Bridgeport, WV. This landfill can accept less-than 50-ppm PCB material and is capable of accepting 23,500 tons per month. They have enough capacity to foresee future operation for the next 30 years at current usage rates. Costs for disposal were quoted at $37/ton, however, no rail access exists at this landfill.

Michigan:

Information has not yet been received from this jurisdiction.

A final step in the program to identify non-TSCA landfills was contacting several full-service waste management companies that operate disposal facilities in various regions of the country. Based on responses received to these inquiries, it has been decided to apply, for purposes of this Feasibility Study, a unit cost of $50 per ton to transport and landfill stabilized non-TSCA sediments. This cost is exclusive of rail car loading and assumes that rail cars will be loaded with approximately 100 tons of material.

HUDSON RIVER PCBs REASSESSMENT FS

APPENDIX E

ENGINEERING ANALYSIS

E.12 TECHNICAL MEMORANDUM: DISTRIBUTION OF SEDIMENT VOLUME BY PCB CONCENTRATION RANGE IN THE THOMPSON ISLAND POOL AND BELOW THOMPSON ISLAND DAM

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NOVEMBER 2000

Distribution of Sediment Volume by PCB Concentration Range in the Thompson Island Pool and Below Thompson Island Dam

1. Introduction

This attachment describes the approach used to estimate the volume of sediments requiring treatment as TSCA wastes. TSCA wastes, because of their higher levels of contamination, involve substantially greater costs in handling and landfilling. Thus it was important to determine a reliable estimate of the volume of these materials from the available data. The volume estimate varies with the remedial scenario, as might be expected. In any river section, the fraction of these materials is greatest in the 10 g/m^2 removal scenario and lowest in the full section removal. On an absolute basis the amount of TSCA material under the 10 g/m^2 removal scenario is roughly three-quarters of the TSCA material mass under the full section removal.

Several data sets were required to estimate the mass of sediment requiring TSCA treatment. In particular, different data sets are available for different river sections and so the TSCA estimate had to be completed differently for each river section. Additionally, a few general assumptions concerning the data and the nature of removal were required before the data could be applied for these purposes. These are as follows:

a) The dredge removal depth was assumed to be approximately equal to the depth of contamination at most sampling sites.
b) Based on (a), the length-weighted-average concentration (LWA) provides the closest approximation to the actual concentration to be removed from the location. To the extent that some overcutting does occur during dredging, use of the length-weighted-average concentration should provide an upper-bound estimate on the actual amount of TSCA waste.
c) In the TI Pool, the 1984 NYSDEC sediment sampling data were taken to represent conditions at the time of dredging. No correction for PCB losses from the sediments were made. Since losses have been documented (LRC - USEPA, 1998), this approach provides an upper bound on the actual amouint of TSCA material to be generated.
d) Below TI Pool, the 1994 USEPA sediment coring data were taken to be representative of river sections 2 and 3. The proportions of TSCA material were estimated from the 1994 for the areas studied and extrapolated to *hot spot* areas not covered in 1994.
e) TSCA material was defined as any sediment having a length-weighted-average concentration greater than 32 mg/kg. This value provides a sufficient margin of safety for the landfills accepting non-TSCA materials, *i.e.*, the chances of a non-hazardous waste landfill accepting TSCA wastes are substantively reduced. (A sensitivity analysis was also performed setting the TSCA boundary at 50 mg/kg.)

An additional calculation was performed from this analysis to estimate the volume of sediment less than 10 ppm in each removal scenario. These materials have the greatest potential for beneficial use subsequent to their removal from the river. Beneficial use can frequently reduce the overall cost of the remediation, as discussed in the main report. In the following discussions, the detailed approach and calculations to estimate the sediment volumes are described for each river section.

2. Estimation of the Mass of TSCA Materials in the TI Pool

The calculation of TSCA materials involved several steps for the TI Pool as listed below:

a) Calculate a length-weighted-average concentration and a depth of contamination at each sampling point.
b) Estimate the area of river bottom to be assigned to each sampling point based on polygonal declustering.
c) Obtain the intersection of the proposed removal boundaries and these polygons to determine the length-weighted-average concentrations in the areas to be removed.
d) Calculate the volume of sediment at each concentration based on the polygons and the depth of sediment contamination.
e) Estimate the volume of material less than the specified concentration for each scenario.

This calculation is based on the length-weighted-average concentrations and contamination depths of 1984 NYSDEC data. Only 1984 data were used to estimate the percentage in TI Pool.

<u>Calculation of the LWA and contamination depth for each 1984 location</u>

The 1984 NYSDEC sediment data have been extensively discussed and analyzed in the Phase 2 reports (DEIR USEPA, 1997, LRC USEPA 1998, DEIR Resp Summ USEPA 1998, LRC Resp Summ USEPA, 1999). This data set represents both core and grab data, with grabs outnumbering cores by about 2 to 1. The process to convert the concentration data to length-weighted-average concentrations is described briefly below.

For the 1984 grab samples, the LWA at each location is set equal to the measured concentration since only one value is available for the site. As part of the sample collection process, NYSDEC also collected sediment texture data and matched pairs of core and grab samples. On the basis of these data, NYSDEC assigned a contamination depth of 12.2 inch to coarse-grained sediment grabs and a depth of 16.9 inches to fine-grained sediment grabs. These depths were used without correction in this analysis.

The calculation of the LWA and depth of contamination for the cores was more involved. It was not appropriate to include all core layers in the calculation since frequently there were deeper layers with essentially no PCB contamination. To avoid the dilution of concentration caused by the inclusion of deep non-detected layers or “cold”-screened layers in the LWA, the criteria listed below were developed and applied. Note that the value of “3.3” is the concentration assigned to “cold”-screened sediment samples based on the analysis in USEPA (1997)- DEIR. Non-detect values were assigned a value of zero by NYSDEC in the original report.

a) If the first non-detected layer appears shallower than the first screen layer and only non-detected or screen layers follow the first non-detected layer, LWA concentration and depth are calculated based on all the layers above the first non-detected layer. For example, in a core with a surface to depth sequence of concentrations (ppm) of 10, 30, 5, 0, 3.3, 3.3, only the first three layers 10, 30, and 5 are used to calculate the LWA and depth of contamination. Similarly, for a core with a profile of 10.5, 0, 3.3, 0, only the first layer, 10.5, was used in the calculations.

b) If the first low level layer is a “cold”-screened result followed by subsequent non-detected or “cold”-screened layers, the LWA is calculated based on all the layers above the first “cold”-screened layer plus the first “cold-screened layer itself. For example, a core with the profile of 10, 30, 5, 3.3, 3.3, 0, the first four layers 10, 30, 5 and 3.3 were used to calculate the LWA.

c) Any non-detected layer or “cold”-screened layer which appears shallower than detected layer(s) were included in LWA concentration calculation. For example, a core with the profile of 0, 122.4, 3.3, 0, the first three layers 0, 122.4 and 3.3 were used to calculate the LWA concentration.

Based on these criteria, the contamination depth ($D_{\text{contamination}}$) of the core samples is equal to:

$$D_{\text{contamination}} = \sum_{i=1}^{n} D_i$$

Where:

D_i is the depth of each core segment. 1 represents the top segment and n is the deepest segment to be included in LWA calculation.

LWA is calculated as:

$$LWA = \frac{\sum_{i=1}^{n} (D_i * C_i)}{D_{\text{contamination}}}$$

Where:

C_i is the measured concentration of each layer.

The results of the LWA calculation are presented on Plate A-3 in Appendix A of this report. In reviewing the plate, it is evident that, like the MPA data presented in the main body of this report, the LWA values correlate with location. The highest LWA values are found in the near-shore environment in previously identified *hot spots* and areas of fine-grained sediment.

Estimate the area of river bottom to be assigned to each sampling point based on polygonal declustering

The second step involves the assignment of river bottom area to each sampling location. This has been done previously for the purposes of estimating sediment inventory (DEIR USEPA, 1997; LRC Resp Summ USEPA, 1999). The same mathematical approach is used here as was performed in Appendix B of the Low Resolution Sediment Coring Report Responsiveness Summary. A brief description of the polygonal declustering technique used in this analysis is transcribed from page 4-33 of the DEIR (USEPA, 1997):

> A simple method for addressing the problem of irregular sample spacing (or coverage) and clustering of data is a graphical technique known as polygonal declustering (Isaaks and Srivastava, 1989). As with other approaches to estimating total mass from spatial data, this relies on a weighted linear combination of the sample values. Weighting is formed graphically, however, without any assumptions regarding the statistical distribution of the data, and spatial correlation is not explicitly modeled. In this method, the total area of interest is simply tiled into polygons, one for each sample, with the area of the polygon representing the relative weighting of that sample. The polygons, called Thiessen polygons or *polygons of influence*, are drawn such that a polygon contains all the area that is closer to a given sample point than to any other sample point. Polygonal declustering often successfully corrects for irregular sample coverage. Because no complicated numerical methods need be applied, polygonal declustering provides a useful rough estimate of total mass to which the estimates obtained by other methods can be compared.

In the analysis presented here, Thiessen polygons are formed around all 1984 cohesive sample points. This procedure was repeated for the noncohesive sample points. Using the side scan sonar sediment classifications (Flood, 1993), the Thiessen polygons are clipped so that the LWA area for the cohesive sample points (based on visual texture classification) is applied only to cohesive areas of the river (defined by side-scan sonar) and, similarly, the LWA area for the noncohesive sample points is applied only to the noncohesive areas. For the side scan sonar sediment classification, cohesive areas are defined as fine- or finer-grained and noncohesive areas are coarse- or coarser-grained based on the original interpretation of the side-scan sonar images (Flood, 1993). Plate A-3 shows the result of this calculation, with each polygon coded according to its LWA.

<u>Obtain the intersection of the proposed removal boundaries and the sample polygons to determine the length-weighted-average concentrations in the areas to be removed</u>.

After assigning all areas of the TI Pool bottom to a specific sampling location, a further calculation was performed using a geographical information system (GIS) to match the areas to be removed with the LWA and depths of contamination estimated from the 1984 data. Each of the removal programs, full section, greater than 3 g/m^2 and greater than 10 g/m^2 yields an area of the TI Pool to be removed. This was matched to the polygons and clipped so that only those polygons contained within each removal zone were considered. Thus the number of polygons was fewest under the 10 g/m^2 scenario and greatest under the 3 g/m^2

<u>Calculate the volume of sediment at each concentration based on the polygons and the depth of sediment contamination.</u>

The volume of each polygon contained within the removal zones was determined in two ways, using the calculated depth of contamination described above, and using the dredge zone depth determined from the collection of sampling points contained within each dredge zone. The estimated volume was simply the product of the polygonal area and this depth.

The volume estimates were then grouped by PCB concentration and normalized to the total volume to be removed to produce the diagrams in Figure 1. These diagrams show the cumulative sediment volume at any given sediment concentration. Two curves are shown on each plot, one for the site-specific depths and one for the assigned dredge zone depths. The agreement between the two approaches is quite close. From these curve it is possible to estimate the percentage of sediment volume above or below any given concentration. For example, sediments at 32 ppm or above represent approximately 37 percent of the volume removed at 10 g/m^2, 28 percent at 3 g/m^2, and 20 percent under the full section removal. Similar but slightly lower values are obtained at 50 ppm (*i.e.*, 29 percent, 21 percent and 15 percent, respectively).

These results indicate that a relatively small portion of the dredged sediment (less than 37 percent in all cases) will require TSCA handling and disposal. It is important to note that this estimate does not account for losses of PCB inventory from the sediment since 1984 as documented in the LRC (USEPA, 1998) nor does it account for the inclusion of any uncontaminated material picked up during dredging. Both these concerns have the potential to decrease the volume of TSCA material by 10 percent or more.

The diagrams in Figure 1 can also be used to estimate the volume of sediment below 10 ppm, which would available for beneficial use. For the three removal scenarios, the percentages less than 10 ppm are 37, 44 and 46 for the 10 g/m^2, 3 g/m^2, and full section removal programs, respectively.

3. Estimation of the Volume of TSCA Materials Below the TI Dam

Below the TI Dam, the data available to estimate sediment volumes is much more limited. In particular, two data sets provide some information but neither is sufficient to estimate sediment volume in the fashion applied to the TI Pool. The first of these data sets, the 1976-1978 sediment survey by NYSDEC is vertically limited, that is, most sample collection depths do not extend below 12 inches. As shown in the LRC (USEPA, 1998), this shortcoming led to the underestimation of sediment inventory in at least one *hot spot.* Thus the 1976-1978 survey cannot be used to estimate sediment volume directly via a polygonal declustering approach. The 1994 USEPA survey is limited spatially, focusing on a limited number of *hot spots.* Thus this data set cannot represent all areas of the region. However, the coverage provided by the 1994 survey can be used for the more limited removal options (10 g/m^2 and 3 g/m^2), as discussed below.

In the 1994 USEPA low resolution sediment coring program, the program objectives below the TI Dam were to spatially characterize the PCB inventories and concentrations in a limited number of *hot spots.* The *hot spots* selected represented more than 75 percent of the mass of PCBs estimated from the 1976-1978 NYSDEC surveys (see Table 1). Based on this coverage, the 1994 survey was deemed to be sufficiently representative of the *hot spot* areas below TI Dam to characterize the sediment volumes. Additionally, the placement of cores in these areas was approximately evenly spaced with no preferential sampling of any area within the *hot spot.* Plate A-8 presents the 1994 results as LWA for each coring location.

Unlike the 1984 data, it was judged that there was an insufficient number of points to apply a polygonal declustering analysis to assign an area and calculate the sediment volume associated with each individual core location. Instead the cores were weighted solely on the basis of their length, effectively assigning an equal area to each core. On this basis, all 1994 cores obtained within the 10 g/m^2 and 3 g/m^2 scenario boundaries were used to estimate the respective distributions of the sediment volumes.

Core length and LWA were determined based on the core segment data, with deeper segments excluded when the concentration fell below 1 ppm. Because of the extremely low detection limits achieved by the USEPA as well as the issue of cross-contamination, it was decided that a 1 ppm cutoff would most accurately represent the true thickness of contaminated sediment with in a core. The procedures for calculating LWA and core length were the same as those used for the 1984 data. The criteria for inclusion of a core segment in the calculation for a single core paralleled that used for the 1984 cores. Specifically, if deeper core segments fell below 1 ppm consistently, all of these segments were excluded from the calculation. For example, in the sequence of 10, 30, 0.8, 0.9, top to bottom, only the first two segments (10, 30) would be included in the LWA and core depth calculations. Cores which had low surface concentrations but higher levels at depth would include all segments until less than 1 ppm was reached at depth. For example, in the top to bottom sequence of 0.7, 3, 4, 0.6, the first three segments would be used in the calculations. Cores with less than 1 ppm concentrations in the top most core segment layer and all lower segments had a LWA and depth based solely on the first segment.

To estimate the distribution of the sediment volume as a function of the LWA, the core lengths, rather than an calculated core volume, were used as weighting factors. In this approach, longer cores are weighed more heavily than shorter ones, essentially accounting for the greater removal depth and volume associated with them. Tables 2 and 3 present the results of the calculations for the 10 g/m^2 and 3 g/m^2 scenarios, respectively. In each case the percentage of sediment volume above 50 ppm, 32 ppm and less than 10 ppm are estimated based on the sum of core lengths with LWA values above or below the criterion relative to the sum of all core lengths. This calculation is equivalent to assigning the same surface area to each core and calculating a volume for each core using the core length for depth.

These calculations estimate a larger proportion of the sediment removal will require TSCA handling below the TI Dam relative to the results from the 1984 data in the TI Pool. Specifically, for the 3 g/m^2 removal scenario, 66 percent of the material removed exceeds 32 ppm as compared to 28 percent for the same conditions in the TI Pool. However, the areas requiring remediation under 3 g/m^2 represent a substantially smaller portion of the river bottom below TI Dam relative to the TI Pool.

A similar condition is seen for the 10 g/m^2 removal scenario, with 77 percent of the material removed requiring TSCA treatment below TI Dam. This is in contrast to the 37 percent estimated for the TI Pool under this removal scenario.

As would be expected the proportion available for beneficial use under these scenarios is a much smaller proportion of the total relative to the TI Pool. Note that the volume proportions estimated here apply to all areas below TI Dam, that is Sections 2, 3a, 3b and 3c.

Finally, it should be noted that a similar set of estimates could not be made for the full section removal scenario because a consistent set of data are lacking. In particular, both the 1976-1978 NYSDEC survey data and the 1991 GE composite samples do not provide sufficient vertical measurements for the purposes of a removal calculation. It is anticipated, however, that the majority of the difference between the 3 g/m^2 scenario and the full section removal in Section 2 would add little to the TSCA volume estimates as well as substantially increase the volume of material for beneficial use.

Table 1
Hot Spot PCB Inventory Below TI Dam

1984 NUS Report		**Areas Covered by LRC**
Hot Spot No.	PCB Quantity (lbs)	PCB Quantity (lbs)
21	360	
22	600	
23	180	
24	520	
25	2,440	2,440
26	460	
27	340	
28	9,090	9,090
29	220	
30	690	
31	8,150	8,150
32	170	
33	950	
34	12,350	12,350
35	2,090	2,090
36	5,000	
37	11,860	11,860
38	1,300	
39	3,720	3,720
40	3,750	
Total	64,240	49,700
Precentage of Estimated inventory		**77.4**

Table 2

Estimation of Sediment Volumes Below TID for the 10 g/m^2 Removal Scenario

Distribution of Length Weighted Average (LWA)

1/2 Log_{10} Bins (ppm)	Total Core Length (in.)	No. of Cores
<-1.5		
<0.0	8	1
<0.5	7	1
<1.0	43	5
<1.5	192	14
<2.0	337	15
<2.5	272	12
<3.0	238	7
	1097	

Sediment Volume Estimates

	Sum of Core Lengths	%Length
<=32 ppm	250	23%
>32 ppm	847	77%
Total	1097	

	Sum of Core Lengths	%Length
<=50 ppm	355	32%
>50 ppm	742	68%
Total	1097	

	Sum of Core Lengths	%Length
<=10 ppm	58	5%
>10 ppm	1039	95%
Total	1097	

Notes:

1. Grouped by length weighted average 1/2 log base 10 steps.
2. Samples with concentrations <1 ppm omitted unless all samples in the core were below 1 ppm.

Table 3

Estimation of Sediment Volumes Below TID for the 3 g/m^2 Removal Scenario

Distribution of Length Weighted Average (LWA)

1/2 Log$_{10}$ Bins (ppm)	Total Core Length (in.)	No. of Cores
<-1.5		
<0.0	8	1
<0.5	24	3
<1.0	104	11
<1.5	307	20
<2.0	337	15
<2.5	272	12
<3.0	238	7
	1290	

Sediment Volume Estimates

	Sum of Core Lengths	%Length
<=32 ppm	443	34%
>32 ppm	847	66%
Total	1290	

	Sum of Core Lengths	%Length
<=50 ppm	548	42%
>50 ppm	742	58%
Total	1290	

	Sum of Core Lengths	%Length
<=10 ppm	136	11%
>10 ppm	1154	89%
Total	1290	

Notes:

1. Grouped by length weighted average 1/2 log base 10 steps.
2. Samples with concentrations <1 ppm omitted unless all samples in the core were below 1 ppm.

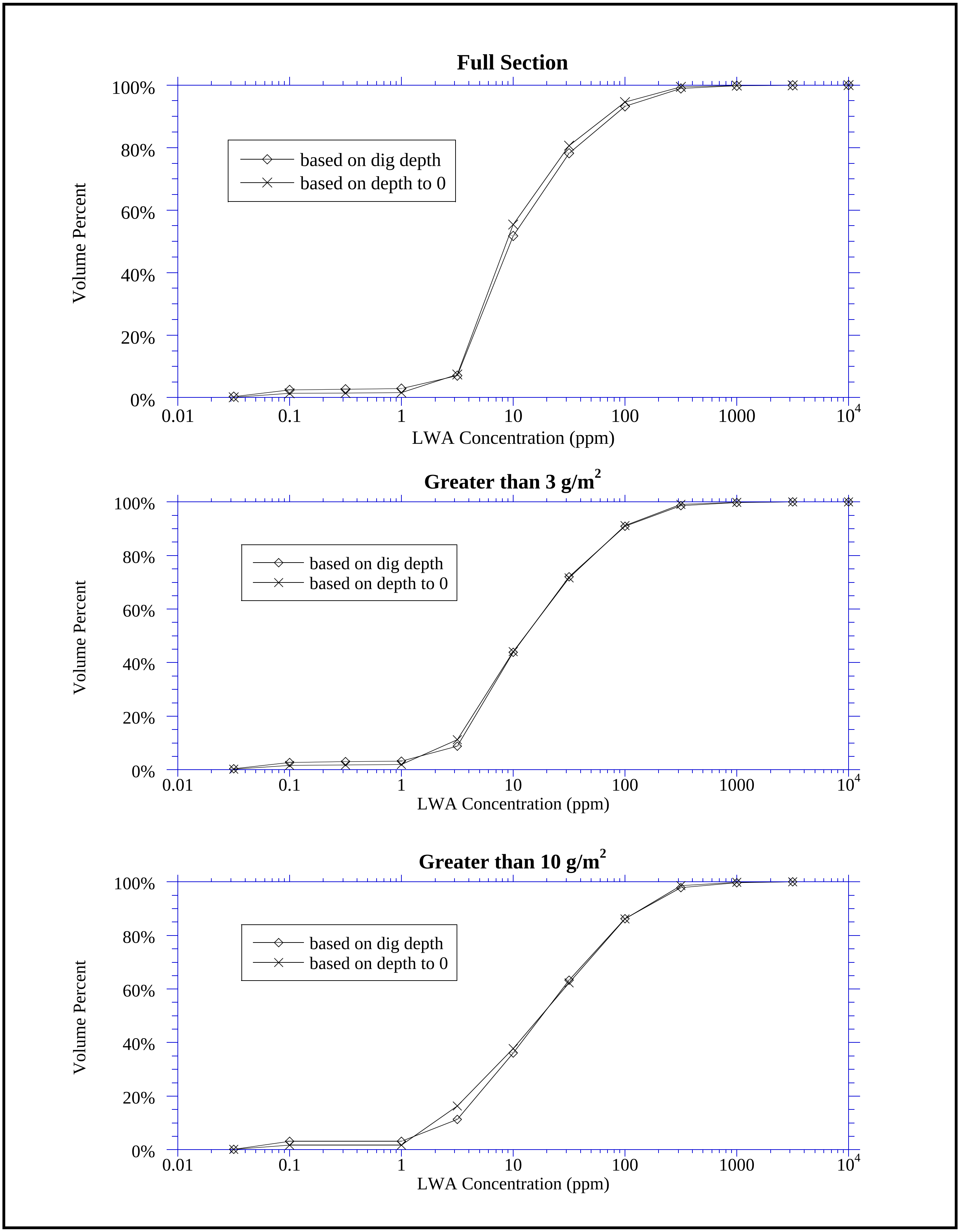

Figure 1

Cumulative Percentage of Sediment Volume Removal based on Length Weighted Average Concentration for Different Alternatives within TI Pool

HUDSON RIVER PCBs REASSESSMENT FS

APPENDIX E

ENGINEERING ANALYSIS

E.13 TECHNICAL MEMORANDUM: ESTIMATION OF SEDIMENT PCB INVENTORIES FOR REMOVAL

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NOVEMBER 2000

Estimation of Sediment PCB Inventories for Removal

1. Estimation of the PCB Inventory in River Section 1

Removal

The PCB inventory of the TI Pool has been extensively examined during the Phase 2 investigation. As discussed in Section 3.3.2.3 of the report, the most current estimate combines the 1992 USEPA side-scan-sonar data with the 1984 NYSDEC sediment survey results (converted to mass per unit area) to estimate the inventory of River Section 1. The NYSDEC 1984 survey represents the only data collection effort of sufficient magnitude to enable the direct calculation of the PCB inventory, estimated to be 15.4 metric tons or about 34,000 pounds. As documented in the LRC and its responsiveness summaries, this inventory is likely to have declined since 1984 but the exact amount of decline can only be estimated for the areas of highest contamination.

For the purposes of the FS, PCB removal estimates were needed for each of the removal scenarios. To accomplish this, the removal zones for each individual removal scenario (10g/m^2, Expanded Hot Spot remediation and Full-Section remediation) and the polygonal declustering results were integrated onto a single map. The intersection of the polygonal declustering results and the scenario-specific removal zones defined a set of polygons representing the sediments to be removed under each scenario. The summation of the mass of PCBs in these polygons was taken as a best estimate of the PCBs to be removed. The mass estimate was calculated using the area of each polygon and the MPA estimate derived from the 1984 data as:

$$Mass_{Removal} = \sum_{i=1}^{n} (Area_i * MPA_i)$$

where:

n is the total number of polygons within the removal zone; and

removal target refers to 10g/m^2, Expanded Hot Spot remediation or Full-Section remediation.

The application of the 1984 data is described in detail in the Data Evaluation and Interpretation Report (USEPA, 1997) and Appendix B of the Responsiveness Summary for the Low Resolution Sediment Coring Report (LRC, USEPA, 1999).

The formula given above was used to estimate the PCB mass removed for the individual removal zones as well as for the entire removal scenario. A table summarizing the mass of PCB removed by scenario is provided in chapter 3 of the FS report and the calculations are not repeated here. An effective removal efficiency of 100 percent was assumed for the estimate of PCB mass removed. Residual sediments were not assumed to be completely free of PCBs however. This is discussed in the main body of the report under the model simulations.

Capping with Dredging

Under this remedial approach, River Section 1 is separated into several zones based on water depth and depth of sediment contamination. These zones undergo various degrees of removal and capping as appropriate. This is described in detail in the main body of the FS. Effectively, the capping with dredging concept divides the river bottom into zones as follows:

For water depth between 0-6 ft:

> If depth of contamination is less than or equal to 2 ft, dredging only with backfill.
> If depth of contamination is greater than 2 ft, dredge to 1.5 ft and then cap and backfill (*i.e.,* dredging followed by capping).

For water depth between 6-12 ft:

> If depth of contamination is less than or equal to 2 ft in the vicinity of dredging only in the 0-6 ft area, dredging only with backfill.
> If depth of contamination is greater than 2 ft, cap and backfill (*i.e.,* capping only).

For water depth greater than 12 ft (navigation channel):

> Dredging only, no capping.

In general, the depth of sediment PCB contamination exceeds 2 ft so the areas without a cap are relatively small under each capping with dredging target area delineation.

The calculation of the mass of PCBs removed under the capping with dredging target area delineations was performed in a fashion similar to that for the removal delineations. Using the Hudson River GIS, the intersection of the polygonal declustering coverage with each of the various capping zones listed above was used to identify the polygons affected by each zone. The estimate for the actual mass removed depended on the zone. For the zones with dredging or dredging and backfill (*i.e.,* less than 2 ft of contamination or greater than 12 ft of water depth), 100 percent removal was applied as follows:

$$Mass_{Removal} = \sum_{i=1}^{n} (Area_i * MPA_i)$$

where:

n is the total number of polygons within the “dredging only” zone.

For zones undergoing capping with dredging (*i.e.,* capping in areas with water depths less than 6 ft and more than 2 ft of contaminated sediment), 50 percent removal was applied to the samples whose contamination depth is greater than 1.5 ft. So, PCB mass removal in the zone of “dredging followed by capping” ($Mass_{DredgingFBC}$) was calculated as follows:

$$Mass_{DredgingFBC} = \sum_{i=1}^{n_1} (Area_i * MPA_i) + \sum_{j=1}^{n_2} (Area_j * MPA_j * 0.5)$$

where:

n_1 = the number of polygons corresponding to the samples whose contamination depth is less than 1.5 ft.;
n_2 = the number of polygons corresponding to the sample whose contamination depth is greater than 1.5 ft.; and
$n_1 + n_2$ = the total number of polygons within the "dredging followed by capping" zone.

Finally, for areas undergoing capping only (*i.e.,* areas with water depths from 6 to 12 ft and more than 2 ft of contaminated sediment), no PCB removal mass was calculated.

Note that the calculation only summarizes the PCB mass removed and not the entire PCB mass remediated by a capping with dredging target area delineation.

2. Estimation of the PCB Inventory in River Section 2 and 3

In River Sections 2 and 3, data are far more limited for the purposes of estimating PCB mass removed. In particular, only two data sets exist which can provide this kind of information, the 1976-1978 NYSDEC survey and the 1994 USEPA low resolution coring program. The former study is limited in its applicability because of its age and more importantly because PCB inventory at depth was not well represented (cores and grabs did not extend below 12 inches in the vast majority of instances). The spatial coverage provided by this survey was also far less extensive than the 1984 survey in River Section 1 but this would not preclude the use of the 1976-1978 survey *per se*.

The 1994 survey provided useful estimates of PCB mass in the eight areas studied. However, its spatial coverage is limited to just these areas and cannot provide a section-wide PCB inventory estimate although these areas are considered representative of the cohesive sediments in this region of the Hudson.

Several approaches were used to examine the PCB inventory in this region. The 1976-1978 NYSDEC survey was used to approximate the proportion of PCBs in cohesive and non-cohesive areas. It was also used to estimate the absolute inventory in the areas outside the Expanded Hot Spot remediation boundary. (It should be noted as well that the 1976-1978 survey data along with the 1994 data were used in constructing the Expanded Hot Spot remediation and Hot Spot remediation boundaries.) The 1994 data were used to estimate the PCB inventories contained within the Expanded Hot Spot remediation and Hot Spot remediation boundaries as well as in the cohesive sediments.

Sediment Removal

Application of the 1976-1978 NYSDEC Survey Data

A review of the Hudson River Reassessment Database and a recent report from NYSDEC prepared by Malcolm-Pirnie (1992) revealed several discrepancies between the data sets. Specifically, some data were found in the Hudson River Reassessment Database that were not included in the Malcolm-Pirnie presentation, and *vice versa*. Additionally some data were assigned different locations in the Hudson River Reassessment Database relative to the Malcolm-Pirnie report. The number of discrepant locations were large and, therefore, had to be reconciled prior to their use. In total, there were 665 sample locations and associated PCB data that were found both on the Malcolm-Pirnie maps and in the USEPA electronic database; 100 locations were found on the Malcolm-Pirnie maps but not in the electronic file; and 154 locations were found in the electronic file but not on the Malcolm-Pirnie map. Of the 154 unique locations in the USEPA database, 12 appeared to match locations on the Malcolm-Pirnie maps but at slightly different coordinates. Lacking further information, it was assumed that the coordinates on the Malcolm-Pirnie maps were correct for these 12 samples. This resolution yielded a total of 907 unique sampling locations. A portion of these data (22 samples) appeared to represent field duplicates. Only the first station listed in the database was used in these instances. This yielded a total of 885 locations for subsequent polygonal declustering calculations.

The data from these locations were used to calculate the PCB inventory (MPA) at the time of the NYSDEC survey. The calculation of the MPA is given in subsection 3.3.4 of the FS. The sampling locations themselves were used to create a polygonal declustering coverage for River Section 2. This coverage with the associated MPA values was used to estimate the PCB inventory outside the Expanded Hot Spot remediation boundary (7.3 metric tons). However, in light of the uncertainties associated with the 1976-1978 survey, as noted above, one half of this value was used as a lower bound estimate for the purposes of PCB mass removal under the Full-Section removal target area delineations.

Application of the USEPA Low Resolution Sediment Coring Data

As discussed above, the 1976-1978 NYSDEC survey was only used to estimate the sediment inventory in the areas outside the Expanded Hot Spot remediation boundary. The areas inside this boundary were characterized by the 1994 low resolution sediment coring survey. This survey was designed to characterize the current inventory in 7 *hot spots* originally defined by NYSDEC. Additionally, this survey was compared with dredge zones later defined by NYSDEC in a draft report from Malcolm-Pirnie (1992). The 1994 USEPA coring effort successfully inventoried these areas of the Upper Hudson and provided a basis for the total PCB inventory in the study areas.

In general, these areas tended to be regions of cohesive sediment as defined by the 1992 USEPA side-scan-sonar survey. As part of the original study design, the areas selected for low resolution sediment coring represented the major portion (more than 75 percent) of the *hot spot* inventories originally identified by NYSDEC (NUS, 1984). This is illustrated in Table RE-1 which lists all of the NYSDEC *hot spots* below TI Dam along with their estimated inventories. Also shown are the seven *hot spot* inventories covered by the USEPA survey and the fraction of the total PCB inventory they represent (77 percent). Thus, although the USEPA study did not cover all areas, it covered a sufficient proportion of the sediment PCB mass so as to permit the estimation of the remaining inventory.

To estimate the PCB inventories of the areas contained within the Expanded Hot Spot remediation and Hot Spot remediation boundaries, the following procedure was applied.

1. All low resolution sediment cores falling within the target area boundaries were selected. Because the Hot Spot remediation boundaries were contained within the Expanded Hot Spot remediation boundaries, the cores selected for the Hot Spot remediation were a subset of those selected to assess the Expanded Hot Spot remediation.

2. As noted in the LRC, these data were log-normally distributed. Thus log-transform statistics were applied to the data to estimate PCB inventory. Of these, 44 fell within the Expanded Hot Spot remediation boundary, while only 37 fell within the Hot Spot remediation boundary. The geometric mean, the simple arithmetic mean and the Minimum Variance Unbiased Estimate (MVUE) of the arithmetic mean of the MPA data from these locations were calculated according to the formulations given in Gilbert (1987). Because the data are log-normal, the MVUE values were selected as the best estimates of the mean MPA. The MVUE of the selected samples were assumed to represent the average MPA for all unmeasured selected areas in River Section 2 under each removal target area delineation. The MVUE was also calculated within each removal zone based on the data collected within that zone. Thus, PCB inventories for the areas surveyed in 1994 were estimated from the points contained within each removal zone while the MVUE of the MPA for River Section 2 was applied to the removal areas not covered by the 1994 survey.

3. The estimate of the PCB inventory for each delineation was calculated as the sum of mass in the measured target area and mass in the unmeasured (extrapolated) area. The mass in the unmeasured area is the product of the MPA (MVUE) based on selected samples and the total unmeasured area selected. The mass in the measured area is the sum of mass in the hot spots. The mass in the target areas is the product of MPA (MVUE) and the surface area.

4. For Section 3, a parallel approach was used, applying the same steps to the low resolution sediment cores available in this region. Of these, 19 fell within the Hot Spot remediation boundary and 24 fell within the Expanded Hot Spot remediation boundary. However, the MVUE from *Hot Spot* 37 was used for the dredge zones containing no low resolution sediment cores. The other dredge zone area containing low resolution sediment cores in this river section is *Hot Spot* 39. This *hot spot* was unusual in that high PCB concentrations were found a depth indicating a high deposition area. This situation is not likely to be representative of the other target areas in River Section 3, so the cores in *Hot Spot* 39 were not used to estimate the mass in the remaining target areas. Also noteworthy, the MPA of this region was substantially less than that for River Section 2, largely because of the very high inventories found in cores from *Hot Spot* 28 in River Section 2. Table RE-2 contains a summary of MVUE for PCB mass per unit area and removal mass below the TI Dam.

The actual PCB masses estimated for the Expanded Hot Spot remediation and Hot Spot remediation scenarios are given in the main body of the FS for River Sections 2 and 3. For the Full-Section removal in River Section 2, the estimate combines the 1994 data for the Expanded

Hot Spot target areas with the 1977 data for the areas outside the target areas. Because of the uncertainties associated with the 1977 data, (*i.e.*, shallow coring depths and potential sediment inventory changes), one half of the mass estimated from the 1977 data (3.65 of 7.3 metric tons) was used as a part of the lower bound estimate given here. Full-Section removal was not delineated for River Section 3 and, therefore, was not calculated.

Capping with Dredging

Capping with dredging in River Sections 2 and 3 is largely defined on the basis of contaminant depth and water depth, as was done for River Section 1. For the purposes of estimating the PCB mass removed under each capping with dredging target area delineation, a calculation approach different from that used in River Section 1 was applied. Since no complete polygonal declustering coverage is available for these two river sections, it was assumed that all the samples are equally representative of the total PCB mass in this area. Thus, the PCB mass removal in the different capping with dredging target areas can be estimated as a proportion of the total PCB mass associated with the removal target areas described above. For the target areas where only dredging occurs, the removal mass is calculated as:

$$Removal\ Mass_{Dredging\ only} = \frac{Area_D}{Area_t} * Mass_T$$

where:

$Area_D$ = the surface area of dredging only target areas;

$Area_T$ = the total capping target area; and

$Mass_T$ = the total mass of PCB removed, as obtained from the removal calculation

The contamination depth needs to be considered in calculating the removal mass in the capping with dredging target boundaries. All the samples which fell within the target boundaries in River Sections 1 and 2 were selected for different capping with dredging delineations. All the low resolution sediment cores falling within the target boundaries were used to estimate the proportion of area with complete removal and the proportion of area with less-than-complete removal (assigned a value of 50 percent removal). Based on the cores, the percentage (*X*) of samples with a contamination depth greater than 1.5 ft was calculated. The PCB removal mass within the target boundaries was then estimated as follows:

$$Removal\ Mass_{D+C} = \frac{Area_{D+C}}{Area_T} * Mass_t * (1 - X) + \frac{Area_{D+C}}{Area_T} * Mass_t * X * 0.5$$

where:

$Area_{D+C}$ = the surface area of dredging followed by capping target area;

$Area_T$ = the total capping target area; and

$Mass_T$ = the total PCB removal mass obtained from the Full-Section PCB removal delineation.

Again, it is assumed that, for the samples with contamination depth greater than 1.5 ft, 50 percent of inventory is removed by dredging 1.5 ft. As in River Section 1, there was no PCB mass removal in the target areas for which only capping is performed.

References

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Table 1
Hot Spot PCB Inventory Below TI Dam

1984 NUS Report		**Areas Covered by LRC**
Hot Spot No.	PCB Quantity (lbs)	PCB Quantity (lbs)
21	360	
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24	520	
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26	460	
27	340	
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29	220	
30	690	
31	8,150	8,150
32	170	
33	950	
34	12,350	12,350
35	2,090	2,090
36	5,000	
37	11,860	11,860
38	1,300	
39	3,720	3,720
40	3,750	
Total	64,240	49,700
Precentage of Estimated inventory		**77.4**

Table RE-2
MVUE for PCB Mass Per Unit Area and Removal Mass in River Section 2 and 3

	MVUE for PCB Mass per Unit Area	
	3 g/m^2 dredging zone [1]	10 g/m^2 dredging zone [2]
River Section 2		
Hot Spot 25	27.9	39.9
Hot Spot 28	158.8	158.8
Hot Spot 31	12.3	19.9
Hot Spot 34	8.7	11.3
Hot Spot 35	17.8	17.8
River Section 3		
Hot Spot 37	16.1	16.1
Hot Spot 39	34.8	30.3
River Section 2 [3]	53.7	69.9
River Section 3 [4]	16.1	16.1

Mass in 3 g/m^2 dredging zone (kg)

	Measured [5]	Calculated [6]	Total
River Section 2	27,151	4,098	31,248
River Section 3	5,410	5,244	10,655
River Sections 2 and 3	32,561	9,342	41,903

Mass in 10 g/m^2 dredging zone (kg)

	Measured [5]	Calculated [6]	Total
River Section 2	21,491	2,137	23,628
River Section 3	5,410	1,312	6,723
River Sections 2 and 3	26,901	3,450	29,038

Notes:

1. MVUE are calculated based on all the samples within the overlay of *hot spot* (NYSDEC) and 3 g/m^2 dredging area.
2. MVUE are calculated based on all the samples within the overlay of *hot spot* (NYSDEC) and 10 g/m^2dredging area.
3. MVUE for Section 2 is based on the entire set of data points from the *hot spots* in the section.
4. MVUE for River Sections 3 is based on *Hot Spot* 37 only. See text for discussion.
5. Measured mass is contributed by the areas where *hot spots* overlay the dredging zones. The mass is equal to the area of the individual polygon multiplied by the MVUE MPA of corresponding hotspot.
6. Calculated mass is contributed by the dredging areas beyond the hot spots. The mass is equal to the area of the individual polygon mutiplied by the regional MVUE MPA (3 g/m^2 dredging scenario, 70.2 for River Section 2 and 23.3 for River Section 3; 10 g/m^2 dredging scenario, 84.2 for River Section 2 and 26 for River Section 3).