HUDSON RIVER PCBs REASSESSMENT RI/FS
PHASE 3 REPORT: FEASIBILITY STUDY

DECEMBER 2000

For

U.S. Environmental Protection Agency
Region 2
and
U.S. Army Corps of Engineers
Kansas City District

Book 1 of 6
Report Text

TAMS Consultants, Inc.

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 2
290 BROADWAY
NEW YORK, NY 10007-1866

December 8, 2000

To All Interested Parties:

The U.S. Environmental Protection Agency (USEPA) is pleased to release the Feasibility Study, which is Phase 3 of the Reassessment Remedial Investigation/Feasibility Study (Reassessment RI/FS) for the Hudson River PCBs Superfund Site. The Feasibility Study identifies and evaluates in detail the potential remedial alternatives for addressing the PCB-contaminated sediments in the Upper Hudson River.

USEPA will accept public comments on the Agency's Proposed Plan, which identifies the Agency's preferred cleanup alternative, and on the Feasibility Study and other supporting analyses, through February 16, 2001. USEPA will hold public meetings on December 12, 2000 in Saratoga Springs, New York and on December 14, 2000 in Poughkeepsie, New York to present the Proposed Plan and the results of the Feasibility Study and to accept public comment. In addition, USEPA is scheduling public meetings in January 2001 to accept additional comment during the public comment period.

If you need additional information regarding the Feasibility Study or the Reassessment RI/FS, please contact Ann Rychlenski at 212-637-3672.

Sincerely yours,

Richard L. Caspe, Director
Emergency and Remedial Response Division

Table Of Contents

400210

HUDSON RIVER PCBs REASSESSMENT RI/FS
PHASE 3 REPORT: FEASIBILITY STUDY

TABLE OF CONTENTS

HUDSON RIVER PCBs REASSESSMENT RI/FS
PHASE 3 REPORT: FEASIBILITY STUDY

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

Page

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

Page

400217

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

Page

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

400221

TABLE OF CONTENTS (CONTINUED)

Page

TABLE OF CONTENTS (CONTINUED)

Page

HUDSON RIVER PCBs REASSESSMENT RI/FS
PHASE 3 REPORT: FEASIBILITY STUDY

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

BOOK 2 - TABLES AND FIGURES

LIST OF TABLES

400225

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

400227

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

TABLE OF CONTENTS (CONTINUED)

400229

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

400231

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

BOOK 3 - PLATES
LIST OF PLATES

HUDSON RIVER PCBs REASSESSMENT RI/FS
PHASE 3 REPORT: FEASIBILITY STUDY

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

400235

TABLE OF CONTENTS (CONTINUED)

BOOK 6 - APPENDICES I

400236

ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
ACHP	Advisory Council on Historic Preservation
AGC	Annual Guideline Concentration
AOC	Administrative Order on Consent
APEG	Alkaline (Alkali Metal Hydroxide) Polyethylene Glycol
ARAR	Applicable or Relevant and Appropriate Requirement
ARCS	USEPA Assessment and Remediation of Contaminated Sediments Program
ATSDR	Agency for Toxic Substance and Disease Registry
AWQC	Ambient Water Quality Criterion
BAT	Best Achievable Technology
BBL	Blasland, Bouck, and Lee
BCD	Base-Catalyzed Decomposition
BMR	Baseline Modeling Report
CADD	Computer-Aided Drafting and Design
CDF	Confined Disposal Facility
CDI	Chronic Daily Intake
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cfs	cubic feet per second
CLU-IN	Hazardous Waste Clean-up Information (USEPA web site)
COPC	Chemicals of Potential Concern
CSF	Cancer Slope Factor
CT	Central Tendency
CWA	Clean Water Act
DEIR	Data Evaluation and Interpretation Report
DMR	Discharge Monitoring Report
DNAPL	Dense Non-Aqueous Phase Liquid
DOSM	Depth of Scour Model
DOT	Department of Transportation
DRE	Destruction and Removal Efficiency
ECD	Electron Capture Detector
ECL	Environmental Conservation Law (New York)
EEC	Extreme Effect Concentration
EE/CA	Engineering Evaluation/Cost Analysis
EIS	Environmental Impact Statement
EO	Executive Order
EPC	Exposure Point Concentration
ERA	Ecological Risk Assessment
ESA	Endangered Species Act
ETWG	Engineering/Technology Work Group
FDA	Food and Drug Administration
FR	Federal Register

ACRONYMS

FRTR	Federal Remediation Technologies Roundtable
FS	Feasibility Study
FSSOW	Feasibility Study Scope of Work
FWIA	Fish & Wildlife Impact Analysis
GAC	Granular Activated Carbon
GC	Gas Chromatography
GCL	Geosynthetic Clay Liner
GE	General Electric Company
GIS	Geographic Information System
GLNPO	USEPAs Great Lakes National Program Office
GRA	General Response Action
HDPE	High Density Polyethylene
HHRA	Human Health Risk Assessment
HHRASOW	Human Health Risk Assessment Scope of Work
HI	Hazard Index
HMTA	Hazardous Materials Transportation Act
HP	Horsepower
HQ	Hazard Quotient
HSI	Habitat Suitability Index
HTTD	High Temperature Thermal Desorption
IBI	Index of Biotic Integrity
ITT	Innovative Treatment Technologies (database)
KPEG	Potassium polyethylene glycol
LOAEL	Lowest Observed Adverse Effect Level
LRC, LRCR	Low Resolution Sediment Coring Report
LTI	LimnoTech, Inc.
LTTD	Low Temperature Thermal Desorption
LWA	Length-Weighted Average
MBI	Macroinvertebrate Biotic Index
M&E	Metcalf and Eddy
MCA	Menzie-Cura and Associates
MCACES	Cost Estimating Software (USACE)
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MDEQ	Michigan Department of Environmental Quality
MEC	Mid Range Effects Concentration
MNA	Monitored Natural Attenuation
MPA	Mass per Unit Area
MS	Mass Spectroscopy
NAAQS	National Ambient Air Quality Standards
NCP	National Oil Spill and Hazardous Substances Pollution Contingency Plan
NEPA	National Environmental Policy Act
NHPA	National Historic Preservation Act

ACRONYMS

NiMo	Niagara Mohawk Power Company
NOAA	National Oceanic and Atmospheric Administration
NOAEL	No Observed Adverse Effect Level
NPL	National Priorities List
NTCRA	Non-Time Critical Removal Action
NYCRR	New York Code of Rules and Regulations
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
NYSDOT	New York State Department of Transportation
NYSPDES	New York State Pollutant Discharge Elimination System
O&M	Operation and Maintenance
OPRHP	Office of Parks, Recreation, and Historic Preservation
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response (USEPA)
OU	Operable Unit
PCB	Polychlorinated Biphenyl
PCRDMP	Post-Construction Remnant Deposit Monitoring Plan
PEL	Probable Effects Level
PMCR	Preliminary Modeling Calibration Report
ppm	part(s) per million (mg/kg or mg/L)
PRG	Preliminary Remediation Goal
PSG	Project Sponsor Group
PVC	Polyvinyl Chloride
RAMP	Remedial Action Master Plan
RAO	Remedial Action Objective
RBMR	Revised Baseline Modeling Report
RBC	Risk-Based Concentration
REACH IT	Remediation and Characterization Innovative Technologies (USEPA database)
RfD	Reference Dose
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
RIMS	Remediation Information Management System
RM	River Mile
RME	Reasonable Maximum Exposure
ROD	Record of Decision
SARA	Superfund Amendments and Reauthorization Act of 1986
SEC	Sediment Effect Concentration
SHPO	State Historic Preservation Office
SITE	Superfund Innovative Technology Evaluation Program
SPDES	State Pollution Discharge Elimination System
SQRT	Screening Quick Reference Tables
TAGM	Technical Assistance Guidance Memorandum (NYSDEC)
TBC	To-be-considered

ACRONYMS

TCDD	2,3,7,8-Tetrachlorodibenzo-p-dioxin
TCP	2,4,6-Trichlorophenol
T&E	Threatened and Endangered
TEC	Threshold Effect Concentration
TEF	Toxicity Equivalency Factor
TEQ	(Dioxin-like) Toxic Equivalent
TI	Thompson Island
TID	Thompson Island Dam
TIN	Triangulated Irregular Network
TLV	Threshold Limit Value
TOC	Total Organic Content
TOGS	Technical and Operational Guidance Series (NYSDEC)
TOPS	Trace Organics Platform Sampler
TQ	Toxicity Quotient
TR	Target Risk
TRV	Toxicity Reference Value
TSCA	Toxic Substances Control Act
TWA	Time-Weighted Average
UCL	Upper Confidence Limit
UET	Upper Effects Threshold
USACE	United States Army Corps of Engineers
USC	United States Code
USDOC	United States Department of Commerce
USDOD	United States Department of Defense
USDOE	United States Department of Energy
USDOI	United States Department of Interior
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
VISITT	Vendor Information System for Innovative Treatment Technologies (USEPA Program)
VLDPE	Very Low Density Polyethylene

400240

DISCLAIMER

Mention of trade names or commercial products in this Feasibility Study is for purposes of evaluating remedial alternatives only, and does not constitute endorsement of any product or manufacturer by the U.S. Environmental Protection Agency.

Executive Summary

HUDSON RIVER PCBs REASSESSMENT FEASIBILITY STUDY
EXECUTIVE SUMMARY
DECEMBER 2000

SITE BACKGROUND

Location and Description

The Hudson River PCBs Superfund Site extends nearly 200 river miles (320 km) from the Fenimore Bridge in Hudson Falls (River Mile [RM] 197.3) to the Battery in New York City (RM 0) at the tip of Manhattan Island. This Feasibility Study (FS) is Phase 3 of the Reassessment Remedial Investigation/Feasibility Study (Reassessment RI/FS), which is being conducted by the United States Environmental Protection Agency (USEPA) to reassess the Agency's 1984 interim No Action decision concerning polychlorinated biphenyls (PCBs) in the sediments of the Upper Hudson River. This Reassessment FS identifies and evaluates in detail the remedial alternatives for PCB-contaminated sediments in the Upper Hudson River. The Upper Hudson River extends for 43 river miles (RM) from Fenimore Bridge in Hudson Falls (RM 197) to the Federal Dam at Green Island in Troy (RM 153.9). The Lower Hudson River extends from the Federal Dam to the Battery (RM 153.9 to 0).

The Reassessment FS is focused on the approximately 40 river miles from the northern end of Rogers Island to the Federal Dam at Troy. This portion of the river was divided into three sections for evaluating remedial alternatives in the FS. River Section 1, which is approximately 6 miles long, extends from the northern end of Rogers Island (RM 194.6) to the TI Dam (RM 188.5) and is also referred to as the Thompson Island (TI) Pool. River Section 2 is approximately 5 miles long and extends from the TI Dam (RM 188.5) to the Northumberland Dam near Schuylerville (RM 183.4). River Section 3 is approximately 29 miles long and extends from below the Northumberland Dam to the Federal Dam at Troy (RM 153.9).

History

PCB contamination in the Upper Hudson is due primarily to the release of PCBs from two General Electric Company (GE) capacitor plants in Fort Edward and Hudson Falls, New York (NY). During an approximate 30-year period ending in 1977, manufacturing processes at these two GE facilities used PCBs in the manufacture of electrical capacitors. PCBs from both facilities were discharged directly into the Hudson River. Estimates of the total quantity of PCBs discharged from the two plants into the river from the 1940s to 1977 range from 209,000 to 1,330,000 lbs (95,000 to 603,000 kg).

Many of the PCBs discharged to the river adhered to sediments and accumulated downstream with the sediments as they settled in the impounded pool behind the former Fort Edward Dam (RM 194.8), as well as in other impoundments farther downstream. Because of its deteriorating condition, the dam was removed by Niagara Mohawk Power Corporation in 1973. During subsequent spring floods, PCB-contaminated sediments were scoured and transported downstream. A substantial portion of these sediments was deposited in relatively quiescent areas of the river, *i.e.*, lower energy areas where the finer-grained sediments with higher PCB concentrations were deposited. These areas were surveyed by New York State Department of Environmental Conservation (NYSDEC) in

1976 to 1978 and 1984, and are described as PCB *hot spots*. These NYSDEC-defined *hot spots*, located between Rogers Island (RM 194) and Lock 2 (RM 163), are areas that typically had average total PCB concentrations of 50 ppm or greater.

In 1975, the New York State Department of Health (NYSDOH) began to issue health advisories recommending that people limit consumption of fish from the Upper Hudson River. In 1976, NYSDEC issued a ban on fishing in the Upper Hudson River from Hudson Falls to the Federal Dam at Troy, due to the potential risks from consumption of PCB-contaminated fish, and a ban on commercial fishing of striped bass, which migrate upriver into the Lower Hudson. NYSDEC lifted the ban against fishing in the Upper Hudson River and replaced it with a catch-and-release fishing program in 1995. NYSDOH continues to recommend that people eat none of the fish in the Upper Hudson and that children under the age of 15 and women of child-bearing age eat none of the fish in the river for the entire length of the Superfund site. In addition, the commercial striped bass fishery in the Lower Hudson is still closed.

The site was proposed for inclusion on the National Priorities List in September 1983 and formally listed in September 1984. USEPA completed an FS and issued a Record of Decision (ROD) for the site in September 1984. The 1984 ROD included the following decisions:

- An interim No Action decision with regard to PCBs in the sediments of the Upper Hudson River;
- In-place capping, containment, and monitoring of exposed "remnant deposit" sediments (in the area of RM 195 to RM 196), and stabilization of the associated riverbanks and revegetation of the areas; and
- A detailed evaluation of the Waterford Water Works treatment facilities, including sampling and analysis of treatment to determine if an upgrade or alterations of the facilities were needed.

Sources of PCBs Upstream of Rogers Island

There are four major potential PCB sources adjacent to the Upper Hudson River between Hudson Falls and Rogers Island, each at various stages of remediation. The four potentially important sources are the GE Hudson Falls plant, the GE Fort Edward plant, Remnant Deposit 1, and Remnant Deposits 2 through 5. The grouping of the remnant deposits is based on differences in the degree of remediation completed. There are two minor potential sources of PCBs upstream of the Fenimore Bridge: atmospheric deposition and the Niagara Mohawk Power Corporation site at Queensbury (located at about RM 209). These sources are considered anthropogenic baseline for purposes of the FS. Based on current data, of the four major sources, only the GE Hudson Falls plant appears to contribute a substantial amount of the PCB loads measured at Rogers Island. The region downstream of Rogers Island contributes between four and five times as much PCB to the Upper Hudson River as does the region upstream of Rogers Island, which includes leakage of PCB-contaminated oil through bedrock near the GE Hudson Falls plant.

In order to reduce the upstream source of PCBs, USEPA has authorized the performance of an Engineering Evaluation/Cost Analysis (EE/CA) to evaluate potential Non-Time Critical Removal Actions (NTCRA) to address the PCBs entering the river in the vicinity of the GE Hudson Falls plant. It is assumed that as a result of this source control removal action, the upstream load at Fort

Edward (Rogers Island) will be reduced from its average current value of 0.16 kg/day (equivalent to an average concentration of 13 ng/L) to 0.0256 kg/day (equivalent to an average concentration of 2 ng/L). Based on discussions with GE regarding a conceptual design, USEPA believes that a source control NTCRA can be completed by January 1, 2005.

REASSESSMENT REMEDIAL INVESTIGATION

In a December 19, 1989 letter to NYSDEC, USEPA announced that it would reassess the 1984 interim no-action decision for PCB-contaminated sediments in the Upper Hudson River. USEPA's decision to conduct the Reassessment RI/FS was based on the 1986 Superfund Amendments and Reauthorization Act's (SARA's) requirement that USEPA conduct five-year reviews at sites where hazardous substances were left in-place, and USEPA's policy decision to include such reviews at sites with pre-SARA RODs; recent advances in PCB treatment technologies; and NYSDEC's request to the Agency that it reassess its 1984 interim No Action decision.

For its Reassessment RI/FS, USEPA used data collected during its own sampling investigations, as well as data collected by many other agencies (*e.g.*, NYSDEC, U.S. Fish and Wildlife Service [USFWS], National Oceanographic and Atmospheric Administration [NOAA]), institutions, and GE. The investigations include sediment surveys, river flow and water quality investigations, fish/biota sampling, air monitoring, and plant/crop uptake studies.

Sixteen years after USEPA's 1984 interim No Action decision, PCB concentrations remain elevated in the Hudson River in the sediment, water, and fish. Concentrations generally decrease with distance down river, away from the original source areas of the GE Hudson Falls and Fort Edward plants. While some changes have occurred during this period, in general, conditions have not improved substantially from about 1995 to the present.

<u>Conceptual Site Model</u>

In the integrated conceptual model of the Hudson River PCBs site, PCBs are released from the two GE plants in Hudson Falls and Fort Edward into the Hudson River. Once in the river, the PCBs adhere to sediments or are carried in the water column. PCBs in the sediment are a continuing source of contamination to the water column and biota, through aquatic and benthic food chains and through processes that have been empirically measured but are not easily modeled (*e.g.*, boat scour, bioturbation). Because the river is a dynamic system, the PCB-contaminated sediments are not stable. Some PCB-contaminated sediment may be buried by deposition of cleaner sediments at some times, but in other places and at other times they may be redistributed locally by scouring. High flow events (*e.g.*, spring floods) may increase the bioavailability of contaminants to organisms in the water column. Organisms moving between the river and shore may also provide a pathway for PCB transfer to the terrestrial ecosystem.

<u>Summary of Site Risks</u>

USEPA examined risks to human health and the environment under baseline conditions in the Revised Human Health Risk Assessment (Revised HHRA, USEPA, 2000q) and Ecological Risk Assessment (Revised ERA, USEPA, 2000p) for the Reassessment RI/FS, respectively. The baseline conditions are equivalent to the No Action remedial alternative and presume no remediation of the

400245

PCB-contaminated sediments of the Upper Hudson River and no additional source control measures at the GE Hudson Falls plant. The risk assessments conclude that current and future concentrations of PCBs in fish are above levels of concern to human health and ecological receptors. For both, eating PCB-contaminated fish is the primary exposure pathway.

Peer Review

In accordance with USEPA guidance and the Peer Review Handbook, the scientific work conducted for the Reassessment underwent external peer review by independent scientific experts. The peer reviewers generally agreed with the findings and conclusions of the reports, although they also requested changes. USEPA issued Responses to Peer Review Comments for each of the peer reviews, as well as a Revised Human Health Risk Assessment and a Revised Ecological Risk Assessment. Revisions to all reports were incorporated into the FS, as appropriate.

ALTERNATIVE DEVELOPMENT

Remedial Action Objectives and Preliminary Remediation Goals

Consistent with the NCP and Agency RI/FS Guidance, USEPA developed remedial action objectives (RAOs) for the site. Preliminary remediation goals (PRGs) were established after review of both the preliminary chemical-specific applicable or relevant and appropriate requirements (ARARs) and risk-based concentrations. The following are the RAOs for the Reassessment FS:

- Reduce the cancer risks and non-cancer health hazards for people eating fish from the River by reducing the concentration of PCBs in fish. The risk-based PRG for protection of human health is 0.05 mg/kg total PCBs in fish fillet based on the RME adult fish consumption rate of 1 meal per week. Other target concentrations are 0.2 mg/kg total PCBs in fish fillet, which is protective at a fish consumption rate of about 1 meal per month and 0.4 mg/kg total PCBs in fish fillet, which is protective of the average angler (CT), who consumes about 1 meal every 2 months. These targets of higher concentrations in fish represent points at which fish consumption advisories might become less stringent (*e.g.*, the "eat none" advisory for the Upper Hudson could be relaxed as conditions improve).

- Reduce risks to ecological receptors by reducing the concentration of PCBs in fish. The risk-based PRG for the ecological exposure pathway is a range from 0.3 to 0.03 mg/kg total PCBs in fish (whole body), which correspond to PCB concentrations of 0.13 to 0.013 mg/kg in fish fillets. The ecological PRG is based on the lowest-observed adverse effects level (LOAEL) and the no-observed adverse effects level (NOAEL) for consumption of whole fish by the river otter, an upper-trophic- level piscivorous mammal ($TQ_{[LOAEL\ or\ NOAEL]\text{-}DIET} = 1$).

- Reduce concentrations of PCBs in river (surface) water that are above ARARs. The ARARs are: 1×10^{-6} µg/L (one part per quadrillion) total PCBs, NYS ambient water quality standard for protection of human consumers of fish; 1.2×10^{-4} µg/L, NYS standard for protection of wildlife; 1×10^{-3} µg/L, federal Ambient Water Quality Criterion; 0.09 µg/L, NYS standard for protection of human health and drinking water sources; and 0.5 µg/L, the federal maximum contaminant level (MCL) for PCBs in drinking water.

- Reduce the inventory (mass) of PCBs in sediment that are or may be bioavailable.

- Minimize the long-term downstream transport of PCBs in the river.

Development of Remediation Targets

Because consumption of fish is the major pathway of concern and fish concentrations are controlled by both sediment and water concentrations, a specific "cleanup value" for sediment was not selected as a goal. Instead, sediment cleanup is considered the means to achieve the RAOs. Areas of sediment for remediation were selected based on the potential for those areas to contribute PCBs to the water column and fish through the food chain. The delineation of the target areas considered a number of factors, primarily the inventory of PCBs in the sediment, but also surface sediment concentrations, sediment texture, bathymetry, and whether the PCB contamination is buried by greater than 12 inches of cleaner sediment. Target areas for remediation were not divided smaller than 50,000 square feet (a little over an acre) because of practical limitations on the number of separate remediation zones that could be accommodated for a project of this size. In addition, areas considered to be rocky, as defined by side-scan sonar, were excluded.

PCB inventory in sediment is represented by samples with a Mass Per Unit Area (MPA) measurement (*i.e.*, grams of PCBs per square meter). MPA represents the total mass of PCBs within a sediment core. MPA was plotted against area of non-cohesive sediment for River Section 1 (and against PCB mass remediated) to determine breakpoints where a small change in MPA would mean a large increase in area or mass to be remediated. This is an engineering evaluation of the efficiency of contamination to be addressed compared to the amount of the sediment surface that would require remediation. Breakpoints were found at approximately 3 g/m^2 and 10 g/m^2. For a core with a depth of one foot, 3 g/m^2 is equivalent to a concentration of approximately 10 mg/kg, and 10 g/m^2 is equivalent to approximately 30 mg/kg.

The MPA target levels are defined as:

0 g/m^2	Full-Section remediation
3 g/m^2	Expanded Hot Spot remediation
10 g/m^2	Hot Spot remediation

These criteria were applied to the three sections of the Upper Hudson to develop remedial target areas for River Sections 1, 2, and 3. In River Section 3, Full-Section remediation was excluded because it would have required remediation of an unreasonably large area (over 2,800 acres) and there are limited data in areas other than the five *hot spots*. Similarly, a cleanup level such as 1 mg/kg (as used for other sites) would have targeted unreasonably large areas in Section 3.

General Response Actions

Following the development of the RAOs and remediation target areas, USEPA updated the General Response Actions (GRAs) identified in the FS Scope of Work and its Responsiveness Summary. The final GRAs are no action, monitored natural attenuation, institutional controls, containment (capping), removal (dredging), *in situ* treatment, *ex situ* treatment, beneficial use, and disposal.

A comprehensive review of technologies and process options was performed by USEPA based on effectiveness, implementability, and cost. During the screening of technologies and process options, the General Response Action of *in situ* treatment was eliminated from further consideration, because no *in situ* treatment was identified that is capable of treating PCB-contaminated sediment in place in the Upper Hudson River.

Development of Alternatives

In order to meet the RAOs, 59 alternative scenarios were developed for remediation of the PCB-contaminated sediments in the three sections of the Upper Hudson River. The alternatives were developed by combining potentially applicable sediment remediation technologies from among those that remained after the technology screening (treatment and disposal options were considered separately, as discussed below). The initial list of alternatives that were evaluated can be grouped into the following alternative categories:

Alternative Category 1: No Action. This alternative is equivalent to baseline conditions. It includes no source control at GE Hudson Falls, no institutional controls, and no action with respect to the PCBs in the sediments in the Upper Hudson River. Five year reviews would be required.

Alternative Category 2: Monitored Natural Attenuation (MNA) (with Source Control at GE Hudson Falls) and Institutional Controls. This alternative includes implementation of source control measures at GE Hudson Falls pursuant to a separate NTCRA and monitoring, but no active remediation, of the PCBs in the sediments. Five year reviews would be required.

Alternative Category 3: Containment (capping) of Target Areas, MNA (with Source Control at GE Hudson Falls) and Institutional Controls. Alternative Category 3 includes placement of an engineered cap on target areas and protection of the cap from damage by boat propellers and anchors, bioturbation and other disturbances with backfill suitable for benthic and fish habitat. Five year reviews would be required.

Alternative Category 4: Removal (dredging) of Target Areas and MNA (with Source Control at GE Hudson Falls) and Institutional Controls Alternative Category includes removal of PCB-contaminated sediment, isolation of residual PCBs in sediments that may remain after dredging through placement of backfill suitable for benthic and fish habitat in target areas from which the sediments are removed, and several post-removal option categories for handling the removed sediments. Five year reviews would be required.

Alternative Category 5: Containment and Removal (capping, after dredging in some areas) of Target Areas and MNA (with Source Control at GE Hudson Falls) and Institutional Controls. Alternative Category 5 includes removal of PCB-contaminated sediment, placement of an engineered cap, protection of the cap from damage by boat propellers and anchors, bioturbation and other disturbances with backfill suitable for benthic and fish habitat, isolation of residual PCBs in sediments that may remain after dredging through placement of backfill in target areas from which the sediments are removed, and several post-removal option categories for handling the removed sediments. Five year reviews would be required.

400248

For alternative categories 3, 4, and 5, several alternatives were developed with a different extent of remediation in River Sections 1, 2, and 3.

Institutional controls (fish consumption advisories) would be utilized with the MNA, Capping and Removal alternatives. Institutional controls are considered to be limited action alternatives, and therefore are not included under the No Action alternative.

Capping alternatives (alternative categories 3 and 5) considered an engineered cap (including a bentonite layer) of approximately 1-1/2 foot total thickness (including 1 foot of bentonite composite material overlain by 0.5 foot of backfill), which was based on the potential for disturbance by boat propeller wash and ice chunks. However, because the addition of this material would greatly alter the geometry of the river (shoreline) in shallow areas, areas with less than 6 feet average draft would first require dredging. In addition, because the river is used for navigational purposes, it is impractical to cap the channel (which later may require navigational dredging). Removal is the only active remediation that would be performed in the channel.

For the removal alternatives, both mechanical and hydraulic dredging were considered to preserve flexibility during the remedial design. The following post-removal option categories were evaluated:

A. Off-site Containment/Disposal of Removed Sediments.

B. Near River *Ex Situ* Treatment of Removed Sediments followed by Offsite Containment/ Disposal of Treated Sediments.

C. Off-site *Ex Situ* Treatment of Removed Sediments followed by Off-site Containment/ Disposal of Treated Sediments.

D. Abandoned Mine Reclamation/Landfill Cover/Construction Fill.

E. Near River *Ex Situ* Treatment of Removed Sediments followed by Abandoned Mine Reclamation/Landfill Cover/Construction Fill.

F. Off-site *Ex Situ* Treatment of Removed Sediments followed by Abandoned Mine Reclamation/Landfill Cover/Construction Fill.

G. Near River *Ex Situ* Treatment of Removed Sediments followed by Manufacture of Commercial Products from Treated Removed Sediments.

H. Off-site *Ex Situ* Treatment of Removed Sediments followed by Manufacture of Commercial Products from Treated Removed Sediments.

All of the above post-removal handling option categories require dewatering of the sediments. They also include appropriate treatment of the water (primarily filtration with polishing by granular activated carbon [GAC] adsorption) to meet NYS Pollution Discharge Elimination System (NYSPDES) requirements before being discharged into the river. Option Category A includes containment/disposal of the removed sediments in an industrial (RCRA Subtitle D) or

TSCA-permitted landfill, depending on the concentration of total PCBs in the bulk dewatered sediments. Option Categories B and C are similar except for the location where the *ex situ* treatment (stabilization) is performed. Option Category D is a form of low-value beneficial use of the removed sediments without the need for any *ex situ* treatment (stabilization). This option category is likely suitable for sediments with relatively low concentrations of total PCBs (typically < 4 or < 10 mg/kg depending on the application and local site-specific requirements).

Option Categories E and F are applicable to sediments with similar concentrations of total PCBs (typically < 4 or < 10 mg/kg) that require some *ex situ* treatment (stabilization) to improve the handling and disposal characteristics of the dredged sediments prior to the low-value beneficial use. They are similar except for the location where the *ex situ* treatment is performed. Option Categories G and H are quite different from options A through F because the PCBs are removed by thermal desorption, plasma arc vitrification, or surfactant washing and chemical treatment, and the sediments (clays, silts, and sands) are converted into higher value, useful commercial products such as architectural tiles, fiberglass, cement, light-weight aggregate, or manufactured soils. Option Categories G and H are designed to allow unrestricted use of these products because they no longer contain PCBs; the categories are similar to each other except for the location where the *ex situ* treatment is performed.

Based on an evaluation of various factors including the method of dredging and the location where ex situ treatment is performed, only Option Categories A, B, D, E, and H were retained for further consideration in the development and screening of alternatives.

Remedial Alternatives Screening

Application of Screening Criteria

The remedial alternatives were screened for effectiveness, implementability, and cost. Consistent with the RI/FS Guidance, effectiveness of a remedial alternative refers to its ability to protect human health and the environment; the screening for this criterion is discussed in greater detail below. The screening for implementability involves both the technical and administrative feasibility of constructing, operating, and maintaining a remedial alternative. The screening for cost includes both capital and O&M costs, where appropriate, as well as present worth analyses.

On the basis of the implementability screening, a new near-river landfill for disposal of treated PCB-contaminated sediments was eliminated. USEPA has long known that much of the community within the Upper Hudson River is opposed to the siting of a new landfill that would receive PCB-contaminated sediment from the river. In recognition of this opposition, and the administrative difficulties that would be encountered in attempting to site a near-river landfill, USEPA determined that a local landfill, though technically feasible, was not administratively feasible.

For similar types of alternatives, the evaluation of the effectiveness screening criterion was based on the relative risks to human health and ecological receptors posed by exposure to PCBs in water, sediment, and fish following implementation of the remedial alternatives. The exposure concentrations were forecast using USEPA's coupled, quantitative models for PCB fate, transport and bioaccumulation in the Upper Hudson River, called HUDTOX and FISHRAND, which were developed for the Reassessment RI/FS. The models were calibrated to an extensive 21-year historical data set.

Since the peer review, USEPA has performed validation runs of its Upper Hudson River models under baseline (No Action) conditions using data for the upstream boundary condition, the hydrograph, and tributary solids loading. With these inputs, USEPA demonstrated that the models are able to predict concentrations in fish that match the mean of the lipid-based fish body burden data within a factor of 2. Nonetheless, USEPA believes that the models, when used in the forecast mode, are best used to predict relative concentrations of PCBs in water, sediment, and fish, rather than absolute concentrations. There are a number of inherent uncertainties, both with respect to the data (or lack thereof) used to calibrate the models and the need to assume certain conditions in the future, such as the hydrograph and tributary solids loading. For these reasons, USEPA also developed key additional lines of evidence to evaluate protection of human health and the environment from (1) sensitivity analyses of the mathematical modeling, (2) estimation of upper bounds for the No Action and MNA alternatives, and (3) analysis of observed trends in recent environmental data, which are independent of the model.

Estimated Upper Bounds for No Action and Monitored Natural Attenuation Alternatives

The efficacy of the No Action and MNA alternatives depends primarily on the gradual depletion and/or burial of sediment PCBs in the bioavailable zone. Given the possibility that concentrations of PCBs in sediment may decline more slowly than predicted by HUDTOX, whether due to the spatial scale of the model or inherent assumptions, such as sediment mixing zone or mixing rate, USEPA developed an approach for estimating upper bounds for the No Action and Monitored Natural Attenuation alternatives. (The rate of decline is much less important for the active remedial alternatives, which rely primarily on sediment removal or capping to limit the exposure of biota to PCBs). The upper bounds were estimated assuming that PCB concentrations in cohesive sediment will decline with a half-life of 50 years, consistent with the 1995-1999 data for PCBs in brown bullhead, a catfish that gets most of its PCB exposure from the sediment through the benthic food chain. In the upper bound estimations, concentrations of PCBs in non-cohesive sediment and the water column are forecast by HUDTOX, which is reasonable given the high degree of agreement between the model output and the water column data. The upper bounds for the No Action and Monitored Natural Attenuation alternatives are considered in evaluating relative risks to human health and the environment posed by the different alternatives.

Modeling for Alternative Screening

Development of potential remedial alternatives was performed based on an evaluation of the data used to delineate remediation target threshold boundaries and a four-step modeling evaluation. The evaluation also considered the potential uncertainties associated with model predictions and other lines of evidence, as identified above. Modeling of remedial alternative scenarios was performed in four stages: 1) modeling of No Action and Monitored Natural Attenuation, 2) preliminary modeling, 3) engineering modeling, and 4) refined engineering modeling. At each stage of the modeling, the results were used to refine the scope of modeling in the next stage.

Modeling was conducted to evaluate the impact of remediation for combinations of the target levels for each river section. It was found that remediation in River Section 1, the Thompson Island

Pool, had the greatest benefit with respect to PCB levels in fish and surface water. The model did not show substantial benefits from remediation in River Section 3, most likely due to the relatively large scale of the model segments in this reach. However, data show increased water column concentrations in this reach resulting from tributary high flow events that caused scour in the mainstem Hudson, thereby elevating the water-column PCB concentrations. For example, a comparison of 1977 and 1994 sediment data showed that over two thirds of the PCB inventory was lost from *Hot Spot* 37. Therefore, certain areas in River Section 3, *i.e., Hot Spots* 36, 37, and the southern portion of 39, were selected for remediation based on PCB inventory and signs of PCB inventory loss. These target areas in River Section 3 are also referred to as Select areas.

Based on analyses of the model output as compared to recent data trends, it appears that the rates of PCB decline with respect to the No Action (no source control) and Monitored Natural Attenuation (with source control) alternatives in the model projections are faster than the rates of decline seen in the monitoring data. Under the modeled remedial alternatives, this over-optimism is eliminated wherever PCB inventory is removed or capped, because projected rates of decline are replaced by specified concentrations in the remediated areas. Consequently, the benefits of remediation based on comparisons of the remediation alternatives to the No Action and Monitored Natural Attenuation alternatives are likely underestimated by the models.

A specialized nomenclature system was used to designate the remedial scenarios (potential remedial alternatives) for the engineering modeling and refined engineering modeling. The first part of the scenario name uses three or more letters to describe the remedial alternative category, *e.g.*, removal (REM) or capping with dredging (CAP). The second part of the remedial scenario name uses numbers or letters to denote the remediation target area for each of the three river sections and the extent of remediation within each river section, sequentially from River Section 1 to River Section 3 (as explained earlier). Therefore, by this nomenclature system, the alternative that involves Full-Section capping with dredging in River Section 1, Expanded Hot Spot capping with dredging of sediments (at or above nominal PCB MPA of 3 g/m^2) in River Section 2, and no remediation of sediments (MNA only) in River Section 3, would be designated as CAP-0/3/MNA.

Screening Factors and Metrics

The alternatives were evaluated by comparing various factors including:

- the mass of PCBs, areas and volumes of sediment targeted for remediation;
- the area capped;
- the volume of sediment removed;
- the surface water quality in each river section;
- the fish body burdens in each river section;
- the PCB load over Federal Dam;
- the propensity for scour in River Section 3 due to flows from the Hoosic River;
- the upstream boundary condition (best estimate of future conditions);
- the need for long-term maintenance of capped areas; and
- the potential long-term risks from leaving contaminated sediments in the river's ecosystem.

Relative improvements in surface water quality, fish body burdens, and the load over Federal Dam obtained by incremental changes in the mass of PCBs, areas and volumes of sediment targeted for remediation in each river section among the alternatives were also examined.

Based on the screening of alternatives for effectiveness, implementability and cost, the most promising scenarios were brought forward into detailed analysis. The following table shows the five alternatives, including No Action, that were retained for detailed analysis:

Characteristics of Alternatives Retained for Detailed Analysis						
Alternative	**Area Remediated (Acres)**	**Area Capped (Acres)**	**Volume Removed (million cy)**	**Estimated PCB Mass Remediated (kg)**	**Estimated PCB Mass Removed (kg)**	**Net Present Worth ($Million)**
No Action	-	-	-	-	-	$0.14
Monitored Natural Attenuation	-	-	-	-	-	$39
CAP 3/10/Select	493	207	1.73	45,600	33,100	$370
REM 3/10/Select	493	-	2.65	45,600	45,600	$460
REM 0/0/3	964	-	3.82	>63,500	>63,500	$570

DETAILED ANALYSIS OF REMEDIAL ALTERNATIVES

Description of Alternatives

The detailed description of the remedial alternatives includes: a description of the alternative, including the technologies comprising the alternative; a description of engineering, safety, environmental, public health, or other considerations that affect the feasibility of the alternative; the aspects of the sediment and surface water contamination problem that the alternative will or will not control; and, a preliminary conceptual engineering design including necessary facilities, equipment, and construction items. A breakdown of the quantities, dimensions, and sizing of major components of the conceptual design is provided as a basis for cost estimation. Consistent with the RI/FS Guidance, the level of detail in the FS is focused on providing cost estimates with an accuracy in the range of -30 percent to +50 percent.

No Action

The No Action alternative consists of refraining from the active application of any remediation technology to sediments in all three sections of the Upper Hudson River. The No Action alternative also excludes any source control removal action (*i.e.*, the NTCRA) in the vicinity of the GE Hudson Falls plant, any administrative actions (including institutional controls, such as fish consumption advisories, which are considered to be limited action under the NCP), and any monitoring. Reviews will be conducted at five-year intervals as required by Section 121(c) of CERCLA. For this alternative, the upstream Tri+ PCB load at Fort Edward (Rogers Island) is assumed to remain constant at 0.16 kg/day indefinitely.

Monitored Natural Attenuation (MNA)

The Monitored Natural Attenuation alternative includes natural attenuation of sediments, institutional controls, long-term monitoring and modeling to track progress, and periodic reviews at five-year intervals. Unlike No Action, the MNA alternative assumes a separate source control removal action (NTCRA) at the GE Hudson Falls plant. It is assumed that as a result of this source control removal action, the average upstream PCB load at Fort Edward (Rogers Island) is reduced from 0.16 kg/day to 0.0256 kg/day on January 1, 2005. Natural attenuation refers to the reduction of toxicity, mobility and volume of contaminants in the sediments by naturally occurring biological, chemical, and physical processes. Institutional controls (*e.g.*, site use restrictions) are implemented as long-term control measures as part of this alternative. These restrictions include continuation or extension of the existing fish consumption advisories, and catch and release restrictions.

Long-term monitoring of PCBs in sediments, the water column, and biota is conducted as part of the MNA alternative. The purpose of the monitoring and modeling is to demonstrate that contaminant reduction is occurring, and that the reduction is achieving regulatory requirements, such as the NYS standard for PCBs in surface water (1×10^{-6} µg/L), for protection of the health of human consumers of fish. Monitoring includes measurements of sediment accumulation rates or erosion/scour, PCB concentrations in the sediment by depth, bioaccumulation by benthic organisms, and the migration or harvesting of contaminated organisms. Monitoring data are used as input parameters and recalibration points in the mathematical models to evaluate progress of the natural attenuation processes against the original predictions. Reviews are conducted at five-year intervals to reassess the long-term appropriateness of continued MNA.

CAP-3/10/Select

This alternative includes capping with dredging to perform Expanded Hot Spot remediation (*i.e.*, in which the nominal MPA targets are 3 g/m^2 or greater) in River Section 1, Hot Spot remediation (*i.e.*, in which the nominal MPA targets are 10 g/m^2 or greater) in River Section 2, and remediation of select areas (*i.e.*, sediments with high-concentration PCB target areas and which are potentially subject to scour) in River Section 3. This alternative also includes dredging in the navigation channel as necessary to implement the remediation. Protection of the cap from damage by boat propellers and anchors, bioturbation and other disturbances is implemented through addition of a layer of backfill material suitable for replacement of fish and benthic habitat. Areas from which sediments are removed are backfilled with appropriate material to isolate residual PCBs in sediments that may remain after dredging is completed. No backfill is placed in the navigation channel. After construction is completed, MNA is implemented in each section of the river until the RAOs are achieved.

The total area of sediments to be capped is approximately 207 acres. The estimated volume of sediments to be removed is 1.73 million cubic yards. Remediation will commence in 2004 and will be completed in 2008. This alternative is performed in conjunction with a separate source control removal action (*i.e.*, NTCRA) in the vicinity of the GE Hudson Falls plant and also relies on institutional controls, such as the fish consumption advisories, and naturally occurring attenuation processes to reduce the toxicity, mobility and volume of the remaining PCBs in the Upper Hudson River sediments after the construction is completed. A review of site conditions will be conducted at five-year intervals, as required by Section 121© of CERCLA.

REM-3/10/Select

This alternative includes Expanded Hot Spot removal (*i.e.*, in which the nominal MPA targets are 3 g/m^2 PCBs or greater) in River Section 1, Hot Spot removal (*i.e.*, in which the nominal MPA targets are 10 g/m^2 or greater) in River Section 2, and removal of select areas (*i.e.*, sediments with high-concentration PCB target areas and which are potentially subject to scour) in River Section 3. This alternative also includes sediment removal in the navigation channel as necessary to implement the remediation. Isolation of residual PCBs in sediments that may remain after dredging is completed through addition of a layer of backfill material suitable for replacement of the fish and benthic habitat. No backfill is placed in the navigation channel. After construction is completed, MNA is implemented in each section of the river until the RAOs are achieved.

The total area of sediments targeted for removal is approximately 493 acres. The estimated volume of sediments to be removed is 2.65 million cubic yards. Remediation will commence in 2004 and will be completed in 2008. This alternative is performed in conjunction with a separate source control removal action (*i.e.*, NTCRA) in the vicinity of the GE Hudson Falls plant and also relies on institutional controls, such as the fish consumption advisories, and naturally occurring attenuation processes to reduce the toxicity, mobility and volume of the remaining PCBs in the Upper Hudson River sediments after the construction is completed. A review of site conditions will be conducted at five-year intervals, as required by Section 121© of CERCLA.

REM-0/0/3

This alternative includes Full-Section removal (*i.e.*, removal of sediments in which the MPA targets are 0 g/m^2 or greater) in River Section 1 and 2, and Expanded Hot Spot removal (*i.e.*, in which the nominal MPA targets are 3 g/m^2 or greater) in River Section 3. This alternative also includes sediment removal in the navigation channel as necessary to implement the remediation. Isolation of residual PCBs in sediments that may remain after dredging is completed through addition of a layer of backfill material suitable for replacement of the fish and benthic habitat. No backfill is placed in the navigation channel.

The total area of sediments targeted for removal is approximately 964 acres. The volume of sediments to be removed is estimated to be 3.82 million cubic yards. This alternative performs the most extensive remediation that can be supported by current data, and has the longest duration. Remediation will begin in 2004 and will be completed in 2010. This alternative is performed in conjunction with a separate source control removal action (*i.e.*, NTCRA) in the vicinity of the GE Hudson Falls plant and also relies on institutional controls, such as the fish consumption advisories, and naturally occurring attenuation processes to reduce the toxicity, mobility and volume of the remaining PCBs in the Upper Hudson River sediments after the construction is completed. A review of site conditions will be conducted at five-year intervals, as required by Section 121© of CERCLA.

Comparative Analysis of Alternatives

Under CERCLA, nine key criteria are utilized in the detailed analysis of remedial alternatives. The first two criteria are threshold criteria that must be met by each alternative. The two threshold criteria are: Overall Protection of Human Health and the Environment, and Compliance with ARARs. The next five criteria are the primary balancing criteria upon which the analysis is based. The five primary balancing criteria are: Long-term Effectiveness and Permanence; Reduction of Toxicity, Mobility or Volume through Treatment; Short-term Effectiveness; Implementability; and Cost. The comparative analysis below encompasses the two threshold criteria and the five balancing criteria, but not the two modifying criteria of state acceptance and community acceptance, which will be evaluated following the public comment period.

Overall Protection of Human Health and the Environment

This evaluation criterion provides a final assessment as to whether each alternative adequately protects human health and the environment. Relative reductions in risk for each remedial alternative as compared to the No Action and Monitored Natural Attenuation alternatives are discussed below. Consideration of the impacts of the upstream boundary concentration is also discussed.

<u>Overall Protection of Human Health</u>

Overall protection of human health was evaluated in two primary ways: the time that it would take under each of the alternatives to reach the fish PRG and the other target concentrations, and the relative reduction in cancer risks and non-cancer health hazards under the five remedial alternatives.

Time to Reach Fish Target Levels

The fish PRG is 0.05 ppm PCBs (wet weight) in fillet. In addition, USEPA considered a target concentration of 0.2 ppm PCBs (wet weight) in fillet based on one fish meal per month, and a target concentration of 0.4 ppm, based on the average consumption rate of one fish meal every two months. The target concentrations correspond to points at which the fish consumption advisories might be relaxed from the current "eat none" recommendation in the Upper Hudson River. The following table shows the time required under each of the alternatives to reach the fish consumption PRG and target concentrations.

Years to Reach PCB Target Concentration in Fish Averaged Over Entire Upper Hudson River

Alternative	0.05 ppm PRG	0.2 ppm (1 meal/ month) target	0.4 ppm (1 meal/ 2 months) target
No Action	>67	>67	>67
MNA	>67	60 to >67	34 to >67
CAP-3/10/Select	>67	35	21
REM-3/10/Select	>67	35	20
REM-0/0/3	>67	26	11

The overall protection of human health achieved by the active alternatives is considerably more than that achieved by the No Action and MNA alternatives. For the CAP-3/10/Select, REM-3/10/Select, and REM-0/0/3 alternatives, risk is reduced through removal or capping with dredging of contaminated sediments in River Sections 1 and 2, and removal of contaminated sediments in River Section 3, followed by Monitored Natural Attenuation.

In River Section 3, all of the active remediation alternatives meet the PRG target concentration of 0.05 ppm PCBs between the years 2050 and 2051 (which is 40 to 43 years after construction is complete, depending on the alternative); the MNA alternative reaches it in the year 2059; and the No Action alternative does not meet the PRG within the modeling time frame. As a result, the PRG of 0.05 ppm also is expected to be attained in the majority of the Lower Hudson River, due to the lower initial concentration of PCBs in the Lower Hudson compared to the Upper Hudson. Due to the continuing PCB load of 2 ng/L assumed after implementation of the source control action in the vicinity of the GE Hudson Falls plant, the PCB concentration in fish averaged over the Upper Hudson is expected to be reduced to a range of 0.09 to 0.14 ppm, which is slightly above the PRG of 0.05 ppm.

The protectiveness of the active remedial alternatives is further enhanced through implementation of institutional controls, such as the fish consumption advisories. The modeled results suggest that the advisories could be relaxed somewhat at various points in the future for the different river sections. Specifically, the 0.2 ppm target concentration is met in River Section 2 in 2044 for CAP-3/10/Select (about 36 years after remediation is complete), 2040 for REM-3/10/Select, and 2034 for REM-0/0/3. In comparison, it is met in 2061 for the base MNA alternative and is not met within the modeled time frame for the estimated upper bound MNA alternative. The 0.2 ppm target concentration is not met within the modeled time frame for No Action or the estimated upper bound No Action alternative.

For the CAP-3/10/Select alternative, the modeling projects that the target concentration of 0.4 ppm is attained in River Section 1 within 16 years of active remediation, within 15 years for REM-3/10/Select, and within 3 years for REM-0/0/3. The target of 0.2 ppm, protective of an adult who consumes one fish meal per month, is attained in River Section 2 within 32 years of active remediation. These time periods are significantly shorter than the time periods projected for attaining the 0.4 ppm target under either the No Action alternative or the MNA alternative.

Relative Reductions in Cancer Risks and Non-Cancer Health Hazards

The model output years included in the exposure calculations were identified on a river section basis using different long-term period starting dates, depending on the construction schedule for each remedial alternative. The long-term exposure period was considered to start immediately after a one-year equilibration period beyond the completion of work in a given river section. For example, if the construction schedule for an alternative requires three years to complete in River Section 1, given a start date in 2004, the construction would be complete at the end of 2006, equilibration would occur over the year 2007, and the long-term period for calculation of cancer risks and non-cancer health hazards would start on January 1, 2008.

Cancer risks and non-cancer health hazards for the entire Upper Hudson River (RMs 189 to 154) and for each section of the river under the active remedial alternatives were compared separately (using the appropriate time frame) to the cancer risks and non-cancer health hazards under the No Action and MNA alternatives, including their estimated upper bounds, to estimate the reduction in cancer risks and non-cancer health hazards achieved by each alternative.

The fish concentration predictions used are the species-weighted averages, based on relative species consumption reported in the 1991 state-wide New York angler survey. The fish consumption rates and time periods assumed for exposure are the same as those utilized in the Revised HHRA. Because the PCB concentration in fish declines for the projected 70-year period covered by this FS, the average concentration (over time) actually declines as the exposure period increases. Thus, the average concentration and, by extension, the average PCB intake in terms of mg/kg-day, in a 7-year exposure period is actually greater than the average concentration over, for example, 12 years. As a result of the declining trend in PCB concentration in fish over time, the average daily dose decreases as the exposure duration increases.

The RME cancer risks and non-cancer health hazards for adult anglers for each alternative and for the entire Upper Hudson River are shown in the table below.

Non-Cancer Health Hazards and Cancer Risks from Fish Ingestion Averaged over the Entire Upper Hudson River

Non-Cancer Health Hazard Index or Cancer Risk	No Action	MNA	CAP-3/10/Select	REM-3/10/Select	REM-0/0/3
HI-RME (2009-2015)	53-80	40-71	15	13	
HI-RME (2011-2017)	48-75	34-66			8
HI-CT (2009-2020)	5.0-7.7	3.4-6.7	1.3	1.2	
HI-CT (2011-2022)	4.5-7.3	2.9-6.3			0.7
Cancer risk - RME (2009-2048)	7.8E-04 to 1.4E-03	4.0E-04 to 1.2E-03	1.8E-04	1.7E-04	
Cancer risk - RME (2011-2050)	7.3E-04 to 1.3E-03	3.5E-04 to 1.1E-03			1.2E-04
Cancer risk - CT (2009-2020)	1.7E-05 to 2.6E-05	1.2E-05 to 2.3E-05	4.5E-06	4.0E-06	
Cancer risk - CT (2011-2022)	1.5E-05 to 2.5E-05	1.0E-05 to 2.1E-05			2.4E-06

The table below shows a summary of predicted RME cancer risk and non-cancer health hazard reductions for all active alternatives compared to the No Action and MNA alternatives, and for MNA compared to No Action.

Summary of Cancer Risk and Non-Cancer Health Hazard Reductions						
	Compared to No Action			**Compared to MNA**		
Alternative	**Upper Hudson & River Section 1**	**River Section 2**	**River Section 3**	**Upper Hudson & River Section 1**	**River Section 2**	**River Section 3**
MNA	<2 to 4-fold	<2 to 4-fold	<2 to <3-fold			
CAP-3/10/Select	4 to 8-fold	4 to 9-fold	<2 to 3-fold	2 to 6-fold	3 to 9-fold	<2-fold
REM-3/10/Select	4 to 8-fold	5 to 11-fold	<2 to 3-fold	2 to 7-fold	3 to 11-fold	<2-fold
REM-0/0/3	6 to 11-fold	7 to 16-fold	3 to 4-fold	3 to 9-fold	4 to 16-fold	<2-fold

Compared to the estimated upper bound of No Action, the REM-0/0/3 alternative achieves an order of magnitude (*i.e.*, 10-fold) or more reduction in RME cancer risks and non-cancer health hazards in the Upper River as a whole, and in River Sections 1 and 2 individually. Predicted reductions in River Section 3 are smaller (approximately three-fold) since sediments included in target areas make up a much smaller fraction of the overall surface area of this section and there is much greater dilution due to tributary flows. When compared to the MNA base forecast, the reductions for the REM-0/0/3 alternative in River Sections 1 and 2 and for the entire Upper River are on the order of three-to-five fold. Reductions for River Section 3 are less than two-fold.

Generally speaking, the more extensive the alternative, the greater the reduction in cancer risk or health hazard. Based on modeling assumptions and considering the average for the Upper Hudson as a whole, non-cancer health hazard reduction under the REM-3/10/Select alternative compares incrementally favorably to that for CAP-3/10/Select (*i.e.*, health hazard reductions are within a few percentage points of each other for these two alternatives). Health hazard reduction under the REM-0/0/3 alternative represents approximately a 10-percentage-point advantage over the REM-3/10/Select alternative while the difference in cancer risk reduction between the two alternatives is only about five percentage points. The differences between comparisons to No Action and MNA are somewhat greater for cancer risk reduction than for non-cancer health hazard reduction.

Since the assumed (separate) upstream source control component is the same for all active alternatives and for MNA, greater extensiveness in sediment remediation yields greater benefits in health hazard reduction and in cancer risk reduction. These increases in benefits, however, are not linearly proportional to increases in the volume or area of sediment remediated. Because these parameters are directly related to cost, it follows that similar increments in risk reduction will come at greater and greater cost, requiring tradeoffs based on analysis of other criteria.

Overall Protection of the Environment

Ecological risks were calculated for each of the three river sections for the river otter and the mink. The river otter is a piscivorous mammal and was the receptor found to be at greatest risk in the Upper Hudson River in the Revised ERA (USEPA, 2000q), due to the high proportion of fish in its diet. The mink is a piscivorous mammal and is known to be sensitive to PCBs. The long-term exposure period for the river otter and mink is considered to start immediately after a one-year equilibration period beyond the completion of work in a given section, as was assumed for human health calculations. Risks to other ecological receptors are assumed to be equal to or less than those calculated for river otter and mink. Moreover, risks to ecological receptors in the Lower Hudson River are assumed to be equal to or less than those calculated for River Section 3 based on lower concentration of PCBs in the Lower Hudson River.

River Otter

River otters were assumed to consume a diet consisting entirely of PCB-contaminated largemouth bass. The TQs calculated for the river otter are based on the LOAEL and NOAEL TRVs of 0.04 mg PCBs/kg/day and 0.004 mg PCBs/kg/day, respectively. The NOAEL and LOAEL ecological toxicity quotients calculated for the river otter for each of the three river sections are shown in the table below. TQs above the target level of one are shown in bold face type. TQ ranges calculated using bounding estimates are presented for the No Action and MNA alternatives.

Ecological Toxicity Quotients - River Otter (25-Year Average)							
	No Action start year 2008	**No Action** start year 2009	**MNA** start year 2008	**MNA** start year 2009	**CAP-3/10/Select**	**REM-3/10/Select**	**REM-0/0/3**
River Section 1 (RM 189)	Modeling time frame is 2008-2032 for CAP-3/10/Select and REM-3/10/Select and 2009-2033 for REM-0/0/3						
LOAEL	**24-30**	**23-29**	**9.7-15**	**9.1-14**	**5.3**	**5.2**	**3.7**
NOAEL	**240-300**	**230-290**	**97-150**	**91-140**	**53**	**52**	**37**
River Section 2 (RM 184)	Modeling time frame is 2009-2033 for CAP-3/10/Select and REM-3/10/Select and 2011-2035 for REM-0/0/3						
LOAEL	**14-27**	**12-26**	**9.2-24**	**7.8-23**	**3.5**	**2.9**	**1.8**
NOAEL	**140-270**	**120-260**	**92-240**	**78-230**	**35**	**29**	**18**
River Section 3 (RM 154)	Modeling time frame is 2010-2034 for CAP-3/10/Select and REM-3/10/Select and 2012-2036 for REM-0/0/3						
LOAEL	**2.4**	**2.3**	**1.2**	**1.1**	0.87	0.86	0.62
NOAEL	**24**	**23**	**12**	**11**	**8.7**	**8.6**	**6.2**

Toxicity quotients calculated for the river otter exceed one for LOAEL and NOAEL comparisons in River Sections 1 and 2 at RMs 189 and 184 and for all NOAEL comparisons in River Section 3 at RM 154. In River Section 3, LOAEL TQs are below one for all active remediation alternatives, but exceed one for the MNA and No Action alternatives.

A TQ of one is not reached by 2067 (the end of the modeling period) on a LOAEL or NOAEL basis in River Section 1 or on a NOAEL basis in River Sections 2 and 3. In River Section 2, on a LOAEL basis a TQ of one is reached in 35 to 52 years with active remediation and not for more than 59 years under the No Action and MNA alternatives. In River Section 3, on a LOAEL basis a TQ of one is reached in 5 to 8 years with active remediation, in 14 years under the MNA alternative, and not for more than 58 years under the No Action alternative.

The table below shows a summary of predicted reductions in river otter TQs for all active alternatives compared to the No Action and MNA alternatives for the modeled time periods presented on the table above, and for MNA compared to No Action. Since the NOAEL is calculated as an order of magnitude higher than the LOAEL in all cases, the reductions for both NOAEL and LOAEL compared to the respective No Action and MNA are the same; therefore only a single result is presented in each case.

Reductions in Ecological Toxicity Quotients - River Otter				
	MNA	**CAP-3/10/Select**	**REM-3/10/Select**	**REM-0/0/3**
River Section 1 (RM 189)				
No Action	2 to 3-fold	5 to 6-fold	5 to 6-fold	6 to 8-fold
MNA		2 to 3-fold	2 to 3-fold	2 to 4-fold
River Section 2 (RM 184)				
No Action	<2 to 3-fold	4 to 8-fold	4 to 8-fold	7 to 14-fold
MNA		3 to 7-fold	3 to 8-fold	4 to 13-fold
River Section 3 (RM 154)				
No Action	2-fold	3-fold	3-fold	4-fold
MNA		<2-fold	<2-fold	2-fold

As may be determined from the table above, reductions in toxicity quotient for the river otter compared to No Action and MNA vary with extensiveness of the remediation. Reductions for the CAP-3/10/Select and REM-3/10/Select alternatives are virtually identical, while those for the REM-0/0/3 alternative are higher. All active alternatives show greater risk reductions than No Action and MNA. Reductions in River Section 2 for the REM-0/0/3 alternative, compared to the estimated upper bounds for both No Action and MNA, exceed an order of magnitude. Compared against the base case for No Action, risk reduction decreases with distance downstream for the CAP-3/10/Select and REM-3/10/Select alternatives. This trend does not consistently hold for other comparisons for River Sections 1 and 2, however. On the other hand, reductions in River Section 3 are consistently smaller than those upstream, since sediments included in target areas make up a much smaller fraction of the overall surface area of this section and there is much greater dilution due to tributary flows.

400261

Mink

Approximately one-third (34 percent) of the mink diet was assumed to consist of PCB-contaminated spottail shiners (*i.e.*, representing fish less than 10 cm in length).The TQs calculated for the mink are based on the LOAEL and NOAEL TRVs of 0.04 mg PCBs/kg/day and 0.004 mg PCBs/kg/day, respectively. The NOAEL and LOAEL ecological toxicity quotients calculated for the mink for each of the three river sections are shown in the table below. TQs above the target level of one are shown in bold face type. TQ ranges calculated using bounding estimates are presented for the No Action and MNA alternatives.

Ecological Toxicity Quotients - Mink (25-Year Average)							
	No Action start year 2008	**No Action** start year 2009	**MNA** start year 2008	**MNA** start year 2009	**CAP-3/10/Select**	**REM-3/10/Select**	**REM-0/0/3**
River Section 1 (RM 189)	Modeling time frame is 2008-2032 for CAP-3/10/Select and REM-3/10/Select and 2009-2033 for REM-0/0/3						
LOAEL	**4.6-5.3**	**4.5-5.2**	**1.7-2.6**	**1.6-2.5**	0.94	0.95	0.70
NOAEL	**46-53**	**45-52**	**17-26**	**16-25**	**9.4**	**9.5**	**7.0**
River Section 2 (RM 184)	Modeling time frame is 2009-2033 for CAP-3/10/Select and REM-3/10/Select and 2011-2035 for REM-0/0/3						
LOAEL	**1.5-2.7**	**1.3-2.6**	0.94-**2.5**	0.79-**2.4**	0.36	0.31	0.19
NOAEL	**15-27**	**13-26**	**9.4-25**	**7.9-24**	**3.6**	**3.1**	**1.9**
River Section 3 (RM 154)	Modeling time frame is 2010-2034 for CAP-3/10/Select and REM-3/10/Select and 2012-2036 for REM-0/0/3						
LOAEL	0.21	0.20	0.11	0.09	0.07	0.08	0.06
NOAEL	**2.1**	**2.0**	**1.1**	0.9	0.75	0.75	0.55

Toxicity quotients calculated for the mink are below or equal to one for LOAEL comparisons for active alternatives in all river sections. In River Section 3, NOAEL comparisons for active remediation alternatives are also below one. Under the No Action and MNA alternatives, all NOAEL and LOAEL TQs in River Sections 1 and 2 exceed one, except for the LOAEL base case for the MNA alternative. LOAEL TQs in River Section 2 exceed one for the No Action alternative and estimated upper bound of the MNA alternative. NOAEL TQs in River Section 3 exceed one for the No Action alternative, whether starting in the Year 2008 or 2009, and for the MNA alternative starting in the Year 2008.

A TQ of one on a LOAEL basis is reached in two to five years with active remediation in River Section 1. Under the MNA alternative, a TQ of one is reached in a time frame of 22 years to more than 60 years, and under the No Action alternative it is not reached for more than 60 years (the extent of the modeling period). In River Section 2, a TQ of one on a LOAEL basis is reached before the long-term modeling period for all active alternatives. Under the base MNA and No Action alternatives, a TQ of one is reached in 10 and 21 years, respectively, while under the estimated upper bounds for these alternatives, it is not reached for more than 59 years. Under active remediation in River Section 3, a TQ of one on a NOAEL basis is reached in four to five years, in 12 years under the MNA alternative, and in more than 58 years under the No Action alternative.

The table below shows a summary of predicted reductions in Mink TQs for all active alternatives compared to the No Action and MNA alternatives, and for MNA compared to No Action. Since the NOAEL is calculated as an order of magnitude higher than the LOAEL in all cases, the reductions for both NOAEL and LOAEL compared to the associated No Action and MNA are the same; therefore only a single result is presented in each case.

Reductions in Ecological Toxicity Quotients - Mink				
	MNA	**CAP-3/10/Select**	**REM-3/10/Select**	**REM-0/0/3**
River Section 1 (RM 189)				
No Action	2 to 3-fold	5 to 6-fold	5 to 6-fold	6 to 7-fold
MNA		2 to 3-fold	2 to 3-fold	2 to 4-fold
River Section 2 (RM 184)				
No Action	<2 to 3-fold	4 to 8-fold	5 to 9-fold	7 to 14-fold
MNA		3 to 7-fold	3 to 8-fold	4 to 13-fold
River Section 3 (RM 154)				
No Action	2-fold	3-fold	3-fold	3-fold
MNA		<2-fold	<2-fold	<2-fold

As may be determined from the table above, reductions in toxicity quotient for the mink compared to No Action and MNA vary with extensiveness of the remediation. Reductions for the CAP-3/10/Select and REM-3/10/Select alternatives are virtually identical (slightly favoring REM-3/10/Select in River Section 2), while those for the REM-0/0/3 alternative are higher. All active alternatives show greater risk reductions than MNA. Reductions in River Section 2 for the REM-0/0/3 alternative, compared to the upper bounds for both No Action and MNA, exceed an order of magnitude. Compared against the base case for No Action, risk reduction decreases with distance downstream for the CAP-3/10/Select and REM-3/10/Select alternatives. This trend does not consistently hold for other comparisons for River Sections 1 and 2, however. On the other hand, reductions in River Section 3 are consistently smaller than those upstream, since sediments included in target areas make up a much smaller fraction of the overall surface area of this section and there is much greater dilution due to tributary flows.

Downstream Transport of PCBs

Remedial action objectives for the site call for minimizing long-term downstream transport of PCBs over the Federal Dam. The table below provides a summary of the annual Tri+ PCB loads passing the dams at the downstream ends of all three river sections for three points in time (years 2003, 2011 and 2035). The year 2003 represents the period immediately preceeding the start of remedial construction under any of the active remedial alternatives, while 2011 represents a period shortly after completion of construction (*i.e.*, 2008 for CAP-3-10-Select and REM-3/10/Select, and 2010 for REM-0/0/3). The year 2035 represents the approximate mid-point of the ends of the ecological modeling time frames for the various alternatives. This is also approximately the end of the period for which cost estimates are prepared (*i.e.*, about 30 years from the start of construction).

Predicted Annual Downstream Transport of Tri+ PCB Load (kg)									
	Thompson Island Dam			Northumberland Dam			Federal Dam		
	Year 2003	Year 2011	Year 2035	Year 2003	Year 2011	Year 2035	Year 2003	Year 2011	Year 2035
No Action	104	88	2011	122	105	60	131	104	62
MNA	104	44	14	123	63	15	131	72	24
CAP-3/10/Select	104	23	11	123	29	11	131	43	20
REM-3/10/Select	104	22	11	123	27	11	131	42	20
REM-0/0/3	104	14	9.5	123	17	9.5	131	34	18

Neither the No Action alternative nor the MNA alternative addresses the scour of PCB-contaminated sediments associated with one-in-three-year to one-in-five-year flow events from the Hoosic River in River Section 3. These events have caused resuspension of PCB loading of 18 kg/day, equivalent to the peak loads at Rogers Island attributed to releases at the Allen Mills structure (USEPA, 1999b). Without addressing PCB-contaminated sediments downstream of the Hoosic River (RM 166), PCB loads over Federal Dam will likely be higher than indicated by the modeling results. All three active remedial alternatives address the scour of PCB-contaminated sediments associated with flow events from the Hoosic River in River Section 3, and are therefore effective in reducing the PCB load over Federal Dam to the Lower Hudson River, with the REM-0/0/3 alternative being most effective. The similarity in modeled Tri+ PCB loads over Federal Dam between the MNA and the active alternatives by the year 2035 and beyond reflects the fact that all are largely controlled by the value assumed for the unknown upstream PCB load. Additional Tri+ PCB loads due to resuspension from dredging operations are estimated to be less than the release estimated from a single 100-year flood event.

Compliance with ARARs

The chemical-specific ARARs for PCBs in the water column are 0.5 μg/L (500 ng/L) federal MCL; 0.09 μg/L (90 ng/L) NYS standard for protection of human health and drinking water sources; 1 ng/L federal ambient water criterion for navigable waters; 0.12 ng/L NYS standard for protection of wildlife; and 0.001 ng/L NYS standard for protection of human consumers of fish.

The first two chemical-specific ARARs for the surface water are met by all five remedial alternatives, and the remaining three chemical-specific ARARs for the surface water are not met by any of the five alternatives for the 70-year model forecast period. The effect of the separate source control NTCRA in the vicinity of the GE Hudson Falls plant is observed in the difference (separation) between the trajectories for the No Action and MNA alternatives. The benefits of active remediation of the sediments are readily apparent in the differences in the trajectories for the MNA alternative and those for the active remediation alternatives. As expected, the water quality is best for the REM-0/0/3 alternative and substantially improved for the CAP-3/10/Select and REM-3/10/Select alternatives, compared to MNA. These differences are most apparent for the first 20 years of the forecast period, between 2005 and 2024. However, even in 2067, towards the end of the forecast period, there is a very substantial difference between the water quality for the No Action alternative (approximately 30 ng/L at TID and Schuylerville and 10 ng/L at Federal Dam) and the other four alternatives (approximately 5 ng/L at TID and Schuylerville and 1.7 ng/L at Federal Dam).

Because there is no active remedial action associated with the sediments for the No Action and MNA alternatives, action-specific and location-specific ARARs do not apply. The three active remedial alternatives will comply with action-specific ARARs (*e.g.*, CWA Sections 401 and 404; TSCA; Section 3004 of RCRA; Section 10 of the Rivers and Harbors Act; New York State ECL Article 3, Title 3, and Article 27, Titles 7 and 9), and location-specific ARARs (*e.g.*, Endangered Species Act; Fish and Wildlife Coordination Act; Farmland Protection Policy Act; National Historic Preservation Act; and New York State Freshwater Wetlands Law).

Long-Term Effectiveness and Permanence

The long-term effectiveness of an alternative is assessed through the following criteria: reduction in residual risk, adequacy of controls, and reliability of controls.

<u>Reduction of Residual Risk</u>

The No Action and MNA alternatives result in continuation of the degraded condition of surficial sediments and surface water quality of the Upper Hudson River for several decades (albeit gradually reduced), especially in River Section 1, regardless of any reduction in the upstream water column loadings. The long-term transport of PCBs over the Federal Dam and to the Lower Hudson River will continue indefinitely, although a substantial portion of this transport is due to the assumed upstream boundary condition; *i.e.*, the PCB load entering the Upper Hudson at Rogers Island. The Tri+ PCB load over the Federal Dam for the No Action alternative is approximately 131 kg (288 lbs) in 2003, 104 kg (229 lbs) in 2011, and 63 kg (138 lbs) in 2035. Similarly, for the MNA alternative, the Tri+ PCB load over the Federal Dam is approximately 131 kg (288 lbs) in 2003, 72 kg (158 lbs) in 2011, and 24 kg (52 lbs) in 2035. In 2035, as a result of the separate source control NTCRA in the vicinity of the GE Hudson Falls plant, the PCB load over Federal Dam is reduced by approximately 62 percent.

For the CAP-3/10/Select alternative, residual risk is reduced through capping 207 acres of PCB-contaminated sediments and removal of 1.73 million cubic yards of sediments containing approximately 33,100 kg (73,000 lbs) PCBs. For this alternative, the PCB load over the Federal Dam is approximately 131 kg (288 lbs) in 2003, 45 kg (98 lbs) in 2011, and 20 kg (44 lbs) in 2035. Soon after construction in 2011, the CAP-3/10/Select alternative results in a 58 percent reduction in the Tri+ PCB load over Federal Dam compared to the No Action alternative and a 40 percent reduction in the PCB load over Federal Dam compared to the MNA alternative. After a longer period of time, in 2035, the CAP-3/10/Select alternative results in a 68 percent reduction in the Tri+ PCB load over Federal Dam compared to the No Action alternative and a 16 percent reduction in the load over Federal Dam compared to the MNA alternative..

The CAP-3/10/Select alternative does not completely eliminate long-term risks for target areas that are capped. Sediments are removed in areas only to the degree necessary for cap installation and, in some areas, highly contaminated sediments may be left in place below the cap and backfill. Anthropogenic or natural processes (*e.g.*, navigation accidents, severe storms, or longer-term changes in the depositional/erosional regime in a given location) may damage or erode and scour the cap materials and redistribute PCB-contaminated capped sediments over wider areas of the Upper Hudson 400265

River. Non-routine repair or replacement of large sections of the cap may have to be undertaken if a breach occurs in a highly contaminated area (*e.g.*, *Hot Spot* 14 in River Section 1 or *Hot Spot* 28 in River Section 2) due to catastrophic events such as a major flood. Depositional buildup of sediments adjacent to the cap could shift currents over the cap creating the potential for erosion in an unexpected area.

The influence of regional aquifer systems on the hydrologic regime of Upper Hudson River has not been evaluated. Groundwater level fluctuations can result from a wide variety of hydrologic phenomena (*e.g.*, groundwater recharge due to seasonal heavy rainfall, or bank-storage effect near the river) and the subsequent inflow of groundwater may breach the cap in multiple areas and transport PCBs into the river. During periods of extremely low flow, sections of the cap could be exposed to the air and a different range of temperatures and other conditions unlike the submerged environment, resulting in freeze-thaw damage or desiccation cracking.

For the two removal alternatives, a total volume of contaminated sediment from 2.65 million cubic yards (REM-3/10/Select) to 3.82 million cubic yards (REM-0/0/3), containing a mass of PCBs from 45,600 kg (100,550 lbs) (REM-3/10/Select) to an estimated mass of more than 63,500 kg (154,700 lbs) (REM-0/0/3) located in areas from 493 to 964 acres (REM-3/10/Select and REM-0/0/3, respectively) of the Upper Hudson River will be remediated. For the REM-3/10/Select alternative, the Tri+ PCB load over the Federal Dam is 131 kg (288 lbs) in 2003, 42 kg (92 lbs) in 2011, and 20 kg (44 lbs) in 2035. Soon after construction in 2011, the REM-3/10/Select alternative results in a 60 percent reduction in the Tri+ PCB load over Federal Dam compared to the No Action alternative and a 42 percent reduction in the load over Federal Dam compared to the MNA alternative. After a longer period of time, in 2035, the REM-3/10/Select alternative results in a 69 percent reduction in the Tri+ load over Federal Dam compared to the No Action alternative and a 17 percent reduction in the load over Federal Dam compared to the MNA alternative.

For the REM-0/0/3 alternative, the Tri+ PCB load over the Federal Dam is approximately 131 kg (288 lbs) in 2003, 34 kg (75 lbs) in 2011, and 18 kg (39 lbs) in 2035. Soon after construction in 2011, the REM-0/0/3 alternative results in a 67 percent reduction in the PCB load over Federal Dam compared to the No Action alternative and a 53 percent reduction in the Tri+ PCB load over Federal Dam compared to the MNA alternative. After a longer period of time, in 2035, the REM-0/0/3 alternative results in a 72 percent reduction in the Tri+ PCB load over Federal Dam compared to the No Action alternative and a 25 percent reduction in the load over Federal Dam compared to the MNA alternative.

The three active remedial alternatives (CAP-3/10/Select, REM-3/10/Select, and REM-0/0/3) also rely on natural attenuation processes such as burial by cleaner sediments, bioturbation, biodegradation, dispersion, dilution through advection and recharge, adsorption, and volatilization to further reduce the concentration of any contaminants that remain after construction is completed. However, modeling results predict that these three alternatives will not completely achieve the PRGs for the site within the modeled period, although RAOs are met in part or in full, as described above. The limitation in meeting PRGs largely stems from the assumption of the upstream Tri+ PCB load at Fort Edward (Rogers Island) of 0.0256 kg/day in 2005. Greater achievement of the PRGs is estimated based on a 0 kg/day assumption. Thus, remediating PCB-contaminated sediment in combination with control of the upstream load can be expected to achieve more PRGs, and to approach the PRGs faster, than either approach alone.

Adequacy of Controls

The No Action and MNA alternatives do not provide for engineering controls on the river sediments. The MNA alternative assumes a separate source control NTCRA in the vicinity of the GE Hudson Falls plant. The existing institutional controls, which rely on voluntary compliance, are not fully adequate in reducing exposure to PCBs due to consumption of contaminated fish. In addition, institutional controls are inadequate for protection of the environment (*e.g.*, ecological receptors).

The CAP-3/10/Select alternative provides for dredging of some contaminated sediments in target areas and placement of an engineered cap over the remaining target areas. Like the MNA alternative, this alternative also provides for institutional controls, such as the fish consumption advisories. The REM-3/10/Select and REM-0/0/3 alternatives provide for removal of contaminated sediments in target areas. These two alternatives also provide for institutional controls, such as the fish consumption advisories.

The planned post-construction fish, water column, and sediment monitoring program allows for tracking the natural recovery of the river after remediation is completed. It also provides data to confirm the need to continue the existing fish consumption advisories and to evaluate the possibility of relaxing the advisories.

Reliability of Controls

Sediment capping, dredging, backfilling and habitat replacement, and off-site disposal/ treatment of removed sediments are, individually, all reliable and proven technologies. However, for the CAP-3/10/Select alternative, proper design, placement, and maintenance of the cap in perpetuity are required for its effectiveness, continued performance, and reliability. This presents a challenge for the Upper Hudson River since the capping concept requires maintenance of nearly 12 miles of long, narrow strips of cap with a high perimeter-to-surface area ratio. A cap placed in a relatively sheltered embayment or cove would be easier to maintain, since it would not be subject to the significant variations in river conditions typical of a river channel. The cap integrity monitoring and maintenance program planned for the CAP-3/10/Select alternative provides for as reasonably reliable maintenance as could be expected, if consistently and thoroughly followed. The challenge lies in overcoming the natural human tendency to relax vigilance as time goes on, especially as the essential rationale for installation of the cap fades from public consciousness. The fish consumption advisories will continue to provide some measure of protection of human health until PCB concentrations in fish are reduced and the PRG for protection of human health is attained. However, even the attainment of acceptable levels in the fish may serve to undermine vigilance in maintaining the cap in the future.

In general, the REM-3/10/Select and REM-0/0/3 alternatives are the most reliable, as there is little or no longer-term maintenance or residual risk associated with the remedial work. Of the removal alternatives, REM-0/0/3 is the most reliable, as it permanently removes the greatest amount of sediment (leaving the least amount of PCBs in the river). The CAP-3/10/Select alternative does not achieve the same degree of reliability due to the potential for defects or damage to the cap, thereby reducing its effectiveness. This alternative would still require all of the sediment handling, processing, and disposal activities needed for the removal alternatives. The No Action alternative is the least reliable. Although the MNA alternative is more reliable than the No Action alternative, it relies more heavily on institutional controls than do the active remedial alternatives to limit exposure to PCBs. Also, the fish consumption advisories may be relaxed sooner under the active alternatives. Institutional controls do not address ecological receptors, and human health risk reduction relies on knowledge of and voluntary compliance with the fish consumption advisories.

Reduction of Toxicity, Mobility, or Volume through Treatment

The No Action and MNA alternatives do not involve any containment or removal of contaminants from the Upper Hudson River sediments. Because the MNA alternative assumes the separate source control NTCRA in the vicinity of the GE Hudson Falls plant, the upstream Tri+ PCB load to the water column is expected to be reduced from 0.16 kg/day to 0.0256 kg/day by January 1, 2005. The No Action and MNA alternatives rely on natural attenuation processes such as burial by cleaner sediments, biodegradation, bioturbation, and dilution to reduce PCB concentrations in sediments and surface water. Biodegradation processes may convert some of the more highly chlorinated PCB congeners (*e.g.*, tetrachlorbiphenyls) to less chlorinated congeners (monochloro- and dichloro-biphenyls) and biphenyl. The degree to which dechlorination affects PCB toxicity remains uncertain and debated within the scientific community. In any case, dechlorination is not expected to continue to extensively modify the PCB inventory over time since it appears to occur only within the first few years of deposition. Natural dilution of the contaminated sediments will also reduce the toxicity, but the overall volume of contaminated sediments would increase as PCBs are contributed to the Upper Hudson from upstream. Concentrations of PCBs in fish will respond slowly over time to decreases in concentrations in sediments and surface water.

For the CAP-3/10/Select alternative, the mobility of the PCBs in capped areas (approximately 207 acres) is reduced because these PCBs are sequestered under the bentonite cap. However, capping does not satisfy the CERCLA statutory preference for treatment. In addition, there is no reduction in the toxicity or volume of the PCBs under the cap. Under this alternative, the mass of PCBs and the volume of contaminated sediments within the Upper Hudson River are permanently reduced because approximately 1.73 million cubic yards of sediment, containing an estimated 33,100 kg (72,973 lbs) of PCBs, are removed from the ecosystem. Because the CAP-3/10/Select alternative also assumes the separate source control NTCRA in the vicinity of the GE Hudson Falls plant, the upstream Tri+ PCB load to the water column is expected to be reduced from 0.16 kg/day to 0.0256 kg/day by January 1, 2005. Additional reduction of the water column loads will result from sediment remediation. After construction of the alternative is completed, natural attenuation processes will provide further, but slower, reductions in the toxicity of PCBs in the remaining sediments and surface water.

For the REM-3/10/Select and REM-0/0/3 alternatives, the mass of PCBs and volume of contaminated sediments in the Upper Hudson River are permanently reduced because sediment volumes from 2.65 to 3.82 million cubic yards (REM-3/10/Select and REM-0/0/3, respectively) containing a mass of PCBs from 45,600 kg (100,550 lbs) (REM-3/10/Select) to an estimated mass of greater than 63,500 kg (139,993 lbs) (REM-0/0/3) are removed from the ecosystem. Because these removal alternatives also assume the separate source control NTCRA in the vicinity of the GE Hudson Falls plant, the upstream Tri + PCB load to the water column is expected to be reduced from 0.16 kg/day to 0.0256 kg/day by January 1, 2005. Additional reduction of the water column loads will result from sediment remediation. Also, as for the CAP-3/10/Select alternative, natural attenuation processes will provide further, but slower, reductions in the toxicity of PCBs in the remaining sediments and surface water after construction of the alternative is completed.

In all three active remediation alternatives, for the mechanical dredging option, the sediments that are removed undergo limited treatment (stabilization with Portland cement) prior to landfill disposal. For the hydraulic dredging option, the sediments that are removed are processed through hydrocyclones, coagulation, sedimentation, and belt filter presses to separate them from the water. However, these sediments do not undergo stabilization prior to landfill disposal. A different treatment process may be employed for the beneficial use option. However, due to the large volume of sediments that would be removed from the river under each of the active alternatives, none of the alternatives satisfies the statutory preference for treatment as a principal element of the remedy (CERCLA Section 121(b)).

Short-Term Effectiveness

The short-term effectiveness of each alternative is addressed through evaluation of the following criteria: protection of the community during remedial actions, protection of workers during remedial actions, potential adverse environmental impacts during construction, and time until remedial response objectives are achieved.

Protection of the Community During Remedial Actions

No construction activities are associated with the remediation of sediments for the No Action and MNA alternatives, so neither alternative increases the potential for direct contact with or ingestion and inhalation of PCBs from the surface water and sediments. The cancer risks and non-cancer health hazards to humans and the adverse effects to ecological receptors due to the PCB-contaminated sediments will persist throughout the short term. Due to the separate source control NTCRA in the vicinity of the GE Hudson Falls plant, the PCB load to the water column is expected to be reduced from 0.16 kg/day to 0.0256 kg/day by January 1, 2005. As a result, cancer risks and non-cancer health hazards to humans and adverse effects to ecological receptors for the MNA alternative are slightly lower than those under the No Action alternative in the short term. For the MNA alternative, the fish consumption advisories will continue to be the only means for protecting human health. There are no such advisories in the No Action alternative.

Risks to ecological receptors and cancer risks and non-cancer health hazards to humans posed by consumption of PCB-contaminated fish will be reduced more rapidly under the active alternatives than under the No Action and MNA alternatives. The fish consumption advisories and restricted access to portions of the river undergoing remediation provides protection from risks to human health for the local community in the short term.

Transfer facilities and treatment areas present potential short-term risks to the community. Therefore, access to these areas will be restricted to authorized personnel. In addition, monitoring and engineering controls will be employed to minimize short-term effects due to material processing activities. Increased traffic will also present an incremental risk to the community. The potential for traffic accidents may increase marginally as additional vehicles are on the road. These effects are likely to be minimal because most transportation of sediments for disposal will be accomplished by rail. In addition to vehicular traffic, there will be increased river traffic. Work areas in the river will be isolated (access-restricted), with an adequate buffer zone so that pleasure craft and commercial shipping can safely avoid such areas. Finally, the increased in-river barge traffic will be monitored and controlled to minimize, to the extent possible, adverse effects on the commercial or recreational use of the Upper Hudson River.

Protection of Workers During Remedial Actions

For the No Action alternative, occupational risks to persons performing the sampling activities (for the five-year reviews) will be unchanged from current levels. A slight increase in occupational risk may be associated with the MNA alternative due to the greater degree of sampling involved in the river (and the separate source control NTCRA in the vicinity of the GE Hudson Falls plant). For the three active remediation alternatives (CAP-3/10/Select, REM-3/10/Select, and REM-0/0/3), potential occupational risks to site workers from direct contact, ingestion, and inhalation of PCBs from the surface water and sediments and routine physical hazards associated with construction work and working on water are significantly higher than for the No Action and MNA alternatives. For these alternatives, as well as the No Action and MNA alternatives, personnel will follow a site-specific health and safety plan and OSHA health and safety procedures, and will wear the necessary personal protective equipment.

Potential Adverse Environmental Impacts during Construction

No construction activities associated with the river sediments are conducted for the No Action and MNA alternatives. Neither continuation of the existing limited sampling activities for the No Action alternative nor the increased monitoring program for the MNA alternative is anticipated to have any adverse effect on the environment, beyond that already caused by the PCB contamination of the sediments in the Upper Hudson River.

For the three active remediation alternatives (CAP-3/10/Select, REM-3/10/Select, and REM-0/0/3), the release of PCBs from the contaminated sediments into the surface water during construction (dredging and cap placement), as well as the transport of PCBs over Federal Dam, will be controlled by operational practices (*e.g.*, control of sediment removal rates; use of enclosed dredge buckets; and use of sediment barriers). Although precautions to minimize resuspension will be taken, it is likely that there will be a temporary increase of suspended PCB concentrations, and possibly in fish PCB body burdens. Studies have shown that such effects are controllable, small, and transient, and that longer term improvement is seen (*e.g.*, Fox River Demonstration Project, 2000; MDEQ, 1999).

Remedial activities may also result in temporary impacts to aquatic and wildlife habitat of the Upper Hudson. Backfilling and habitat replacement measures will be implemented to mitigate these impacts. A monitoring program will be established to verify the attainment of the habitat replacement objectives. Although the degree of impact will be directly related to the area remediated and volume dredged, these differences among the alternatives are not considered to be substantial due to their transient nature and the mitigation measures that will be utilized.

As part of this evaluation, a semi-quantitative analysis of the possible increase in PCB loads and concentrations due to sediment resuspension was performed for the regions downstream and outside of the target areas. These areas in fact represent the largest portion of the Upper Hudson within the site boundaries. This calculation is intended to describe the mean increase in water column PCB concentration over each dredging season in these areas.

Resuspension losses for the CAP-3/10/Select alternative apply only to the areas undergoing dredging. Areas undergoing capping only are assumed to yield minor additional resuspension. Since this alternative involves the least sediment removal of the three engineered alternatives, additional PCB loads are smallest. Only mechanical dredging, as represented by an enclosed bucket dredge, is considered for sediment removal under this alternative. For the REM-3/10/Select and REM-0/0/3 alternatives, the short-term impacts of a 12-inch cutterhead dredge and an enclosed bucket dredge are considered for sediment removal. For all comparisons between the two dredging methods, the production rate of dredge spoil material is the same for both methodologies. Specifically, the production rate of a 12-inch cutterhead dredge is comparable to that of three 4-cubic-yard enclosed bucket dredges, given productivity assumptions made for dredging concepts in this FS.

The resuspension rate calculated for the bucket dredge represents a relatively conservative estimate since the available data describe the impacts of a less sophisticated dredge than that selected for the engineering concepts for all active remedial alternatives. For this reason, although the results indicate somewhat greater PCB concentrations and loads due to mechanical dredges versus hydraulic equipment, resuspension will not be the major consideration in selecting one dredging concept over another. Rather, other engineering issues, such as sediment transfer, processing and handling, as well as operational logistics, will be more important.

The magnitude of the short-term impacts due to resuspension varies with the overall scope of the alternative, in terms of volume of material excavated. The table below shows a summary of the extensiveness of each alternative and the expected short-term impacts due to resuspension during dredging.

Summary of Sediment Resuspension Impacts

Metric	No Action	MNA	CAP-3/10/Select	REM-3/10/Select	REM-0/0/3
Implementation schedule	NA	NA	2004-2008 5 yrs	2004-2008 5 yrs	2004-2010 7 yrs
Sediment volume removed (10^6 cy)	NA	NA	1.7	2.7	3.8
Increase in average Tri+ PCB concentration (ng/L)	NA	NA	5 (mechanical)	4 (hydraulic) 7 (mechanical)	3 (hydraulic) 5 (mechanical)
Baseline Tri+ PCB load (kg) over FD: •2004-2008 •2004-2010	 461 (92/yr) 637 (91/yr)	 295 (59/yr.) 383 (55/yr)			
Additional PCB load (kg) from resuspension	NA	NA	32 (6/yr) (2004-2008)	28 (6/yr, hydraulic) 47 (9/yr, mechanical) (2004-2008)	29 (4/yr, hydraulic) 48 (7/yr, mechanical) (2004-2010)

It is important to place these estimated increases in the Tri+ PCB load in perspective. In all river sections, these expected increases represent relatively minor changes as compared to current or projected water column concentrations. Indeed, these additions are within the year-to-year and season-to-season variations regularly observed in the Upper Hudson. They are also well below the order-of-magnitude increase in mean water column concentrations seen in the early 1990s. The water column PCB concentration increases observed in the early 1990s resulted in an approximate doubling of some fish levels. Thus, by analogy, the PCB releases associated with dredging for any of the three active alternatives should have only a minor impact on fish body burdens in the Upper Hudson.

In addition to the examination of the increase in PCB concentration, the analysis also included an estimate of the Tri+ PCB mass released by dredging operations. The additional release from any of the three active alternatives is less than the PCB release estimated from a single 100-year flood event (*i.e.,* about 60 kg). As discussed in the RBMR, the 100-year flood was not expected to have a major impact on fish or river PCB levels, with associated increases not lasting more than one to two years. With the remedial releases spread out over five or seven years, the impact should be much smaller with a residual impact (after completion of construction) of even shorter duration than the 100-year flood.

Based on these analyses, it appears unlikely that the removal of sediments associated with any of the three alternatives will yield substantially higher levels of PCB in the water or fish of the Upper Hudson during dredging. For the REM-3/10/Select and REM-0/0/3 alternatives, water column concentrations may reach from 25 to 60 percent over those forecast using HUDTOX in River Sections 2 and 3 but the higher levels are short-lived. Based on the similarity to the release associated with the 100-year flood event, it is unlikely that the residual effects will last more than a few years after the construction is completed.

For the CAP-3/10/Select alternative there is a potential transient impact from the temporary exposure of deeper, contaminated sediments during the time interval between excavation and cap placement. It may be possible to reduce impacts associated with exposure of deeper sediments by detailed planning of all phases of the dredging and capping operations. However, the level of coordination between the different elements of this alternative will render the overall remedial program under CAP-3/10/Select particularly complex. In addition, it will not be possible to fully avoid water quality and related ecological impacts resulting from the temporary exposure of contaminated sediments that are targeted for capping. Due to the transient and variable nature of this exposure, the impact cannot be quantified. Nonetheless, barring a major flood event, it is unlikely to be greater than that originating from sediment resuspension.

<u>Time until Remedial Response Objectives Are Achieved</u>

For all five alternatives, the risk-based PRG for protection of human health of 0.05 ppm PCBs (wet weight) in fish fillets is not met in any of the river sections in the short term. The target concentration of 0.2 ppm PCBs (one meal per month) in fish fillets is also not met in any river section in the short term for all five alternatives. The alternate target concentration of 0.4 ppm PCBs (one meal every two months) in fish fillets is not met in River Sections 1 and 2 in the short term by any of the five alternatives, but is met in River Section 3 in the year 2010 for the three active remediation alternatives and in the year 2011 for the MNA alternative. The 0.4 ppm PCBs target fish concentration is not met in the short term in River Section 3 by the No Action alternative.

The risk-based PRG for protection of the environment is a range from 0.3 to 0.03 mg/kg in whole fish (this corresponds to a range from 0.13 to 0.013 mg/kg total PCBs in fish fillets), based on the LOAEL and NOAEL fish concentrations consumed by the river otter. The corresponding LOAEL and NOAEL whole fish target concentrations for the mink are 0.7 and 0.07 mg/kg PCBs. For the river otter, the PRGs are not met in River Sections 1, 2, and 3 in the short term for all five remedial alternatives. For the mink, the LOAEL target concentration is not met in River Section 1 in the short term, but is met in River Sections 2 and 3 prior to 2010 for the three active remediation alternatives. For the mink, under the MNA alternative, the LOAEL target concentration is not met in River Sections 1 and 2 in the short term, but is met in River Section 3 prior to 2010. For the mink, the NOAEL target concentration is not met in River Sections 1, 2, and 3 in the short term for any of the five remedial alternatives.

Implementability

The implementability of the alternatives are compared through evaluation of the following criteria: technical feasibility, administrative feasibility and availability of services.

Technical Feasibility

Both the No Action and MNA alternatives are technically feasible.

Technical feasibility for the active remediation alternatives is discussed below in terms of the main components of the alternatives: dredging (mechanical and hydraulic), capping, transfer facilities, and rail transport and disposal.

Dredging Feasibility

Mechanical Dredging

Removal of targeted sediments solely by mechanical means has been evaluated for the CAP-3/10/Select, REM-3/10/Select, and REM-0/0/3 alternatives. Removal of targeted sediments by hydraulic dredging has also been evaluated for the REM-3/10/Select and REM-0/0/3 alternatives. With regard to mechanical dredging, the following are the principal distinctions between the capping and removal alternatives:

- Capping requires the least total dredging (about 35 percent less than REM-3/10/Select) and least annual output (about 35 percent less than REM-3/10/Select);
- REM-0/0/3 requires the most removal work (about 43 percent more than REM-3/10/Select);
- Annual removal rates for REM-3/10/Select and REM-0/0/3 are approximately equal; and
- REM-0/0/3 entails significantly more removal of sediments in shallow cuts (less than 2.0 feet) than does REM-3/10/Select.

Technical feasibility includes evaluation of the capability of mechanical equipment to productively remove as little as one or two feet of sediment. As a result of recent advances in mechanical systems, buckets are now available that can efficiently remove sediments in wide, shallow cuts. Therefore, it has been concluded that efficient removal of sediments, as proposed under each of the three active alternatives, is technically feasible.

Feasibility was also evaluated in terms of the ability of mechanical dredging systems to maintain acceptably low rates of sediment resuspension. Based on an analysis of sediment resuspension during dredging operations, it is concluded that substantial water quality impacts are not expected to occur as a result of mechanical dredging operations. Thus, from the perspective of sediment resuspension, each alternative that involves mechanical dredging is considered feasible.

Hydraulic Dredging

Hydraulic dredging has been evaluated for the REM-3/10/Select and REM-0/0/3 alternatives. Under these alternatives, most removal will be accomplished with a suction cutterhead dredge; dredging in River Section 3 will be accomplished by means of mechanical equipment. The principal differences between the use of hydraulic and mechanical systems, insofar as those systems have been evaluated in this FS, are as follows:

- Only one hydraulic dredge is needed to remove targeted sediments in River Sections 1 and 2, as opposed to several mechanical dredges;
- Hydraulically dredged sediments are conveyed to the transfer facility by means of a slurry pipeline and not in barges;
- Hydraulically dredged sediments are dewatered and not stabilized; and
- Hydraulic dredging entails operation of a substantial water treatment facility.

Hydraulic dredging is considered technically feasible for either active alternative to which it is being applied. One distinction between REM-0/0/3 and REM-3/10/Select is that REM-0/0/3 entails substantially more removal of sediments where contamination is limited to the upper 1.0 or 1.5 feet. Since it is not considered practical to dredge less than two feet of sediment with the selected hydraulic technology, it will be necessary to dredge 90,000 cubic yards of non-targeted sediments should hydraulic dredging be selected under the REM-0/0/3 alternative.

As for the mechanical equipment discussed above, sediment resuspension rates and water quality impacts have also been estimated for hydraulic dredging. Based on available data, it has been calculated that hydraulic dredging operations will resuspend 40 percent less sediment than will mechanical removal operations for the same production rate. This analysis, however, does not reflect a number of recent improvements made to mechanical systems which were specifically formulated to reduce resuspension and for which published data is not yet available. Therefore, the difference in performance between the two technologies (mechanical and hydraulic dredging) estimated, is not expected to be a determining factor in equipment selection and the two technologies are considered equally feasible from the perspective of sediment resuspension.

Capping Feasibility

Capping involves considerably less dredging than does the corresponding removal alternative since principal reliance is being placed on an impervious cap to effectuate the remediation. Evaluation of the AquaBlok™ system is currently in progress at several sites and final feasibility of this technology must await results of those studies. However, the materials of which AquaBlok™ is composed have served reliably in other, similar applications, and, therefore, there is reasonable expectation that AquaBlok™ will ultimately prove to be technically feasible. The scheduling of in-river work (dredging and capping) and overall program logistics will be somewhat more complex under the CAP-3/10/Select alternative than under REM-3/10/Select or REM-0/0/3.

Transfer Facilities Feasibility

Each active alternative, as evaluated in this FS, requires that transfer facilities be established at two locations: one facility would be located adjacent to River Section 1, and another would be in the Port of Albany area. Utilization of these sites is somewhat different under the capping and mechanical dredging alternatives. About 35 percent less dredged material would be processed annually at the transfer facilities if the capping alternative were selected. This suggests a substantially lower level of activity at the transfer facilities (and potentially smaller sites). However, capping also requires that large quantities of AquaBlok™ be manufactured and distributed throughout the river. Doing so may substantially increase the use of the transfer facility sites (or result in separate sites being set up for distribution of AquaBlok™). Consequently, establishing transfer facilities at two locations for either the capping or mechanical removal remedies is considered equally feasible.

Should hydraulic dredging be selected as the removal technology, establishing a transfer facility adjacent to River Section 1 will be somewhat complicated by the need to operate relatively large slurry processing and water treatment systems. Several acres may be needed to house these systems and any associated equipment. Nonetheless, it is expected that a transfer/processing site can be assembled should hydraulic dredging be the selected dredging technology.

Rail Transport and Disposal Feasibility

The capping alternative would result in least stabilized dredged material being shipped to off-site disposal facilities. The two removal alternatives generate approximately the same quantity of stabilized dredged material on an annual basis. Thus, the scale of rail operations for the REM-3/10/Select and REM-0/0/3 is approximately the same. However, REM-0/0/3 has a duration of seven years and REM-3/10/Select has a duration of five years. It is expected that railroads that serve the Upper Hudson area can handle the additional traffic that would be generated by any of the alternatives.

Administrative Feasibility

In general, the principal administrative task under the MNA alternative is the institutional controls, such as the fish consumption advisories. Fish consumption advisories and a "catch and release only" fishing restriction are currently in place, so institutional controls are considered administratively feasible.

For the active remediation alternatives (CAP-3/10/Select, REM-3/10/Select, and REM-0/0/3), it is expected that the two transfer facilities, constructed on land adjacent to the Upper Hudson River, will be considered "on-site" for the purposes of the permit exemption under CERCLA Section 121(e), although any such facilities will comply with the substantive requirements of any otherwise necessary permits. Since the requirements for these facilities are equivalent for all three alternatives, assuming mechanical dredging, there is little difference in the administrative feasibility among the three. The hydraulic dredging option for the REM-3/10/Select and REM-0/0/3 alternatives will require somewhat greater land area, but properties meeting the requirements appear to exist. Although procurement of appropriate properties with reasonably close rail access presents certain marketplace and administrative challenges, research conducted for this FS suggests that sufficient options exist to provide workable solutions under a variety of possible scenarios.

It is assumed that review and concurrence on siting and design of these facilities by the State of New York will be obtained in a reasonably expeditious manner. While it is possible that local opposition to permanent dredged sediment disposal in the vicinity of the Upper Hudson River may translate to concerns regarding (and possible local administrative opposition to) a temporary northern transfer facility, it is likely that the tangible concerns can be addressed by proper design and engineering controls. It is also expected that, for any of the active remedial alternatives, there will be substantial restrictions on construction activity, including controls on the types of dredging and capping equipment to be used, restrictions on the speed of operations, constraints on barge filling practices, and controls on temporary storage of contaminated dredge spoils. Construction activities will also have to be coordinated with the Canal Corporation, which operates the Locks on the Upper Hudson River from May through November.

The major difference among the three alternatives in regard to local administrative feasibility relates to the lengths of the respective construction programs. The CAP-3/10/Select and REM-3/10/Select alternatives are projected to require five years of construction each, while the REM-0/0/3 alternative is estimated at seven years. Compensating economic benefits (expected to be roughly proportionate to the overall cost of each alternative) to the labor force for both skilled and unskilled workers, as well as local businesses such as lodging and food services and equipment and raw materials suppliers, may mitigate potential local administrative opposition.

Since the concepts for these alternatives call for shipment of sediments to disposal by rail, local highways will not be required to carry substantially increased heavy truck traffic, although some increase will be experienced during mobilization activities and possibly for delivery of certain materials and commodities. If beneficial use of dredged sediments proves a reality during design and implementation, some options may entail additional truck traffic, but the possibility exists for moving the material to the southern transfer facility by barge for loading onto trucks so as to minimize impacts on the secondary, local highway systems.

<u>Availability of Services</u>

For the No Action and MNA alternatives, the necessary services are available. For the active remedies, the services and materials listed below appear to present the principal limitations.

Barges and Towboats

Since most commercial activity on the Upper Hudson has ceased, it is not likely that a sufficient number of barges and tow boats suitable for river work can be readily found in the project vicinity. Obtaining barges and towboats will necessitate early planning for procurement and may require that some equipment be fabricated for this program. The number of barges and towboats required for mechanical dredging related to the REM-3/10/Select and REM-0/0/3 alternatives is approximately the same since the volume of material being removed on an annual basis is approximately the same. With regard to the CAP-3/10/Select alternative, the quantity of material being removed is approximately 35 percent less than that under the REM-3/10/Select alternative. Even though the capping operation will also require barges and towboats, the amount of work required for capping and backfill under CAP-3/10/Select is about the same as the amount of work required for backfill alone under REM-3/10/Select. Consequently, the difference in the number of barges and towboats required is not strictly proportional to the difference in dredging volume between the two alternatives. It is estimated that the number of barges and towboats will be about 20 to 25 percent less for CAP-3/10/Select.

Hydraulic dredging utilizes only three to four larger-capacity hopper barges (loaded to 1000 tons) to transport dewatered sediments from the northern to the southern transfer facility, while mechanical dredging utilizes about four hopper barges and seven or eight lower-capacity deck barges (loaded to 200 tons) for transport of sediments directly to the northern and southern transfer facilities. Because hydraulic dredging will require fewer barges and towboats than a comparable mechanical dredging program, there will be a substantially reduced requirement for procurement or fabrication of barges associated with hydraulic dredging.

Rail Cars

Availability of rail cars fluctuates with economic conditions. The number of cars required to support operations for any active alternative is directly proportional to the volume of material processed on an annual basis. Therefore, on an annual basis, CAP-3/10/Select will require approximately one-third fewer cars than either of the removal alternatives. Since the active remedial alternatives are relatively long-term projects, and will require considerable pre-planning, it is expected that the needed rolling stock can be obtained for any of the active alternatives.

Cement

The amount of Portland cement required varies with the volume of sediment processed for an alternative. Specifically, hydraulic dredging for either of the removal alternatives is projected to require no stabilizing agent due to the use of mechanical dewatering. The CAP-3/10/Select alternative requires about one-third less stabilizing agent than either REM-3/10/Select or REM-0/0/3 on an annual basis. Availability of this commodity also fluctuates with economic conditions. However, since there are several potential, less costly substitutes for Portland cement, it is not likely that adverse conditions in the Portland cement market would make project implementation infeasible, although, depending on the amount required, use of substitutes could conceivably be more costly due to the potentially higher volume to be disposed.

Cost

Capital, O&M and Present Worth Cost Estimates

The present worth costs for all five alternatives have been estimated for the year 2000 using a 7 percent discount rate. The net present worth, capital costs, and the O&M costs for all five alternatives, including the beneficial use option, are presented in the table below.

Comparison of Costs			
Base Case Alternatives - Mechanical Removal and Landfill Disposal			
Alternative	Total Capital Costs	Average Annual O&M	Present Worth of Project
No Action	$ 0	$ 15,000	$ 140,000
Monitored Natural Attenuation	$ 508,000	$3.6 million	$39 million
CAP-3/10/Select	$ 504 million	$3.5 million	$370 million
REM-3/10/Select	$ 658 million	$3.2 million	$460 million
REM-0/0/3	$ 929 million	$3.4 million	$570 million
Beneficial Use Option			
Alternative	Total Capital Costs	Average Annual O&M	Present Worth of Project
CAP-3/10/Select	$ 459 million	$3.5 million	$370 million
REM-3/10/Select	$ 585 million	$3.2 million	$460 million
REM-0/0/3	$ 806 million	$3.4 million	$570 million
Hydraulic Removal and Landfill Disposal Option			
Alternative	Total Capital Costs	Average Annual O&M	Present Worth of Project
REM-3/10/Select	$ 637 million	$ 3,200,000	$ 460,000,000
REM-0/0/3	$896 million	$ 3,350,000	$ 570,000,000

Cost Sensitivity Analyses

Sensitivity analyses have been performed to assess the significance that changing principal features of the CAP-3/10/Select and REM-3/10/Select and REM-0/0/3 alternatives will have on overall project costs. Based on results of the base case analysis, it becomes evident that parameters that influence the quantity of sediments needing to be stabilized, shipped, and disposed have the greatest impact on costs. In addition, disposal costs for sediments classified as TSCA-regulated materials are significantly greater than for those considered to be non-TSCA materials. Thus, the sensitivity analysis addresses changes in several parameters that influence either the volume of sediment removed and the fraction of removed sediments considered to be TSCA-regulated.

The sensitivity of the cost estimates for the three active remediation alternatives was evaluated for the following four parameters:

- An increase in the assumed non-TSCA threshold concentration from 33 mg/kg to 50 mg/kg PCBs;

- An adjustment of the remediation target area boundary by plus or minus 50 feet;
- A reduction in cap thickness for the CAP-3/10/Select alternative from 12 inches to 6 inches; and,
- An adjustment of the depth of removal for the REM-3/10/Select and REM-0/0/3 alternatives by plus or minus 1 foot.

Of the several parameters that have been evaluated, changing dredging depth has the greatest effect on cost. A change of one foot in targeted removal impacts the total present value of removal alternatives by up to 30 percent. This is because this change has the greatest effect on the volume targeted for removal of any of the variations examined. The design support investigation will obtain current information to refine the target area delineation and the associated sediment volumes. Varying other parameters, such as the assumed non-TSCA threshold PCB concentration and the targeted removal areas, results in considerably smaller effects on costs.

The table below presents a summary of the cost sensitivity analyses. It should be noted, however, that beneficial use of the sediments may markedly alter the outcome of the sensitivity analysis. Remedial costs, in the base case, are heavily influenced by the stabilization, shipping, and disposal components of the overall remedial system. As the shipping of sediments to TSCA and non-TSCA landfills is reduced, project costs will become more sensitive to factors such as the assumed TSCA PCB concentration threshold and potentially less sensitive to dredging depth. The true ability of beneficial use to reduce costs cannot be assessed until a detailed strategy for its implementation is developed.

Summary of Cost Sensitivity Analyses

Cost Sensitivity Analysis	CAP-3/10/Select	REM-3/10/Select	REM-0/0/3
Present Worth of Total Costs (Base Case)	$370 million	$460 million	$570 million
Original Depth of Removal + 1 ft	NA	$552 million	$739 million
Original Depth of Removal - 1 ft	NA	$369 million	$399 million
Target Area + 50 ft	$ 405 million	$503 million	$576 million
Target Area - 50 ft	$ 283 million	$378 million	$540 million
TSCA Disposal at 50 ppm instead of 33 ppm	$ 361 million	$449 million	$556 million
Cap Thickness of 6 in. instead of 1 ft	$ 342 million	NA	NA

Since transportation costs and tipping fees are such a large fraction of overall remedial costs (approximately 50 percent of the capital cost for the REM-3/10/Select alternative is related to transportation and disposal, exclusive of sediment stabilization), it is useful to provide context for these costs by considering alternate approaches. One possibility would be to reduce the distance that stabilized sediments must be hauled. In order to assess the cost implications of the landfill being closer to the Upper Hudson, rough cost estimates were generated for options not considered in development of alternatives (since they were screened out based on administrative infeasibility).

In one case it was assumed, for purposes of this analysis, that a lined landfill, dedicated to handling dredged material, could be constructed within a one-day round-trip (by truck) of one of the

400279

transfer facilities. A second option was also evaluated assuming that the distance to the landfill would allow a truck to make two round trips each day. An additional disposal option considered was the use of a Confined Disposal Facility (CDF) constructed adjacent to River Section 1. This concept would consist of a naturally lined landfill that would receive hydraulically dredged sediments from River Sections 1 and 2 and mechanically dredged sediments from River Section 3. In this case, essentially all off-site transportation costs would be eliminated as would the need for northern and southern transfer facilities (although a transfer operation would be needed immediately adjacent to the CDF).

The following tabulation presents a comparison of costs for the REM-3/10/Select alternative considering the various transportation and disposal options evaluated:

Option	Distance to Disposal Site (miles)	Estimated Capital Costs ($million)
Existing Permitted Landfills	250 to >1000	$660
New Landfill-one RT/day	< 200	$520
New Landfill-two RT/day	< 100	$460
Confined Disposal Facility	Near-River	$200 to $250

As shown in the table above, capital costs associated with a CDF are lowest (by over $400 million) because all off-site transportation is eliminated and because neither the northern nor southern transfer facilities is necessary. Disposal in a new dedicated landfill would reduce project cost by about $130 million if the landfill were within 200 miles of the transfer facilities. If the landfill were situated within 100 miles of the Upper Hudson, capital costs for the REM-3/10/Select alternative could be reduced by about $200 million or approximately 30 percent. For disposal in a new dedicated landfill, much of the difference in the costs compared to more remote disposal is related to the TSCA-regulated material. Estimated costs for disposal of the non-TSCA material at a new landfill, including transportation, are only about 25 percent less than those for remote disposal, while costs for disposal of TSCA-regulated material are less than half (*i.e.*, about 60 percent less).

Summary of Comparative Analysis

The major differences among the three active alternatives (CAP-3/10/Select, REM 3/10/Select and REM 0/0/3) are related to the technologies used (i.e., capping with dredging, or dredging alone), the physical extent of the remediation as applied to theUpper Hudson River. Differences in the evaluation of the alternatives against the NCP criteria flow from these three elements. The table below presents a summary of the comparative analysis among the alternatives.

Remedial Alternatives Comparative Analysis Summary

Criterion	No Action	MNA	CAP-3/10/Select	REM-3/10/Select	REM-0/0/3
Overall Protection of Human Health and the Environment	Not protective. Human health and ecological risks continue to be above acceptable levels. No upstream source control.	Not protective. Human health and ecological risks continue to be above acceptable levels. Assumes upstream source control.	Substantial improvement in protection of human health and the environment through reduced risks to humans and ecological receptors.	Substantial improvement in protection of human health and the environment through reduced risks to humans and ecological receptors.	Most protective of human health and the environment due to largest reduction in risks.
Fish PRGs for Human Health PRG is 0.05 ppm in fillet. Other target PCB concentrations are 0.2 ppm and 0.4 ppm in fillet.	PRGs and other target criteria not met, except 0.4 ppm in RS 3 in 2014. All RME cancer risks greater than 10E -6.	0.05 ppm PRG met in RS 3 in 2059; not met elsewhere. 0.2 ppm target met in RS 2 in 2061 and RS 3 in 2019. 0.4 ppm target met in 2011 - 2030 depending on river section.	0.5 ppm PRG met in RS 3 in 2051; not met elsewhere. 0.2 ppm target met in RS 2 (2044) and RS 3 (2014); not met in RS 1. 0.4 ppm target met in 2010-2028 depending on river section.	0.5 ppm PRG met in RS 3 in 2051; not met elsewhere. 0.2 ppm target met in RS 2 (2040) and RS 3 (2014); never in RS1. 0.4 ppm target met in 2010-2025 depending on river section.	0.5 ppm PRG met in RS 3 in 2050; not met elsewhere. 0.2 ppm target met in RS 2 (2034) and RS 3 (2013); not met in RS 1. 0.4 ppm target met in 2010-2015 depending on river section.
Fish PRGs for Ecological Receptors: Otter NOAEL 0.03 ppm in whole fish. (0.013 ppm in fillet) Otter LOAEL 0.3 ppm in whole fish. (0.13 in fillet) Mink targets are 0.07 ppm (NOAEL) and 0.7 ppm (LOAEL) in whole fish.	Mink LOAEL met in RS 3. No other ecological criteria are met.	Otter NOAEL PRG not met in RS 1 or 2; met in RS 3 in 2025. mink achieves LOAEL target in RS 1 in 2025.	Most protective ecological PRG (otter NOAEL) not met in any river section. Otter LOAEL PRG not met in RS 1 but met in RS 2 in 52 years and in RS 3 in 8 years. Mink achieves LOAEL target in RS 1 in 45 years, and before 2010 in RS2. Mink NOAEL target not met in RS 1 or 2; met in 5 years in RS 3.	Most protective ecological PRG (otter NOAEL) not met in any river section. Otter LOAEL PRG not met in RS 1 but met in RS 2 in 52 yrs and in RS 3 in 8 years. Mink achieves LOAEL target in RS 1 in 4 years, and before 2010 in RS 2. Mink NOAEL target not met in RS 1 or 2; met in 5 years in RS 3.	Most protective ecological PRG (otter NOAEL) not met in any river section. Otter LOAEL PRG not met in RS 1 but met in RS 2 in 35 years and in RS 3 in 5 years. Mink achieves LOAEL target in RS 1 in 2 years, and before 2010 in RS 2 and RS 3. Mink NOAEL target not met in RS 1; met in 52 years in RS 2;and met in 4 years in RS 3.

Remedial Alternatives Comparative Analysis Summary

Criterion	No Action	MNA	CAP-3/10/Select	REM-3/10/Select	REM-0/0/3
Overall Protection of Human Health and the Environment (continued) PCB transport at Federal Dam	PCB transport over Federal Dam projected to be: 131 kg in 2003 104 kg in 2011 63 kg in 2035	PCB transport over Federal Dam projected to be: 131 kg in 2003 72 kg in 2011 24 kg in 2035	Projected PCB transport at Fed. Dam: 131 kg in 2003 43 kg in 2011 20 kg in 2035	Projected PCB transport at Fed.Dam 131 kg in 2003 42 kg in 2011 20 kg in 2035	Projected PCB transport at Fed. Dam: 131 kg in 2003 31 kg in 2011 18 kg in 2035
Compliance with ARARs (MCL - 0.5 mg/L; 0.09 NYS std for drinking water(DW); 1 ng/L federal navigable std; 0.12 ng/L NY std for wildlife; 0.001 ng/L NY std for fish consumption.	MCL and NYS std for DW protection are met. Other stds not met. Assumes constant 13 ng/L upstream input; concentration at Federal Dam is 10 ng/L in 2067.	MCL and NYS std for DW protection are met. Others are not met. Conc at Federal Dam is 1.7 ng/l in 2067.	MCL and NYS std for DW protection are met. Others are not met. Conc at Federal Dam is 1.7 ng/L in 2067.	MCL and NYS std for DW protection are met. Others are not met. Conc at Federal Dam is 1.7 ng/L in 2067.	MCL and NYS std for DW protection are met. Others are not met. Conc at Federal Dam is 1.7 ng/L in 2067.
Long Term Effectiveness and Permanence Based on: Reduction in residual risk, Adequacy of controls, and Reliability of controls.	Not effective.	Limited effectiveness. Risk reduction through burial is not permanent. Surveys show fish consumption advisories not fully effective (14 percent non-compliance).	Select removal is effective/permanent. Capping requires ongoing monitoring and maintenance. Effectiveness limited to areas and volumes actually remediated. Volume removed: 1.7 million cubic yards	Removal is permanent and effective. No ongoing maintenance required. Monitoring conducted (as for all alternatives): Volume removed: 2.7 million cubic yards.	Removal is permanent and effective and exceeds that under REM-3/10/Select. No ongoing maintenance required. Monitoring conducted (as for all alternatives): Volume removed: 3.8 million cubic yards.

Remedial Alternatives Comparative Analysis Summary

Criterion	No Action	MNA	CAP-3/10/Select	REM-3/10/Select	REM-0/0/3
Reduction of Toxicity, Mobility, or Volume through Treatment	No reduction through treatment.	No reduction through treatment. Some reduction through natural attenuation. Hudson Falls source assumed to be reduced from 0.16 to 0.0256 kg/day.	Mobility of PCBs under 207 acres of cap is reduced; 33,100 kg of PCBs are removed permanently. GE Hudson Falls source assumed to be reduced from 0.16 to 0.0256 kg/day.	46,500 kg of PCBs (in 2.7 million cubic yards of contaminated sediment) removed permanently. GE Hudson Falls source assumed to be reduced from 0.16 to 0.0256 kg/day.	63,500 kg of PCBs (in 3.8 million cubic yards of contaminated sediment) are removed permanently. GE Hudson Falls source assumed to be reduced from 0.16 to 0.0256 kg/day.
Short-Term Effectiveness Short-term impacts from construction include temporary loss of benthic habitat (habitat replacement will mitigate); temporary loss of recreational and aesthetic values. Degree of impact related to area capped and volume removed. Current Tri+ PCB load is 109 kg/yr.	Existing risks continue. No construction-related impacts. Tri+PCB load at Federal Dam is 461 kg for 2004-2008 (92 kg/yr); 637 kg for 2004-2010 (91 kg/yr).	NTCRA assumed to reduce upstream Tri+ PCB load to 0.0256 kg/day in 2005, thus reducing short-term risks compared to No Action. No construction-related impacts. Tri+PCB load at Federal Dam is 295 kg for 2004-2008 (59 kg/yr); 383 kg for 2004-2010 (55 kg/yr).	Assumes NTCRA. 33% less dredging than REM-3/10/Select & 55% less than REM-0/0/3. Resuspension generates 32 kg Tri+ PCB load at FD for 2004-2008 (6 kg/yr); ~10% increase over MNA; within yr-to-yr fluctuation of No Action.	Assumes NTCRA. ~50% more dredging than CAP-3/10/Select & ~30% less than REM-0/0/3. Resuspension generates 28 kg (6 kg/yr) (hydraulic) to 47 kg (9 kg/yr) (mechanical) Tri+ PCB load at FD in 2004-2008; ~10-16% increase over MNA; impact to river water less than release from 100-yr flood.	Assumes NTCRA. ~45% more dredging than REM-3/10/Select & more than double CAP-3/10/Select. Resuspension generates 29 kg (4 kg/yr) (hydraulic) to 48 kg (7 kg/yr) (mechanical) Tri+ PCB load at FD in 2004-2010; ~10-13% increase over MNA; impact to river water less than release from 100-yr flood.

400283

Remedial Alternatives Comparative Analysis Summary

Criterion	No Action	MNA	CAP-3/10/Select	REM-3/10/Select	REM-0/0/3
Implementability Implementability considers technical feasibility, administrative feasibility, and availability of services to implement the alternative.	Implementable. Requires no action.	Implementable. Requires voluntary compliance with fish consumption advisory for protection of human health.	Technically feasible though selected capping technology is still undergoing demonstration and in-river work requires greater coordination than for other active alternatives. Administratively feasible. Less intensive use of in-river and rail transportation systems than removal alternatives thus less demand on related services.	Technically feasible since both mechanical and hydraulic dredging equipment is available to productively remove sediments. Administratively feasible. Services available but planning needed to procure barges, towboats, and railcars.	Technically feasible since mechanical dredging equipment is available to productively remove sediments in one foot cuts. Technically feasible by hydraulic dredge provided two foot minimum cut is maintained. Administratively feasible. Services available but planning needed to procure barges, towboats, and railcars.
Cost Cost in terms of Net Present Worth (NPW) Costs for active alternatives based on landfilling removed sediments at licensed landfills located outside Hudson River valley.	NPW-$0.14 million	NPW - $39 million	Capital NPW - $345 million O&M NPW - $24 million Total NPW - $369 million	Capital NPW - $448 million O&M NPW - $13 million Total NPW - $461 million	Capital NPW - $556 million O&M NPW - $13 million Total NPW - $569 million

Chapter 1

1. INTRODUCTION TO THE FEASIBILITY STUDY (FS)

The Hudson River PCBs Superfund Site extends nearly 200 river miles (320 km) from the Fenimore Bridge in Hudson Falls (River Mile [RM] 197.3) to the Battery in New York City (RM 0) at the tip of Manhattan Island (see Figure 1-1). This Feasibility Study (FS) is Phase 3 of the Reassessment Remedial Investigation/Feasibility Study (Reassessment RI/FS) that is being conducted for the site by the United States Environmental Protection Agency (USEPA) to reassess the Agency's 1984 interim No Action decision concerning polychlorinated biphenyls (PCBs) in the sediments of the Upper Hudson River. The FS, prepared in accordance with USEPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA,* Interim Final, October 1988 (OSWER Directive Number 9355.3-01) (hereafter as the RI/FS Guidance), the Feasibility Study Scope of Work (FSSOW) (USEPA, 1998d), and the FSSOW Responsiveness Summary (USEPA, June 1999k), contains remedial alternatives that have been evaluated by USEPA as a basis for determining an appropriate course of action for those sediments in order to protect human health and the environment. The area of the Upper Hudson River evaluated for active remediation addressed in this Reassessment RI/FS is the river bed between the Fenimore Bridge at Hudson Falls (just south of Glens Falls) and the Federal Dam at Troy. Plate 1 presents a general site location map of the Upper Hudson River.

1.1 Purpose and Organization

1.1.1 Purpose: Overview of the Feasibility Study Process under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as Amended (CERCLA)

The purpose of an FS is to evaluate an appropriate range of remedial alternatives, including No Action, that will reduce risks to human health and the environment at a Superfund site, based on data, analyses, and other information generated during the RI/FS process. The terms "remedy" and "remedial action" are defined in CERCLA, 42 USC § 9601(24), as "those actions consistent with permanent remedy taken instead of or in addition to removal actions in the event of a release or threatened release of a hazardous substance into the environment, to prevent or minimize the release of hazardous substances so that they do not migrate to cause substantial danger to present or future public health or welfare or the environment."

Remedies selected by USEPA must be protective of human health and the environment, cost-effective, and utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable. Furthermore, CERCLA requires that remedial actions selected by USEPA comply with applicable or relevant and appropriate requirements (ARARs), unless USEPA justifies a waiver from an ARAR that will not be met. In accordance with CERCLA, USEPA will favor remedies that permanently and significantly reduce the volume, toxicity, or mobility of hazardous substances through treatment over remedial actions not involving such treatment (42 USC § 9621(b)(1)).

The National Oil and Hazardous Substances Pollution Contingency Plan (commonly referred to as the National Contingency Plan, or NCP), 40 CFR Part 300, contains USEPA's regulations for implementing CERCLA. Section 300.430 of the NCP, in conjunction with the RI/FS Guidance, sets forth the development and evaluation process for remedial alternatives. This process is represented in a flow chart in Figure 1-2 and consists of the following steps:

- Perform a remedial investigation to collect data necessary to characterize the site, including risks to human health and the environment presented by hazardous substances at the site, for the purpose of developing and evaluating effective remedial alternatives (40 CFR § 300.430(d));
- Establish remedial action objectives specifying contaminants and media of concern, potential exposure pathways, and remedial goals. Remediation goals establish acceptable exposure levels that are protective of human health and the environment (40 CFR § 300.430(e)(2));
- Identify and evaluate potentially suitable remedial technologies (40 CFR § 300.430(e)(2)(ii));
- Assemble suitable technologies into alternative remedial actions (40 CFR § 300.430(e)(2)(iii));
- Develop and screen potential remedial alternatives based on long-term and short-term effectiveness, implementability, and cost (40 CFR § 300.430(e)(7)); and

- Conduct a detailed analysis of a limited number of alternatives that represent viable approaches to remedial action after evaluation in the screening stage. The detailed analysis in the FS consists of an assessment of individual remedial alternatives against the first seven of the nine evaluation criteria established in the NCP, and a comparative analysis that focuses on the relative performance of each alternative against those criteria. Detailed analysis with respect to the final two criteria, state acceptance and community acceptance, is conducted by USEPA after release of the FS Report and issuance of the Proposed Plan (40 CFR § 300.430(e)(9)).

1.1.2 Organization of the Feasibility Study Report

The components of this FS Report are identified in CERCLA regulations (40 CFR § 300.430) and the RI/FS Guidance; however, the organization and format of this FS have been modified somewhat as appropriate, both for clarity and to reflect the nature of the work performed.

This FS report, which is Phase 3 of the Reassessment RI/FS, is submitted in six books. Book 1 (this document) contains the text, the organization of which is described below. Book 2 contains the tables and figures. Book 3 contains the plates. Books 4 through 6 contain the appendices, which provide detailed information that supports the text.

The text (Book 1) is organized into nine chapters.

- Chapter 1 (this chapter) provides introductory and background material, and summarizes what has been learned about the nature and extent of PCB contamination in the river, as well as the current knowledge of PCB fate, transport, and bioaccumulation and risks to human health and the environment posed by PCBs in the Hudson River. This is based on Phase 2 investigations and other available data.

- Chapter 2 presents the potential ARARs, which are the federal and state environmental laws and regulations that remedies must meet and may form the basis of the preliminary remediation goals. Included in this chapter are other to-be-considered (TBC) criteria, which are non-promulgated criteria, advisories, guidance, and proposed standards issued by federal or state governments. TBCs are not legally enforceable but may be considered in the development and evaluation of alternatives.

- Chapter 3 presents the remedial action objectives (RAOs) for the site, general response actions (GRAs) for achieving the RAOs, and the criteria for identifying areas of the river for potential remediation.

- Chapter 4 presents a review of technologies that may be utilized for the general response actions identified in Chapter 3. The technologies are screened for applicability for use in developing remedial alternatives specifically for the Hudson River PCBs site.

- Chapter 5 presents the development and conceptual description of remedial alternatives.

- Chapter 6 presents the screening of remedial alternatives for effectiveness, implementability, and cost, resulting in a limited number of alternatives being retained for detailed evaluation.

- Chapter 7 presents the alternative-specific human health and ecological risk assessments.

- Chapter 8 presents detailed descriptions and analyses of features unique to each alternative according to each of the seven criteria required to be evaluated in the FS Report.

- Chapter 9 provides the comparative analysis of the remedial alternatives, along with a discussion of the cost sensitivity analyses performed.

1.2 Background Information

In December 1990, USEPA issued a Scope of Work (SOW) for reassessing the No Action decision for the Hudson River PCBs site. The SOW indicated that the Reassessment RI/FS would be conducted in three phases:

- Phase 1 - Interim Characterization and Evaluation;
- Phase 2 - Further Site Characterization and Analysis; and
- Phase 3 - Feasibility Study.

In August 1991, USEPA issued a Phase 1 Report that described the results of Phase 1 studies (USEPA, 1991a). The Phase 1 Report contains a compilation of background material, a discussion of findings, and a preliminary assessment of risks, and identifies data gaps and data needs. This report served as the basis for the development of the Phase 2 investigations. The Phase 2 work began in December 1991 and is now complete. A series of reports and responsiveness summaries has been released as a result of the Phase 2 work. These reports are listed in Table 1-1. In accordance with CERCLA 40 CFR § 300.430, this FS builds upon the previous investigations and reports completed for the site.

1.2.1 Site Description

The Hudson River flows in a generally southerly direction approximately 315 miles from its source at Lake Tear-of-the-Clouds on Mount Marcy in the Adirondack mountains to the Battery in New York City. The Hudson River PCBs Superfund Site extends nearly 200 river miles (320 km) from the Fenimore Bridge in Hudson Falls (RM 197.3) to the Battery in New York City (RM 0) at the tip of Manhattan Island. The Superfund site traditionally has been divided into the Upper Hudson River and Lower Hudson River, based on physical and chemical characteristics. The Upper Hudson River extends from Fenimore Bridge in Hudson Falls to the Federal Dam at Green Island in Troy (RM 153.9), a distance of about 43 river miles. The Lower Hudson River extends from the Federal Dam to the Battery (RM 153.9 to 0).

Within the Upper Hudson River, the first 2.7 miles are not a major focus of the Reassessment RI/FS because the PCB contamination in this area largely has been addressed. The area between the Fenimore Bridge and the former Fort Edward Dam (RM 194.8), a distance of about 2.5 miles, consists primarily of rocky outcrops and little sediment, or areas of sediment that have already been remediated (*i.e.*, the remnant deposits, which are discussed in greater detail in Section 1.3.2 and Appendix A). The area between the former Fort Edward Dam and the northern end of Rogers Island, a distance of about 0.2 mile, contains shallow, fast-moving water and primarily coarse-grained sediments that are believed to have minimal PCB inventory.

The portion of the Upper Hudson River being considered for sediment remediation extends from the former Fort Edward Dam to Federal Dam. This portion of the river was divided into three sections for evaluating remedial alternatives in the FS. These three river sections are shown on Figure 1-2. River Section 1 consists of the Thompson Island (TI) Pool. This river section extends about 6.3 miles from the former Fort Edward Dam (RM 194.8) to the TI Dam at RM 188.5. For practical purposes, this section is considered to start at the northern end of Rogers Island at RM 194.6. River Section 2 extends from the TI Dam (RM 188.5) to the Northumberland Dam (for convenience, sometimes referred to as Lock 5) near Schuylerville (RM 183.4), an extent of about five river miles. River Section 3 extends from below the Northumberland Dam to the Federal Dam at Troy (RM 153.9), an extent of nearly 29 river miles.

1.2.1.1 Hydrology

The Upper Hudson River is entirely freshwater and non-tidal. The mean annual flow of the Hudson River at Fort Edward is approximately 4,800 cubic feet per second (cfs) (USGS, 2000). Downstream of Fort Edward, the river is joined by several tributaries, the most significant of which are the Batten Kill, the Fish Creek, and the Hoosic River. The combined total of the tributaries significantly increases the flow of the Upper Hudson by the time it reaches Waterford, where the mean annual flow of the river is approximately 8,400 cfs. At its confluence with the Mohawk River (RM 156), the river flow reaches an annual average of 12,300 cfs (USGS, 2000).

There are eight dams with locks in the portion of the Upper Hudson River that is considered in this Reassessment RI/FS. The locks and dams form a series of pools in the river. The flow in the Upper Hudson is controlled by these dams, and to a lesser degree, by wetlands and backwaters in the vicinity of the river, which act as a buffer for high and low flow conditions. The flow in the Upper Hudson is also controlled by several reservoirs above Glens Falls, the most significant of which is Great Sacandaga Lake (USEPA, 1984b). It is expected that minimum average daily flow at Fort Edward will be maintained in the range of 1,500 cfs to 4,000 cfs, depending on conditions at the Great Sacandaga Lake (Erie Boulevard Hydropower, 2000).

The mean gradient of the river between Fort Edward and the Federal Dam at Troy is about three feet per mile. The gradient within each pool is much smaller than the mean gradient, with major elevation drops between the pools at the dams. The width of the Upper Hudson above Lock 4 in Stillwater is approximately 400 feet. The Upper Hudson has an average depth of less than 8 feet in the shoal areas, and approximately 18 feet in the channel, with a maximum depth of more than 45 feet in a section below TI Dam. The total surface area of the Upper Hudson is approximately 3,900 acres.

The Champlain Canal is coincident with portions of the Hudson River, extending from Waterford (RM 158) on the Hudson to Whitehall at the southern end of Lake Champlain. The Champlain Canal is 60 miles long, including 37 miles of canalized Hudson River from Waterford to Fort Edward, and 23 miles of land-cut sections. The canal diverges from the river at Fort Edward just below Lock 7 and proceeds in a northeasterly direction to Lake Champlain. Additional land cut areas exist at Stillwater, Northumberland, and Fort Miller. The portion of the river from Waterford to the Federal Dam is considered part of the Erie Canal.

1.2.1.2 River Bed Geology

Sediments of the Upper Hudson have been extensively investigated during Phase 2 of the Reassessment RI/FS, including a geophysical investigation consisting of side-scan sonar, bathymetric soundings, and subbottom profiling. Evaluation of sonar images and other data suggests that sediment distribution patterns are locally complex (USEPA, 1997a and 1998b, and Appendix H). Bedrock, cut away to form the Champlain Canal, is exposed in some areas, while lacustrine silts and clays of glacial age are exposed in other areas. Coarser-grained sediments are often observed in the channel while finer sediments are more common in shallow water. Wood chips are present in surface sediments in many locations, as well as sediment mounds likely created by historic disposal of dredged spoils in the river. PCB *hot spots* previously defined by the New York State Department of Environmental Conservation (NYSDEC), as identified on Table 1-2, are generally coincident with areas of fine-grained sediments, including silts and clays, where suspended matter with a high affinity for PCBs is most likely to settle. (Channel maintenance dredging subsequent to NYSDEC's delineation based on 1977/78 sampling has likely eliminated *Hot Spots* 1 through 4, located in the channels around Rogers Island.)

Sediment texture classifications were also reported in the 1984 NYSDEC sediment survey of the Thompson Island Pool (TI Pool) (Brown *et al.*, 1988). These classifications, based on an average of grab and core samples, indicated a composition of about 37 percent gravel, 26 percent fine sands, 11 percent fine sand with wood chips, 9.4 percent clay, 5.4 percent coarse sand, and about 9 percent other types (including hybrids comprised of the listed types, such as "gravel with wood chips" and "fine sand and gravel").

1.2.1.3 Wetlands and Floodplains

Both federal and state freshwater wetlands exist adjacent to the Upper Hudson River. The 100-year floodplains of the Upper Hudson and tributaries are available from Flood Insurance Rate Maps prepared by the Federal Emergency Management Agency (FEMA). The width of the 100-year floodplain ranges from approximately 400 to over 5,000 feet in the vicinity of the Upper Hudson River. Areas adjacent to the Upper Hudson River include forested shoreline wetlands, transitional uplands, and vegetated backwaters (emergent marsh and scrub-shrub wetlands).

1.2.1.4 Archaeological, Historic, and Cultural Resources

The approximately 40-mile stretch of the Upper Hudson River that is the focus of this FS has been an important a source of energy, natural resources, and transportation to the region from its population by prehistoric peoples to the present time. During the thousands of years following the final northerly retreat of the Wisconsin Glacier approximately 14,000 years ago, the river and its drainages gradually transformed the landscape, providing a rich habitat and supporting a substantial prehistoric population.

The Hudson Valley has figured prominently in the historical and cultural development of the United States. The valley was home to a league of five Native American nations from the mid-1400s to approximately 1600. Following Henry Hudson's exploration up the Hudson River in 1609, looking for a quick passage to China for the Dutch East India Company, the area was first heavily settled by the Dutch. From the 17^{th} through 19^{th} centuries, this region was gradually settled by European immigrants who cleared more of the land, established towns, and built a variety of industries along the river. Efforts to maximize the industrial use of the river led to the construction of locks, dams, gates, channels, and related structures.

During the French and Indian War and the American Revolution, the Hudson River often proved to be of vital logistical importance and was the site of numerous military engagements. The Revolutionary War Battle of Saratoga fought along the Hudson River in 1777 was won by the Americans and led to the French alliance and eventual victory and independence. The foundry at West Point supplied munitions to the Union forces during the Civil War.

The 60-mile (96.5-km) Champlain Canal was completed in 1825. This canal linked the Upper Hudson River at Troy, New York with the southern end of Lake Champlain at Whitehall, New York. During the heyday of the Champlain Canal, between 1823 and the early 20^{th} century, thousands of canal boats passed between Lake Champlain and the Hudson River, transporting raw materials and finished products.

Recently, the Hudson River has been designated an American Heritage River because of its important role in American history and culture. Through this program, which is an initiative to more effectively use the federal government's many resources, environmental, economic, and social concerns will be addressed in a plan that is designed by local communities. The American Heritage Rivers initiative is intended to help communities revitalize their rivers and the banks along them --the streets, the historic buildings, the natural habitats, the parks--to help celebrate their history and their heritage.

A site file search of the records of the New York Office of Parks, Recreation, and Historic Preservation (OPRHP), the New York State Museum, and the National Register of Historic Places was conducted in 1990 for a small portion of the area along the Hudson River PCBs site, in the towns of Moreau and Fort Edward (Collamer & Associates, Inc., 1990). That search resulted in the documentation of 20 previously identified cultural resources, including the following:

- Three prehistoric sites (one of which was a stratified, multi-component seasonal campsite);
- One site dating to the French and Indian War;
- One multi-component prehistoric site also containing French and Indian War and Revolutionary War encampments;
- The Fort Edward Blockade site;
- One cultural resource without any available description;
- The Satterlee Lane Historic Deposits;
- Eight historic houses or former house sites;
- A site described as Ferry Landing;
- A mid- to late-19th century mill site;
- The site of a ferry house and blockhouse; and
- The site of the Royal Blockhouse.

1.2.1.5 Demographics and Land Use

Four counties (Albany, Washington, Rensselaer, and Saratoga) lie adjacent to the Upper Hudson River between Troy (Federal Dam) and Hudson Falls. Saratoga and Washington Counties have experienced growth between 1990 and 1999, 10.2 percent and 1.4 percent respectively, while Rensselaer and Albany Counties have experienced population declines of 1.9 percent and 0.3 percent, respectively; total population of those counties, according to July 1999 estimates by the US Department of Commerce, Bureau of the Census, is just under 700,000. Warren County, in which Glens Falls is located, is just to the northwest of the Hudson River PCBs site.

In the area adjacent to the Upper Hudson River, forests and farmlands surround urban centers and historic villages. There are apple orchards and dairy farms, parks, nature preserves, and gardens. Portions of the agricultural land lie within New York State Agricultural Districts and include parcels considered to be prime farmland. In addition to apples, other crops include corn and hay used for forage, and small quantities of cash crops such as oats and wheat. Industrial use is typically located near urban centers such as Albany and Troy and includes hydroelectric plants, manufacturing (brake linings, paper products, clothing, garden equipment) and paper mills. In addition to agriculture and industry, recreation and tourism are popular throughout the Hudson River Valley.

Boating is available on the river and on the Erie and Champlain Canals; marinas and docks can be found along the waterway. Schaghticoke Canal Park sits at Lock 4 of the Champlain Canal, Schuylerville has a large waterside town park, and other town parks lie along the river, including two in Fort Edward. A marina and hotel complex has been proposed for the southern end of Rogers Island. Area festivals include various county fairs such as those in Washington and Rensselaer Counties.

1.2.1.6 Water Use

The cities of Waterford, Poughkeepsie, and Rhinebeck, as well as the Highland and Port Ewen Water Districts, obtain their water supplies directly from the Hudson River. In addition, a water intake near Chelsea, which is north of Beacon, may be used to supplement New York City's water supply during periods of drought. Waterford is the only municipal water intake in the Upper Hudson River. The treatability study at Waterford Water Works, which was completed in 1990 pursuant to USEPA's 1984 ROD, indicated that the treated water met standards applicable to the public water supplies at that time. It should be noted that the town of Halfmoon has proposed to use the Upper Hudson River as a source of public water supply.

Industrial and commercial purposes such as cooling, manufacturing process, and fire protection, and generation of hydroelectric and thermal power, are more common uses of Hudson River water, which is also used for domestic (watering lawns and gardens) and agricultural purposes (irrigation). There are no records of water withdrawal for agricultural uses, as permits are not required for irrigation withdrawals.

1.2.1.7 Ecological Resources

The Hudson River provides diverse habitats for all trophic levels of the river's ecosystem. Plants, plankton, aquatic invertebrates, fish, amphibians, reptiles, birds, and mammals use the Hudson River for feeding, reproduction, and shelter. In addition to the aquatic communities associated with the river, animals living in wetland, floodplain, and upland communities are also dependent on the river.

During the field sampling effort for the Ecological Risk Assessment, a baseline vegetative survey was performed at nine stations in the Upper Hudson River. A plant ecologist conducted the survey by identifying dominant submergent and emergent vegetation observed in intertidal, bank, and upland areas, when possible. A list of species identified during the field investigation is provided in Table B-6 of the Baseline Ecological Risk Assessment (ERA) (USEPA, 1999c).

Similar plants were present at the nine Upper Hudson River stations, including nearly all the same dominant submergent plants (*e.g.*, wild celery, water chestnut). The most prevalent aquatic plant noted was water chestnut (*Trapa natans*), which was abundant along nearly the entire river.

Water chestnut is an introduced species, whose rosettes of floating leaves crowd together in mats, choking freshwater shallows, limiting boat access, and shading out other submergent vegetation (Stanne *et al.*, 1996). Some locations in the Upper Hudson (*e.g.*, the western channel at Griffin Island) were inaccessible due to the thick mats of water chestnut encountered during the ecological sampling. However, these water chestnut beds may harbor large populations of invertebrates and young fish.

Emergent species (*e.g.*, arrow arum, pickerelweed) were located at about half the stations sampled. Generally, areas of the river with reduced flow velocity allow fine-grained sediments to settle out, providing favorable conditions for plant growth. Vegetation observed on the river bank varied, but a majority of locations included silver maple *(Acer saccharinum)* and white ash (*Fraxinus americana*).

The dominant macroinvertebrates found in the 1992 ecological sampling were isopods, midges, worms, amphipods, and clams (USEPA, 2000q, Table 2-2). Vertebrates potentially found in or along the Upper Hudson River, including fish, amphibians, reptiles, birds, and mammals, are discussed in the Revised ERA (USEPA, 2000q).

1.2.2 Site History

During an approximate 30-year period ending in 1977, manufacturing processes at two GE facilities, one in Fort Edward, New York and the other in Hudson Falls, New York, used PCBs in the manufacture of electrical capacitors. PCBs from both facilities were discharged directly into the Hudson River; estimates of the total quantity of PCBs discharged from the two plants into the river from the 1940s to 1977 range from 209,000 to 1,330,000 pounds (95,000 to 603,000 kg) (USEPA, 1991a).

Many of the PCBs discharged to the river adhered to sediments and accumulated downstream with the sediments as they settled in the impounded pool behind the former Fort Edward Dam (RM 194.8), as well as in other impoundments farther downstream. Because of its deteriorating condition, the dam was removed by Niagara Mohawk Power Corporation in 1973. During subsequent spring floods, PCB-contaminated sediments were scoured and transported downstream. A substantial portion of these sediments was deposited in relatively quiescent areas of the river, *i.e.*, lower energy areas where the finer-grained sediments with higher PCB concentrations were deposited. These areas were surveyed by NYSDEC in 1976 to 1978 and 1984, and are described as PCB *hot spots*. These NYSDEC-defined *hot spots*, located between RM 194 at Rogers Island to Lock 2 at RM 163, are areas that typically had average total PCB concentrations of 50 parts per million (ppm) or greater.

Not all the PCB-contaminated sediments behind the former dam were transported downstream, however; five areas of contaminated sediments were exposed due to lowering of the river water level when the Fort Edward Dam was removed. These five areas remained upstream of the former dam and are known as the remnant deposits.

In 1974, the New York State Department of Transportation (NYSDOT) dredged approximately 250,000 cubic yards of sediment from the channels adjacent to Rogers Island for navigational purposes. The dredged materials were disposed of in Special Area 13, which is located along the west bank of the river just south of Rogers Island. Another 384,000 cubic yards of sediment were removed from the east and west channels in 1974 and 1975 and disposed of in the Moreau Landfill, located on the west shore of the river opposite the southern end of Rogers Island (just north of Special Area 13).

A 1975 legal action brought by NYSDEC against GE resulted in a $7 million program for the investigation of PCBs and the development of methods to reduce of remove the threat of PCB contamination. In 1975, the New York State Department of Health (NYSDOH) began to issue health advisories recommending that people limit consumption of fish from the Upper Hudson River. In 1976, NYSDEC issued a ban on fishing in the Upper Hudson River from Hudson Falls to the Federal Dam at Troy, due to the potential risks from consumption of PCB-contaminated fish, and a ban on commercial fishing of striped bass, which migrate upriver into the Lower Hudson. NYSDEC lifted the ban against fishing in the Upper Hudson River and replaced it with a catch-and-release fishing program in 1995. Since 1976, NYSDOH has recommended that people eat none of the fish in the Upper Hudson and that children under the age of 15 and women of child-bearing age eat none of the fish in the river for the entire length of the Superfund site. In addition, the commercial striped bass fishery in the Lower Hudson is still closed.

Although commercial uses of PCBs generally ceased in 1977, PCBs from GE's Fort Edward and Hudson Falls plants continued to contaminate the Hudson River after that date, due primarily to erosion of the contaminated remnant deposits, discharges of PCBs via bedrock fractures and other releases from the GE Hudson Falls plant, as well as erosion from contaminated deposits above the water line near the GE Fort Edward plant outfall and discharges of contaminated water from the former Fort Edward plant outfall pipe (Tofflemire, 1984; NYSDEC, 1999f). The PCB-contaminated former outfall pipe and pipe bedding were removed from the riverbank near the Fort Edward plant in 1996 (NYSDEC, 1999f).

NYSDEC removed about 14,000 cubic yards of contaminated sediments from Remnant Deposit 3A in 1978. Those sediments were placed in a secure encapsulation site in Moreau, along with some 215,000 cubic yards of sediment that had been dredged by NYSDOT to clear the navigation channel east of Rogers Island. Unstable river banks of two sites were reinforced at that time. Three sites were revegetated to prevent public contact with the sediments and to minimize erosion and release of PCBs into the environment.

In September 1980, Congress passed an amendment to the Clean Water Act (CWA) under Title 1, Section 116 (a) and (b), entitled "The Hudson River PCB Reclamation Demonstration Project." Under this legislation, funds up to $20 million could be authorized by the USEPA Administrator for, among other things, the demonstration of technologies for removal of PCBs from Hudson River sediments, provided that the Administrator determined that funds were not first available under Section 116 or 311 of the CWA or from the then-proposed Comprehensive Environmental Response, Compensation, and Liability Act of 1980. The intended demonstration was to clean up about 20 *hot spots* involving approximately 360,000 cubic yards of sediment. Congress authorized the USEPA to make grants to the NYSDEC in order to carry out the intent of the amendment.

In accordance with the National Environmental Policy Act (NEPA) and requirements in the CWA, Section 116, USEPA issued a Draft and Supplemental Environmental Impact Statement (EIS) in 1981, and a Final EIS in 1982. In December 1982, a NEPA ROD was signed in which the USEPA Administrator determined that funds for addressing this problem were available under CERCLA, and that the problem rated sufficiently high to be considered for inclusion on the National Priorities List (NPL). The site was proposed for the NPL in 1983.

Under Superfund, a Remedial Action Master Plan (RAMP) was initiated to evaluate all available information and assess feasible remedial options. In 1984, before the RAMP was completed, the Hudson River PCBs site was listed on the NPL, and, as a result, became eligible for CERCLA funding. The RAMP was subsequently changed to an FS, since the RAMP contained all the necessary information to meet the statutory requirements of an FS. The FS was issued in April of 1984.

USEPA issued a ROD for the site in September 1984 (USEPA, 1984a). The 1984 ROD does not address PCB DNAPL seeps near the GE Hudson Falls plant, the existence of which was unknown at the time. USEPA recognized that PCB contamination in the Upper Hudson River sediments needed to be addressed, but selected an interim No Action remedy for the sediments because, in the Agency's view, the reliability and effectiveness of available remedial technologies at that time was uncertain. The ROD contained the following decisions:

- An interim No Action decision with regard to PCBs in the sediments of the Upper Hudson River;
- In-place capping, containment, and monitoring of exposed "remnant deposit" sediments (in the area of RM 195 to RM 196), and stabilization of the associated riverbanks and revegetation of the areas; and
- A detailed evaluation of the Waterford Water Works treatment facilities, including sampling and analysis of treatment to see if an upgrade or alteration of the facilities was needed.

USEPA notified GE of the remedy selected in the 1984 ROD and offered the company the opportunity to implement the selected remedy for the remnant deposits and Waterford drinking water supply evaluation. GE declined USEPA's offer. NYSDEC, with funding provided by USEPA, conducted the evaluation at the Waterford Water Works. The study was released in 1990 and found that PCB concentrations were below analytical detection limits after treatment and met standards applicable to public water supplies. In addition, NYSDEC prepared a design for the in-place containment of the remnant deposits.

In March 1989, GE offered to assume responsibility for the implementation of the in-place containment remedy for the remnant deposits. USEPA issued a September 27, 1989 Administrative Order on Consent to GE requiring the company to prepare a remedial design report for the construction of access roads to the remnant deposits, and to submit a design for the in-place containment of the remnant deposits incorporating the NYSDEC-prepared design, plus any USEPA-approved refinements to that design. USEPA also issued a September 27, 1989 Administrative Order to GE requiring the company to construct and maintain the access roads to the remnant deposits.

GE performed the in-place containment of the remnant deposits under a 1990 consent decree with USEPA. The in-place capping of these remnant deposits included installation of a geosynthetic clay cap and a two-foot layer of soil over the affected areas, followed by grading and revegetating to minimize erosion. The river banks were stabilized with rock to prevent scouring. Cap construction and the erection of gates to limit site access were completed in 1991.

In May 1983, following USEPA's decision to address the contaminated sediments under CERCLA and to discontinue funding the Demonstration Project under CWA § 116, New York State, the Hudson River Sloop Clearwater, and other environmental groups, filed suit to compel the USEPA to award the balance of the $20 million stipulated under Section 116 of the CWA so the demonstration project could proceed. In May 1984, USEPA signed a settlement agreement whereby the Agency would make a grant to New York State of approximately $18 million for dredging and disposal of PCBs if the state obtained an acceptable disposal site with all the necessary state and federal permits within three years. This deadline was later extended.

NYSDEC had obtained a conditional approval for a disposal site ("Site 10") in Fort Edward in 1982, although the approval was revoked by the New York State Supreme Court following a lawsuit by Washington County Citizen Environmentalists Against Sludge Encapsulation ("CEASE") that challenged the Site 10 approval because, among other things, the proposed Site 10 violated local zoning laws.

NYSDEC submitted a new application for an alternate disposal site (Site G) after the New York Court of Appeals upheld the Supreme Court's decision regarding Site 10. In 1987, however, coincident with hearings associated with the Site G application, the New York State legislature amended the NYS Environmental Conservation Law to eliminate local zoning and land-use regulations from consideration in the siting of a hazardous waste disposal facility. By this time, other issues in CEASE's legal challenge were resolved, thus eliminating the rationale for revoking Site 10.

The New York State Hazardous Waste Facility Siting Board rejected the use of Site G in part because of its smaller size relative to Site 10. Also, Site 10 ranked more favorably than Site G in NYSDEC's evaluation of proposed disposal sites against the criteria in 6 NYCRR Part 361. After the Siting Board voted in favor of NYSDEC's proposed dredging project and use of Site 10, the NYSDEC Commissioner directed the Project Sponsor Group (*i.e.*, NYSDEC staff responsible for the Demonstration Project) to conduct additional designs and reapply for the use of Site 10 for containment of contaminated river sediments, as well as material to be excavated from the remnant deposits and dredge spoil sites. NYSDEC now favored a project that was of a larger scale than the Demonstration Project, and which would remediate as much of the PCBs in the Upper Hudson River as possible. NYSDEC prepared the necessary design documents for Site 10 and, on December 15, 1989, NYSDEC issued its Hudson River PCB Project Action Plan which, among other things, laid out the potential scope of a comprehensive cleanup of PCB contamination in the Hudson River system. Under the Project Action Plan, a total of approximately 3 million cubic yards containing

250,000 pounds of PCBs would be removed from the Upper Hudson River. The estimated cost for removal and encapsulation only was $280 million. The plan indicated that costs associated with decontamination technologies were uncertain but "could more than triple the total costs of the Project."

In a December 19, 1989 letter to NYSDEC, USEPA announced that it would reassess the 1984 interim no-action decision for PCB-contaminated sediments in the Upper Hudson River. USEPA's decision to conduct the Reassessment was based on the 1986 Superfund Amendments and Reauthorization Act's (SARA's) requirement that USEPA conduct five-year reviews at sites where hazardous substances were left in-place under a prior remedy, and USEPA's policy decision to include such reviews at sites with pre-SARA RODs; recent advances in PCB treatment technologies; and a request to conduct the Reassessment from NYSDEC. In its letter, USEPA informed NYSDEC that, because NYSDEC had not met a December 15, 1988 deadline for obtaining the necessary State permits, certificates and approvals for the project, and since NYSDEC's Demonstration Project had been superseded by the larger remediation project outlined in the Project Action Plan, the Demonstration Project under CWA § 116 should be closed out, after which USEPA would make the remaining CWA § 116 funds available to the State for the construction of wastewater treatment facilities. NYSDEC did not pursue the Project Action Plan following USEPA's decision to conduct the Reassessment.

In September 1991, elevated PCB concentrations (nearly 100 times greater than those of the previous month, and higher than any reported since the early 1980s) were again detected in Hudson River water. GE later attributed the higher levels to the collapse of a wooden gate structure within the abandoned Allen Mill located adjacent to the GE Hudson Falls capacitor plant (RM ~197) (O'Brien and Gere, 1993b). As reported by GE, the gate had kept water from flowing through a tunnel cut into bedrock below the mill, which contained oil-phase PCBs that migrated there via subsurface bedrock fractures.

From 1993 to 1995, extensive PCB contamination was detected in water conduits within the mill, and approximately 45 tons of PCB-bearing oils and sediments were eventually removed

400304

(O'Brien and Gere, 1995). In 1994, GE documented the presence of PCB dense non-aqueous phase liquid (DNAPL) seeps in a dewatered portion of the river bottom at Bakers Falls adjacent to the Hudson Falls plant site. GE instituted a number of mitigation efforts that have resulted in a decline, but not total cessation, of these seeps (O'Brien and Gere, 1995). GE is conducting remedial activities at the GE Hudson Falls plant site under an Order on Consent between the NYSDEC and GE. A more in-depth discussion of external PCB sources, including the GE facilities, the remnant deposits, and other sources in both the Upper and Lower Hudson River, is contained in the Data Evaluation and Interpretation Report (USEPA, 1997a).

In order to reduce the upstream source of PCBs, USEPA has authorized the performance of an Engineering Evaluation/Cost Analysis (EE/CA) to evaluate potential Non-Time Critical Removal Actions (NTCRA) to address the discharge of PCBs into the river in the vicinity of GE's Hudson Falls plant. It is assumed that as a result of this source control removal action, the upstream Tri+ PCB load at Fort Edward (Rogers Island) will be reduced from its average current value of 0.16 kg/day (equivalent to an average concentration of 13 ng/L) to 0.0256 kg/day (equivalent to an average concentration of 2ng/L). GE has discussed with USEPA and NYSDEC a conceptual approach to contain the release of PCB oil from the vicinity of the Hudson Falls facility. Assuming that the conceptual approach proposed by GE, or a similarly effective system, is available to address the Hudson Falls source, USEPA believes that a source control NTCRA can reasonably be completed by January 1, 2005.

1.3 Nature and Extent of Contamination

The study of PCBs in the Upper Hudson River has occurred over a period of many years, and continues to this day. As a result, the ending date of the data available has changed with each of the reports issued as part of the Reassessment RI/FS, and it is possible that conditions in the river have changed since some of the earlier reports were written (*i.e.*, between 1991 and 1995). This section summarizes information on the nature of the contamination (PCBs) and also presents available evidence on the extent of PCB contamination in the Upper Hudson River, including sources of PCBs, and the extent of PCB contamination in the three principal affected media: river water, sediments, and fish. This information provides the starting point for the FS evaluation of future conditions with and without remedial intervention. Data collection focused on the Upper Hudson River, as this part of the river was the part under consideration for possible remediation. Data for the FS are contained in Release 5.0 of the database for the Hudson River PCBs Reassessment RI/FS (October, 2000).

1.3.1 Nature of Contamination

The contaminants studied in the Reassessment RI/FS for the Hudson River PCBs site are, by definition, polychlorinated biphenyls (PCBs). PCBs consist of a group of 209 distinct chemical compounds, known as congeners, that contain one to ten chlorine atoms attached to a biphenyl molecule, with the generic formula of $C_{12}H_{(10-x)}Cl_x$, where x is an integer from one to ten. Homologue groups are identified based on the number of chlorine atoms present, for example, monochlorobiphenyls contain one chlorine atom, dichlorobiphenyls contain two chlorine atoms, and trichlorobiphenyls contain three chlorine atoms.

Commercially manufactured PCBs consisted of complex mixtures of congeners, known under various trade names. The PCBs utilized by GE were manufactured by Monsanto Corporation, the company that manufactured 95 percent of the PCBs sold in the US, and marketed under the general trade name "Aroclors." About 140 to 150 different congeners have been identified in the various commercial Aroclors, with about 60 to 90 different congeners present in each individual Aroclor.

1.3.1.1 Analysis of PCBs

Interpretation of historical trends in PCB concentrations may be enhanced by consideration of the changes in analytical methods that have occurred over time. This provides greater consistency in the data. For instance, the recent methods using capillary-column gas chromatography that yields PCB congener results, whereas older methods use chromatographic analyses based on packed-column quantitation that yielded Aroclor equivalents. Because an Aroclor is a complex mixture of many individual congeners, interpretation of the older packed-column data raises technical issues. In addition, packed-column Aroclor quantitation methods have changed over time, and these changes have implications for the interpretation of historical trends in the data and the development of statistical relationships.

A commercial PCB mixture consists of many individual congeners, each with its own set of chemical properties. Introduction of PCBs into the environment quickly changes the original mixture and the relative proportions of the congeners. Processes such as weathering, dechlorination, and biological accumulation affect the individual congeners to varying degrees. Thus, analytical Aroclor quantitations on environmental samples are not directly comparable to actual concentrations of PCB congeners. Results of capillary column analyses do not have a direct interpretation as "Aroclors;" however, total PCB concentration is readily estimated as the sum of individual congener concentrations. Translation methods were developed to make the older data sets consistent with congener-based quantitations; the development and implementation of the translation process are discussed in the Revised Baseline Modeling Report (RBMR) (USEPA, 2000a) and the Low Resolution Sediment Coring Report (LRC) (USEPA, 1998b). Tri+ PCBs, the sum of trichloro- through decachlorobiphenyl concentrations, provides a common basis for use of the various data sets.

PCBs have been used in a variety of substances, including dielectric fluids in capacitors and transformers, printing inks, plasticizer in paints, carbonless paper, coolants, lubricants, adhesives, dusting agents, and several other applications (Safe, 1990). Their chemical and physical stability and electrical insulating properties account for this widespread usage, but make them more persistent in the environment. As noted, Monsanto Corporation produced more than 95 percent of the PCBs used in the United States from 1930 to 1977, when PCB sales were generally prohibited under provisions of the Toxic Substances Control Act (TSCA). The most widely marketed mixtures include Aroclors 1016, 1221, 1242, 1248, 1254, and 1260. Aroclor 1232, one of the suite of seven Aroclors commonly quantified in USEPA methods, is a roughly 50:50 mixture of Aroclors 1221 and 1242. At least two higher molecular weight Aroclors were also produced, Aroclor 1262 and Aroclor 1268, but these were less common.

The first two digits in the Aroclor number represent the atomic mass of carbon (or the presence of 12 carbon atoms) and the second half is the weight percent of chlorine in the mixture (*e.g.*, Aroclor 1242 is 42 percent chlorine by weight). The exception to this nomenclature is Aroclor 1016, which is 41 percent chlorine by weight, not 16 percent. The difference between Aroclor 1242 and Aroclor 1016 is in homologue composition rather than percent chlorine; 1016 contains a smaller percentage of homologues with five or more chlorines (less than 0.5 percent, as compared with approximately 6.5 percent in Aroclor 1242).

PCB Measurements

Estimates of the total PCB mass present in the sediments in 1984 are sensitive to the methods and assumptions used to convert concentration data to mass units, as well as to any inaccuracies in the methods used to estimate concentration and density.

The estimates of total PCB mass depend directly on the total PCB concentrations reported by NYSDEC. This total is based on the sum of Aroclor quantitations (specifically Aroclors 1242, 1254, and 1260), which may not accurately reflect the actual sum of PCB congeners present, particularly when environmental degradation has altered the congener composition of the original Aroclors. This issue was addressed in the LRC (USEPA, 1998b). This discussion describes how the 1984 measurements closely approximate the Tri+ sum of congeners and do not represent the monochloro- and dichlorobiphenyl fractions.

The analytical protocol used by NYSDEC (Brown and Werner, 1984) called for most, but not all, samples to be screened by gas chromatography/mass spectrometry (GC/MS) prior to deciding whether to undertake a more expensive gas chromatography analysis with an electron capture detector (GC/ECD). GC/ECD results were regarded as strictly preferable when both were available; GC/MS estimates were substituted only when GC/ECD data were not available.

400308

Estimation of the Sediment PCB Inventory Based on 1984 Data

The 1984 NYSDEC PCB data are reported on a concentration basis as ppm (milligram per kilogram [mg/kg] or microgram per gram [μg/g]) in sediment on a dry-weight basis. For mass estimation, these concentrations must be converted by multiplying by the density. Summing mass in the vertical dimension yields mass per unit area (MPA). Mass units are additive (unlike concentration) and appropriate for spatial analyses, such as kriging or polygonal declustering.

1.3.1.2 Chemical and Physical Properties of PCBs

PCBs are colorless or straw-colored and vary in consistency from liquid (for lower molecular weight Aroclors such as 1221) to viscous liquids (*e.g.*, Aroclor 1254) or waxy solids (Aroclor 1260). PCBs typically have very low water solubility; the solubility generally decreases as chlorination increases (Table 1-3). Differences in solubility of Aroclors are in turn a function of the congener and homologue composition of each Aroclor, with lower molecular weight Aroclors (*e.g.*, Aroclor 1221) being dominated by less-chlorinated congeners (*e.g.*, trichlorobiphenyls) than higher molecular weight Aroclors (*e.g.*, Aroclor 1260).

Tables 1-3 through 1-5 provide some details on PCB Aroclors. Table 1-3 provides approximate Aroclor composition and properties on a homologue (level of chlorination) basis. Table 1-4 provides some physical constants for PCB homologue groups. Table 1-5 provides congener-specific composition of seven of the common commercial Aroclors. The values in Table 1-5 were derived from congener-specific analysis of Aroclor standards performed as part of the Reassessment RI/FS. The data reported on the table are generally in good agreement with literature values on congener composition of Aroclors; however, there is no literature consensus on the exact composition of commercial Aroclors due to variability in manufacturing (Erickson, 1997).

1.3.1.3 Biological and Toxicological Properties of PCBs

PCBs are lipophilic, that is, they tend to accumulate in fatty tissue. The higher the number of chlorine atoms, the lower the water solubility and the greater the tendency to accumulate in lipids, with the exception of the most highly chlorinated PCBs. The mechanism of action by which PCBs may cause adverse effects once they enter a living organism is discussed below.

PCBs are classified as a B2 (probable human carcinogen) by USEPA (1996c). Earlier studies found high, statistically significant incidences of liver tumors in rats ingesting Aroclor 1260. Mechanistic studies are beginning to identify several congeners that have dioxin-like activity and may promote tumors by different modes of action. PCBs are absorbed through ingestion, inhalation, and dermal exposure, after which they are transported similarly through the circulation. This provides a reasonable basis for expecting similar internal effects from different routes of environmental exposure. Information on relative absorption rates suggests that differences in toxicity across exposure routes are small. The human studies are being updated; currently available evidence is "inadequate, but suggestive" (USEPA, 1996c).

PCBs have been shown to induce a variety of adverse effects in mammals including:

- Mortality, as seen by a decrease in survival;
- Cancer, such as liver hepatomas;
- Reproductive effects including estrus cycle effects, decreased conception, decreased litter size, and decreased sperm motility;
- Developmental effects including decreased fetal weight and survival; decreased motor function, learning and memory effects, and hyperactivity;
- Neurological effects including decreases in dopamine levels; and behavior changes such as lethargy;
- Systemic damage including gastrointestinal, hematological, liver, and thyroid effects, decrease in body weight gain; and

400310

- Immunological effects such as increased infections, decreased antibody concentrations and response, and thymus effects.

The Revised ERA and Revised HHRA (USEPA, 2000q and USEPA, 2000p, respectively) contain discussions of the toxicological effects of PCBs.

1.3.2 Sources of PCBs in the Upper Hudson River

Rogers Island (RM 194.6) forms the northern boundary to the TI Pool and defines the upstream end of the HUDTOX modeling grid. Monitoring at Rogers Island is used to assess PCB loads originating above the TI Pool and entering the model as an upstream forcing function. The region above Rogers Island can be divided into two domains. The first of these domains represents sources of PCBs entering the upstream boundary of the Hudson River PCBs site from above the Fenimore Bridge in Hudson Falls (RM 197.3). The second domain represents sources adjacent to the Upper Hudson River at the northern end of the site between Hudson Falls and Rogers Island.

There are two potential sources of PCBs upstream of the Fenimore Bridge: atmospheric deposition and the Niagara-Mohawk Power Corporation (NiMo) site at Queensbury (located at about RM 209). These sources are considered anthropogenic baseline for purposes of the FS. Since specific information on PCB load resulting from atmospheric deposition is not available, the remaining discussion in subsection 1.3.2.1 below on the upstream baseline focuses on the NiMo Queensbury site. Additional information is provided in Appendix A. As discussed in the DEIR (USEPA, 1997a) and the LRC Responsiveness Summary (USEPA, 1999b), the region above the GE plant at Hudson Falls is a minor contributor to the total PCB load entering the TI Pool.

There are four major potential PCB sources adjacent to the Upper Hudson River between Hudson Falls and Rogers Island, each at various stages of remediation. The four potentially important sources are the GE Hudson Falls plant, the GE Fort Edward plant, Remnant Deposit 1, and Remnant Deposits 2 through 5. The grouping of the remnant deposits is based on differences in the degree of remediation completed. A brief summary of the history and the current conditions is provided in subsections 1.3.2.2 through 1.3.2.5 below; these sources are discussed in greater detail in Appendix A of this FS.

The discussion in this subsection and in those immediately following (1.3.3 through 1.3.5) is based on significant data collection efforts conducted between 1976 and 2000 by USEPA, NYSDEC, USGS, NOAA, and GE, as culled from the Hudson River PCBs Reassessment RI/FS project database. The latest version of the database is Release 5.0 (October, 2000). A summary of the samples collected and analyses performed is provided in Table 1-6.

1.3.2.1 Upstream Baseline - Niagara-Mohawk Power Corporation Queensbury Site

Remedial activities were conducted at the NiMo Queensbury site, including the river, under the direction of NYSDEC. Subsequently, contamination in fish in the vicinity of the site was reduced. Some PCB contamination remains in the river near the site and is found in fish collected near the site. Even though the current contribution of this site to the load at Hudson Falls is unknown, its effect is small in comparison to the source conditions between Hudson Falls and Rogers Island. Currently, the total baseline concentration for Tri+ PCBs from all sources above Hudson Falls is in the range of 1 to 2 ng/L. However, NYSDEC is evaluating possible further remediation at the site that may affect (*i.e.*, reduce) the baseline PCB input into the Upper Hudson River.

1.3.2.2 GE Hudson Falls Facility

This site represents one of the two original discharge locations for PCB contamination from GE. The facility is no longer in operation, and the only activity on site is related to the remediation. Since the cessation of manufacturing discharges, extensive evidence has been found, beginning in 1983, to show that this facility still continues to leak PCBs into the Hudson River. The largest documented leakage event occurred during 1991 to 1993, apparently initiated by a partial failure within the abandoned Allen Mill structure near Bakers Falls in 1991. PCB loads originating from this structure were quite large during this period (*e.g.*, 250 kg/month in September 1991) but have since been greatly reduced. A significant amount of GE remedial work planned and conducted under NYSDEC jurisdiction reduced loads significantly by 1996 (to about 10 ng/L on average) relative to earlier years (about 100 ng/l in 1991), although the load appears to have increased somewhat in the 1998–99 time frame (to about 13 ng/L on average).

Based on a review of the most recent data (GE, 1998-99), it is estimated that leakage from this site contributes the vast majority of the roughly four to eight kg of PCBs per month that travel past Rogers Island under current conditions. Congener patterns in PCB loads at Rogers Island indicate the presence of freshly released Aroclors 1242, consistent with the observed leakage of non-aqueous phase PCB-bearing oils from the bedrock beneath the GE facilities. Further efforts by GE to reduce this leakage are ongoing.

In addition, USEPA has authorized the performance of an Engineering Evaluation/Cost Analysis (EE/CA) to evaluate potential Non-Time Critical Removal Actions (NTCRAs) to address the discharge of PCBs into the river in the vicinity of GE's Hudson Falls facility. It is assumed that as a result of this separate source control removal action, the upstream Tri+ PCB load at Fort Edward (Rogers Island) will be reduced from its average current value of 0.16 kg/day (equivalent to an average concentration of 13 ng/L) to an average of 0.0256 kg/day (equivalent to an average concentration of 2ng/L). GE has discussed with USEPA and NYSDEC a conceptual approach to contain the release of PCB oil from the vicinity of the Hudson Falls facility. Assuming that the conceptual approach proposed by GE, or a similarly effective system, is available to address the Hudson Falls source, USEPA believes that a source control NTCRA can reasonably be completed by January 1, 2005. If achievable, these added reductions of the input at Bakers Falls are likely to have a significant impact on the overall attainable PCB concentrations in all media (water, sediment, and fish) in the Upper Hudson after possible sediment remediation, much more so than the effect of any reductions north of Hudson Falls; however, the actual extent to which the leakage at Bakers Falls can be reduced and the time in which any such reductions can be achieved have yet to be established.

1.3.2.3 GE Fort Edward Facility

This facility is located slightly farther from the Hudson River than the Hudson Falls facility and is underlain by a layer of silt and clay, as opposed to the bedrock at the Hudson Falls facility. Thus, while historical discharges from the Fort Edward facility were undoubtedly large, since the cessation of operation, discharges and leakages have been minor in comparison to those emanating from the Hudson Falls facility. It is believed that the majority of post-1977 contamination originating from this site was probably associated with bank erosion of contaminated soils and sediments around the former discharge pipe. These materials are being addressed under a January 2000 NYSDEC Record of Decision. It is presumed that this action will reduce the PCB loads into the river at this location.

1.3.2.4 Remnant Deposit 1

Remnant Deposit 1 is the only one of the five remnant deposits not addressed by the remedial efforts conducted by GE in 1987 to 1991. As such, the sediments of this deposit have been available for subsequent resuspension and transport downstream. It is most likely that this occurs during large flow events when river velocities are sufficient to resuspend large quantities of sediment. Diffusive exchange can also occur during lower flow conditions. While these processes undoubtedly occur on some level, the congener pattern evidence suggests that these processes cannot be major contributors to the annual load at Rogers Island. This is based on the assumption that this source would yield a somewhat weathered congener pattern, which is not in evidence in the weekly monitoring data at Rogers Island. Thus, like the source area associated with the GE Fort Edward facility, this area may have been important historically but it is unlikely to contribute a significant portion of the Rogers Island PCB load under the normal range of flow conditions. However, given the fact that this area remains uncontrolled, the possibility remains that a large flow such as a 100-year flood may release a substantial mass of PCBs from this area.

1.3.2.5 Remnant Deposits 2 through 5

Evidence for the remobilization of sediments from behind the former Fort Edward Dam, collectively referred to as the remnant deposits, is extensive. Data on water column loads as well as the obstruction of the canal itself all point to the transport of these materials downstream. However, since the completion of the engineered caps at Remnant Deposits 2 through 5 in 1991, movement of these materials has been greatly limited. Any contamination that originates from these deposits would have to reach the river via groundwater. In other settings this may be important but in this instance there is little evidence that this is occurring. Again relying on the congener patterns of the Rogers Island sample, and incorporating the partition coefficient data collected by USEPA in 1993, there is little evidence to suggest a significant water-borne transport source of PCBs to the river from these remnant deposits. The Rogers Island signal clearly matches that of the measured leakages from the Hudson Falls facility, as shown in Appendix A, both of which are consistent with a freshly released PCB mixture. Remedial efforts at this location have reduced a formerly important source to a negligible one.

1.3.2.6 Summary of PCB Sources between Rogers Island and Hudson Falls

Of the four potential sources in the portion of the Hudson River between Hudson Falls and Rogers Island, only the source at Bakers Falls appears to contribute significant amounts of the PCB loads measured at Rogers Island. The monitoring data at Rogers Island clearly define the source as one originating from "fresh" Aroclors, thus eliminating the other potential sources discussed. PCB loads originating above Hudson Falls have also been recently reduced and are unlikely to contribute more than a few percent of the annual load at Rogers Island. For perspective, the regions downstream of Rogers Island contribute between four and five times as much PCB as does the region upstream of Rogers Island.

1.3.3 PCBs in the Water Column

The dominant sources of PCB load to the water column of the Upper Hudson River can be separated into two groups: (1) bedrock seeps and other discharges upstream of the former Fort Edward Dam above Rogers Island; and (2) PCB mobilization from the extensive deposits of contaminated sediments stored in the TI Pool and, to a lesser extent, other downstream dam pools. USGS monitoring of PCBs in the water of the Upper Hudson River began in 1977. Evaluation of these data (USEPA, 1997a) indicates that annual PCB loads at Stillwater (reflecting all upstream sources) were approximately 3,000 kg/yr in 1977-79, and 1000 kg/yr in 1980-84, then declined to about 200 kg/yr by 1991. From 1980 to 1991, the upstream loads at Rogers Island appear to have declined from about 500 kg/yr to less than 200 kg/yr. The declining trend in loads at Stillwater primarily reflects the washout of readily erodible PCB-contaminated sediments left by the dam removal and shows a gradual increase in the relative importance of sources upstream of Rogers Island.

More intensive monitoring of PCBs in water by GE began in April 1991 and has continued to present. Data from the Rogers Island station (RM 194.2) clearly show the effect of the Allen Mill gate structure failure, with elevated concentrations from late 1991 until 1995 (Figure 1-4). From 1996 on, concentrations at this station have been much lower, averaging 13 ng/L.

PCB concentrations at the TI Dam west (TID-West) station also show a response to the 1991 event, but less pronounced than at Rogers Island (Figure 1-5). Specifically, as the upstream source was controlled, the TI Dam concentrations did not fall off as fast, reflecting the presence of a significant PCB source in the contaminated sediments of River Section 1. Concentrations at this station from January 1996 through March 2000 average 90 ng/L and exhibit a strong seasonal component that typically peaks in early summer. During the summer of 1998 (June-September) the average concentration was 134 ng/L. In addition, five observations in excess of 300 ng/L were noted during the winter of 1999-2000.

The concentration data indicate significant gains in PCB load across the TI Pool. The concentrations may be converted to load estimates by integration with the flow series, using a ratio estimator (as described in the DEIR). In 1999,Tri+ PCB load is estimated to be approximately .93 kg/day from the TID-West sampling station above TI Dam. Estimating load gain across the TI Pool as the difference in loads at Rogers Island and TID-West yields an estimate for this time period of a gain of 0.78 kg/day. During this same period, approximately 0.04 kg/day total Tri+ PCB load derived from upstream of Bakers Falls, and about 0.10 kg/day from the Bakers Falls area. The recent rate of apparent load gain across the TI Pool is consistent with the estimated load gain over the entire period of record from 1991 to 1999 of 0.72 kg/day, indicating that PCB load continues to be generated from the TI Pool at an approximately constant rate; the fact is that despite orders-of-magnitude reduction of input at Bakers Falls, the load across the TI Pool has remained fairly constant.

Samples collected at the TID-West station at the TI Dam are believed to be biased high relative to PCB concentrations actually transported across the dam under some flow conditions. This results from the incomplete mixing of near-shore and center channel water during the warmer months of the year when the river flow is low. Near-shore waters generally have higher PCB concentrations relative to the center channel, which is attributed to the release of PCBs from fine-grained sediments. Center channel concentrations appear to be on the order of 50 to 80 percent of the TID-West concentrations under these conditions. Even after adjusting for this potential bias, the Tri+ load generated from the TI Pool was still on the order of 0.6 kg/day on an annual basis in 1999 (0.58 kg/day for 1991 to 1999), and represents the main source of PCB load present at the TI Dam.

In recent years, GE has also resumed monitoring at the Route 29 bridge in Schuylerville. Average total PCB concentrations in water from the GE monitoring stations for the most recent data (January 1999-March 2000) are summarized in Table 1-7. As noted in the DEIR and RBMR (USEPA, 1997a and 2000a), concentrations below Schuylerville tend to reflect the same loads present at Schuylerville, with a reduction in concentration associated with tributary dilution.

The spatial trends in water column PCB concentrations can be determined from the Phase 2 transect sampling effort and the GE weekly monitoring results. The analysis of these data is presented in the DEIR (USEPA, 1997a), the LRC Responsiveness Summary (USEPA, 1999b), and the DEIR/LRC Response to Peer Review Comments (USEPA, 2000j). The sediments of River Section 1 (the TI Pool) are the major source of PCBs to the water column throughout the year, with the majority of the release occurring from May to October. Based on the level of source control at the GE Hudson Falls facility documented in the GE/QEA Modeling Report (QEA, 1999) and in subsequent monitoring data, the sediments of River Section 1 have clearly become the dominant PCB source year-round in the post-1996 period.

In addition, there is evidence of a sediment-based PCB source in River Section 2 between the TI Dam and Schuylerville (*i.e.*, below the TI Dam). Both the USEPA and GE data show an additional but smaller PCB load gain between the dam and Schuylerville. This load is similar in PCB composition to that produced by the sediments of River Section 1. Below Schuylerville, there is little evidence for additional significant PCB contributions, based on the lack of additional PCB load from Schuylerville to Waterford.

In fact, the data suggest near-conservative transport behavior of the Tri+ PCB load from TI Dam to Waterford (that is, the load at the TI Dam is equal to the load at Waterford), as discussed in the DEIR/LRC Response to Peer Review Comments (USEPA, 2000j). During late spring and summer conditions, the total PCB load is not conservative and declines downstream of the TI Dam. However, the decline is largely confined to the less-chlorinated homologues, suggesting the occurrence of another process that selectively affects these homologues. Gas exchange or aerobic degradation are likely candidates for this loss.

1.3.4 PCBs in Sediment

Historically, the highest PCB sediment concentrations have been observed in cohesive sediments of River Section 1. Concentrations generally decrease with distance down river, away from the source area, although areas of elevated sediment concentrations, initially identified by NYSDEC as *hot spots,* are found in depositional areas throughout the Upper Hudson.

River Section 1 (the TI Pool) has been the subject of several large sediment surveys, each of which attempted to map sediment PCB inventories and areas of concentrated contamination. NYSDEC completed the first major survey of the TI Pool and the Upper Hudson between 1976 and 1978. This survey was used to identify 40 areas of highly contaminated sediments (*hot spots*), 20 of which were located in the TI Pool. In 1984, NYSDEC completed a second, more intensive survey of the TI Pool. On the basis of this survey, NYSDEC (M. Brown *et al.*, 1988 and NYSDEC, 1992) identified areas or polygons of elevated sediment contamination.

Because of the scale and coverage of the 1984 NYSDEC survey, it has been considered a benchmark in attempting to assess and understand sediment PCB inventories in the Upper Hudson River. The 1984 sediment survey revealed a high degree of heterogeneity in the distribution of PCBs in the sediments of River Section 1. Indeed, it was not unusual for samples taken only a few meters apart horizontally to exhibit order-of-magnitude differences in PCB concentrations, and results along some transects across the river ranged from nondetectable to greater than 1,000 mg/kg. On the other hand, it was also clear that there was spatial correlation in PCB concentrations, reflected in the delineation of a number of PCB *hot spots*.

As a part of the Reassessment Phase 2 investigation, the low resolution sediment coring program was intended to assess the applicability of the 1984 survey to recent PCB inventories. This was accomplished by reoccupying selected 1984 sampling locations and collecting new cores to form a basis for comparison. The low resolution sediment coring program provided an alternate means of assessing these fluxes by using the PCB inventories found in the sediments to explain removal and deposition processes. In River Section 1, 63 sites originally sampled in 1984 were selected and reoccupied in 1994, providing a ten-year period of integration. The premise for analysis was: "Has the sediment inventory of PCBs increased or decreased during the intervening ten years?" While the premise itself was simple, there was concern that sediment heterogeneity, differing sedimentation rates, analytical technique differences, and other issues would confound the ability to discern true changes in the sediment inventory. Despite these concerns, the data showed that a significant loss of sediment inventory from selected *hot spots* had occurred between 1984 and 1994. Subsequent resampling of a subset of these locations in 1998 by GE confirmed the sediment inventory losses. While the 1984 data are the primary basis for estimation of PCB inventory in River Section 1 due to their unmatched sample density, changes in inventory since 1984 must also be taken into account.

1.3.4.1 Sediment PCB Inventory Estimates

An estimate of the 1984 sediment total PCB inventory in River Section 1 using geostatistical analysis is presented in Chapter 4 of the DEIR (USEPA, 1997a). This estimate used data from the 1984 NYSDEC sediment samples but did not consider sediment texture. Sediment texture is relevant because PCB concentrations are strongly correlated with the texture of shallow sediments; higher concentrations of PCBs are found in areas of finer-grained, shallow sediments. A similar degree of correlation was noted between total PCB concentration and the side-scan sonar signal itself. The side-scan sonar results form the basis for the assignment of sediment texture, discussed in more detail in the following paragraphs. LRC Figures 3-19 and 3-30 illustrate the strength of the relationships among total PCBs, sediment texture, and side-scan sonar signal. The mean PCB concentration varies nearly an order of magnitude in correlation with these properties.

The current estimate of the PCB inventory in River Section 1 based on the 1984 data is presented in Appendix B of the Responsiveness Summary for the LRC (USEPA, 1999b). This estimate takes into account the relationship between PCB mass and sediment texture. The purpose of the analysis was to provide an estimate of the sediment PCB inventory while also providing separate estimates for areas of fine-grained and coarse-grained sediments.

Sediment texture information is available in two forms: visual texture classification for the sample points collected in 1984 and side-scan sonar sediment classification for the bottom of River Section 1, obtained in 1992. Subsection 4.1.1 of the DEIR contains a complete discussion of the side-scan sonar analysis. In this analysis, the NYSDEC core and grab samples are separated into cohesive and non-cohesive groups based on the 1984 visual texture classification. Non-cohesive sediments typically are coarse-grained, such as medium to coarse sand or gravel. Fine-grained sediments, such as fine sands, silts, and clays, are generally considered cohesive sediments, and in general, samples classified as predominantly clay, silt, or fine sand were classified as cohesive sediment. The remaining samples that are predominantly sand, coarse sand, or gravel are assigned to the non-cohesive group. There are 503 cohesive sample locations (221 grabs, 282 cores) and 591 non-cohesive sample locations (470 grabs, 121 cores).

In the Phase 2 analysis, Thiessen polygons were formed around all 1984 cohesive sample points. This procedure was repeated for the non-cohesive sample points. Using the side-scan sonar sediment classifications, the Thiessen polygons are clipped so that the mass per unit 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 mass per unit area for the non-cohesive sample points is applied only to the non-cohesive areas. For the side-scan sonar sediment classification, cohesive areas are defined as fine- or finer-grained and non-cohesive areas are coarse- or coarser-grained based on the original interpretation of the side-scan sonar images (Flood, 1993). The means of calculating the mass per unit area is described in Section 3.5. The following quote is a brief description of the Theissen polygon technique used in this analysis, as presented in the DEIR (USEPA, 1997a).

> 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.

The revised sediment total PCB mass estimate for River Section 1 based on this approach is 15.4 metric tons, a minor revision to the estimate of 14.9 metric tons provided in the LRC Responsiveness Summary Appendix B (USEPA, 1999b). The revision resulted from a quality control review of the original analysis. Both values agreed closely with the kriging analysis result presented in the DEIR of 14.5 metric tons. The estimated trichloro- and higher homologue inventory present in 1984 can be calculated by multiplying the mass of total PCBs by 0.944, as discussed in Chapter 4 and Appendix E of the LRC. As discussed in the LRC, it is likely that the 1984 measurements most accurately represent the sum of the trichlorinated to decachlorinated biphenyls (Tri+ PCBs). The estimate for the Tri+ inventory of River Section 1 is 14.5 metric tons (15.4 tons x 0.944). As discussed in Appendix E of the LRC, the inventory of Tri+ PCBs is considered relatively well known for 1984, while the total PCB inventory is less well known and, in fact, may be underestimated by a large percentage.

1.3.4.2 Additional Sediment Inventory Studies

The subsequent low resolution sediment coring program conducted by USEPA (USEPA, 1998b) reexamined sediment inventories in several areas of River Section 1, specifically, a subset of fine-grained sediment zones exhibiting elevated PCB concentrations. This study demonstrated that the PCB inventories in these locations had been subject to a statistically significant degree of loss. The results of this study indicated that sediment inventories within the fine-grained sediments of River Section 1 and downstream areas were not inherently stable and were, in fact, subject to remobilization. Although the mechanisms responsible for the remobilization are not well known, the evidence from both Phase 2 of the Reassessment RI/FS and subsequent GE studies strongly indicates declines in these inventories over time.

A thorough summary of sediment conditions is difficult to obtain from direct monitoring because the concentrations in sediments show a high degree of local variability, and intensive sampling is difficult and expensive. Information on surface sediment concentrations in the early 1990s derived from the USEPA Phase 2 sampling program and the GE 1991 sampling effort is provided in the DEIR, LRC, and RBMR. The samples were obtained between RM 186 and RM 194 and were largely focused toward the fine-grained sediments. A limited amount of additional data was collected by GE in 1998 and 1999, primarily upstream of RM 186, and focused on *hot spot* areas. Surface sediment concentrations (0 to 1-, 2-, or 5-cm samples) are shown in Figure 1-6. The average concentration of all GE surficial sediment samples (0-5 cm) collected during this period was 41 mg/kg, with a maximum of 640 mg/kg. A number of GE's 1998-99 samples were co-located with USEPA 1994 samples and NYSDEC 1984 samples. A comparison of the co-located samples is provided in Appendix D. Both the 1994 and 1998 samples indicate a substantive decrease in sediment PCB inventory relative to 1984; however, no consistent decrease in surface concentrations between 1994 and 1998-99 is evident in this comparison. In fact, 14 out of 25 co-located samples showed an increase in concentration, suggesting that PCBs that had been buried are being uncovered through scour/erosion or other processes in those areas. These results confirm that significant concentrations of PCBs remain near surface in the Upper Hudson, at depths where they may be available to biota.

A more integrated picture of recent sediment concentrations is provided by the HUDTOX model output. As reported in the RBMR (USEPA, 2000a), HUDTOX uses the more spatially-intensive sediment sampling from past decades as a foundation to project a best-estimate of current conditions on a segment-averaged basis. Data generated for various matrices in the Upper Hudson River have been analyzed and reported both on an Aroclor basis and on a congener/homologue basis. As discussed in the RBMR, there are potential significant differences in analytical methodologies, and these data are best combined through conversion to a common quantitation basis. The quantitation basis chosen in the RBMR is the sum of trichloro- through decachlorobiphenyls, or Tri+ PCBs. Reported Aroclor data are therefore converted to Tri+, using the translation equations presented in the RBMR, and combined with homologue data for Tri+.

These are separated into estimates for cohesive and non-cohesive sediments, as the two sediment types show different concentrations as well as different spatial patterns in concentration.

1.3.5 PCBs in Fish

PCB concentrations observed in fish are the result of exposure to the concentrations of PCBs in both water and surface sediment. Because biota integrate exposures over time, they provide a time-averaged indicator of trends in exposure concentrations.

NYSDEC continues to collect and analyze fish tissue data from many locations in the Upper Hudson River, and has provided results through 1999. Recent data include PCB analyses both against Aroclor standards and on a congener/homologue basis; however, as discussed in subsection 1.3.1, the Aroclor data have been converted to a Tri+ PCBs. For example, 1998 Tri+PCB concentrations of PCBs in the TIP averaged about 28.6 mg/kg in carp, and about 16.1 mg/kg for largemouth bass. Average wet weight concentrations of Tri+ PCBs in fish for 1998 are presented in Table 1-8A.

Because PCBs tend to accumulate in fatty tissues, it is also useful to examine concentrations on a lipid basis, as shown in Table 1-8B. These lipid-based Tri+ concentrations are generally similar to those observed earlier in the 1990s and reported in Table 4-5 of the RBMR. Some data also exist for 1999 for largemouth bass and are consistent, as shown in Figure 1-8.

Time trends of lipid-based Tri+ concentrations for two key species between Stillwater and Coleville (RM 168.1 - 176) are shown in Figures 1-7 and 1-8. The Stillwater-Coleville portion of the river was used for this analysis due to the extent and continuity of the sampling record there. Concentrations in yearling pumpkinseed (Figure 1-4) are known to respond strongly to water column exposure concentrations (RBMR), and the observed trend in pumpkinseed body burdens resembles that seen in the water column, with a strong decline in the late 1970s and early 1980s, followed by a more gradual decline and flattening out of the trend. Pumpkinseed results for 1992 appear to show the impact of the Allen Mill event. In contrast, body burdens in largemouth bass are believed to be more closely tied to sediment pathways, and may also integrate over several years of exposure. The largemouth bass results (Figure 1-8) do not show a clear response to the Allen Mill event, and appear to have been nearly stable throughout the 1990s despite reduction in the upstream sources of PCBs.

Fish body burdens have shown to decline with river mile to about the same degree as the changes in the sediment PCB concentration. This analysis is presented in Appendix K of the ERA (USEPA, 1999c). Similarly, the average molecular weight of the PCB body burden in fish samples increased with distance from the Upper Hudson River source areas. Differences in total PCB concentration among species was shown to be significant based on their food source. However, on a lipid basis, the interspecies differences disappeared and the largest changes in PCB concentration coincided with river mile. Similarly, the molecular weight of the PCB body burdens in fish was found to vary by river mile and not by feeding guild. These results indicate that PCB uptake and biomagnification of individual congeners in fish is largely related to distance downstream of the GE Hudson Falls and Fort Edward facilities and not to trophic level.

In addition, the reason for the increase in molecular weight with distance downstream is not known but may be attributed to one or more several possible causes, including decreasing importance of water column exposure for fish due to declining water column concentrations, particularly for lighter congeners. Alternatively, water column concentrations may simply become higher in molecular weight due to replenishment from less-dechlorinated Lower Hudson sediments, yielding a higher molecular weight for water-based exposure. Lastly, metropolitan New York discharges present higher molecular weight mixtures for fish exposure in the saline portion of the lower Hudson.

1.4 Fate, Transport, and Bioaccumulation of PCBs in the Upper Hudson River

The factors controlling PCB loading, fate, transport, cycling between environmental compartments, and bioaccumulation in the Upper Hudson River are presented primarily in the DEIR (USEPA, 1997a), the accompanying LRC (USEPA, 1998b), the RBMR (USEPA, 2000a), and the cited responsiveness summaries addressing public comment on the documents (USEPA, 1998a;

USEPA 1999b; USEPA, 2000b). This section summarizes some of the key findings regarding PCB dynamics that are of relevance to the FS.

1.4.1 Geochemical Investigations

The current understanding of PCB fate, transport, and bioaccumulation in the Upper Hudson River is compiled in several of USEPA's Phase 2 reports, specifically the DEIR (USEPA, 1997a), the LRC (USEPA, 1998b), and the RBMR (USEPA, 2000a). The geochemical investigations and interpretations are contained in the DEIR and accompanying documents. Key conclusions of this report are:

1. The area of the site upstream of the TI Dam represents the primary source of PCBs to the freshwater Hudson. This includes the GE Hudson Falls and Fort Edward facilities, the remnant deposit area and the sediments of River Section 1 (the TI Pool).

2. The PCB load originates from the sediments in River Section 1 and has a readily identifiable homologue pattern that dominates the water column load from the TI Dam to Troy from May through October.

3. Sediment inventories will not be naturally "remediated" via dechlorination. The extent of dechlorination is limited, resulting in probably less than ten percent loss from the original mass.

4. There is little evidence of widespread burial of PCB-contaminated sediment by clean sediment in River Section 1. Burial is seen at some locations, but more core sites showed loss of PCB inventory than showed PCB gain or burial.

5. As of 1994, there has been a statistically significant loss of from 4 to 59 percent (best estimate 45 percent) of the PCB inventory from highly contaminated sediments in the TI Pool and a net loss of inventory from *hot spot* sediments between the TI Dam and the Federal Dam at Troy.

400326

6. The comprehensive 1984 sediment survey provides the best basis for estimating the spatial distribution of PCBs and the total PCB inventory in River Section 1, and an analysis of the side-scan sonar 500 kHz signal and the 1984 NYSDEC sediment PCB survey indicated that the acoustic signal could be used to predict the level of sediment PCB contamination.

In sum, the sediments of River Section 1 strongly impact the water column, generating a significant water column load and exposure concentration whose congener pattern can often be seen throughout the Upper Hudson. The decrease in PCB inventories in the more highly contaminated sediments of River Section 1 and from several of the studied *hot spots* below River Section 1, along with the indication of an inventory gain in the coarse sediments of River Section 1, indicate that PCBs are being redistributed within the Hudson River system. These results show that the stability of the sediment deposits cannot be assured.

Burial of contaminated sediment by cleaner material is not occurring universally. Burial of more PCB-contaminated sediment by less contaminated sediment has occurred at limited locations, while significant portions of the PCB inventories at other *hot spots* have been re-released to the environment. It is likely that PCBs will continue to be released from Upper Hudson River sediments.

Patterns of contamination found throughout the Hudson all contain the "fingerprint" of GE-related contamination. In the freshwater Hudson, GE-related contamination represents 80 to 100 percent of the in-place and water-borne contamination. In the Upper Hudson, this percentage is quite close to 100 percent. In the saline Hudson, GE-related contamination represents perhaps 50 percent of the in-place and recently deposited PCB inventory.

1.4.2 Modeling Analysis

The modeling effort for the Reassessment RI/FS was designed to replicate existing data on PCB distribution and to predict future levels of PCBs in Upper Hudson River sediment, water, and fish. The models are used in concert with geophysical data interpretations in this FS to help evaluate and compare the effectiveness of various remedial scenarios. Results of the modeling analysis, including calibration and baseline prediction of No Action, are presented in the RBMR (USEPA, 2000a). The overall goal of the modeling effort was to develop scientifically credible models capable of answering the following principal questions:

1. When will PCB levels in fish populations recover to levels meeting human health and ecological risk criteria under continued No Action?

2. Can remedies other than No Action significantly shorten the time required to achieve acceptable risk levels?

3. Are there contaminated sediments now buried that are likely to become "reactivated" following a major flood, possibly resulting in an increase in contamination of the fish population?

Key findings from the modeling analyses, under conditions of no remedial action being performed in the Upper Hudson River, are summarized below.

1. Sediment deposition is occurring, on average, in most of the Upper Hudson, but not at rates sufficient for sequestration of PCBs stored in sediment.

2. PCB concentrations in water are driven by PCBs stored in sediments under current conditions.

3. Over the long term, the upstream boundary concentration of PCBs will limit the amount of natural attenuation that can take place.

4. Occurrence of a 100-year peak flow does not appear likely to cause a catastrophic resetting of the system, with massive mobilization of PCB stores now buried at depth.

5. Both sediment and water column concentrations represent important sources of exposure to biota.

6. Over the long term, PCB concentrations in fish will become increasingly controlled by the upstream boundary condition.

1.4.3 Transport of PCBs in Upper Hudson River Sediments

The original sources of the vast majority of PCB contamination in the Upper Hudson River were the discharges from the GE plants in Fort Edward and Hudson Falls, New York. Over the past 50 years, these PCBs have adhered to the sediments (sands, silts and clays) and these sediments now serve as a continuing source of contamination for the water column and biota.

These sediments migrate downstream by both suspended load and bed-load transport. Bed-load transport represents particles that roll or saltate along the river bottom without being brought into resuspension. Since these particles are not transported into the water column, they have no effect on the suspended sediment concentration. However, the effects of bed-load transport are significant in the changes in the thickness of the sediment bed, and increase the rate of PCB desorption from the transported sediments into the water column.

The processes that determine the fate of PCBs in the Upper Hudson River may be divided into two categories, *i.e.* transport, and transfer and reaction. Transport is the physical movement of PCBs caused by the net advective movement of water, mixing, and resuspension/deposition of solids to which PCBs are adsorbed. It is dependent on the flow and dispersion characteristics in the water column and the settling velocity and resuspension rate of the solid particles. Transfer and reaction include movement of PCBs among air, water, and solid phases of the system, and biological (or biochemical) transformation or degradation of the PCBs. The processes involved in transfer and reaction include volatilization, adsorption, dechlorination, bioturbation, and biodegradation. PCBs are present in the Upper Hudson River in three phases that interact with each other: freely dissolved; sorbed to particulate matter or solids; and complexed with dissolved (or colloidal) organic matter.

These complex sediment and water exchange processes govern the mechanisms that in turn contribute to bioaccumulation of PCBs in the fish via both benthic and pelagic food webs. These highly variable and complex processes include sediment resuspension and settling, biological mixing (bioturbation), sediment bedload transport, anthropogenic disturbances such as boat and barge traffic, flood events, ice-rafting, and other such related processes. The net result of these processes is that, in general, the distribution of PCBs in the sediments of the Upper Hudson River is very heterogeneous. This heterogeneity is apparent from examination of the 1977 and 1984 NYSDEC data (including the *hot spot* delineation), the 1994 USEPA data, and the 1991, 1998, and 1999 GE data.

PCB loss or gain from the sediment can take many forms. Scour, diffusion, groundwater advection, and biological activity can all potentially remove PCBs from a given location. Biological activity in the form of anaerobic microbial dechlorination can also serve to decrease PCB concentration in the sediments. PCB inventories can be increased chiefly by deposition, either with sediment contaminated by newly released PCBs or with redeposited sediments from other contaminated locations. Until 1996-1997 when GE reduced PCB discharge from the Hudson Falls plant, it is likely that sediment deposition involved significant amounts of both fresh and redeposited material (GE, 1991-1997). Tracing and estimating all of the various fluxes represents a daunting task made all the more difficult by inherent spatial and temporal variations.

1.4.4 Long-Term Sequestration of PCBs

Long-term sediment sequestration of PCBs is clearly not assured, as demonstrated by several observations made during the Phase 2 investigation. These include:

1. The statistically significant loss of the sediment PCB inventory from highly contaminated sediments in the TI Pool between 1984 and 1994. Samples collected by GE in 1998 (see Appendix D [Modeling Uncertainty]) also show inventory loss in comparison to 1984 data.

2. The continued loading of PCBs from the sediments of the Upper Hudson to the water column despite the controls placed on releases from the GE Hudson Falls plant.

3. The scouring of PCB-contaminated sediments from the Upper Hudson resulting from the Hoosic River spring flow in 1993.

4. The apparent upward movement (*i.e.*, loss) of the sediment inventory in *Hot Spot* 28 based on a comparison of GE and USEPA data.

5. The occurrence of high PCB concentrations in the surface sediments (0-5 cm) of *Hot Spot* 14 as documented by GE in 1999.

1.4.5 PCB Transport from the Upper Hudson to the Lower Hudson

PCBs are transported from the Upper Hudson River to the Lower Hudson (*i.e.*, south of the Federal Dam at Troy). The mass of total PCBs transported over the Federal Dam to the Lower Hudson declined from about 3,000 to 4,000 kg/year in the late 1970s to about 150 to 500 kg/year by the late 1980s or early 1990s (USEPA, 1991a). The most recent estimate of Tri+ PCBs, based on 1998 GE data from a monitoring station at Schuylerville, is 214 kg/yr; the estimated (modeled) average for the 1990s is about 290 kg/yr over Federal Dam, with a modeled daily average Tri+ PCB concentration of 30.25 ng/L.

An evaluation of PCB concentrations in sediments below Federal Dam is limited by the lack of a synoptic study of this region. An assessment of the Lower Hudson region performed in the 1980s (Bopp and Simpson, 1989) indicated that the New York Harbor total PCB concentration was 0.8 mg/kg in the 1970 and 0.5 to 0.7 mg/kg in the 1980s. Sample data from the 1993 ecological investigation showed a sharp drop in sediment PCB concentrations between RM 140 and RM 150, with PCB concentrations ranging from less than 0.1 mg/kg to about 1.5 mg/kg (with a fairly high degree of scatter) at nine stations between RM 144 and RM 24. The modeled average PCB concentration in sediments at Federal Dam was 0.4 mg/kg in the 1990s.

1.5 Baseline Human Health and Ecological Risk Assessments

USEPA uses human health risk assessment as a tool to evaluate the likelihood and degree of chemical exposure and the possible adverse health effects occurring or which may occur as a result of exposure to one or more chemical or physical stressors, and ecological risk assessments to evaluate the likelihood of adverse ecological effects associated with such exposure. The reports use current USEPA policy and guidance as well as additional site data and analyses to supplement and refine the preliminary human health and ecological risk assessments presented in the Phase I Report (USEPA, 1991a). The reports referenced previously (in Section 1.2 of this FS) and associated documents pertaining to assessment of human health and ecological risk are, unless otherwise specified, referred to collectively in this FS as the Revised Human Health Risk Assessment (Revised HHRA) and the Revised Ecological Risk Assessment (Revised ERA), respectively.

1.5.1 Risks to Human Health

The Revised HHRA quantitatively evaluated both cancer risks and non-cancer health hazards from exposure to PCBs in the Upper Hudson River and Mid-Hudson River. The Revised HHRA evaluates both current and future risks to young children, adolescents, and adults in the absence of any remedial action and institutional controls, such as fish consumption advisories. The basic steps of the Superfund human health risk assessment process are the following: 1) data collection and analysis to determine the nature and extent of chemical contamination in environmental media, such as sediment, water, and fish; 2) exposure assessment, which includes identification of possible exposed populations and an estimation of human chemical intake through exposure routes such as ingestion, inhalation, or skin contact; 3) toxicity assessment, which is an evaluation of chemical toxicity including cancer and non-cancer health effects from exposure to chemicals; and 4) risk characterization, which describes the likelihood and degree of chemical exposure at a site and the possible adverse health effects associated with such exposure.

Adults, adolescents, and young children were identified as receptors possibly exposed to PCBs in the Upper Hudson River due to fishing and recreational activities (swimming, wading), as well as from living adjacent to the Upper Hudson River and inhaling volatilized PCBs in the air. Cancer risks and non-cancer health hazards were calculated for each of these receptors, as shown on Table 1-9. To protect human health and provide a full characterization of the PCB cancer risks and non-cancer health hazards, both an average (central tendency) exposure estimate and a reasonable maximum exposure (RME) estimate were calculated. The RME is the maximum exposure that is reasonably expected to occur in the Upper Hudson River under baseline conditions, and is not a worst-case scenario.

The exposure pathways identified in the Revised HHRA are ingestion of fish, incidental ingestion of sediments, dermal contact with sediments and river water, and inhalation of volatilized PCBs in air. For these exposure pathways, central tendency and RME estimates were calculated using point estimate analyses, whereby an individual point estimate was selected for each exposure factor used in the calculation of cancer risks and non-cancer health hazards. Incidental ingestion of river water while swimming was not evaluated for the Upper Hudson River because the river water meets drinking water standards for PCBs (*i.e.*, the Federal Maximum Contaminant Level for PCBs of 0.0005 mg/L [40 CFR § 141.32(e)(45)]). Tri+ PCB concentrations in fish, water, and sediment are based on modeled forecasts as presented in the RBMR (USEPA, 2000a), which assumed an upstream boundary condition (*i.e.*, PCB concentration entering the study area north of RM 195) of 10 ng/L.

The Revised HHRA shows that cancer risks and non-cancer health hazards exceed acceptable levels for an individual ingesting PCB-contaminated fish from the Upper Hudson River under the reasonable maximum exposure (RME) scenario. Consistent with USEPA policy, the risk managers in the Superfund program evaluate the cancer risk and non-cancer health hazards to individuals under RME conditions in the decision-making process. The Revised HHRA indicates that fish ingestion represents the primary pathway for PCB exposure and for potential adverse health effects, and that cancer risks and non-cancer health hazards from other exposure pathways are generally below levels of concern. The results of the Revised HHRA are used in the FS to establish acceptable exposure levels in the development of remedial alternatives for PCB-contaminated sediments in the Upper Hudson River.

USEPA has classified PCBs as probable human carcinogens and known animal carcinogens. Other long-term adverse health effects of PCBs observed in laboratory animals include a reduced ability to fight infections, low birth weights, and learning problems.

The major findings of the HHRA are:

- Eating fish is the primary pathway for humans to be exposed to PCBs from the Hudson.

- Under the RME scenario for eating fish, the calculated cancer risk is one in 1,000. This excess cancer risk is 1,000 times higher than USEPA's goal of protection and ten times higher than the highest cancer risk level generally allowed under federal Superfund law.

- For non-cancer health effects, the RME scenario for eating fish from the Upper Hudson results in a level of exposure to PCBs that is more than 100 times higher than USEPA's reference level (hazard index [HI]) of one for young children. For adolescent it is 74 times higher and for the adult it is 65 times higher than the reference level of one.

- Under the baseline conditions, the point estimate RME cancer risks and non-cancer health hazards would exceed USEPA's generally acceptable levels (cancer risk range of 10^{-4} to10^{-6} and non-cancer hazard index of one) for a 40-year exposure period beginning in 1999.

- Risks from being exposed to PCBs in the river through skin contact with contaminated sediments and river water, incidental ingestion of sediments, and inhalation of PCBs in air are generally within or below USEPA's levels of concern.

The HHRA for the Upper Hudson was externally peer-reviewed and a response to peer review comments developed (USEPA, 2000m). The Revised HHRA incorporates changes made in reponse to the peer review comments (USEPA, 2000p).

400334

The Revised HHRA also evaluated cancer risks and non-cancer health hazards posed by PCBs in the Mid-Hudson River (Federal Dam at Troy to Poughkeepsie) (USEPA, 2000p); these are presented in Table 1-10. PCB concentrations in fish, water, and sediment are based on modeled forecasts as presented in the ERA (USEPA, 1999c). The major findings of the report were:

- Eating fish is the primary pathway for humans to be exposed to PCBs from the Mid-Hudson River.

- Under the RME scenario for eating fish, the calculated risk is approximately seven in 10,000. This excess cancer risk is more than 700 times higher than USEPA's goal of protection (1×10^{-6}, or 1 in 1,000,000) and above highest cancer risk level generally allowed under federal Superfund law.

- For non-cancer health effects, the RME scenario for eating fish from the Mid-Hudson results in a level of exposure to PCBs that is 34 times higher for adults, 37 times higher for adolescents, and 53 times higher for young children than USEPA's reference level (HI) of one.

- Under baseline conditions, the RME cancer risks and non-cancer health hazards for eating fish would be above USEPA's generally acceptable levels (*i.e.*, cancer risks exceed 1×10^{-4}, or 1 in 10,000, and non-cancer health hazards exceed 1.0) for a 40-year exposure period beginning in 1999.

- For the fish consumption pathway, average cancer risks lie within the risk range of 10^{-6} to 10^{-4}, and non-cancer health hazards under central tendency or average assumptions fall slightly above the USEPA's reference level (HI) of one.

- Risks from exposure to PCBs in the Mid-Hudson River through skin contact with contaminated sediments and river water, residential ingestion of river water as a source of drinking water, incidental ingestion of sediments, and inhalation of PCBs in air are below USEPA's levels of concern for cancer and non-cancer health effects.

1.5.2 Ecological Risks

The Revised ERA quantitatively evaluated the current and future risks to the environment in the Upper Hudson River (Hudson Falls, New York to Federal Dam at Troy, New York) and the Lower Hudson River (Federal Dam to the Battery in New York City) posed by PCBs, in the absence of remediation.

The Superfund ecological risk assessment process includes the following: 1) identification of contaminants of concern; 2) development of a conceptual model, which identifies complete exposure pathways for the ecosystem; 3) identification of assessment endpoints, which are ecological values to be protected; 4) development of measurement endpoints, which are the actual measurements used to assess risk to the assessment endpoints; 5) exposure assessment, which describes concentrations or dietary doses of contaminants of concern to which the selected receptors are or may be exposed; 6) effects assessment, which describes toxicological effects due to chemical exposure and the methods used to characterize those effects to the receptors of concern; and 7) risk characterization, which compares the results of the exposure assessment with the effects assessment to evaluate the likelihood of adverse ecological effects associated with exposure to chemicals at a site.

The contaminants of concern identified for the site are PCBs. Assessment endpoints are explicit expressions of actual environmental values (*i.e.*, ecological resources) that are to be protected. The assessment endpoints that were selected for the Hudson River are sustainability of benthic community, which serves as a food source for local fish and wildlife, and sustainability (survival, growth, and reproduction) of local fish (forage, omnivorous, and piscivorous) populations, insectivorous bird and mammal populations, waterfowl populations, omnivorous mammal populations, and piscivorous and semi-piscivorous bird populations.

400336

The measurement endpoints identified for the Revised ERA are:

- Benthic community indices, such as richness, abundance, diversity, and biomass;
- Concentrations of PCBs in fish and invertebrates to evaluate food-chain exposure;
- Measured and modeled total PCB body burdens in receptors (including avian receptor eggs) to determine exceedance of effect-level thresholds based on toxicity reference values (TRVs);
- Measured and modeled toxicity equivalent quotient (TEQ)-based PCB body burdens in receptors (including avian receptor eggs) to determine exceedance of effect-level thresholds based on TRVs;
- Exceedance of criteria for concentrations of PCBs in river water that are protective of fish and wildlife;
- Exceedance of guidelines for concentrations of PCBs in sediments that are protective of aquatic health; and
- Field observations.

Representative receptors selected as models for the Revised ERA were the benthic macroinvertebrate community; fish species including pumpkinseed (*Lepomis gibbosus*), spottail shiner *(Notropis hudsonius)*, brown bullhead *(Ictalurus [now Ameiurus] nebulosus)*, white perch (*Morone americana)*, yellow perch (*Perca flavescens)*, largemouth bass (*Micropterus salmoides)*, and striped bass (*Morone saxatilis)*; birds, including tree swallow (*Tachycineta bicolor*), mallard (*Anas platyrhychos*), belted kingfisher (*Ceryle alcyon*), great blue heron (*Ardea herodias*), and bald eagle (*Haliaeetus leucocephalus*); and mammals, including little brown bat *(Myotis lucifugus)*, raccoon (*Procyon lotor*), mink (*Mustela vison*), and river otter (*Lutra canadensis*).

The exposure assessment describes complete exposure pathways and exposure parameters (*e.g.*, body weight, prey ingestion rate, home range) used to calculate the concentrations or dietary doses to which the receptors of concern may be exposed due to chemical exposure. Previously issued Reassessment RI/FS documents *i.e.*, the DEIR (USEPA, 1997a) and the RBMR (USEPA, 2000a) provide current and future (*i.e.*,measured and modeled) concentrations of PCBs in fish, sediments, and river water, and the data collected for the Reassessment form the basis of the site data collection and analyses that were used in conducting the Revised ERA. Exposure parameters were obtained from USEPA references, scientific literature, and directly from researchers.

The effects assessment describes the methods used to characterize particular toxicological effects of PCBs on aquatic and terrestrial organisms due to chemical exposure. These measures of toxicological effects, called TRVs, provide a basis for estimating whether the chemical exposure at a site is likely to result in adverse ecological effects. TRVs were selected based on lowest-observed-adverse-effects-levels (LOAELs) or no-observed-adverse-effects-levels (NOAELs) from laboratory or field-based studies reported in the scientific literature. These TRVs examine the effects of PCBs and dioxin-like PCB congeners on the survival, growth, and reproduction of fish and wildlife species in the Hudson River. Reproductive effects (*e.g.*, egg maturation, egg hatchability, and survival of juveniles) were generally the most sensitive endpoints for animals exposed to PCBs.

Risk characterization examines the likelihood of adverse ecological effects occurring as a result of exposure to chemicals, and discusses the qualitative and quantitative assessment of risks to ecological receptors with regard to toxic effects. Risks are estimated by comparing the results of the exposure assessment (measured or modeled concentrations of chemicals in receptors of concern) to the TRVs developed in the effects assessment. The ratio of these two numbers is called a toxicity quotient, or TQ. TQs equal to or greater than one ($TQ \geq 1$) are typically considered to indicate potential risk to ecological receptors; for example, reduced or impaired reproduction, or recruitment of new individuals. A probabilistic dose-response analysis was also performed to determine the percentage of selected piscivorous bird and mammal populations that are predicted to experience decreased fecundity (fertility) due to PCB exposure.

To integrate the various components of the Revised ERA, the results of the risk characterization and associated uncertainties were evaluated to assess the risk of adverse effects in the receptors of concern as a result of exposure to PCBs originating in the Hudson River. This approach considers both the results of the TQ analysis and field observations for each assessment endpoint. However, as field observations are not available for many species and can be subjective, they were given less weight than the TQ analysis. For the mammals and most birds, TQs for the dioxin-like PCBs were greater than the TQs for total PCBs.

The results of the Revised ERA indicate that receptors in close contact with the Hudson River are at an increased ecological risk primarily as a result of exposure to PCBs in prey. This conclusion is based on a TQ approach, in which measured or modeled body burdens, dietary doses, and egg concentrations of PCBs were compared to appropriate TRVs, and on field observations. On the basis of these comparisons, receptors are at risk. In summary, the major findings of the report were:

- Piscivorous fish (*e.g.*, largemouth bass and striped bass) and omnivorous fish (*e.g.*, brown bullhead) in the Hudson River may be adversely affected (*i.e.*, reduced survival, growth, and/or reproduction) from exposure to PCBs. Forage fish are unlikely to be affected outside of River Section 1 (the TI Pool).

- Birds and mammals that feed on insects with an aquatic stage spent in the Hudson River, such as the tree swallow and little brown bat, may be adversely affected (*i.e.*, reduced survival, growth, and/or reproduction), particularly insectivorous mammals living in the TI Pool area.

- Waterfowl feeding on animals and plants in the Hudson River are unlikely to be adversely affected (*i.e.*, reduced survival, growth, and/or reproduction) from exposure to PCBs.

- Omnivorous animals such as the raccoon that derive a large portion of their food from the Hudson River may be adversely affected (*i.e.*, reduced survival, growth, and/or reproduction) from exposure to PCBs.

- Birds and mammals that eat PCB-contaminated fish from the Hudson River, such as the bald eagle, belted kingfisher, great blue heron, mink, and river otter, are at risk at the population level. PCBs may adversely affect the survival, growth, and reproduction of these species. Piscivorous mammals are at the greatest risk due to their feeding patterns.

- Fragile populations of threatened and endangered species, represented by the bald eagle, are particularly susceptible to adverse effects from PCB exposure.

- PCB concentrations in water and sediments in the Upper and Lower Hudson River generally exceed standards and criteria and guidelines established to be protective of the environment.

- The risks to fish and wildlife are greatest in the Upper Hudson River (in particular the TI Pool) and decrease as PCB concentrations decrease down river. Based on modeled future PCB concentrations, piscivorous species are expected to be at considerable risk through 2018 (the entire forecast period; risks were not modeled beyond this period).

1.6. Public Outreach and Peer Review

The Reassessment RI/FS process also includes public outreach and peer review of technical documents. The implementation of these activities for the Hudson River PCBs Reassessment RI/FS is summarized below.

1.6.1 Public Outreach

At the outset of Phase 1, USEPA designed a Community Interaction Program (CIP) that addressed the complexities of communication and public participation associated with a project whose geographic area includes communities and political jurisdictions along a 200-mile stretch of the Hudson River, and involves interested parties in as many as 14 counties. This program, entirely unique to USEPA, is based on a community relations plan (CRP) prepared according to CERCLA community relations guidance, and consists of a three-tiered committee structure starting with four community-level liaison groups, providing maximum opportunity for all interested parties to participate in the project.

The chairperson and two cochairpeople of the four liaison groups make up a steering committee chaired by the USEPA's Community Relations Coordinator. The function of the steering committee is to bring individual liaison group issues to the table to share with the other groups and to raise those issues and questions to the USEPA project team and management.

The top tier in the structure is the Hudson River PCBs Site Reassessment RI/FS Oversight Committee (HROC), chaired by the Deputy Director of USEPA Region 2's Emergency Remedial Response Division (ERRD). Each liaison group chairperson sits on that committee, along with representatives of state and federal agencies who have jurisdiction or an interest in the Hudson River and the project. GE also has a seat on this committee.

An adjunct group called the Scientific and Technical Committee (STC) comprised of scientists and researchers - all volunteers - was established to be available to USEPA throughout the project to provide advice and input on specific technical issues when requested. Members came from all over the country to participate.

More than 65 regular meetings of various types - joint liaison group meetings, steering committee meetings, HROC meetings, STC meeting, and public and press availability sessions - have been held at locations up and down the river on both sides of the Hudson between Glens Falls and Poughkeepsie, New York, during the eleven years of the project. Sixteen information repositories have been maintained, where copies of the reports and other documents prepared for the Reassessment RI/FS can be reviewed by the public, and USEPA has hosted a number of special events such as a coring demonstration, presentations by subject matter specialists, and a call-in public availability session.

1.6.2 Peer Review

In accordance with USEPA guidance and the *Peer Review Handbook*, the scientific work conducted for the Reassessment that is the basis for this proposed action has undergone external peer review. USEPA's six major Phase 2 Reports have undergone external peer review by five panels of independent experts. These reports were the PMCR (USEPA, 1996a), the geochemistry reports (DEIR [USEPA, 1997a], and the LRC [USEPA, 1998b]), the HHRA (USEPA, 1999d), ERA (USEPA, 1999c), and RBMR (USEPA, 2000a). Each peer review panel was asked to address specific questions, together called the "charge," regarding the methods USEPA used, the findings and conclusions of the report being reviewed, and controversial issues that were identified by the public prior to the peer review meeting. In addition, the panels were invited to address any other issues that were not specifically identified in the charge.

The peer reviewers generally agreed with the findings and conclusions of the reports, although they also requested revisions. USEPA issued Responses to Peer Review Comments for each of the Peer Reviews as well as the Revised HHRA and the Revised ERA, which include all changes made to address the peer review comments on those reports. Revisions were incorporated, as appropriate, into the FS.

In addition, the Scientific and Technical Committee described previously, has provided peer input into the various documents USEPA prepared as part of the Reassessment.

Chapter 2

2. IDENTIFICATION OF POTENTIALLY APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS (ARARs) AND TO-BE-CONSIDERED (TBC) CRITERIA

This FS was developed following the basic methodology outlined in 40 CFR § 300.430 and further discussed in the RI/FS Guidance. Section 121(d) of CERCLA requires that remedial actions comply with state and federal applicable or relevant and appropriate requirements (ARARs), as defined below, unless a waiver is justified. ARARs are used to assist in determining the appropriate extent of site cleanup, to scope and formulate remedial action alternatives, and to govern the implementation of a selected response action.

The potential ARARs for the Hudson River PCBs site in each of the three categories (chemical-specific, location-specific, and action-specific), along with other to-be-considered (TBC) criteria, are summarized in Table 2-1 through 2-3 and discussed below. It should be noted that ARARs are potential in this FS and in the Proposed Plan, and become final upon issuance of the ROD.

In the absence of federal- or state-promulgated ARARs, or in the case where ARARs are judged to be inadequately protective, certain criteria, advisories, guidance values, and proposed standards may be used for developing remedial action alternatives or for determining what is protective to human health and the environment (*i.e.*, to set preliminary remediation goals). These criteria, advisories, guidance values, and proposed standards are identified by USEPA as "to-be-considered" (TBC) criteria. TBCs are not legally binding and do not have the status of ARARs.

2.1 Definition of ARARs

ARARs, as defined in CERCLA Section 121(d), are:

- Any standard, requirement, criterion, or limitation promulgated under federal environmental law; and

400344

- Any promulgated standard, requirement, criterion, or limitation under a state environmental or facility siting law that is more stringent than the associated federal standard, requirement, criterion, or limitation.

If a state is authorized to implement a program in lieu of a federal agency, state laws arising out of that program constitute the ARARs instead of the federal authorizing legislation. A stringency comparison is unnecessary because state regulations under federally authorized programs are considered to be federal requirements.

"On-site" with regard to CERCLA remedial response actions means the areal extent of contamination and all suitable areas in very close proximity to the contamination necessary for implementation of the response action. On-site actions must comply with ARARs, but must only comply with the substantive requirements of a regulation and not the administrative requirements (CERCLA Section 121(e)(1)). Substantive requirements are those requirements that pertain directly to actions or conditions in the environment. Examples include health-based or risk-based standards for hazardous substances (*e.g.*, maximum contaminant levels [MCLs] in drinking water) and technology-based standards (*e.g.*, RCRA standards for landfills). Administrative requirements include permit applications, reporting, record keeping, and consultation with administrative bodies, and are not necessary for on-site CERCLA cleanup (Section 121(e)(1)). Although consultation with the state and federal offices responsible for issuing the permits is not required, it is recommended for compliance with the substantive requirements.

Off-site actions must comply only with requirements that are legally applicable. Off-site actions must comply with both the substantive and administrative parts of those requirements.

Compliance with employee protection requirements of the Occupational Safety and Health Act (OSHA) is specifically required by 40 CFR §300.150. OSHA standards are not considered ARARs because they directly apply to all CERCLA response actions. In addition, OSHA requirements are more properly viewed as employee protection, rather than environmental, requirements, and thus the process outlined in CERCLA Section 121(d) for the attainment or waiver of ARARs does not apply to OSHA standards.

2.1.1 Applicable Requirements

Applicable requirements are those cleanup standards, control standards, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at an NPL site. "Applicability" implies that the remedial action or the circumstances at the site satisfy all of the jurisdictional prerequisites of a requirement, including the party subject to the law, the circumstances or activities that fall under the authority of the law, the time period during which the law is in effect, and the types of activities the statute or regulations require, limit, or prohibit.

2.1.2 Relevant and Appropriate Requirements

Relevant and appropriate requirements are those cleanup standards, control standards, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that, while not "applicable" to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at an NPL site, address problems or situations sufficiently similar (relevant) to those encountered, and are well-suited (appropriate) to circumstances at the particular site. Requirements must be both relevant and appropriate to be ARARs. During the FS process, relevant and appropriate requirements have the same weight and consideration as applicable requirements.

The term "relevant" was included so that a requirement initially screened as nonapplicable because of jurisdictional restrictions could be reconsidered and, if appropriate, included as an ARAR for a given site. For example, MCLs would be not applicable, but relevant and appropriate, for a site with groundwater contamination in a potential (as opposed to an actual) drinking water source.

The relevance and appropriateness of a requirement can be judged by comparing a number of factors, including the characteristics of the remedial action, the hazardous substances in question, or the physical circumstances of the site, with those addressed in the requirement. The objective and origin of the requirement are also considered. A requirement that is judged to be relevant and appropriate must be complied with to the same degree as if it were applicable. However, it is possible for only part of a requirement to be considered relevant and appropriate, the rest being dismissed if not judged to be both relevant and appropriate in a given case.

2.1.3 Other Requirements To Be Considered

To-be-considered requirements, or TBCs, are non-promulgated criteria, advisories, guidance, and proposed standards issued by federal or state governments. TBCs are not potential ARARs because they are neither promulgated nor enforceable, although it may be necessary to consult TBCs to interpret ARARs, or to determine preliminary remediation goals when ARARs do not exist for particular contaminants, or are not sufficiently protective. Compliance with TBCs is not mandatory, as it is for ARARs.

2.1.4 Waiver of ARARs

According to CERCLA Section 121(d)(4), an ARAR may be waived by USEPA, provided protection of human health and the environment is still achieved, under the following six specific conditions:

- The selected remedial action is only part of a total remedial action that will attain ARARs when completed;
- Compliance with such requirements will result in greater risk to human health and the environment than alternative options;
- Compliance with such requirements is technically impracticable from an engineering perspective;
- The selected remedial action will provide a standard of performance equivalent to other approaches required under applicable regulations;
- The requirement is a state requirement that has been inconsistently applied in similar circumstances at other remedial actions within the state; or

- Attainment of the ARAR would entail extremely high costs relative to the added degree of reduction of risk afforded by the standard such that remedial action at other sites would be jeopardized (*i.e.*, fund balancing).

2.2 Development of ARARs

Under the description of ARARs set forth in the NCP and CERCLA, many federal and state environmental requirements must be considered. ARARs and TBCs fall into three broad categories, based on the manner in which they are applied at a site:

- **Chemical-specific.** These are health- or risk-based numerical values or methodologies that establish concentration or discharge limits, or a basis for calculating such limits, for particular contaminants. Examples of chemical-specific ARARs are drinking water MCLs, ambient air quality standards, or ambient water quality criteria for PCBs. If more than one such requirement applies to a contaminant, compliance with the more stringent applicable ARAR is required.

- **Location-specific.** These are restrictions based on the concentration of hazardous substances or the conduct of activities in specific locations. Examples of natural site features include wetlands, scenic rivers, and floodplains. Examples of man-made features include historic districts and archaeological sites. Remedial action alternatives may be restricted or precluded depending on the location or characteristics of the site and the requirements that apply to it.

- **Action-specific.** Action-specific requirements set controls or restrictions on particular kinds of activities related to the management of hazardous substances, pollutants, or contaminants, and are primarily used to assess the feasibility of remedial technologies and alternatives. Examples of action-specific ARARs include Resource Conservation and Recovery Act (RCRA) monitoring requirements and TSCA disposal requirements.

Chemical-specific, location-specific, and action-specific ARARs and TBCs are all considered in the development and evaluation of remedial alternatives. Chemical- and location-specific ARARs

400348

typically are identified during scoping of the RI/FS and during the site characterization phase of the RI. Action-specific ARARs are identified during the development of the remedial alternatives in the FS.

When an alternative is selected, it must be able to fulfill the requirements of all ARARs (or a waiver must be justified). ARARs pertaining both to contaminant levels and to performance or design standards should be attained at all points of potential exposure, or at the point specified by the ARAR itself. Where the ARAR does not specify the point of compliance, there is discretion to determine where the requirement shall be attained to be protective.

2.3 Chemical-Specific ARARs

Chemical-specific ARARs provide either actual cleanup levels or a basis for calculating such levels. For example, surface water criteria and standards, as well as air standards, provide necessary cleanup goals for the Hudson River PCBs contamination.

Chemical-specific ARARs are also used to indicate acceptable levels of discharge to determine treatment and disposal requirements and to assess the effectiveness of remedial alternatives. Table 2-1a lists and summarizes potential federal and state chemical-specific ARARs. Chemical-specific ARARs will apply to every alternative developed in later phases of the FS. Chemical-specific TBCs are listed in Table 2-1b.

2.3.1 Federal Chemical-Specific ARARs [1]

Safe Drinking Water Act - 42 USC § 300f *et seq.*; 40 CFR Part 141

Regulations promulgated under the Safe Drinking Water Act establish enforceable MCLs for PCBs (40 CFR Part 141) and non-enforceable maximum contaminant level goals (MCLGs) for

[1] The Federal Food, Drug, and Cosmetic Act is neither a federal or state environmental law nor a facility siting law. Therefore, the Food and Drug Administration (FDA) tolerance level for PCBs in commercially caught fish (2 mg/kg; Federal Food, Drug, and Cosmetic Act, 21 USC § 301 *et seq.*; 21 CFR § 109.30(a)(7)) is not an ARAR for this site.

finished water provided to consumers. MCLs for known and probable human carcinogens are established using an acceptable risk range of 10^{-4} to 10^{-6} (56 FR 3526 [January 30, 1991]). The MCL for total PCBs is 0.0005 ppm (0.5 μg/L). The drinking water MCL for PCBs is an ARAR because a number of communities use the Hudson River water as a drinking water source. Non-zero MCLGs must be attained for groundwater or surface waters that are potential sources of drinking water (40 CFR § 300.430(e)(2)(I)(5)(B)); in other words, when the MCLG is greater than zero, the MCLG is considered an ARAR. The MCLG for all carcinogens, including PCBs, is zero. Where the MCLG is established at a zero value, only the MCL must be attained (40 CFR 300.430(e)(2)(I)(5)(C)). Therefore, because the MCLG for PCBs is zero, only the MCL for PCBs (and not the MCLG) is an ARAR.

Federal Water Pollution Control Act, as amended by the Clean Water Act (CWA) - 33 USC § 1251 *et seq.*; 40 CFR Part 129

The Federal Water Pollution Control Act provides the authority for USEPA to establish water quality criteria. The toxic pollutant effluent standards are promulgated at 40 CFR 129. The ambient water criterion for PCBs in navigable waters is established at 0.001 μg/L (40 CFR § 129.105(a)(4)).

2.3.2 New York State Chemical-Specific ARARs

New York Environmental Conservation Law (ECL), Article 15, Title 3 and Article 17, Titles 3 and 8; 6 NYCRR Parts 700-706

Water quality standards are established under various sections of the New York ECL, including Article 15 (ECL § 15-0313) and Article 17 (ECL §§ 17-0301, 17-0303, and 17-0809). The water quality standards for PCBs established at 6 NYCRR § 703.5 (and also published in NYSDEC's Technical and Operational Guidance Series [TOGS] Memo 1.1.1, June 1998) are 0.09 μg/L for potable water sources; 0.001 ng/L for protection of human health based on fish consumption; and 0.12 ng/L (1.2 x 10^{-4} μg/L) for the protection of wildlife.

2.3.3 Chemical-Specific Criteria, Advisories, and Guidance to be Considered

The chemical-specific TBC criteria discussed below are from federal and state criteria and guidance documents, and are summarized on Table 2-1b.

Biota

International Joint Commission - United States and Canada - Great Lakes Water Quality Agreement of 1978, as amended

The concentration of total PCBs in fish tissue (whole fish, calculated on a wet weight basis) should not exceed 0.1 μg/g (0.1 mg/kg) for the protection of birds and animals that consume fish.

National Oceanic and Atmospheric Administration (NOAA) - Damage Assessment Center: Reproductive, Developmental, and Immunotoxic Effects of PCBs in Fish - A Summary of Laboratory and Field Studies

This report (NOAA, 1999a) indicates that the effective concentrations for reproductive and developmental toxicity fall within the ranges of PCB concentrations found in some of the more contaminated Hudson River fish. However, there are an insufficient number of studies to assess the immunotoxicity of PCBs in fish.

Fish larvae survival can be reduced by concentrations of 1.3 to 4 ppm (mg/kg) wet weight PCBs in the bodies of the fish larvae. Improper functioning of the reproductive system and adverse effects on development may result from adult fish liver concentrations of 25 to 70 ppm of Aroclor 1254.

PCB Congener BZ#77 has been shown to cause reproductive and developmental effects in field and laboratory studies at concentrations of 0.3 ppm to 5 ppm (wet weight) in the livers of adult fish, eggs, or embryos. Egg deposition was reduced at 0.3 ppm, pituitary gonadotropin decreased and adult mortality increased at 0.6 ppm, reduced larval survival was observed at 1.3 to 4 ppm, retinoids decreased at 1.5 ppm, and the percent of females and gonad growth decreased at 4 to 5 ppm BZ#77.

NYSDEC Division of Fish and Wildlife - Niagara River Biota Contamination Project: Fish Flesh Criteria for Piscivorous Wildlife

This report (NYSDEC, 1987) provides a method for calculating PCB concentration criteria in fish flesh for the protection of piscivorous wildlife, and establishes a final fish-flesh criterion of 0.11 mg/kg PCBs.

Sediment

USEPA Office of Emergency and Remedial Response - Guidance on Remedial Actions for Superfund Sites with PCB Contamination

This guidance document (USEPA, 1990a) provides guidance on the investigation and remedy selection for PCB-contaminated Superfund sites. It also provides preliminary remediation goals for various contaminated media and identifies other considerations important to protect human health and the environment.

The document presents cleanup levels for freshwater sediment based on an equilibrium partitioning approach and the freshwater ambient water quality criterion (AWQC) of 0.01 μg/L. For example, the cleanup level is 1.9 μg/g (1.9 mg/kg) at 10 percent organic carbon, and 0.19 μg/g at 1 percent organic carbon. Sediment PCB concentrations of 1 to 2 mg/kg are protective of migratory birds.

USEPA Great Lakes National Program Office, Assessment and Remediation of Contaminated Sediments (ARCS) Program - Calculation and Evaluation of Sediment Effect Concentrations for the Amphipod *Hyalella azteca* and the Midge *Chironomus riparius*

This document (USEPA, 1996b) provides sediment effects concentrations (SECs), which are defined as the concentrations of a contaminant in sediment below which toxicity is rarely observed and above which toxicity is frequently observed. For freshwater, the threshold effects level (TEL) is 32 ng/g (32 μg/kg) total PCBs; the probable effects level (PEL) is 240 ng/g total PCBs; and the no effects concentration (NEC) is 190 ng/g total PCBs.

400352

NOAA - Damage Assessment Office: Development and Evaluation of Consensus-Based Sediment Effects Concentrations for PCBs in the Hudson River

This report (NOAA, 1999b) provides estuarine, freshwater, and marine sediment effects concentrations for total PCBs. The threshold effect concentration (TEC) is 0.04 mg/kg; the mid-range effect concentration (MEC) is 0.4 mg/kg; and the extreme effect concentration (EEC) is 1.7 mg/kg total PCBs.

NOAA - Screening Quick Reference Tables (SQRTs) for Organics

The SQRTs provide PCB concentrations in freshwater sediment (dry weight basis). The lowest ARCS *H. azteca* TEL is 31.6 ppb (31.6 μg/kg); the TEL is 34.1 ppb; the PEL is 277 ppb; and the upper effects threshold (UET) is 26 ppb (Microtox bioassay).

NYSDEC Division of Fish, Wildlife and Marine Resources - Technical Guidance for Screening Contaminated Sediment

This document (NYSDEC, 1999a) provides sediment screening values for metals and non-polar organic contaminants, such as PCBs, in units of micrograms of contaminant per gram organic carbon in sediment (μg/go). Table 1 of this guidance document lists sediment criteria for total PCBs of 0.0008 μg/go for freshwater, based on human health bioaccumulation, 2760.8 μg/go for freshwater based on benthic aquatic life acute toxicity, 19.3 μg/go for freshwater based on benthic aquatic life chronic toxicity, and 1.4 μg/go in freshwater based on wildlife bioaccumulation.

2.4 Location-Specific ARARs

Potential location-specific ARARs are presented in Table 2-2a and location-specific TBCs are in Table 2-2b.

2.4.1 Federal Location-Specific ARARs

Section 404 of the CWA (Federal Water Pollution Control Act, as amended), 33 USC § 1344; 33 CFR Parts 320 - 329

Section 404 of the CWA establishes requirements for issuing permits for the discharge of dredged or fill material into navigable waters of the United States, and includes special policies, practices, and procedures to be followed by the US Army Corps of Engineers (USACE) in connection with the review of applications for such permits. These regulations apply to all existing, proposed, or potential disposal sites for discharges of dredged or fill materials into US waters, including wetlands. USEPA may prohibit fill if there is an unacceptable adverse impact on the receiving water body. In accordance with CERCLA section 121(e)(1), no federal, state, or local permits are required for remedial action conducted entirely on site, although the remedial action must comply with the substantive requirements of CWA Sections 404 and 33 CFR Parts 320-329.

CWA Section 404 (33 USC § 1344), 40 CFR Part 230

No activity that adversely affects an aquatic ecosystem (including wetlands) shall be permitted if there is a practical alternative available that has less adverse impact. If there is no practicable alternative, then the adverse impacts of the activity must be minimized.

TSCA, Title I, 15 USC§ 2601; TSCA Facility Requirements (40 CFR 761.65 - 761.75)

TSCA and TSCA facility requirements provide siting guidance and criteria for storage (761.65), incinerators (761.70), and chemical waste landfills (761.75). TSCA and associated regulations are described in subsection 2.5.1 of this FS.

Statement of Procedures on Floodplain Management and Wetlands Protection; 40 CFR Part 6, Appendix A

These procedures set forth USEPA policy and guidance for carrying out Executive Orders (EO) 11990 and 11988.

EO 11988 - Floodplain Management - requires federal agencies to evaluate the potential effects of actions that may be taken in a floodplain and to avoid, to the extent possible, long-term and short-term adverse affects associated with the occupancy and modification of floodplains, and to avoid direct or indirect support of floodplain development wherever there is a practicable alternative.

EO 11990 - Protection of Wetlands - requires that activities conducted by federal agencies avoid, to the extent possible, long-term and short-term adverse affects associated with the modification or destruction of wetlands. Federal agencies are also required to avoid direct or indirect support of new construction in wetlands when there are practical alternatives; harm to wetlands must be minimized when there is no practical alternative available. These requirements are applicable to alternatives involving remedial actions (including construction) in wetlands. Federal wetlands, based on National Wetlands Inventory maps (USFWS, 2000), and New York State regulated wetlands, based on NYSDEC maps (Cornell University, 2000), are present throughout the entire Upper and Lower Hudson River (see Plate 1 of the Revised ERA [USEPA, 2000q]).

Endangered Species Act (ESA), 16 USC§ 1531 *et seq.*; 50 CFR Parts 17, Subpart I, and 50 CFR Part 402

The ESA of 1973 and subsequent amendments provide for the conservation of threatened and endangered species of animals and plants, and the habitats in which they are found. The act requires federal agencies, in consultation with the Secretary of the Interior, to verify that any agency-supported action is not likely to jeopardize the continued existence of any endangered or threatened species or its critical habitat, or result in the destruction or adverse modification of a critical habitat of such species. Exemptions may be granted by the Endangered Species Committee.

The bald eagle (*Haliaeetus leucocephalus*), a federal-listed threatened species and a NYS-listed endangered species, winters along the Upper Hudson River. NYSDEC has radio-tracked bald eagles in the Upper Hudson River area over the past two winters, and has identified some important perching/feeding/and roosting areas (Nye, 2000). The short-eared owl (*Asio flammeus*), a NYS-listed endangered species, also may occur along the upper river (NYSDEC, 2000). A raptor concentration area has been identified in Washington County by the NY Natural Heritage Program (NYSDEC, 2000).

Many federal or NYS-listed threatened and endangered species are found in the Lower Hudson River (see subsection 2.1.3 and Table 2-7 of Revised ERA). These include five invertebrates, two fish, six amphibians and reptiles, seven birds, two mammals, and many plants. Federal-listed endangered species found in or along the river include the Karner blue butterfly (*Lycaeides melissa samuelis*), shortnose sturgeon (*Acipenser brevirostrum*), peregrine falcon (*Falco peregrinus*), and Indiana bat (*Myotis sodalis*).

Within the tidal (lower) portion of the Hudson River, 34 sites have been designated as Significant Coastal Fish and Wildlife Habitats under the NYS Coastal Management Program (NYSDOS, 1987). Five additional sites have been identified as containing important plant and animal communities to bring the total number of sites to 39 (see Table 2-8 of Revised ERA; USEPA 2000q; derived from NYSDOS and the Nature Conservancy, 1990). These areas are unique, unusual, or necessary for continued propagation of key species. Habitats (and their associated communities) present in significant habitats include freshwater and brackish water shallows, mudflats, marshes, swamp forest, deepwater, and creeks. Many areas provide spawning areas for fish and are used as resting and feeding areas for migratory birds.

Fish and Wildlife Coordination Act, 16 USC § 662

The Fish and Wildlife Coordination Act requires consideration of the effects of a proposed action on wetlands and areas affecting streams (including floodplains), as well as other protected habitats. Federal agencies must consult with the United States Fish and Wildlife Service (USFWS) and the appropriate state agency with jurisdiction over wildlife resources prior to issuing permits or undertaking actions involving the modification of any body of water (including impoundment, diversion, deepening, or otherwise controlled or modified for any purpose). The requirements of this act are applicable for alternatives involving remediation activities in wetlands or floodplains.

Farmland Protection Policy Act of 1981, 7 USC § 4201 *et seq.*; 7 CFR Part 658

This act regulates the extent to which federal programs contribute to the unnecessary and irreversible conversion of farmland to non-agricultural uses. Federal agencies must use the criteria (40 CFR § 658.5) to identify and take into account the adverse effects of their programs on the preservation of farmland; to consider alternative actions that could lessen adverse effects; and to ascertain that their programs are, to the extent practicable, compatible with state and local government and private programs and policies to protect farmland.

National Historic Preservation Act of 1966 (NHPA); 16 USC § 470 *et seq.*; 36 CFR Part 800

Under Section 106 of the NHPA, federal agencies must take into account the effects of their actions on any district, site, building, structure, or object included in, or eligible for inclusion in, the National Register of Historic Places. Implementing regulations for Section 106 established by the Advisory Council on Historic Preservation (ACHP), established under 36 CFR Part 800, provide specific criteria for identifying adverse effects of federal undertakings on historic properties. Effects to cultural resources listed on, or eligible for listing on, the National Register of Historic Places are evaluated with regard to the Criteria of Adverse Effect. If the undertaking results in adverse effects, then the agency must consult with the State Historic Preservation Office (SHPO) and other consulting parties to develop ways to avoid, reduce, minimize, or mitigate the impact of the undertaking on historic properties. An initial review of sites potentially subject to the regulation is presented in subsection 1.2.1 of this FS.

2.4.2 New York State Location-Specific ARARs

New York ECL Article 24 Title 7, Freshwater Wetlands; 6 NYCRR Parts 662 - 665

Freshwater wetlands of New York State are protected under Article 24 of the ECL, commonly known as the Freshwater Wetlands Act (FWA). Wetlands protected under Article 24 are known as New York State regulated wetlands. The regulated area includes the wetlands themselves and a protective buffer or adjacent area that extends 100 feet landward of the wetland boundary. All freshwater wetlands with an area of 12.4 acres or greater are depicted on a set of maps published by NYSDEC. Wetlands less than 12.4 acres may also be mapped if they have unusual local importance. Four classes of wetlands (Class I, the most valuable, through Class IV, the least valuable) have been established and are ranked according to their ability to perform wetland functions and provide wetland benefits. Vegetative cover, ecological associations, special features, hydrological and pollution control features, distribution, and location are factors considered in the determination of wetland benefit.

Regulated activities include, among others, dredging, draining, excavation, and removal of sand, soil, mud, shells, gravel, and other aggregate from any freshwater wetland (ECL § 24-0701(2)). Regulations on activities are provided in 6 NYCRR Part 665; procedural requirements are specified in 6 NYCRR Part 663.

New York ECL Article 3, Title 3; Article 27, Titles 7 and 9; 6 NYCRR § 373-2 - General Facility Standards

Location standards, which establish construction requirements for a hazardous waste facility in a 100-year floodplain, are provided in 6 NYCRR § 373-2.2(j)(1).

New York State ECL Article 11, Title 5 - Endangered and Threatened Species of Fish and Wildlife - Species of Special Concern; 6 NYCRR Part 182

The New York State endangered species legislation enacted in 1970 was designed to complement the federal ESA by authorizing NYSDEC to adopt the federal endangered species list so that prohibitions of possession or sale of federally listed species and products could be enforced by state enforcement agents. The state list can therefore include species that, while plentiful elsewhere, are endangered in New York. The law was amended in 1981 to authorize the adoption of a list of threatened species that would receive protection similar to endangered species. In addition to the threatened species list, NYSDEC also adopted a list of species of special concern, species for which a risk of endangerment has been documented by NYSDEC. The law and regulations restrict activities in areas inhabited by endangered species. The list of state-regulated species in the Upper and Lower Hudson River is presented in the Revised ERA (USEPA, 2000q). The taking of any endangered or threatened species is prohibited, except under a permit or license issued by NYSDEC. The destroying or degrading the habitat of a protected animal likely constitutes a "taking" of that animal under NY ECL § 11-0535.

2.4.3 Location-Specific Criteria, Advisories, and Guidance to Be Considered

The location-specific TBC criterion identified for this FS is listed in Table 2-2b.

USEPA Office of Solid Waste and Emergency Response - Policy on Floodplains and Wetland Assessments for CERCLA Actions, August 1985

Superfund actions must meet the substantive requirements of the Floodplain Management Executive Order (EO 11988) and the Protection of Wetlands Executive Order (EO 11990) (see Table 2-2a: Location-Specific ARARs). This memorandum discusses situations that require preparation of a floodplains or wetlands assessment, and the factors that should be considered in preparing an assessment, for response actions taken pursuant to Section 104 or 106 of CERCLA. For remedial actions, a floodplain/wetlands assessment must be incorporated into the analysis conducted during the planning of the remedial action.

2.5 Action-Specific ARARs

Action-specific ARARs are usually technology- or activity-based limitations that control actions at CERCLA sites. After remedial alternatives are developed, action-specific ARARs pertaining to proposed site remedies provide a basis for assessing the feasibility and effectiveness of the remedies. For example, action-specific ARARs may include hazardous waste transportation and handling requirements, air and water emissions standards, and landfilling and treatment requirements of TSCA and RCRA. Potential action-specific ARARs are presented in Table 2-3a. Action-specific TBCs appear in Table 2-3b.

2.5.1 Federal Action-Specific ARARs

TSCA, Title I, 15 USC Section 2605; 40 CFR §761.50 - 761.79

TSCA provides USEPA with authority to require testing of both new and existing chemical substances entering the environment, and to regulate them where necessary. TSCA requirements do not apply to PCBs at concentrations less than 50 ppm. USEPA guidance provides that the form and concentration of the PCB contamination be determined on an "as found" basis, rather than on the original form and concentration of PCB materials prior to their release. PCBs can not be diluted, however, to escape TSCA requirements.

TSCA establishes prohibitions and requirements for the manufacturing, processing, distribution in commerce, use, disposal, storage, and marking of PCBs. 40 CFR Part 761 includes provisions for incineration, disposal, storage for disposal, chemical waste landfills, decontamination, clean-up policy, record keeping, and reporting for PCBs.

Subpart D of 40 CFR 761, as revised June 29, 1998, with technical corrections in June 1999, contains the following applicable provisions regarding PCBs:

- **40 CFR § 761.50** identifies disposal requirements for various PCB waste types.

- **40 CFR § 761.61** addresses cleanup and disposal options for PCB remediation waste, which includes PCB-contaminated sediments and dredged materials. Disposal options for PCB remediation waste include disposal in a high-temperature incinerator, an approved chemical waste landfill, or a facility with a coordinated approval under 40 CFR § 761.77. PCB remediation waste containing PCBs at concentrations less than 50 ppm may be disposed of off site in an approved disposal facility for the management of municipal solid waste, or in a disposal facility approved under 40 CFR part 761. 40 CFR §761.61(c) allows a USEPA Regional Administrator to approve a risk-based disposal method that will not pose an unreasonable risk of injury to human health or the environment.

400360

- **40 CFR 761.65** states that PCB waste must be removed from storage within one year from the time it was removed from service for disposal, and identifies storage facility and container requirements. An exemption from this regulation exists for containerized non-liquid PCBs (soil, rags, debris), which may be stored for up to 30 days from the date they were removed from service for disposal at a facility not meeting the technical requirements. A request for an extension of up to one additional year may be made to the USEPA Regional Administrator. PCBs may be stored at facilities in compliance with RCRA provisions (RCRA section 3004 or 3006). Storage in floodplains is prohibited. This section may be applicable should dredged materials be stored before incineration or land disposal.

- **40 CFR § 761.70** covers the incineration of PCBs. Incinerators for the burning of PCBs must be approved by the USEPA Regional Administrator for incinerators operating only in Region II or the Director, Exposure Evaluation Division for multi-region facilities, pursuant to 40 CFR § 761.70(d), which lists application requirements. Specific technical requirements for incineration of non-liquid PCBs (40 CFR § 761.70(b)) include:

  - Air emissions no more than 0.001 g PCBs/kg PCBs in feed,
  - Combustion efficiency (CO_2/CO ratio) minimum of 99.9 percent,
  - Monitor feed at 15-minute intervals,
  - Continuous temperature monitoring,
  - Stack gas monitoring at startup and any change of conditions (O_2, CO, CO_2, NO_x, HCl, total chlorinated organics, PCBs, and particulate matter),
  - Combustion and operation monitoring (continuous for O_2 and CO, and periodic for feed when either the combustion or feed monitoring systems fail), and
  - Water scrubbers to control HCl emissions.

- **40 CFR § 761.75** applies to facilities used for land disposal of PCBs. In general, a chemical waste landfill for PCBs must be approved by the USEPA Regional Administrator. The landfill must meet technical requirements that include, but are not limited to, the following: soil consistency surrounding the landfill (*e.g.*, either permeability $\leq 10^{-7}$ cm/sec or a synthetic liner); siting requirements (not in flood zones; not hydraulically connected to surface water); flood protection; topography; and appropriate record maintenance (40 CFR 761.75 (b)).

- **40 CFR § 761.79** provides decontamination standards and procedures for removing PCBs that are regulated for disposal from water, organic liquids, and other materials.

RCRA Section 3004, 42 USC § 6924; 40 CFR Part 264

40 CFR Part 264 lists standards applicable for an owner or operator of hazardous waste treatment, storage, and disposal facilities. This part includes general facility standards, releases from the facility, contingency plan, and emergency procedures for the generator of hazardous waste, landfills and incinerators. Much of the RCRA program has been authorized in New York State. In accordance with USEPA policy, the authorized portions of the New York State RCRA program, rather than the federal regulations, constitute ARARs. Therefore, only those federal RCRA regulations that have not been fully authorized in New York State are cited below as potential federal ARARs. Specific sections of 40 CFR Part 264 that may constitute ARARs are listed below.

40 CFR § 264.13(b)(8) requires the owner or operator of a facility that treats, stores, or disposes of hazardous wastes to develop and follow a written waste analysis plan.

40 CFR § 264.232 addresses surface impoundments, and details the design, construction, operation, monitoring, inspection, and contingency plans required for a RCRA surface impoundment. Wastes must be managed in accordance with 40 CFR 264 Subparts BB (Air Emission Standards for Equipment Leaks) and CC (Air Emission Standards for Tanks, Surface Impoundments, and Containers).

Section 404(b)(1) Guidelines for Specification for Disposal Sites for Discharge of Dredged or Fill Material; 40 CFR Part 230

Establishes guidelines for specification of disposal sites for dredged or fill material. Except as otherwise provided in the CWA Section 404(b)(2), no discharge of dredged or fill material is permitted if there is a practicable alternative to the proposed alternative which would have less adverse impact on the aquatic ecosystem, so long as the alternative does not have other significant adverse environmental consequences. The guidelines include criteria for evaluating whether a particular discharge site may be specified.

Section 404(c) of the CWA, 33 USC § 1344(c); 40 CFR Part 231; 33 CFR Parts 320, 323, and 325

These regulations apply to all existing, proposed, or potential disposal sites for discharges of dredged or fill materials into US waters, which include wetlands. The regulations include special policies, practices, and procedures to be followed by the USACE in connection with the review of applications for permits to authorize such discharge of dredged or fill material.

Section 10, Rivers and Harbors Act, 33 USC § 403; 33 CFR Part 322

USACE approval is generally required to excavate or fill, or in any manner to alter or modify the course, location, condition, or capacity of the channel of any navigable water of the United States. In accordance with CERCLA Section 121(e)(1), no federal, state, or local permits are required for remedial action that is conducted entirely on site, although the remedial action must comply with the substantive requirements of Section 10 of the Rivers and Harbors Act and 33 CFR Part 322.

Hazardous Materials Transportation Act (HMTA), as amended, 49 USC §§ 5101 - 5127; 49 CFR Part 171: Department of Transportation Rules for Transportation of Hazardous Materials

This regulation outlines procedures for packaging, labeling, manifesting, and transporting of hazardous materials to a licensed off-site disposal facility.

2.5.2 New York State Action-Specific ARARs

New York State ECL Article 27, Title 7; 6 NYCRR Part 360 - Solid Waste Management Facilities

These regulations identify the requirements for design, construction, operation and closure, and other solid waste management activities for solid waste management facilities.

New York State ECL Article 27, Title 11; 6 NYCRR Part 361 - Siting of Industrial Hazardous Waste Facilities

This regulation establishes criteria for siting industrial hazardous waste treatment, storage, and disposal facilities, regulates the siting of new industrial hazardous waste facilities located wholly or partially within New York State, and identifies criteria by which the facilities siting board will determine whether to approve a proposed industrial hazardous waste facility.

New York State ECL Article 27, Title 3; 6 NYCRR Part 364 - Standards for Waste Transportation

These regulations identify the requirements for the collection, transport, and delivery of regulated wastes, including hazardous wastes.

New York State ECL Article 27, Title 9; 6 NYCRR Parts 370 and 371 - Standards for Hazardous Waste Management

6 NYCRR Parts 370 and 371 provide specific New York State regulations for activities associated with hazardous waste management. Part 371 identifies and lists wastes considered hazardous under New York State law. The Part 371 regulations generally follow the federal RCRA regulations and definitions. However, §371.4(e)(1) specifically adds PCBs at concentrations of 50 ppm or greater (on a dry weight basis; with the exception of liquid wastes), including dredged materials, to the state's list of hazardous wastes. (PCBs are regulated under the federal TSCA program, not under RCRA.)

400364

New York State ECL Article 3, Title 3; Article 27, Titles 7 and 9; 6 NYCRR Part 372 - Hazardous Waste Manifest System and Related Standards

These regulations outline standards for generators and transporters of hazardous waste, and standards for generators, transporters, and treatment, storage, or disposal facilities relating to the use of hazardous waste manifest system.

New York State ECL Article 3, Title 3; Article 27, Titles 7 and 9; 6 NYCRR Part 373 - Hazardous Waste Management Facilities

These regulations establish requirements for treatment, storage, and disposal of hazardous waste; permit requirements; and construction and operation standards for hazardous waste management facilities.

New York State ECL Article 27, Title 13; 6 NYCRR Part 375 - Inactive Hazardous Waste Disposal Sites

These regulations establish requirements for the development and implementation of inactive hazardous waste disposal site remedial programs.

New York State ECL Article 27, Titles 9; 6 NYCRR Part 376 - Land Disposal Restrictions

These regulations require that PCB wastes including dredge spoils with PCB concentrations greater than 50 mg/kg be disposed of in accordance with federal PCB regulations at 40 CFR 761.

New York State ECL, Article 19, Title 3 - Air Pollution Control Law; 6 NYCRR Parts 200-257 - Air Pollution Control Regulations

The NYSDEC regulations that pertain to emissions are 6 NYCRR Parts 200, 202, 211, 212, 219, and 257. The emission of air contaminants that jeopardize human, plant, or animal life, are ruinous to property, or cause a level of discomfort is strictly prohibited (6 NYCRR 211). Adopted pursuant to New York State's Air Pollution Control Law, and submitted to and approved by USEPA pursuant to Section 110 of federal Clean Air Act, 42 USC § 7401. The USEPA-approved New York State regulations are listed at 40 CFR § 52.1679.

New York State ECL Article 15, Title 5, and Article 17, Title 3; 6 NYCRR Part 608 - Use and Protection of Waters

These regulations cover excavation and fill of the navigable waters of the state. No person, local public corporation or interstate authority may excavate from or place fill, either directly or indirectly, in any of the navigable waters of the state or in marshes, estuaries, tidal marshes and wetlands that are adjacent to and contiguous at any point to any of the navigable waters of the state, and that are inundated at mean high water level or tide, without a permit (6 NYCRR 608.5). In accordance with CERCLA Section 121(e)(1), no federal, state, or local permits are required for remedial action that is conducted entirely on site, although the remedial action must comply with the substantive requirements of this statute and associated regulations.

New York ECL Article 17, Title 8; 6 NYCRR Part 750-758 - Water Resources Law

These regulations provide standards for storm water runoff, surface water, and groundwater discharges. In general, they prohibit discharge of any pollutant to the waters of New York without a SPDES permit. In accordance with CERCLA Section 121(e)(1), no federal, state, or local permits are required for remedial action that is conducted entirely on site, although the remedial action must comply with the substantive requirements of the Water Resources Law.

New York ECL Article 17, Title 5

It shall be unlawful for any person, directly or indirectly, to throw, drain, run or otherwise discharge into such waters organic or inorganic matter that shall cause or contribute to a condition in contravention of applicable standards (identified at 6 NYCRR § 701.1).

New York ECL Article 11, Title 5

The Fish and Wildlife Law against water pollution provides that no deleterious or poisonous substances shall be thrown or allowed to run into any public or private waters in quantities injurious to fish life, protected wildlife or waterfowl inhabiting those waters, or injurious to the propagation of fish, protected wildlife or waterfowl therein.

2.5.3 Action-Specific Criteria, Advisories, and Guidance to be Considered

After review of federal and state sources, the following action-specific TBC criteria and guidance were identified (see Table 2-3b).

USEPA - Covers for Uncontrolled Hazardous Waste Sites

This guidance document (EPA/540/2-85-002; USEPA, 1985) provides criteria for covers for uncontrolled hazardous sites which include a vegetated top cover, middle drainage layer, and low permeability layer.

USEPA Rules of Thumb for Superfund Remedy Selection

This document (EPA 540/R-97/013; USEPA, 1997d) describes key principles and expectations, as well as "best practices" based on program experience, for the remedy selection process under Superfund. Major policy areas covered are risk assessment and risk management, developing remedial alternatives, and ground-water response actions.

USEPA Land Use in the CERCLA Remedy Selection Process

This document (OSWER Directive No. 9355.7-04; USEPA 1995) Presents information for considering land use in making remedy selection decisions at NPL sites.

USEPA Contaminated Sediment Strategy

This document (EPA/823/R-98/001; USEPA 1998e) establishes an Agency-wide strategy for contaminated sediments, with the following four goals: 1) prevent the volume of contaminated sediments from increasing; 2) reduce the volume of existing contaminated sediment; 3) ensure that sediment dredging and dredged material disposal are managed in an environmentally sound manner; and 4) develop scientifically sound sediment management tools for use in pollution prevention, source control, remediation, and dredged material management. The strategy includes the Hudson River in its case studies of human health risks.

USEPA Structure and Components of Five-Year Reviews; Supplemental Five-Year Review Guidance Second Supplemental Five-Year Review Guidance

These documents (OSWER Directive 9355.7-02, USEPA 1991; OSWER Directive 9355.7-02A, USEPA 1994; and OSWER Directive 9355.7-03A, USEPA 1995) provide guidance on conducting Five-Year Reviews for sites at which hazardous substances, pollutants, or contaminants remain on-site above levels that allow for unrestricted use and unlimited exposure. The purpose of the Five-Year Review is to evaluate whether the selected response action continues to be protective of public health and the environment and is functioning as designed.

NYSDEC Division of Air Resources: Air Guide 1 - Guidelines for the Control of Toxic Ambient Air Contaminants

This document provides guidance for the control of toxic ambient air contaminants in New York State. Current annual guideline concentrations (AGCs) for PCBs are 0.01 $\mu g/m^3$ for inhalation of evaporative congeners (Aroclors 1242 and below) and 0.002 $\mu g/m^3$ for inhalation of persistent highly chlorinated congeners (Aroclors 1248 and above) in the form of dust or aerosols.

NYSDEC Technical and Operational Guidance Series (TOGS) 1.1.1 Ambient Water Quality Standards and Guidance Values

TOGS 1.1.1 provides guidance for developing discharge limitations and monitoring conditions for discharges to surface waters (NYSDEC, 1998).

NYSDEC TOGS 1.2.1 - Industrial SPDES Permit Drafting Strategy for Surface Waters

TOGS 1.2.1 provides guidance for writing permits for discharges of wastewater from industrial facilities and for writing requirements equivalent to SPDES permits for discharges from remediation sites.

400368

NYSDEC TOGS 1.3.1 - Waste Assimilative Capacity Analysis & Allocation for Setting Water Quality Based Effluent Limits

TOGS 1.3.1 provides guidance to water quality control engineers in determining whether discharges to waterbodies have a reasonable potential to violate water quality standards and guidance values.

NYSDEC TOGS 1.3.2 - Toxicity Testing in the SPDES Permit Program

TOGS 1.3.2 describes the criteria for deciding when toxicity testing will be required in a permit and the procedures which should be followed when including toxicity testing requirements in a permit.

NYSDEC TOGS 1.3.7 - Analytical Detectability & Quantitation Guidelines for Selected Environmental Parameters

TOGS 1.3.7 provides method detection limits and practical quantitation limits for pollutants in distilled water.

NYSDEC Technical and Administrative Guidance Memorandum (TAGM) 4031 - Fugitive Dust Suppression and Particulate Monitoring Program at Inactive Hazardous Waste Sites

TAGM 4031 provides guidance on fugitive dust suppression and particulate monitoring for inactive hazardous waste sites.

NYSDEC Interim Guidance on Freshwater Navigational Dredging, October 1994

This document (NYSDEC, 1994a) provides guidance for navigational dredging activities in freshwater areas.

NYSDEC Division of Fish, Wildlife and Marine Resources - Fish and Wildlife Impact Analysis (FWIA) for Inactive Hazardous Waste Sites, October 1994

This document (NYSDEC, 1994b) provides the rationale and methods for sampling and evaluating impacts of a site on fish and wildlife during the remedial investigation and other stages of the remedial process.

400370

Chapter 3

3. IDENTIFICATION OF REMEDIAL ACTION OBJECTIVES (RAOs) AND RESPONSE ACTIONS

Remedial action objectives (RAOs) serve as guidelines in the development of alternatives for site remediation. RAOs specify the contaminants and media of concern, exposure routes and potential receptors, and an acceptable concentration limit or range for each contaminant for each of the various media, exposure routes, and receptors. The basis and development of the RAOs are presented in Section 3.1. The RAOs, listed in Section 3.2, are then used to establish specific remedial goals for contaminated media; these preliminary remedial goals (PRGs) presented in Section 3.3 serve to focus the development of alternatives or remedial technologies that can achieve the remedial goals. Section 3.4 discusses the limitations of remediation in meeting some of the PRGs.

Section 3.5 presents the development of the selection criteria to identify sediments for remediation. The resulting estimates for areas and volumes to be remediated are also provided. General response actions (GRAs) for achieving the RAOs and PRGs are identified in Section 3.6.

3.1 Basis and Development of Remedial Action Objectives

The results of the revised human health risk assessment (Revised HHRA), as identified in Chapter 1, were used to calculate risk-based concentrations (RBCs) of PCBs corresponding to various cancer risks and non-carcinogenic human heath hazards. The results of the revised ecological risk assessment (Revised ERA), based on no-observed-adverse-effects-levels (NOAELs) and lowest-observed-adverse effect levels (LOAELs), were used to calculate toxicity quotients (TQs) for ecological receptors. These risk assessments were summarized in Section 1.5 of this FS.

RAOs are developed in order to set targets for achieving PRGs (ARARs and RBCs that are protective of human health and the environment) early in the remedial alternative development process. The RAOs should be as specific as possible, without unduly limiting the range of alternatives that can be developed.

400372

In the original 1984 FS (USEPA, 1984b), the contaminants of concern were total PCBs, which remain the contaminants of concern for this Reassessment RI/FS. The principal site-related risks to both human and ecological receptors are associated with the consumption of PCB-contaminated fish. A range of RBCs for PCBs in fish has been calculated (Section 3.2) based on these completed risk assessments. The concentrations of PCBs in fish are in turn a function of both the sediment and water concentrations of PCBs, and are, to some extent, species-dependent.

Using the linear FISHPATH component of the FISHRAND model, fish PCB concentrations were calculated using various assumptions of inputs to the system (*i.e.*, upstream water column Tri+ PCB loadings) and theoretical possible final (post-remediation) Tri+ PCB surface sediment concentrations in the Upper Hudson River. The calculated fish concentrations indicated that it would be extremely difficult to meet some of the PRGs, especially ecological PRGs based on NOAELs, with the current upstream Tri+ PCB concentration on the order of about 13 ng/L (based on data from the last three years).

In consideration of the factors discussed above, USEPA has established the following RAOs for the Hudson River Reassessment FS, where applicable:

- Reduce the cancer risks and non-cancer health hazards for people eating fish from the Hudson River by reducing the concentration of PCBs in fish.

- Reduce risks to ecological receptors by reducing the concentration of PCBs in fish.

- Reduce PCB concentrations in river (surface) water that are above ARARs.

- Reduce the inventory (mass) of PCBs in sediment that are or may be bioavailable.

- Minimize the long-term downstream transport of PCBs in the river.

3.2 Calculation of Risk-Based Concentrations for Human and Ecological Receptors

The Revised HHRA and Revised ERA for the Hudson River PCBs site were used to back-calculate RBCs for this FS, as described below.

3.2.1 Human Health Risk-Based Concentrations

RBCs that are protective of human health were calculated for consumption of PCB-contaminated fish by an adult. For the fish consumption pathway, the ingestion of PCBs is based on consumption of the (species-weighted) fillet. The RBCs in fish fillets (RBC_F) were calculated (see Appendix A) and are presented below for various target risk levels for cancer risks, and for a non-cancer hazard index (HI) of 1. RBC_F values were developed for both the reasonable maximum exposure (RME) and central tendency (CT) scenarios.

Target Risk or Non-Cancer Hazard Index	Central Tendency (CT) (mg/kg PCBs in fillet)	Reasonable Maximum Exposure (RME) (mg/kg PCBs in fillet)
10^{-4}	$RBC_F = 13$	$RBC_F = 0.2$
10^{-5}	$RBC_F = 1.3$	$RBC_F = 0.02$
10^{-6}	$RBC_F = 0.13$	$RBC_F = 0.002$
HI = 1.0	$RBC_F = 0.44$	$RBC_F = 0.044$

3.2.2 Ecological Risk-Based Concentrations (RBCs)

Risks to ecological receptors at various trophic levels were calculated. Fish concentrations were back-calculated for different risk levels (see Appendix A). The ecological receptors assessed are the river otter and mink, and the risk levels assessed were the NOAEL and the LOAEL concentrations resulting in a toxicity quotient (TQ) of 1. Because risk to the bald eagle egg is similar (or slightly lower than) risk to the otter, the otter PRG is considered to be protective of the eagle. Target concentrations are presented in the table below. For ecological receptors, the target concentrations are based on the whole-body fish concentration (not fillet), as ecological receptors consume the entire fish, although calculated fillet concentrations, corresponding to the whole body concentration, are also presented for comparative purposes. Dioxin-like toxic equivalents (TEQs) are based on dioxin-like PCB congeners.

Available data are almost entirely for fish fillets. Conversion factors developed for the Revised ERA, based on USEPA research (USEPA, 1997a), suggest that the corresponding whole body concentration is greater than the fillet concentration by a factor of about 2.5 for the largemouth bass. This is based on evaluating whole body versus standard fillet lipid content.

Ecological Receptor Species	NOAEL Target Fish Concentration		LOAEL Target Fish Concentration	
	(mg/kg PCBs in whole fish)	(mg/kg PCBs in fish fillet) *	(mg/kg PCBs in whole fish)	(mg/kg PCBs in fish fillet) *
Otter (TEQ-dietary)	0.015	0.006	0.4	0.16
Mink (TEQ-dietary)	0.034	NA (note 1)	1.0	NA[1]
Otter (dietary)	0.03	0.013	0.3	0.13
Mink (dietary)	0.07	NA (note 1)	0.7	NA[1]

*The fillet values are calculated values based on the conversion factor of 2.5 (whole body to fillet concentration) for largemouth bass. The fillet value is presented to provide a consistent framework for comparison between ecological and human health risk-based concentrations (which are based on fillets) for larger piscivorous fish, which are consumed by humans as well as by the river otter.

[1] The mink consumes forage fish (*e.g.*, spottail shiner) which are not typically consumed by humans; therefore no fillet concentration is applicable.

3.3 Preliminary Remediation Goals (PRGs)

PRGs were established after review of both the potential site ARARs (presented in Chapter 2) and RBCs (presented above in Section 3.1). The PRGs established for achieving the RAOs for the site are as follows:

- Reduce the cancer risks and non-cancer health hazards for people eating fish from the Hudson River by reducing the concentration of PCBs in fish.

The risk-based PRG for the protection of human health is 0.05 mg/kg PCBs in fish fillet based on the RME adult fish consumption rate of one meal per week. Other target concentrations are 0.2 mg/kg total PCBs in fish fillet, which is protective at a fish consumption rate of about one meal per month, and 0.4 mg/kg PCBs in fish fillet, which is protective of the average angler who consumes about one meal every two months. These targets of higher concentrations in fish represent points at which fish consumption advisories might become less stringent (*e.g.*, the "eat none" advisory for the Upper Hudson could be relaxed as conditions improve).

- Reduce risks to ecological receptors by reducing the concentration of PCBs in fish.

The risk-based PRG for the ecological exposure pathway is a range from 0.3 to 0.03 mg/kg total PCBs in fish (whole body), which corresponds to PCB concentrations of 0.12 to 0.012 mg/kg in fish fillets. The ecological PRG is based on the LOAEL and NOAEL for consumption of whole fish by the river otter, an upper trophic level piscivorous mammal ($TQ_{[LOAEL\ or\ NOAEL]\text{-}DIET} = 1$). Consideration was also given to use of TEQ-based NOAEL of 0.015 mg/kg (whole body) for dioxin-like PCBs; however, use of this criterion requires congener-specific data that are not routinely available, and would not necessarily achieve greater protection of wildlife. Furthermore, there is more uncertainty associated with the TEQ-based NOAEL than the PCB-based NOAEL.

- Reduce PCBs in sediments in order to reduce PCB concentrations in river (surface) water that are above surface water ARARs.

The ARARs for surface water are:

- 1×10^{-6} μg/L (one part per quadrillion) total PCBs, the New York State (NYS) ambient water quality standard for the protection of health of human consumers of fish;
- 1.2×10^{-4} μg/L, the NYS standard for protection of wildlife;
- 1×10^{-3} μg/L, the federal ambient water quality criterion for navigable waters;
- 0.09 μg/L, the NYS standard for protection of human health and drinking water sources; and
- 0.0005 mg/L (0.5 μg/L), the federal maximum contaminant level (M.C.L.) for PCBs in drinking water.

400376

No specific numerical PRGs were developed for the final two RAOs:

- Reduce the inventory (mass) of PCBs in sediment that are or may be bioavailable.
- Minimize the long-term downstream transport of PCBs in the river.

Use of PRGs does not preclude the development and consideration or selection of alternatives that attain other risk levels. Final selection of the appropriate level of risk is made based on the balancing of criteria in the remedy selection step of the process. Site-specific considerations that may affect the achievement of these PRGs are discussed immediately below (Section 3.4).

3.4 Limitations on Meeting PRGs

Current and future concentrations of PCBs in the water at the upstream end of the Upper Hudson River (*i.e.*, upstream of Rogers Island [RM 194.6]) are expected to limit the ability of remedial actions to achieve the stringent PRGs for fish and water established for the site. These fall into two categories: limitation of analytical (measurement) systems that may impact verification of stringent PCB PRGs (subsection 3.4.3), and uncertainty associated with the effect of ongoing or planned remediation upstream of Rogers Island conducted by GE and others (subsections 3.4.1 and 3.4.2).

3.4.1 Surface Water PRGs

Achievable and verifiable remediation targets for water are constrained by continued releases of PCBs into the river system, as well as by the aforementioned limitations of current analytical methodologies discussed in subsection 3.4.4. These continued releases are defined as the PCB load entering the site from upstream of Rogers Island (RM 194.6). These upstream loads are not subject to remedial actions within this FS, but these are largely being addressed separately. Existing data show the presence of low-concentration inputs (detectable concentrations of less than 2 ng/L) north of known GE inputs (*i.e.*, from Glens Falls and north) as well as PCB leakage from bedrock at the GE Hudson Falls plant. Each of these issues is discussed below.

The upstream baseline for the Reassessment RI/FS is defined as the PCB conditions observed in the river above the GE Hudson Falls plant, *i.e.*, just above Bakers Falls Dam at RM 196.1. It is not equivalent to an uncontaminated background condition, as a number of sources of PCB loads are present upstream of Bakers Falls (see Appendix A). Concentrations of PCBs in the water and fish upstream of Baker Falls are, however, much lower than those below Bakers Falls.

A potential PCB source above Bakers Falls between RM 196.1 and RM 210 is the NiMo Queensbury Site, as shown on Figure 3-1. NYSDEC is currently evaluating the feasibility of further remediation at this site.

Water column data are less extensive than fish data in the region extending upstream of Glens Falls, both temporally and spatially. USEPA data (1997a) suggest mean total PCB concentrations in water that are less than 2 ng/L and probably less than 1 ng/L are typical in this part of the river. PCBs are not detected in most samples (at a reporting limit of 11 ng/L) in the more frequent but less sensitive GE data at Fenimore Bridge, just upstream of Bakers Falls Dam, although the results do show occasional spike concentrations that are quite high (387 ng/L maximum). It is most likely, however, that these values are the result of remedial activities by GE at its Hudson Falls plant and at Bakers Falls Dam. This is based on the observation that the homologue patterns of the spikes are very different from the normal patterns seen at the station. The pattern of the spike concentrations closely resembles the Aroclor mixtures released by GE.

Additionally, the spike concentrations are principally found in the period 1995-1996, during which time the Baker Falls Dam was undergoing replacement. These concentrations were reduced following the completion of the remedial and repair activities at the Bakers Falls Dam completed in 1996. The otherwise irregular and low concentrations seen at Bakers Falls suggest that the reported PCB levels can be attributed to other non-PCB compounds in solution that interfere with the PCB measurements. A true local source generating 1 to 2 ng/L to the water column would have a more consistent homologue signal, as can be seen in the fish data from this region.

3.4.1.1 Baseline Input at Glens Falls

PCBs are typically present at low concentrations in watersheds affected by human activity, and the Hudson River is no exception. Limited data (see USEPA, 1997a) suggest that the upstream concentration of PCBs in water, as measured north of any of the former GE facilities (*i.e.*, at Glens Falls and Fenimore Bridge), is in the range of about 1 ng/L total PCBs, although this value is somewhat uncertain due to the limited number of measurements and the fact that the reported values are on the extreme low end of the analytical detection range. It is likely that the input at Glens Falls is lower now than in 1993, due to the remediation conducted since then at the NiMo Queensbury site. However, due to the relatively high quantitation limits of the GE data at Glens Falls and Fenimore Bridge (11 ng/L PCBs in water), this cannot be confirmed analytically from the available data.

3.4.1.2 Current Inputs at Bakers Falls

Data from both USEPA and GE indicate that there is continued leakage of PCBs into the river through the bedrock at Bakers Falls, despite efforts by GE to control the source. Data from GE's 1997–99 sampling at Rogers Island suggested that this input results in an average total PCB concentration in water of about 13 ng/L, although there are wide fluctuations, and the concentration is also based on measurements at or below the low end of the analytical detection level. The 13 ng/L estimate is calculated by averaging the 1997-1999 Rogers Island water column sampling data; a value of one-half the detection limit, or 5.5 ng/L, is assigned to samples in which PCBs were reported as not detected.

Remedial activities currently being planned and implemented in the vicinity of the GE Hudson Falls plant are intended to reduce this input. However, neither the timing nor the achievable degree of reduction is known. Over the period 1997 to 1999, in-place controls have reduced the PCB load to an equivalent annual concentration of 13 ng/L. For modeling purposes, it has been assumed that this level is representative of loading conditions over the next several years. Thus, this value has been used to represent upstream boundary conditions in the near term (1999-2004) for the majority of the modeling of active remedial scenarios, described in greater detail in Chapter 5, as well as for modeling of the No Action scenario.

Some modeling scenarios were run utilizing an upstream boundary Tri+ PCB concentration of 30 ng/L. Based on review of the monitoring data, this value was considered to represent a reasonable worst-case scenario, taking into account the variability of the data. Some scenarios were also run using a concentration of 0 ng/L; in other words, it was assumed that there was no PCB input from upstream of Rogers Island. The zero-input assumption provides the theoretical limit on the maximum benefit of remediation or attenuation of upstream sources.

3.4.2 Fish PRGs

PCB concentrations in biota are driven by concentrations in water and sediment. The existence of upstream boundary loads will result in non-zero PCB concentrations in both water and sediment. As a result, concentrations in fish will also remain above zero in the presence of the upstream load.

Even if the PCB input from the Bakers Falls source was substantially reduced, PCB concentrations in fish would not return to zero due to the input of baseline loads from above Bakers Falls. Data collected both for the reassessment RI/FS, as well as extensive annual monitoring data collected by NYSDEC (as presented in the ERA; USEPA, 1999c), show that there are detectable concentrations of PCBs even in fish caught north of any of the former GE plants at Hudson Falls and Fort Edward, confirming the presence of an upstream baseline load. One of those sources is the NiMo Queensbury site and another is atmospheric fallout. While there is some yearly and inter-species variability, the available data for four species (largemouth bass, brown bullhead, yellow perch, and white perch) suggest that the upstream concentration of total PCBs in fish fillets above Bakers Falls in recent years is approximately 0.2 mg/kg (Note that the Tri+ PCB and total PCB concentrations are essentially the equal in Huson River fish tissue). Recent remedial activities in the region above Bakers Falls can be expected to continue to result in lower PCB levels in fish.

Monitoring data on fish body burdens obtained by NYSDEC represents the most extensive record both temporally and spatially. The PCB data for the most recently available samples (1998-1999) show that fish body burdens were one to three orders of magnitude lower in this region relative to River Section 1 and other locations downstream.

400380

3.4.3 Limitations on Verifying Compliance with PRGs

The analytical method utilized by USEPA for the Reassessment RI/FS has a practical limitation of accurate quantitation of approximately 1 ng/L for monochlorobiphenyls, 0.05 ng/L for dichlorobiphenyls through hexachlorobiphenyls, and 0.05 to 0.1 ng/L for heptachlorobiphenyls through decachlorobiphenyls on 17-liter water samples (USEPA, 1997a). Although data are reported below these concentrations, the reliability and accuracy of the data at lower concentrations are less certain. This analytical method was developed specifically for the Reassessment RI/FS and represented the state-of-the-art at the time the analysis was conducted; it is unlikely that this detection limit can be improved upon significantly in the near future. Therefore, the true value of the PCB input from Glens Falls is only estimated.

The analytical method utilized by GE has a quantitation limit about ten times higher (11 ng/L) than that utilized by USEPA for the Reassessment RI/FS. While the GE method is a congener-specific method and is capable of detecting significant inputs into the river, it is less useful in determining low-level PCB concentrations (below 10 ng/L).

The most stringent river water PRG (based on the New York surface water standard) is 0.001 ng/L. It is evident from the available analytical methodologies that compliance with this PRG cannot easily be verified, since current commercially available methodologies can achieve reliable quantitation only at concentrations two to four orders of magnitude higher than this value. One potentially applicable method is the NYSDEC Trace Organics Platform Sampler (TOPS), a high volume sampler providing lower detection limits for PCBs than methods generally available commercially, reportedly capable of reporting down to the 1 x 10^{-6} μg/L (0.001 ng/L) NY water quality standard.

3.5 Selection of Sediment Target Areas for Remediation

In order to develop remedial alternatives, it was necessary to identify the sediments that might appropriately be targeted for remediation. Criteria for making this identification are presented in subsection 3.5.1, followed by the available data and their use in various measurements (metrics) for assessing these criteria, discussed in subsection 3.5.2. In subsection 3.5.3, the criteria are described for the three levels of sediment remediation that were used to construct the remedial scenarios. Subsection 3.5.4 describes the application of the criteria to the river, with the resulting estimates of sediment volumes, areas, and PCB mass.

In previous sections of the FS, italics have been used to designate areas of high PCB concentrations delineated by NYSDEC, as in "*Hot Spot* 28" or, more generally "*hot spots.*" This convention is retained through the FS when specifically referring to these NYSDEC-delineated areas with their originally-defined boundaries. Where the term "hot spot" is used to mean target areas delineated according to the criteria for the FS, using all available data sets, italics are not used.

3.5.1 Target Area Selection Considerations

Having identified the sediments of the Upper Hudson as the primary source of PCBs to the freshwater Hudson (USEPA, 1997a, 1998a, 1998b, and 1999b), it was then necessary to identify those sediments whose remediation would have the greatest impact in achieving the RAOs and PRGs (*e.g.*, reducing fish body burdens and PCB transport). Additionally, it was important to identify those sediments with the greatest potential for subsequent PCB release, considering PCB concentration and inventory as well as susceptibility to remobilization.

In identifying the sediment target areas, several approaches were used. The selection of sediment areas for remediation was based largely on geochemical and statistical interpretations of the data, including observations concerning PCB transport, changes in sediment inventory, sediment PCB distribution, and impacts on the biota. The observations and analyses that weighed most heavily in the selection of remedial areas are described below. Taken together, these observations and analyses provide a sound basis for the selection of remedial target areas presented later in this chapter. The observation and its implications for remediation are described in each of the following items.

Based on the lines of evidence described below, PCB inventory, PCB surface concentration, sediment texture, and proximity to shore must all be considered in the selection of sediment remedial areas. PCB inventory provides an approximate measure of the potential for long-term release and recontamination of the immediate area as well as those areas downstream. Surface concentration provides a measure of the immediate exposure conditions associated with the sediment. Incorporating the noted correlation among sediment (fine-grained) texture, near-shore proximity, PCB inventory, and biological activity, it is possible to identify areas of the Upper Hudson that are likely to represent potential long-term sources. It is only by considering the criteria together, rather than alone, that achievement of the RAOs and PRGs can be maximized.

The lines of evidence in support of these criteria include the following:

1. PCB loads and concentrations in the Upper Hudson have a strong seasonal dependence, with maximum sediment release rates occurring from late May to mid-June. These release rates gradually decline throughout the summer and largely cease by late fall. The dependence is clearly not flow-related (see next bullet) and strongly suggests a biologically mediated process (see Appendix D). This observation suggests that the majority of this load is derived from sediments in biologically active zones, that is, in near-shore environments that support a high density of plants and animals.

2. May through September water column PCB concentrations at the TID-West station have little flow dependence and show little decline over the period 1996 to 1999 (see Appendix D). The concentrations do, however, vary substantively throughout the year. Peak concentrations occur from late May to mid-June and gradually decline throughout the summer. This is in contrast to water temperature (a possible indicator of diffusive sediment-water exchange), which does not peak until August. Similar monthly peak concentrations have been observed for June through September for the period 1996 to 1999, despite flow rates varying by a factor of four. That is, water column PCB concentrations at TID-West have been the same each June, July, August, and September for these years in spite of a large variation in summer time flow during this period. However, within each year, June is quite different from September.

   The consistency in near-shore conditions from year to year, independent of flow, suggests the existence of quasi-steady-state exchange processes that regulate the water column concentrations in the near-shore environment. Additionally, these results suggest that near-shore water-column conditions are controlled by processes that are able to tap a relatively large PCB inventory, hence the lack of decline in water-column concentrations in the last four years. These results indicate that near-shore PCB concentrations and related biological exposures are the result of processes that occur in the near-shore environment.

3. The TID-West station is considered a good representation of near-shore water column conditions because it is located at the western wing wall of the TI Dam and to the west of the main channel of the river. The PCB concentrations at this station are frequently but not always higher than those of the center channel of the river. Typically, the PCB concentration at this station matches that of the center channel under greater than average flow conditions (greater than 5,000 cfs) and during the cooler months of the year when biological activity is low. The fact that this station differs from the main channel largely during warm, low flow conditions shows the continued importance of near-shore releases. This station also documents the net increase of PCB load and concentration originating in the near-shore environment over the period 1991 to the present.

4. The near-shore areas contain the majority of the cohesive (fine-grained) sediments. These areas would also be expected to be the most active in terms of biological activity in the sediment since they are relatively rich in organic matter and are frequently vegetated. These areas are also expected to be the predominant areas for biological exposure to PCBs via both sediment and water column exposure since plants and animals are concentrated in these areas. The strong indication of a biologically mediated PCB release process and the likely coincidence of extensive sediment PCB contamination and areas of greater biological activity suggest that the majority of the annual PCB release from the sediments originates from the near-shore cohesive sediments.

5. Since the release process is probably biologically mediated, there is no inherent dependence of the release rate upon sediment concentrations, unlike processes such as diffusion. Rather, it is the coincidence of PCB contamination, cohesive sediment texture, and biological activity in the near-shore environment that creates the most likely source of PCBs for both water column transport and biological exposure.

400384

6. Further evidence of the importance of near-shore, cohesive sediments can be seen in the summer and fall float survey results obtained by GE in 1996 and 1997 (O'Brien and Gere, 1998; QEA, 1999). Figure 3-2 presents a map of the TI Pool locations occupied during these surveys. In these results, near-shore water column concentrations (east and west shore) were substantially higher than those of the main channel; Figure 3-3 illustrates that these concentrations were sometimes as much as five times higher. Near-shore water column results showed localized areas of high PCB concentrations, suggesting that these are areas of increased sediment release. These results indicate that the near-shore environment is responsible for the majority of the PCB load carried by the river in the warmer months of the year.

7. In a similar fashion, the congener patterns of the main channel and near-shore water column concentrations suggest a simple pattern of mixing between the upstream source and that originating in the near-shore sediments. An examination of the molar dechlorination product ratio (MDPR) as a function of the concentration reveals a tight relationship between the two that can be expressed by a simple linear combination of two end-members. This expression describes the relationship between the MDPR and the water concentration in River Section 1 as a concentration-weighted average of the ratios, assuming an upstream condition defined by the Rogers Island concentration and a near-shore sediment source with a single or narrowly varying ratio that gradually adds additional PCBs to the water column. This yields the following relationship:

$$MDPR_i = TPCB_{RI} * (MDPR_{RI} - MDPR_{nss}) * \frac{1}{TPCB_i} - MDPR_{nss}$$

$$MDPR_i = \frac{TPCB_{RI} * MDPR_{RI} + (TPCB_i - TPCB_{RI}) * MDPR_{nss}}{TPCB_i}$$

Simplifying:

$$MDPR_i = K * \frac{1}{TPCB_i} - MDPR_{nss}$$

where:

$MDPR_i$ =	MDPR at location in River Section 1. This can be anywhere in the TI Pool.
$MDPR_{nss}$ =	MDPR of the near-shore source (assumed constant in each sampling event).
$MDPR_{RI}$ =	MDPR of the water column concentration at Rogers Island (assumed constant for each event).
$TPCB_i$ =	Total PCB concentration in the water column at *i*.
$TPCB_{RI}$ =	Total PCB concentration in the water column at Rogers Island at the start of the float survey. This value represents the portion of the water column concentration derived from the GE leakages and is a constant for each event.
K =	a constant for each event, given as $TPCB_{RI}*(MDPR_{RI} - MDPR_{nss})$

Thus the relationship between the MDPR and the reciprocal water column concentration yields a linear relationship with the ratio of the sediment source as the y-intercept. The results for the four float surveys were analyzed in this fashion, as shown in Figure 3-4. In each diagram, a regression is plotted for the MDPR and the reciprocal water column concentration. Notably, the regressions yield high R^2 values (0.65 to 0.88), indicating that the data are well explained by the model. Also important is the convergence to a narrow range of values for the MDPR (0.74 to 0.87), with greater agreement within the month pairs (*i.e.,* September 24 and 25 events and the June 4 and 17 events). The results at Rogers Island consistently yield a value of about 0.2 for the MDPR. Extrapolations of the curves to this value yield estimated water column concentrations in the range of 8 to 28 ng/L, well within the range measured during this time period. The variation in the slope of the line is largely the result of variations in the concentration at Rogers Island (Figure 3-5). Nonetheless, the entire data set is consistent with this model and implicates the near-shore environment with its higher water column concentrations and MDPR values as the source of the additional PCB everywhere in River Section 1.

8. The float survey results also indicated the absence of substantial sediment-derived water column PCB loads upstream of the areas that contained large amounts of fine-grained sediments. That is, water column loads measured at Rogers Island (RM 194.6) remained largely unchanged for the first 1.5 miles downstream (*i.e.*, to RM 193). Between RM 194.6 and 193, areas of fine-grained sediments are very limited. The first major areas of fine-grained sediments are found below RM 193, specifically *Hot Spots* 6, 7, and 8. The facts that (1) little load gain is seen in the first 1.5 miles of River Section 1 where the river is primarily lined with coarse-grained sediments, and (2) the appearance of a sediment-derived load is coincident with the presence of fine-grained sediments are additional evidence suggesting a causal relationship between fine-grained sediments and the increased water-column PCB loads observed in River Section 1. The data supporting these observations are illustrated in Figure 3-6, which presents the observed load gain and the cumulative area of fine-grained sediments as a function of river mile in River Section 1 for each of the four float survey events. These results implicate the near-shore environment as the major source of the sediment-derived PCB loads from River Section 1.

9. The evaluation of the 1994 USEPA and 1984 NYSDEC sediment surveys presented in the LRC and the associated responsiveness summary (USEPA, 1998b; 1999b) indicates that fine-grained areas of River Section 1 underwent significant PCB mass loss during the period 1984 to 1994. Similar scale inventory losses were seen in several major fine-grained sediment deposits downstream of the TI Dam as well. While some of the examined areas appeared unchanged, others appeared to have lost substantial portions of their PCB inventory, as much as 50 percent or more. The extent of loss was found to correlate with the original PCB inventory measured in 1984 (*i.e.*, the greater the 1984 inventory, the greater the proportion of mass that was lost). These observations suggest that the stability of PCB inventories contained within the sediments cannot be assured indefinitely. Additionally, these results indicate that PCBs in many areas were not being isolated or sequestered by sediment deposition, as has been asserted. Rather, the results suggest that historical deposits of PCBs continue to be available for recontamination of surface sediments and the biota. A similar analysis performed using coring data obtained by GE in 1998 yields a similar result. Specifically, the 1998 sites were designed to match a subset of the paired 1994 USEPA and 1984 NYSDEC sites. The matched pairs of GE and NYSDEC values show levels of loss

from the sediment similar to those calculated for the USEPA-NYSDEC pairs (see Appendix D). These results indicate that long-term "storage" of PCBs in the sediments of the Upper Hudson is not assured. More importantly, the PCBs re-released from the sediments are then again available to contaminate surface sediments and biota downstream. It is likely that the re-release process serves to sustain surface PCB concentrations, thereby limiting the recovery of the river surface sediments and the biota body burdens derived from the surface sediments, although the process mechanisms have not been identified.

10. An additional important observation from the low resolution sediment coring effort was the presence of peak PCB concentrations in the top-most segment of the majority (60 percent) of the low resolution cores. In most cases this placed the maximum concentrations within 9 inches of the sediment surface and near or within the biologically available zone. Thus, the majority of the PCB inventory of the sediments does not appear to be isolated from the biologically active zone in the fine-grained areas examined.

11. Similar evidence was obtained by GE in coring sites associated with *Hot Spot* 14 in 1998. Ten cores were obtained from this *hot spot*, several of which showed surface (0 to 5 cm) concentrations 30 mg/kg and higher (Figure 3-7). Two of the sites had concentrations over 200 mg/kg (270 and 630 mg/kg) in this layer, indicating the presence of historical PCB contamination at the sediment surface. Most cores collected had PCB concentrations greater than 100 mg/kg in the 5- to 10-cm layer. Based on the high resolution coring results obtained by both USEPA and GE, mean concentrations on suspended matter have not exceeded this level since the early 1980s. Mean suspended solids PCB concentrations over 200 mg/kg were last observed in the 1970s. Thus, these materials must be relatively old (at least pre-1985) despite their proximity to the surface. While the mechanism to maintain such historical concentrations at or near the surface is not known, it is clear from these data that historical materials and their associated PCB concentrations continue to be available to the surface sediments, the water column, and the biota.

12. Side-scan sonar results obtained in 1991 and 1992 indicated multiple areas undergoing scour based on surface morphology (Flood, 1993). These features were sufficiently large enough to be discernable at the resolution of approximately one square foot. Figure 3-8 shows where

such areas were identified between Rogers Island and the Northumberland Dam. The identification of such features in some areas does not preclude the occurrence of resuspension elsewhere but rather simply identifies those areas undergoing sufficient levels of resuspension to form discernable, scour-related surface features. In River Section 1, the majority of these areas are found in cohesive sediments. The clear presence of such scour-related features is further evidence for the lack of long-term stability in the sediments.

13. An important consideration in selecting potential remedial target areas is the hydrology of the Upper Hudson River. The Upper Hudson River is a partially regulated river with several run-of-the-river dams. As such it is still subject to large flows that can modify the river bed and transport large quantities of sediment from the river bed. These processes have been examined as discussed in the RBMR (USEPA, 2000a). However, the Upper Hudson does not accumulate sediment everywhere in its bed, although some portions of it, particularly those areas behind dams, may in fact collect sediment. The long-term stability of deposition in such environments cannot be assured given the dynamic nature of the river and the high energies available for sediment transport. This is in sharp contrast to a lake or reservoir, in which mean linear velocities are frequently zero and remain that way for hundreds or thousands of years. However, even in lakes, deposition is far from homogeneous, with near-shore environments frequently exhibiting no net deposition simply due to wind-driven resuspension that serves to "focus" lake sediments into the deeper portions of the lake. The point here is not to suggest that near-shore Hudson sediments behave like those in lakes, but rather to demonstrate that sediment environments are not inherently stable.

14. Since the sediments of the river cannot be considered inherently stable, the PCB inventory contained within those sediments cannot be assured to be permanently sequestered. Processes which move the sediments serve to transport PCBs to other locations downstream as well as to uncover PCBs below the surface of the sediment. Thus the PCB inventory represents an important criterion for the selection of remedial areas.

15. While PCB inventories in fine-grained sediments appear correlated with areas of expected biological activity and areas of increased water column PCB concentrations, it is also observed that surface concentrations are well-correlated with fish body burdens (see the

bivariate analysis of sediment, water, and fish body burdens in the RBMR (USEPA, 2000a). Thus, while PCB inventories and their lack of consistent long-term stability must be considered in selecting remedial action areas, so must surface PCB concentrations. Surface sediment PCB concentration represents an important alternative criterion for selection of remedial areas, separate from the criterion of sediment PCB inventory. Although inventory and concentration are correlated, the relationship is not exact, as will be discussed later in this section.

16. Another line of evidence supporting the selection of remedial areas was obtained from the high resolution sediment cores collected by the USEPA in 1992 and by GE in 1998. The results from these cores indicate that PCB concentrations in recent deposition have not appreciably increased or declined over the last ten years, despite the major changes in the upstream loads to the river. This observation suggests that historical PCBs from the sediments represent a major continuing source to the Upper Hudson, since recent deposition has not responded to the changes upstream and instead has remained elevated, close to the levels seen in the sediments prior to the Allen Mills event. The high resolution cores represent unique environments where deposition occurs regularly and resuspension is largely absent. Core samples collected both by USEPA and GE show little variability in sediments deposited from the late 1980s to the time of core collection, despite an increase, and then decrease, of more than an order-of-magnitude in the PCB load at Rogers Island during this period.

The absence of any substantive variation in these levels suggests three possibilities: first, that little deposition was occurring over the period, thus yielding little new highly contaminated sediment; second, that the PCB levels in the cores were primarily governed by other sources such as the sediments; or third, that vertical mixing via bioturbation served to completely homogenize the sediment concentrations. While vertical mixing is a possibility for the GE coring efforts conducted four years after the major release period, it is not a plausible explanation for the 1992 cores since they were collected in the middle of the Allen Mill event. Given that the third explanation (mixing by bioturbation) could not apply to the 1992 cores, it is not a very likely explanation for the lack of variation in the 1998 cores since they were obtained from similar environments.

400390

Further evidence for the lack of substantive vertical mixing was developed by Olsen *et al.* (1980), based on the cesium-137 profiles observed in Hudson River cores. Olsen concluded that extensive vertical mixing would serve to smooth the cesium-137 peak observed in each core, reducing the cesium distributions to uninterpretable profiles. Due to the uniqueness of these cores (*i.e.,* the fact that they are datable) and their locations in a very sheltered environment, the assumption of a lack of bioturbation in these high resolution cores cannot be extended to the rest of the river. Indeed, bioturbation is a likely mechanism for PCB release from the sediments, as discussed above.

Based on these considerations only the first two possible explanations remain viable. With regard to the first explanation concerning lower deposition rates, suspended solids loads were somewhat reduced after 1990 (USEPA, 2000a), possibly due to the capping of the remnant deposits. Alternatively, it is also possible that unstable sediments in the main channel above Fort Edward resulting from the removal of the Fort Edward Dam are no longer prevalent. Thus, the possibility of slower deposition is real. This would also mean that little of these greatly increased loads associate with the Allen Mills Event was captured within the sediments of the Upper Hudson River. Alternatively, or perhaps in addition to this explanation, the occurrence of significant PCB releases from the historical sediments elsewhere in the river could serve to maintain the steady, high levels seen in the recently deposited materials recorded by the cores. Either by lack of burial or by re-release, both scenarios support the importance of historical sediments to PCB levels in the Hudson.

The USEPA models do not of themselves permit a direct identification of these sediments, since the spatial resolution of the models (about ten acres in River Section 1, and larger than ten acres in River Sections 2 and 3) is much greater than the minimum size of an area that would be selected for dredging (about one acre). Moreover, the model application requires the synthesis of mean PCB contamination levels and inventories for large areas of the Hudson, integrating much of the detail available within the various sediment data sets. Nonetheless, the model can be applied in estimating the net effect of remediation on scales comparable to the model segment lengths. In the identification of the specific target areas for remediation and the preferential selection of cohesive or non-cohesive sediments for remediation, the model is most appropriately used to provide a general guide and estimate an overall impact.

In particular, it was important to recognize the limitations of the modeling analysis. Specifically, despite the large amount of data assembled, there was little data to constrain the relative contributions by cohesive and non-cohesive sediments to the water column transport or biological uptake. While contributions from the sediment by resuspension can be approximated using sediment physical properties and the GE resuspension model SEDZL, the main means of PCB transport from the sediment to the water column is not flow-driven and was empirically represented in the model. This process was responsible for more than 50 percent of the PCB mass transfer to the water column. While the data collected were sufficient to describe the net contribution by this process, little data were available that could be applied to the model to estimate the relative release rates and exchange processes among the various sediment zones. Nearly all data collected serve to integrate these contributions but cannot discern them individually. Thus, on both a spatial scale and on the basis of the transfer mechanisms, the models cannot provide complete information to direct the selection of the remedial target areas.

The parameters used in the modeling efforts to characterize the relative contributions of cohesive and non-cohesive sediments were assigned using best professional judgment, generating an internally consistent modeling result that matches the calibration data set. However, the assumed values do not represent a unique solution to the modeling analysis; other sets of assumptions concerning the relative importance of cohesive and non-cohesive sediments may also yield acceptable calibrations. This indicates that the model forecast results are more uncertain than the hindcast results, as discussed in Appendix D. Importantly, the model results are most uncertain with regard to remedial actions involving various combinations of cohesive and non-cohesive sediment remediation, since only their combined contribution, and not their relative contributions, is well known. This results, in part, from the difference in the spatial scales for the model *vs.* the minimum size of an area that would be remediated.

The model response to the various remedial scenarios was considered in estimating the overall effectiveness of each scenario, thus indirectly verifying the selection of areas for remediation.

3.5.2 Application of the Available Data to Identification of Sediments for Remediation

The Upper Hudson has been the subject of a large number of sediment sampling events. In nearly every case, however, data collection goals were somewhat different, with some studies focusing on PCB inventory and some on concentration. Additionally, the definition of "surface" sediment has varied considerably among studies. Lastly, analytical techniques have varied over time. As a result, comparing conditions among the various data sets is enhanced by correcting for these differences. The actual application of the various data sets will be discussed by example later in this text.

Comparisons among the various data sets first required resolution among the different analytical schemes used by the different investigations. These issues have been dealt with extensively in the Phase 2 reports, *i.e.*, the DEIR (USEPA 1997a), LRC (USEPA 1998b), and RBMR (USEPA, 2000a), and are not repeated here. To summarize the approach, the reconciliation of the historical, packed-column, Aroclor-based techniques with the more recent, capillary column, congener-based analysis was accomplished by aligning the individual packed-column and congener chromatographic "peaks," and summing the results into a single consistent basis. Because of known limitations in the historical techniques, this reconciliation of PCB measures could only be done for the heavier portions of the PCB spectrum, that is, the trichloro and higher homologues. The sum of this fraction of the PCB spectrum has been defined as the Tri+ sum. Few reliable measures of the lighter (lower molecular weight) congeners, that is, the monochloro- and dichlorobiphenyls , exist in the historical data prior to 1991. This represents an important exclusion because the majority of the spatially representative sediment data was collected prior to 1991.

3.5.2.1 Definition and Calculation of the PCB Metrics

In the selection of remedial areas, the evaluation of the extent of contamination employed several different metrics (measurement bases), including four PCB-based parameters: "surface" concentration; mass per unit area (MPA); length-weighted average (LWA); and maximum concentration. Data from the various data sets were transformed into these metrics as was appropriate, depending upon the type and quality of information available and the desired description of contamination. Other data sets were used as well, including sediment texture (as defined by side-scan sonar) and river bathymetry. The various PCB metrics mentioned above have been used extensively in the Phase 2 reports. The definitions and derivations of these metrics are given below.

Each of these metrics provides a different perspective on the extent of contamination and thus all are useful in the identification or remedial target areas. However, the various historical data sets did not always lend themselves to the calculation of all of these values, as discussed in the next section.

"Surface" Concentration

This parameter is meant to represent the PCB concentration in the surficial sediments, that is, the sediments in contact with the overlying water column, fish, and benthic invertebrates. Depending upon the mechanisms of exchange and contact, the effective depth of "surficial" sediments for each of these three entities may be quite different. Knowing the effective depth in each instance implies knowing the mechanisms of exchange. As discussed above, this is clearly not the case for sediment-water exchange.

The depth of surficial sediments has been operationally defined in a different manner for each of the various sampling programs, beginning in 1976. Notably, a value for "surface" concentration can be obtained from cores and grab samples. However, while the depth of the coring interval is well defined, that from a grab sample is not. Typically these grab samples are assumed to represent between 5 and 15 cm of depth as measured from the surface. For core samples, the depth of surficial sediments among the larger sediment collection programs was defined as approximately 10 cm in 1976-1978 (NYSDEC), 30 cm in 1984 (NYSDEC), 5 cm in 1991 (GE), 23 cm in 1994 (USEPA), and finally 2 cm in 1998 (GE). (Note that GE also collected samples from 2 to 5 cm in 1998 to permit a comparison to its 1991 data.) To add to the uncertainty in estimating the historical "surface" concentrations, both the 1976-1978 and 1984 sampling efforts incorporated a large number of grab samples. Depths for these samples are essentially unknown but are believed to be less than 15 cm (6 in). Thus these events have wide depth ranges internal to their data sets.

As a result of the wide disparity in the definition of surficial sediments, direct comparison among the studies using this parameter is greatly limited. Differences in surface concentrations from one study to another may result from actual changes in sediment conditions or may simply represent the effect of different sampling depths. Nonetheless, surface concentrations within each study were used in the selection of remedial areas since these values are expected to most closely represent the nearer-term exposure conditions to the biota as well as the properties of the sediments in continuous contact with the water column.

Length-Weighted Average Concentration

Length-weighted average concentration (LWA) is defined as the mean concentration at a given coring location based on the number of core segments, their individual lengths, and PCB concentrations. Essentially, the LWA is mathematically equivalent to the value that would be obtained if the entire core was processed as a single sample. The formula for LWA is as follows:

$$LWA = \frac{\sum_{i=1}^{no.\ core\ segments} Conc_i * l_i}{\sum_{i=1}^{no.\ core\ segments} l_i}$$

where:

$Conc_i$ = PCB concentration in core segment i

l_i = length of core segment i

This parameter was used extensively in the low resolution sediment coring analysis (USEPA, 1998b) and is described further there. Figure 3-9 illustrates the calculation of this parameter. It should be noted that this parameter is sensitive to the depth cored at a location. That is, if several layers are obtained below the interval of sediment contamination, these serve to "dilute" the LWA value. For this reason, the LWA calculation did not include layers with PCB concentrations lower than 1 mg/kg.

Calculation of a true LWA is contingent on collection of a core. Clearly this calculation cannot be performed for a grab. Thus, this limits the usefulness of this parameter in data sets where many grabs have been collected. In their analysis of the 1976-1978 and 1984 data sets, NYSDEC developed relationships between grabs and cores for the purpose of this calculation. However, this calculation is highly uncertain and is essentially just a means of incorporating and integrating the core and grab data on a large scale.

Maximum Concentration

This parameter is simply defined as the maximum concentration obtained at a location. For grab samples, it is simply the reported value. For cores, it is the maximum value found among the core segments obtained at the location. This parameter is used along with its location in the core to assess the depth of contamination as well as the availability of the PCB inventory to the surficial sediments. Thus, cores whose maximum values are found in the top-most segment indicate that much or most of the PCB inventory is relatively near the surface. Conversely, cores whose maxima are found in deeper segments have a relatively smaller fraction of their inventory available to the surficial sediments. This approach is generally utilized for sediment cores with thick segments (nominally greater than 9 inches or 23 cm) and relatively long lengths (greater than 15 cm), where sufficient sediment depth was represented to document the displacement of the PCB maximum below the biologically available portion of the sediment. Additionally, the results from analysis of these data must be contrasted with the documented sediment inventory losses described in the LRC (USEPA, 1998b). That is, inventory losses were seen even when the concentration maxima had moved below the top-most core segment. In these cases, however, the maximum value was substantially lower than that measured previously.

PCB Mass per Unit Area

The last of the main PCB metrics used in the selection of remedial areas is PCB mass per unit area (MPA). Unlike the previous three metrics, each of which represents concentration, MPA is expressed in units of contaminant mass per area of river bottom (*i.e.*, g/m^2), not mass of contaminant per unit mass of sediment (*e.g.*, mg/kg). The MPA represents the total amount of PCB mass found in the sediments below each square meter of sediment surface. MPA is most easily determined from core results because these can be readily integrated into this form. Figure 3-9 presents a typical calculation of the MPA for a core.

In calculating the MPA for a core, core segment length, core segment concentration, and core segment solids density must all be measured or estimated. The solids density (*i.e.*, solids-specific weight) is a necessary component to account for differences in sediment density. Solids-specific weight can vary from roughly 0.5 to 1.3 g/cc and thus strongly affects the calculation. For example, if two sediment samples have the same PCB concentration but one has half the solids-specific weight (*e.g.*, 0.6 g/cc *vs* 1.2 g/cc), the more dense sample has twice the PCB mass in the same volume. The formula for the calculation of the MPA is as follows:

$$MPA = \sum_{i=1}^{no.\ core\ segments} Conc_i * \rho_i * l_i$$

where: $Conc_i$ = PCB concentration in core segment *i*

ρ_i = solids-specific weight of core segment *i*

l_i = length of core segment *i*

Thus, the MPA represents the integration of the PCB content of the core over its length by summing the mass of PCB found in each segment.

The main underlying assumption in the use of the MPA is that the entire sequence of PCB contamination at the sampling site is represented in the core. To the extent this is true, integration of the core provides an unbiased estimate of the sediment inventory, regardless of the rate of deposition. This is different from the "surface" sediment concentration, which may or may not be closely correlated with underlying sediments, depending upon the sampling conditions, core segment intervals, and the current rate of PCB loss or gain by the sediments, among other factors. In calculation of the MPA for short cores or grab samples, assumptions concerning the unrepresented sediment contamination are necessary. In both the 1976-1978 and 1984 NYSDEC surveys, correlations between sediment inventories and surface sediment concentrations were developed and applied to estimate the sediment inventories. This approach yields relatively high uncertainty when predicting the inventory at discrete locations, but should yield reasonably accurate estimates when applied over large areas, incorporating multiple coring and grab sample sites. The reduction in uncertainty at larger scales results from the averaging of the individual estimates. That is, while individual inventory estimates may be far from the true value, the average of the individual estimates will approach the true mean if a sufficient number of samples is collected.

MPA provides a simple basis to estimate total PCB mass over a large area, given as the product of the mean MPA and the area under consideration. Additionally, more recent and more accurate surveys have not characterized the Upper Hudson River as extensively as the earlier surveys. As a result, the data used to select various areas for remediation have been derived from several surveys, utilizing the more current data whenever possible but relying on the historical data to fill data gaps. MPA provides the best means for integrating the results of the major data sets (*i.e.,* 1976-1978 NYSDEC, 1984 NYSDEC, and 1994 USEPA), since estimation of MPA was a goal of each of them. Notably, the GE sediment survey data are not considered in this fashion because of the use of sample composites, designed to represent mean conditions but providing little detail appropriate for the identification of remedial areas. (GE data were mainly considered in assessing "surface" sediment concentrations.)

Calculation of the MPA is readily accomplished for the 1984 NYSDEC and 1994 USEPA sediment inventory investigations, in part because the studies were specifically designed for this purpose. The 1994 survey consisted exclusively of cores that are readily converted to MPA. The 1984 survey collected the greatest number of cores of any survey of the TI Pool, and thus much of the results could readily be converted to MPA. In fact, MPA was the main metric for this study, with much of the data presented in this form. As previously discussed, NYSDEC performed an extensive analysis, correlating sediment MPA with texture, "surface" concentration, and depth of contamination so as to permit the estimation of MPA for all sampling points, both cores and grabs. Applying these data, the 1984 NYSDEC survey provided a benchmark estimate of the inventory of River Section 1 based on the MPA metric. USEPA further refined this estimate using geostatistical techniques and the side-scan sonar results (USEPA, 1997a; USEPA, 1999b).

The MPA was also estimated as a part of the 1976-1978 NYSDEC sediment survey. Tofflemire and Quinn (1979) and NYSDEC (1992) both developed a basis to relate the 1976-1978 shallow cores (0-4 in) and surface grab samples to an estimate of the MPA at each location. These approaches are outlined in the LRC (USEPA, 1998b), with details provided in the original reports. As mentioned above, this approach will yield individual location estimates with relatively high levels of uncertainty, but when considered over large areas should yield accurate estimates of sediment inventory. These calculations were the basis for the comparisons of 1976-1978 and 1994 inventories made in the LRC (USEPA, 1998b).

MPA was found to correlate strongly with "surface" concentrations for both the 1984 and 1994 data sets. This correlation results from the observation that the majority of the cores in both data sets have their maximum concentration in the uppermost core segment. Hence the MPA is largely determined by the same core segment as describes the "surface" concentration. This correlation would not occur if the majority of PCB mass was buried at each location (*i.e.*, if the majority of the PCB mass was found in deeper core segments). The correlations within each of the data sets will be discussed individually later in this section.

MPA correlates even more strongly with LWA, as might be expected from the calculation shown in Figure 3-9. Both MPA and LWA incorporate the core segment lengths and PCB masses. The most important difference between them is the use of a density term (solids-specific weight) in the MPA. Because of the inverse correlation of PCB concentration and solids-specific weight (*i.e.*, higher PCB concentrations occur in sediments with a lower mass of solids per unit volume of sediment), the most contaminated core segments tend to weigh less heavily in the MPA calculation than in the LWA calculation.

Many factors affect the PCB inventory over time and hence the measures of that inventory (*i.e.*, MPA and other concentration metrics). For example, losses via porewater migration or resuspension will decrease the MPA but not necessarily the surficial PCB concentration, depending upon the exchange mechanisms and the extent of PCB inventory below the "surface." However, burial, if it occurs, will serve to increase the MPA slightly, as additional PCB mass is added by the newly deposited sediments while causing a decline in the surface concentration as the less contaminated sediments cover the existing sediment inventory of PCBs. The same change in surface concentration can occur if PCBs are released from the sediment while causing a decrease in the MPA.

The LWA has similar concerns. Deposition by less contaminated sediments serves to decrease the LWA as the PCB inventory increases. This is a result of averaging the recently deposited, less contaminated sediment with the higher concentrations in the existing PCB inventory. The additional contaminated sediment inventory is spread out over a greater depth of sediments. Losses from the sediment serve to decrease both the inventory and the LWA. Hence, only the MPA can be used to track PCB release or storage in the sediment, and thus is the reason MPA is used as a basis for comparison among studies. Its use in the selection of remedial areas is in recognition of the more variable nature of "surface" concentration as well as the need to consider the fate of PCBs that do not currently reside at the "surface" but rather in regions of the sediment where biological mixing, resuspension, porewater migration, and other processes may return these materials to the surface.

As discussed above, there is much evidence for the occurrence of sediment resuspension in the Upper Hudson (Flood, 1993) as well as the absence of long-term burial in many locations (USEPA, 1998b). Additionally, the main PCB flux from the sediments appears to be biologically mediated, originating from the near-shore environment. By their nature, these processes are not inherently limited to surficial sediments. Resuspension serves to remove the surface layer and expose underlying sediments, while biological activity can extend down 10 and perhaps as much as 15 cm into the sediment; therefore, neither the deeper historical PCB "surface" (0-30 cm) concentration data nor the more recent shallower PCB "surface" (0-5 cm) concentration data is necessarily a good indicator of the potential for PCB release in the future. To this end, the MPA, which reflects the entire PCB inventory measured at a location, represents the better measure of the long-term release potential.

3.5.2.2 Application of the Available Data

In identifying potential sediment target areas for remediation, several data sets were used, representing PCB as well as non-PCB data. The number of data sets to apply to the selection of remedial zones varied by river section, with the River Section 1 having the greatest number. The amount of available data decreased moving downstream from River Section 1. The available data sets and their application are described below in chronological order based on date of collection. Table 3-1 provides a list of the data utilized in the selection of potential remediation target areas in River Sections 1, 2, and 3.

NYSDEC 1976-1978 Sediment Survey

This survey produced an extensive set of grab and core samples covering most of the Upper Hudson between Fort Edward and Waterford. Many of the samples were obtained as part of river cross-sections (*i.e.,* a set of samples collected in a line extending from the east shore to the west shore of the river). Additional cores and grabs were taken in areas of fine-grained sediment. These samples were used by NYSDEC to define the original *hot spots.*

Two separate analyses were completed on these data, the first by Tofflemire and Quinn (1979) of the NYSDEC and a second by Malcolm Pirnie for NYSDEC (NYSDEC, 1992). Because of the greater number of grab samples obtained relative to cores, both reports attempted to use the coring data as a basis to estimate conditions below the sediments represented by the grab samples. PCB concentrations to a depth of 12 inches (30 cm) were estimated for each grab location based on the relationship between surficial (0-10 cm) and deeper (10-30 cm) sediments as documented by the core samples obtained during the surveys. This relationship was developed by Malcolm Pirnie to estimate the LWA for each location. The USEPA applied the Malcolm Pirnie relationship to the 1976-1978 data set (NYSDEC, 1990). The results of this calculation were used in the remedial target area selection process.

"Surface" concentrations were represented by grab samples and the top core segments. These sample were considered representative of the top ten cm of sediment.

The MPA values for these data are limited in two aspects. First, the coring data and the grab estimates are limited to the 0- to 30-cm interval. Thus, the estimate of the MPA may be biased low due to the lack of representation of sediment below 30 cm. The potential importance of this underestimation was documented in the LRC (USEPA, 1998b), which described the extensive inventory associated with *Hot Spot* 28 that had not been documented by the 1976-1978 survey. Secondly, additional uncertainty is associated with the lack of density measurements for many of the 1976-1978 sampling locations. Density values for these samples were estimated from sediment texture considerations.

The Aroclor-based PCB analytical data from this survey were used to estimate total PCB and Tri+ concentrations. The conversion algorithms are described in the RBMR (USEPA, 2000a).

Recognizing the limitations of this survey as well as its age, more recent surveys were used to estimate PCB parameters whenever possible. In particular, the subsequent 1984 NYSDEC survey was used in River Section 1. Nonetheless, the 1976-78 survey remains the most spatially extensive and was used to evaluate many areas in River Sections 2 and 3. In using these data, all of the available PCB metrics were used (*i.e.*, "surface" concentration, LWA, and MPA), with greater emphasis placed on "surface" concentration and LWA.

NYSDEC 1984 Sediment Survey

Like the previous survey, the 1984 investigation produced a large set of grab and core samples. However, there were several important differences between the 1984 and the 1976-1978 surveys. The 1984 survey was limited to River Section 1. Cores collected in this survey were typically advanced to two feet, twice the core depth of the 1976-1978 survey. Density was determined for most samples. Grab samples were only obtained when coring was unsuccessful, thus coring was preferentially performed in fine-grained sediment areas where sediments are more easily obtained by this method. This survey represents the most detailed investigation of any section of the Upper Hudson River and forms the primary data set for the selection of remedial target areas in River Section 1.

Data from the 1984 investigation was originally analyzed by NYSDEC as reported in Brown, *et al.* (1988). This analysis, like the prior NYSDEC work, sought to apply the coring data results to the grab samples to estimate the mass of PCBs beneath the depth examined by the grab samples. While focusing largely on the MPA, the technique used by the NYSDEC could be used to estimate both MPA and LWA. In their report, NYSDEC placed greater emphasis on estimating and employing the MPA in their analysis of River Section 1. This emphasis by NYSDEC, as well as the reasons previously described, confirm the importance of this metric as an aid in assessing the long-term PCB release potential from the sediment.

400402

The 1984 sediment data have been extensively analyzed as part of the Phase 2 investigation. The results of the analyses are reported in the DEIR (USEPA, 1997a), the LRC (USEPA, 1998b) and the LRC Responsiveness Summary (USEPA, 1999b). As a part of these analyses, the data were converted to Tri+ estimates to make them directly comparable to other investigations.

The 1984 samples were originally analyzed using one or two methods. Nearly all samples were analyzed using a screening technique. A large subset of these samples was then analyzed using a more rigorous Aroclor-based chromatographic method. The original screening results were classified into three groups: "cold"; "warm"; and "hot." Based on the subsequent chromatographic analysis, these classifications were assigned nominal values, based on the median of the subset of samples analyzed more rigorously. This procedure is described in the DEIR (USEPA, 1997a). Thus the 1984 data fall into two categories from an analytical perspective: screened, and quantitated. Both data sets are used in the selection of remedial areas. As it happened, the majority of the screened samples represents low levels of contamination (*i.e.,* "cold, <10 ppm," or "10<<50" [greater than 10 and less than 50 ppm]), so that samples used to select target areas for remediation were nearly all quantitative data.

In the 1984 study, the data set contains two different "surface" sediment definitions: sediment obtained from the cores (0-30 cm); and sediment obtained from grab samples (depth unknown but assumed to be 0-10 cm or less). Thus the concentration results for "surface" sediments from cores and grab samples are not readily used together since they represent clearly different sediment depths. However, these data remain useful for estimating "surface" concentrations in general since the data set is so extensive.

While all PCB metrics developed from the 1984 data were employed (*i.e.,* "surface" concentration, maximum concentration [cores only], LWA, and MPA), it is useful to note the correlation of surface concentration and MPA. This is illustrated in Figure 3-10. The two graphs in the figure represent the correlations of the "surface" concentration with MPA for the core and the grab data, using only the quantitative results. From these diagrams it can be seen that the results are strongly correlated. This is to be expected for the core results, since the "surface" concentration is represented by the 0-30 cm segment and the majority of the PCB inventory was found to reside in this layer for most cores. The result for the grabs is expected as well since the relationship between concentration and MPA used for the grab samples was developed from the core data. Nonetheless, these diagrams illustrate the effective relationship between MPA and concentration as measured. For both data sets, the "surface"concentration corresponding to an MPA of 3 g/m^2 is approximately 10 mg/kg, and the "surface" concentration corresponding to an MPA of 10 g/m^2 is approximately 30 mg/kg. Since these parameters are so closely related for the 1984 data set, selection of remedial areas based on an MPA or "surface" concentration criterion will tend to identify the same areas. The discussion and derivation of the 3 g/m^2 and 10 g/m^2 criteria are provided immediately after this subsection.

The 1984 sediment data represented the main data set for the selection of remedial areas in River Section 1 based on PCB criteria. All four PCB metrics were determined from the data (note that no PCB maxima were determined from the grab samples) and examined in the selection process.

General Electric 1991 Sediment Composite Survey

GE conducted a survey of the Upper Hudson in 1991 by collection of cores from approximately 1,000 sites. The sediments from these sites were composited based on collection depth and field classification into 309 samples representing three separate depths (0-5, 5-10, and 10-25 cm), or 92 composite samples for each depth. An additional 35 composites consisted of grab sample locations. Only one depth is represented by these composites. These samples represented various areas in the Upper Hudson from Rogers Island to Lock 3.

The stations included in individual composite samples were separated by relatively long distances, up to 1.5 miles below the TI Dam and closer to 0.5 mile in River Section 1. Sample composites were constructed with the intention of matching sediment types (*i.e.,* silts with silts, sands with sands, etc.). However, composites frequently crossed the river, potentially combining sediments from different environments despite the similarity of texture. Additionally, main channel composites were constructed from grab samples, not cores; thus, the true depth of sampling is not well constrained, although it is believed to be on the scale of 2 to 5 cm.

These samples (GE, 1991) were analyzed by capillary column chromatography, and the data were reported as PCB congeners, which were readily converted to a Tri+ basis for this evaluation.

400404

The 1991 GE data were used strictly on a concentration basis, since MPA and LWA were not considered to be well defined in this context. In particular, the limited sample depth (25 cm or 10 in) would potentially yield underestimates for these parameters if substantial PCB inventories were present below this level. Additionally, given the great spatial extent of the samples and the tendency for composites to blur significant areas of high concentration, these data were only used from a review or confirmation perspective. No specific criteria were developed for these data.

USEPA 1992 Side-Scan Sonar Survey

As a part of the extensive geophysical survey conducted during the Reassessment RI, River Sections 1 and 2 were surveyed using side-scan sonar. These acoustic data were used to assess the physical properties of the river bottom, including sediment texture and morphology (Flood, 1993; USEPA, 1997a). The interpretation of these data included the delineation of areas of fine-grained (cohesive) sediment, coarse-grained (non-cohesive) sediment, and rocky areas. The 1984 NYSDEC sediment survey showed the cohesive areas to have significantly higher PCB concentrations relative to non-cohesive areas. This finding was confirmed by the USEPA's low resolution sediment coring program conducted in 1994.

The sediment texture delineations were used in a subsequent reanalysis of the 1984 sediment data (USEPA, 1999b) that was used in turn to prepare the mapping of the river MPA and "surface" concentrations used in selection of remedial areas in River Section 1. Additionally, the noted coincidence of higher PCB levels and fine-grained sediment added fine-grained sediment texture to the list of criteria used in the selection of remedial areas. This criterion was considered secondary to that of the PCB metrics, in part due to the occurrence of glacial clays at the sediment surface. Nonetheless, this criterion was an important consideration in selecting the remedial target areas.

USEPA 1992 Bathymetric Survey

For the Reassessment RI, USEPA also obtained bathymetric data throughout the surveyed areas of River Sections 1 and 2 during the geophysical investigation. These data, which were used to generate bathymetric maps to identify regions of shallow water as well as the main channel of the river, were utilized to support selection of remedial areas based on the supposition that the shallow regions of the river contain relatively higher sediment PCB levels. To this end, bathymetry aided in defining remedial area boundaries for areas already defined as contaminated based on PCB data. In River Section 3, bathymetric data obtained from NOAA navigational charts (NOAA, 2000) were used only in engineering design, not in identification of remedial areas.

USEPA 1994 Low Resolution Sediment Coring Program

Another part of the Reassessment RI involved collection of low resolution sediment cores from the Upper Hudson. These cores were intended to provide current estimates of the PCB sediment inventory for the purposes of comparison with the previous NYSDEC studies discussed above. The cores averaged about 57 cm (22 in) in length, consisting of nominally 23-cm (9-in) segments. The last 5- to 10-cm interval (*i.e.*, the bottom) of the core were analyzed for cesium-137 to establish whether the core included all post-1954 deposition, thereby representing the entire PCB inventory at each location. Seventy cores were collected at 13 clusters in River Section 1. However, the tightly grouped nature of the samples was not appropriate for estimating large area inventories, so these samples were merely considered as an additional set of data for examination. They could not be used to estimate the absolute PCB concentrations or MPA for sediments on a broad scale.

In River Sections 2 and 3, the low resolution sediment coring program examined a total of seven of the historically defined *hot spots*, as originally identified by NYSDEC. NYSDEC's original analysis indicated that these *hot spots* contained about 75 percent of the *hot spot* PCB inventory below the TI Dam. Thus, although only 7 of the 20 *hot spots* below the TI Dam were sampled in the LRC, the majority of the known PCB mass in these regions was surveyed. In these *hot spots*, sampling was done with the express purpose of estimating sediment inventory on a *hot spot* scale. On this basis, these samples were used to estimate the PCB metrics for each of the seven *hot spots* studied.

Quantitation of PCBs in these samples was reported on a congener basis and therefore could be easily converted to a Tri+ basis for analysis and comparison with the other data sets. Like the 1984 data set, the estimation of "surface" concentrations from these samples was based on relatively thick segments (23 cm). MPA and LWA, however, were readily calculated from the data. Also, again like the 1984 data, the "surface" concentration and the MPA were correlated as shown in the upper diagram of Figure 3-11. The MPA criteria of 3 g/m^2 and 10 g/m^2 corresponded to Tri+ PCB concentrations of 9 and 25 mg/kg, respectively. These values were quite similar to those determined from the 1984 data set (10 and 30 mg/kg respectively).

In the lower diagram of Figure 3-11, the correlation between MAP and LWA is shown for the low resolution cores. This correlation is higher than that shown in the upper diagram. This is to be expected, since both MPA and LWA use the majority of core segments at each location. The MPA criteria of 3 g/m^2 and 10 g/m^2 corresponded to LWA values (8 and 24 mg/kg, respectively) very similar to the corresponding "surface" concentration values. This is expected as well, since the top-most segment generally contained the majority of the PCB inventory. Thus MPA, LWA, and "surface" concentration were largely determined by the same core segment, that is, the top one, in each core.

Overall, these data proved most useful in River Sections 2 and 3 where their spatial coverage was designed to aid in estimating *hot spot* scale conditions. These data were supplemented by the 1976-78 data to examine other *hot spots* as well as the areas outside the *hot spots*.

General Electric 1998 Sediment Composite Survey

In 1998, GE undertook a second round of sediment composite sampling. This effort was not as extensive as the first and was largely limited to River Section 1. The survey attempted to replicate many of the 1991 composites, although overall distances represented by individual composites were generally shorter and no cross-channel compositing was performed. Sampling occurred at a total of 165 sampling locations, with two depths obtained per location (0-2 and 2-5 cm). These locations were composited at the two depths to yield 19 samples per depth interval. Three composite grab samples were generated as well, with an undefined depth of collection presumed to be the top few centimeters. Sample composites were examined as part of the remedial target area selection process as measures of "surface" sediment only, due the limited sampling depth. Again, due to their great spatial extent and limited depth, these data could only be used from a review or confirmation perspective. No specific criteria were developed from these data.

400407

General Electric 1998-1999 Sediment Coring Program

In 1998 and 1999, GE collected a number of cores from the Upper Hudson. This coring program really represented a series of small coring studies, each with its own goals. Core slicing intervals, maximum core depth, and distance to other GE coring locations varied among the cores. As a result, the cores obtained are not representative of large areas of the river. To utilize these data, the core results were assembled so as to provide estimates of the 0- to 5-cm concentrations whenever possible. Estimating "surface" concentrations in this fashion was the main application of this data set.

Some subsets of the data focused on *Hot Spots* 14, 16, and 28. These cores could provide data on "surface" (0-5 cm) and shallow (5-15 cm) sediment concentrations, but in most instances the cores were too shallow to be used for an MPA or LWA calculation.

Analytically, these data were similar to the 1991 sediment data and therefore were easily converted to the Tri+ PCB basis.

Like the other GE data, these data were not sufficient to provide a basis to classify large areas of Upper Hudson sediments. These data were used on a review or confirmational basis to support the choices made based on the more extensive data sets.

Summary of Data Sets Available

As a result of the variable data coverage documenting Upper Hudson sediments, no single data set provides a sufficient basis to select areas for remediation in every section of the river. Therefore, coverage of the three sections had to be pieced together to assess PCB contamination, weighing both extent of data coverage as well as the age of the data. Table 3-2 outlines the application of the data sets available in each river section. It should be noted that where one data set presents the main basis of information, the other data sets were used to supplement those data whenever possible. These data sets are noted on Table 3-2 as well.

3.5.3 Criteria for Selection of the Remedial Target Areas

This subsection contains a description of the criteria that were used to develop the three levels (thresholds) of sediment remediation, which in turn were used to construct the remedial scenarios. These criteria were derived based on the information presented in the foregoing discussions, taking into consideration the available data for each river section. While these criteria provide a set of selection parameters, it is important to note that they are applied more as guidelines rather than as absolute rules, for two primary reasons: engineering limitations must also be considered, and much of the existing data is relatively old. Current conditions are unlikely to precisely match historical ones, although it can be anticipated that areas of historically higher PCB concentrations will continue to be contaminated relative to current mean or median conditions. However, considering the age of some of the data as well as the documented variability of the sediment contamination, it is not appropriate to apply the criteria on a strict basis. Rather, the criteria are used to identify remedial areas where elevated levels of PCB contamination are characteristic of the area.

The anticipated remedial operations are not "surgical" in nature and thus it is not appropriate or productive to attempt to remove all sediments exceeding a specified threshold value. It is important to recognize that the purpose of remediation is not to remove all PCB-contaminated sediments exceeding some specified threshold. Given the importance of the near-shore environment to both ecological exposures and PCB release from the sediment, the focus of the application of each remediation threshold will be sufficient reduction of PCB mass and concentration to achieve the RAOs, not to target every isolated contaminated area.

The analyses performed as part of the Reassessment RI have documented the tendency for higher levels of PCB contamination to coincide with fine-grained sediments in the near-shore environment. Additionally, statistical analysis of PCB contamination shows it to occur in patterns aligned with the direction of flow, similar to that seen in the sediment texture itself. Nonetheless, PCB contamination can vary significantly over short distances. Conditions wherein a high concentration is surrounded by a number of low values or vice versa are fairly common. These considerations played an important role in selecting the remedial areas for the Hot Spot and Expanded Hot Spot remediation criteria, since these were intended to reduce PCB levels and exposure without addressing all occurrences of PCB contamination, as noted above. In particular, engineering considerations determined that the minimum unit of area selected for remediation be 50,000 square feet (sq ft).

Since the modeling analysis does not provide a strict numerical value for PCB removal or capping, criteria for identifying sediments targeted for remediation are derived both from the considerations described in this subsection and from general considerations from the modeling analysis. Having identified and selected criteria on this basis, the model was used to compare and contrast the proposed remedial scenarios derived from these criteria. Ultimately, this analysis will be used to calculate the estimated reduction in risk resulting from the remedial scenarios, and thereby indirectly support the selection criteria.

3.5.3.1 Development of Mass per Unit Area (MPA) Criteria

Based on its evaluation of the existing database for the PCB-contaminated sediments, USEPA decided to use MPA as one of the primary criterion for the selection of remedial areas. Three different thresholds were developed to represent a range of remedial activity. The most extensive in each section was the selection of all sediments greater than 0 g/m^2 PCBs (in other words, all sediments within an area; referred to as Full-Section remediation). The other two thresholds were sediments with a nominal MPA greater than 3 g/m^2 (Expanded Hot Spot Remediation) and sediments with a nominal MPA greater than 10 g/m^2 (Hot Spot Remediation). The latter two thresholds were developed from an analysis of the 1984 data set as discussed below.

As discussed previously (subsection 3.4.2.2), the 1984 data set represents the most comprehensive coverage of any major area in the Upper Hudson in any given year. As such, it is considered to be characteristic of the sediment contamination in the Upper Hudson River in general, and so can be used to assess the relationships among river sediment area, MPA, and PCB concentration. That is, what areas are identified by a given MPA threshold? Similarly, how much of the estimated sediment PCB inventory is contained within the sediments whose MPA is greater than the same given threshold?

400410

To answer these questions and derive an MPA target criterion, the relationship among MPA, sediment area, and PCB mass were plotted for River Section 1 using the 1984 data. The sediment data are presented first as a pool-wide basis, then by cohesive and non-cohesive sediment areas. Figure 3-12 presents three diagrams, representing the relationship among MPA, PCB mass, and sediment area for River Section 1. The two upper diagrams of this figure represent area and mass plotted against MPA. In both diagrams, an initial gradual increase in area or mass with decreasing MPA gives way to a sharp rise in these parameters as relatively low values of MPA are approached. Also notable are two distinct rises in the relationships of remediation area and mass with MPA, one between 7 and 8 g/m^2 and one between 1 and 2 g/m^2. These features were not expected and prompted further analysis of the data.

The results for the cohesive and non-cohesive sediments were examined separately to see if these rises in area and mass were present in both sediment distributions. Figures 3-13 and 3-14 present the MPA, PCB mass, and sediment area relationships for the two sediment types, respectively. The cohesive sediments show no break in slope at 1 and 8 g/m^2. The non-cohesive sediments show a more pronounced break in slope at these MPA values. Further investigation into the non-cohesive sediment data showed these breaks resulted from the inclusion of the screened samples. As described above, the 1984 data set included both analyzed and screened samples. Two of the screening classifications comprised the majority of the screened results, "cold, <10 ppm," and "10<<50" (greater than 10 and less than 50 ppm). As it happened, the vast majority of the screened data fell in the non-cohesive areas. Each of these categories was assigned a discrete value: "10<<50" was assigned a value of 18.2 mg/kg and "cold, <10 ppm" was assigned a value of 3.3 mg/kg. These assignments were based on the median value of the samples in each of the groups that were both screened and analyzed. The details of this analysis are provided in Chapter 4 of the DEIR (USEPA, 1997a). After considerations of density and sampling depth, these values translate to 7 and 1 g/m^2. It became apparent that these categories represented a large number of sampling locations, 101 at 7 g/m^2 and 326 at 1 g/m^2. In 1984, there were 1,138 locations in all, thus the relatively high number of occurrences at these discrete values produces the breaks in the MPA curves.

Recognizing that these samples would represent a range of MPAs centered on these discrete values, a secondary set of curves has been generated by a weighted average calculation. These are shown on the diagrams as dashed curves. These curves are expected to more closely represent the true relationships between MPA and the other variables, by partially redistributing the values associated with the screened samples.

In the bottom-most diagrams in Figures 3-12, 3-13, and 3-14, the relationships between PCB mass in the sediments and area remediated are represented for the whole pool, cohesive sediments only, and non-cohesive sediments, respectively. These relationships are defined from their relationships with MPA. Two points are noted on each curve, 3 g/m^2 and 10 g/m^2. These values were selected based on the relationship between mass removed and area affected.

The 3 g/m^2 value was selected as a criterion that represents a theoretical removal of about 90 percent of the PCB inventory in River Section 1 (Table 3-3). That is, if all sediment areas with MPA greater than 3 g/m^2 were removed, 90 percent of the estimated PCB inventory would also be removed. This is accomplished by the remediation of only 47 percent, or 235 acres, of the total river bottom area within River Section 1, a total of approximately 520 acres. This value was chosen to remediate large fractions of both the cohesive and non-cohesive PCB inventories, 98 percent and 84 percent, respectively. A larger fraction of the cohesive area (60 percent) is selected relative to the non-cohesive area (40 percent), as might be expected given the tendency for higher PCB inventories in the cohesive sediment (USEPA, 1997a).

The 10 g/m^2 criterion was selected to represent a theoretical removal of about 65 percent of the sediment PCB inventory. Note that this criterion only selects about 17 percent (85 acres) of the river bottom area within River Section 1. In fact, this criterion focuses the remediation on the cohesive sediments, removing nearly 90 percent of the PCB inventory associated with these sediments. This criterion results in the selection of only 37 percent of the non-cohesive PCB inventory. Thus, the cohesive sediment PCB mass removed represents 70 percent of the total mass removed. The distribution of river bottom area selected yields a similar proportion between cohesive and non-cohesive sediment. The areas included under the 10 g/m^2 criterion include 36 percent of the cohesive sediment area, but only 9 percent of the non-cohesive sediment area. Thus, 80 percent of the total area meeting the 10 g/m^2 criterion consists of cohesive sediment.

Both thresholds (3 g/m^2 and 10 g/m^2) have the potential to remediate the vast majority of the PCB mass while affecting less than half of the TI Pool sediment area. These thresholds also capture the majority of elevated "surface" concentrations as well, discussed later in this section. As shown previously, based on the 1984 NYSDEC and 1994 USEPA data, an MPA of 3 g/m^2 represents an average "surface" (0- to 12-inch) Tri+ PCB concentration of approximately 10 mg/kg, and an MPA of 10 g/m^2 represents an average "surface" concentration of approximately 30 mg/kg. Lastly, it is important to note that the MPA criteria developed here and summarized in Table 3-3 form only one of several considerations in selecting areas for remediation. In particular, engineering considerations as well as data uncertainty will act to reduce the estimates of mass to be remediated under the Hot Spot and Expanded Hot Spot remediation scenarios relative to the theoretical limits set by the strict data interpretation described above. The complete set of criteria for each of the three remedial threshold is presented below.

3.5.3.2 Remediation Threshold Criteria

The criteria for each of the three remediation thresholds - Full-Section remediation, Expanded Hot Spot remediation, and Hot Spot remediation - are described below.

Full-Section Remediation

This threshold involves the remediation of all sediment in the entire river section, with the exception that areas are excluded based solely on engineering issues and sediment texture. That is, accessibility by the remedial equipment is the major limitation in deciding whether an area receives remediation. The engineering issues themselves are described later in this report. The only other concern in this regard is the identification of rocky areas of the river bottom. In general, these areas have not been demonstrated to harbor significant PCB inventories or concentrations, nor are they readily treated using standard dredging equipment. As a result, areas defined as rocky are excluded under this remediation scenario. It should be noted that this threshold (Full-Section remediation) is only developed for River Sections 1 and 2.

Expanded Hot Spot Remediation

The criteria for the selection of remedial areas under this threshold were designed to identify and treat the majority of fine-grained PCB contamination as well as similarly contaminated areas of coarse-grained sediments in the river section. Effectively, this sediment target threshold includes nearly all significant near-shore contamination and reduces PCB contamination near or in the river channel. To accomplish this, the following criteria were established:

1. Remediate sediment with a MPA greater than 3 g/m^2;
2. Remediate "surface"sediment concentrations greater than 10 mg/kg;
3. Select contaminated locations in proximity to other locations of comparable level of contamination (*i.e.*, meeting criteria 1 or 2 immediately above), so as to generate a target area of sufficient size (see criterion 4, below) for remediation;
4. Select a minimum area to be remediated of no less than 50,000 sq ft; and
5. Select remediation area boundaries based on sediment texture bounds and bathymetry, where appropriate.

These criteria were applied to the Upper Hudson River to identify areas for Expanded Hot Spot remediation for each of the three river sections.

Hot Spot Remediation

The criteria for the selection of remedial areas under this threshold were designed to identify and treat a smaller area of the river as compared to the Full-Section and Expanded Hot Spot remediation thresholds while still capturing the worst conditions measured. Effectively, this scenario is limited to the fine-grained areas in the near-shore environment. Given the likelihood that the near-shore environment is both the main PCB release area and the main area of biological exposure, this remediation was designed to provide a substantive reduction in release and exposure. To accomplish this, the following criteria were established for the Hot Spot remediation threshold:

1. Remediate sediment with a MPA greater than 10 g/m^2;
2. Remediate "surface"sediment concentrations greater than 30 mg/kg;

400414

3. Select contaminated locations in proximity to other locations of comparable level of contamination (*i.e.*, meeting criteria 1 or 2 immediately above), so as to generate a target area of sufficient size (see criterion 4, below) for remediation
4. Select a minimum area for remediation of no less than 50,000 sq ft; and
5. Remediate area boundaries based on sediment texture bounds and bathymetry, where appropriate.

These criteria were applied to the Upper Hudson River to identify areas for Hot Spot remediation in each of the three river sections.

3.5.4 Criteria Application

The application of the criteria described above yields a substantial volume of sediment, regardless of the remediation target threshold. The range in volume is approximately two-fold from the smallest scale (Hot Spot remediation) to the largest scale (Full-Section remediation) effort. Table 3-4 presents a summary of the remediation volumes on a section basis. To construct the sediment volumes for the remedial scenarios described later in the FS, one need only match the river section with its assigned level of remediation and sum the values to obtain the volume for the entire Upper Hudson. Results for areas affected and mass of PCBs removed, based on the 1984 data, are also presented in Table 3-4.

The discussions above describe the criteria used for the selection of sediment areas for remediation. The selection criteria for the Full-Section remediation are based solely on engineering considerations that are discussed later in this report. A more detailed description of the areas included within the Full-Section threshold, including figures illustrating the areas involved, is presented later in this FS. For the other two remedial thresholds, however, the criteria given above could not be applied in an absolute way due to conflicting considerations (*e.g.*, area size *vs.* degree of contamination). In light of this, it is useful to see several examples as to how these criteria were applied.

3.5.4.1 Examples of the Areas Selected Under the Expanded Hot Spot Remediation

The Expanded Hot Spot remediation threshold considered MPA and "surface" concentration. Typically, these criteria lead to the same or similar area selections. Five examples of the criteria application are provided for the Expanded Hot Spot remediation: two from River Section 1; two from River Section 2; and one from River Section 3.

River Section 1 (I)

The first example covers the river in the vicinity of *Hot Spot* 8, RM 191 to 192.5. This area of the river has seen a fairly extensive amount of study, with data available from all eight data sources listed previously. Figure 3-15 illustrates each of the data sets examined in this area, with MPA and "surface" concentrations calculated for the 1976-78, 1984, and 1994 investigations. As a result, there are a total of 19 data representations (*i.e.,* 19 diagrams) on the figure, including diagrams of the original NYSDEC *hot spot* boundaries, the Expanded Hot Spot remediation scenario boundaries, and the Hot Spot Remediation scenario boundaries. Each diagram in the figure represents the same area of the river, with a different data representation superimposed on the map. Sample locations have been color-coded by concentration or MPA on a log-scale, with half-log steps (factor of 3.16 or $10^{1/2}$), in recognition of the log-normal distribution that is characteristic of PCB contamination in the Upper Hudson (USEPA, 1997a). The same color coding is used in all point representations of the data. That is, the range of values 3.2 to 10 is always bright blue for all sampling point representations, both MPA and concentration. The only exception is the polygonal declustering results for 1984, which uses a different color scheme.

Also shown on each map are the boundaries relating to rock or rocky areas of the river bottom, dredge spoil mounds, and islands, each of which are unlikely to be included in the remedial areas selected. Two bathymetric contours are shown on each diagram, at 6.5 and 12.5 feet, as an aid in locating the shoals and channel. Finally, the remediation boundaries are shown in each diagram to illustrate how the boundaries compare with the data used to derive them.

Three remedial target areas have been identified in Figure 3-15. The largest and most important of these areas is found along the eastern shore, coincident with the original NYSDEC *Hot*

400416

Spot 8. The other two are found along the western shore, one at RM 192 and the other at RM 191.5, corresponding to *Hot Spot* 9. In the first two diagrams of Figure 3-15, the 1976-1978 NYSDEC sediment survey results are plotted as MPA and "surface" concentrations, respectively. These data show a general coincidence of higher values within the selected areas. However, these data were not strictly considered in determination of the target area since they were superseded by the more extensive and definitive 1984 survey, which is represented in the next four diagrams of the figure. In the first two of the 1984 diagrams, the data have been represented as individual points. For the 1984 MPA diagram, locations marked by bright blue or lighter colors are nearly all contained in the selected areas. The river channel near RM 191.8 has several blue points scattered among the darker markers that would, strictly speaking, meet the MPA criteria. However, these locations represent grab samples with low surface concentrations (less than 10 mg/kg; see the next diagram) found outside the cohesive areas (see the sixteenth diagram), and are therefore not included. The 1984 diagrams show how the more contaminated locations in both concentration and MPA are not only coincident but also are captured within the remediation boundaries.

Diagrams 5 and 6 show the 1984 data in a Thiessen polygon representation. This approach has been previously presented in the LRC Responsiveness Summary (USEPA, 1999b) and summarized in Chapter 1, and is therefore not repeated here. Essentially, the polygons have been assigned values based on their locations within the side-scan sonar boundaries and their proximity to 1984 samples of similar sediment texture. Thus, cohesive sediment samples were used to define polygon properties in cohesive sediment areas and non-cohesive sediments were applied to polygons in non-cohesive areas. As can be seen on these diagrams, the vast majority of the polygons with elevated MPA or "surface" concentration lie within the target remediation areas included within the Expanded Hot Spot criterion. Note that the threshold color for MPA is yellow while the threshold color for "surface" concentration is the faded green. An occasional polygon with MPA or concentration above the threshold lies outside or partly outside the boundaries, but these areas are scattered and therefore do not meet the third criterion, proximity to other contaminated areas. In some instances, the remediation boundary crosses through a polygon. In most cases, the sampling point has been included but the polygon has been clipped based on bathymetry, sediment boundaries, or simply the assessment that the remainder of the area (polygon) is relatively far from the sampling location and therefore poorly known.

The next three diagrams represent the composite samples from the 1991 GE investigation. Application of these data for selection purposes is problematic due to the manner in which the samples were obtained. The compositing process creates a mechanical average of the samples and limits the high and low values. Additionally, the GE composite samples spanned long distances and frequently crossed sediment boundaries as defined by the side-scan sonar results. As a result, these data are only useful to confirm areas of high PCB concentrations, but are not used to eliminate marginal areas. The three diagrams represent the GE composites from 0 to 5 cm, 5 to 10, cm and 1 to 25 cm. In general, the eastern remedial area is confirmed by the GE samples as exceeding the criterion of 10 mg/kg in the "surface" layer. The western remedial areas are not completely coincident with the GE composites; therefore, the samples are of limited usefulness. Note that several composites cross the river in the vicinity of the western remedial areas.

Diagrams 10 and 11 represent the 1994 USEPA low resolution coring data in the region. While these data are not sufficient to redefine the remedial boundaries, they serve to confirm the general level of contamination. Sediment inventories and "surface" concentrations appear lower in most matched locations but are still above the threshold criteria for both parameters.

Diagrams 12 and 13 represent the 1998 GE composite samples at 0 to 2 and 2 to 5 cm depth intervals, respectively. These data have the same limitations as the 1991 results but still confirm the elevated concentrations along the eastern shore. Diagrams 14 and 15 represent the 1998-1999 GE coring data from the area. These data, like the 1994 USEPA results, confirm the existence of higher PCB levels in the remedial areas, with conditions similar to those seen in 1994.

Diagram 16 represents the 1992 side-scan sonar interpretation. The basic approach for establishing the remedial boundaries becomes evident through an examination of this diagram in conjunction with the 1984 MPA diagrams. Essentially, areas of higher contamination were identified with the 1984 data and then bounded using the side-scan sonar interpretation. Subsequent data served to substantiate this approach and confirm the continued existence of contaminated sediments in terms of both PCB inventory and "surface" concentration. Diagrams 17 and 18 are provided simply for reference to permit a comparison of the Expanded Hot Spot remediation areas to the original NYSDEC *hot spots* and the less extensive Hot Spot remediation.

River Section 1 (II)

Figure 3-16 represents the area near *Hot Spot* 14, between RM 189.6 to 190.6. The figure is structured in the same manner as Figure 3-15. Here again, the 1984 data set is the basis for identifying areas of contamination. The side-scan sonar boundaries are used as guides for the remedial area boundaries. Data collected subsequent to the 1984 study confirm these areas as contaminated. The exceptional area in this figure is the remedial area to the west of Griffin Island. This region is not characterized by high MPA (greater than 3 g/m^2) values based on the 1984 data, although some marginal MPA values (3 to 10 g/m^2) were obtained in 1994. However, high surface concentrations were obtained in 1984 and 1994, and these data are further supported by the 1991 GE composites for the area. On this basis, the area was selected for remediation. It should be noted that this area also contains the location used by NYSDEC for its spring fish monitoring station. Elevated concentrations of PCBs in fish were also found in this area (*e.g.*, PCB concentrations in largemouth bass averaged over 23 ppm in 1997, based on NYSDEC data for Griffin Island [USEPA, 2000t]), further supporting the selection of this area for remediation.

River Section 2 (I)

Figure 3-17 represents the area around *Hot Spot* 28, RM 185.2 to 186.2 from Section 2 of the river. There are six fewer diagrams on this figure than on Figures 3-15 and 3-16 because no 1984 NYSDEC samples and no 1998 GE cores were obtained in this area. The 1976-1978 NYSDEC data showed this area to be contaminated, as is evident in the first two diagrams. The 1994 results showed the NYSDEC data to have seriously underestimated the sediment inventory in this area (USEPA, 1998b), as can be seen by comparing diagrams 1 and 6. Diagram 6 shows a larger proportion of locations greater than 100 g/m^2. The 1991 GE composite results for the area (diagrams 3, 4, and 5) do not suggest elevated "surface" concentrations. However, the GE composites extend over such long horizontal distances that they are of little value in delineating remedial areas. As shown in diagrams 8 and 9, the 1998 GE cores were few in number but nearly all the GE composites confirmed the presence of PCB contamination exceeding the criteria.

Definition of the remediation boundaries was based on the side-scan sonar results for the area and the 1994 sediment data. This can be observed by comparing the remediation boundaries with the 1994 data and the side-scan sonar map in diagram 11. The only difference between the Expanded Hot Spot remediation and the Hot Spot remediation for this area is the exclusion of the shore area below RM 185.6. This exclusion is based on the relatively low levels of concentration observed in this area in the 1976-1978 survey. No subsequent data were obtained in this area.

River Section 2 (II)

Figure 3-18 is a representation of the area around *Hot Spots* 34 and 35, RM 183.25 to 184.25, in River Section 2. Like the previous area, no 1984 data and no 1998 composite data are available. Additionally, no 1998-1999 coring data are available either. This reduces the figure to 10 diagrams. The 1976-1978 data show this region to contain many contaminated locations with "surface" concentrations frequently greater than 100 mg/kg. The 1991 GE composite data are again very limited in their usefulness due to the length of river from which composites were generated. The 1994 data set produces values that are still above the thresholds for MPA and concentration, but are relatively lower than those observed in 1976-1978. This is consistent with the conclusions of the LRC (USEPA, 1998b). The fact that both inventory and concentration decline suggests loss to the water column and hence to locations downstream. The 1994 data, while not as extensive as the 1976-1978 data, are still considered sufficiently representative of the area to indicate the continued contamination of cohesive sediments in the region. Thus the 1994 data along with the side-scan sonar are used to define the remedial areas. The remedial areas for the Hot Spot remediation are also shown on the figure. These areas are also largely defined from the side-scan sonar data, with a truncation of the northern extent of remediation based on the lack of substantive levels in the 1976-1978 data set and the lack of any subsequent sampling.

River Section 3

Hot Spot 36 in River Section 3 is the last example area to be examined for the Expanded Hot Spot remediation, as shown in Figure 3-19. The available data for this area is more limited than any previously described. Only 1976-1978 NYSDEC samples and 1991 GE composites are available for the area. While the 1976-1978 data document an extensive inventory and elevated "surface" concentrations, particularly around the 6.5-ft contour, the 1991 GE sample data do not appear to include this area. Some of the discrepancies may be due to differences in the USEPA and GE maps of the region. Nonetheless, the GE samples are composited over such a long area that they lack the ability to discern local PCB contamination. Side-scan sonar data were not available for River Section 3, but some data on sediment texture was obtained by GE during a sediment probing study, surveying the river bottom with a long, thin pole. These results are considered only approximate but suggest the continued presence of fine-grained sediments in this area. Consideration of the 1976-1978 sediment data and the GE sediment probe study was the basis of the boundaries shown in Figure 3-19. It should be noted that none of the area around *Hot Spot* 36 was selected for the Hot Spot remediation because of its generally lower level of concentration.

3.5.4.2 Examples of the Areas Selected under the Hot Spot Remediation

In Figures 3-15 to 3-19, one diagram representing the Hot Spot remediation is included for comparison with the Expanded Hot Spot Remediation. In Figures 3-17, 3-18, and 3-19, the boundaries are similar enough that further discussion is not needed. However, in River Section 1, the differences between the two remediation approaches are less straightforward, largely due to the greater abundance of data. To demonstrate this, two examples are shown, corresponding to the first two examples given above.

Figure 3-20 presents the area around *Hot Spot* 8. The diagrams in Figure 3-20 correspond exactly to those in Figure 3-15, the difference being a less extensive remediation area. The data presented in Figure 3-20 are identical to those shown in Figure 3-15. The best place to begin the comparison is with diagrams 18 and 19 in the figures. These permit a direct comparison of the areas selected. In general, the areas included under Hot Spot remediation are narrower as well as less extensive than those included under Expanded Hot Spot remediation. The large eastern shore remediation area is narrower off the islands and no longer extends across the width of the river at the northern end of the example area. The southernmost end is also trimmed. These adjustments are developed from the Thiessen polygons shown in diagrams 5 and 6. Note the lesser extent of areas greater than 10 g/m^2 as compared to areas greater than 3 g/m^2. Some of the adjustment is designed to follow the cohesive/non-cohesive boundary more closely, such as at the southern end of the eastern remediation area.

The areas defined for the Hot Spot remediation are also supported by the 1994 MPA and 1998 MPA results, although these data are not sufficient to redefine the boundaries (see diagrams 10 and 14, respectively). These areas are less well-supported by the later PCB concentration data. The 1991 and 1998 GE composites only show elevated concentrations in the deeper segments on the eastern shore but again, these samples cover long distances and areas outside the selected areas and so serve to minimize local maximums. The 1994 "surface" concentrations showed a good correspondence with the MPA for two of the three areas. The area on the southwest shore had low surface concentrations relative to the 30 mg/kg threshold, but was still selected since the MPA exceeds the Hot Spot remediation threshold (10 g/m^2). The 1998 GE core data were generally supportive as well, with exceedances in the selected areas for both MPA and "surface" concentration. Overall, the areas selected for the Hot Spot remediation tended to be closer to shore as well as more concentrated within the cohesive sediments, noted previously in Figures 3-12 through 3-14.

Figure 3-21 represents the Hot Spot remediation areas in the vicinity of *Hot Spot* 14, corresponding to Figure 3-16. Again the diagrams in Figure 3-21 correspond exactly to those in Figure 3-16, simply with the Hot Spot remediation areas indicated. A comparison of diagrams 18 and 19 shows that the areas selected for Hot Spot remediation are narrower and less extensive than those for the Expanded Hot Spot remediation, as anticipated. In particular, the large areas of non-cohesive sediments along the eastern shore of Griffin Island (the western side of the main river channel) have been excluded by the application of higher MPA and concentration thresholds. These areas fall just below the Hot Spot remediation criteria and just within the Expanded Hot Spot remediation criteria. The Hot Spot Remediation criteria tend to leave a few scattered areas in exceedance of the thresholds. The reduced areas are consistent with the 1991 to 1998 USEPA and GE sediment data. Diagrams 8 through 14 document the elevated MPA and concentrations found in these areas. A large area (polygon) exceeding the MPA threshold can be seen in the main river channel at RM 189.8. This polygon was not selected under either remediation threshold because it is based on a single point located in among the rocky areas to the east of the channel. The point can be seen in diagram 4 at roughly RM 189.8.

These examples highlight the main difference between the two remediation approaches. The MPA and concentration thresholds of the Hot Spot remediation tend to leave out the less contaminated non-cohesive sediments that border the cohesive sediments or the shorelines. Both

Hot Spot and Expanded Hot Spot remediation criteria include the majority of contaminated cohesive sediments.

3.5.4.3 Capture Efficiency

To assess the net effect of the various criteria used to develop the Ful-Section, Expanded Hot Spot, and Hot Spot remediation thresholds, USEPA calculated the "capture efficiency" of each approach to assess the degree to which the areas targeted for remediation include the areas meeting a strict application of the threshold criteria. The capture efficiency is the percentage of area within a river section containing PCB-contaminated sediment at or exceeding the threshold MPA that is targeted for remediation (*i.e.*, captured). Capture efficiency is best determined using the 1984 NYSDEC data set for River Section 1 (TI Pool), because only this data set is sufficiently detailed to estimate the removal and residual percentages. However, similar capture efficiencies would be expected for River Sections 2 and 3 if the data for these sections allowed similar calculations to be performed.

For Full-Section remediation, all sediment is remediated, so the PCB-based criteria are effectively an MPA of 0 g/m^2 or greater and a "surface" concentration of 0 mg/kg or greater. Full-Section remediation addresses 97 percent of the 15,400 kg of PCBs in River Section 1, based on the 1984 data. (The percentage is less than 100 since areas within River Section 1 which are unavailable [inaccessible] for treatment due to various engineering or access limitations are excluded from Full-Section remediation.) Table 3-4 presents estimates for mass of PCBs remediated in each of the river sections. For River Section 1, the percentage of the total PCB inventory addressed by each remediation scenario is listed. For River Sections 2 and 3, however, it is not possible to calculate a percentage of PCB mass remediated, because the data are insufficient to estimate the total PCB inventory within these sections.

The Expanded Hot Spot remediation captures 86 percent of all locations with an MPA of 3 g/m^2 or greater, 77 percent of all locations with MPAs of 1 g/m^2 or greater, 87 percent of all locations with a "surface" concentration of 10 mg/kg or greater, and 85 percent of all locations with "surface" concentration of 3.2 mg/kg or greater. Put another way, the Expanded Hot Spot remediation, which is based primarily on an MPA of 3 g/m^2, leaves behind only 23 percent of all areas with an MPA of

1 g/m^2 or more and only 15 percent of all areas with a "surface" concentration of 3 mg/kg or more. Simply stated, even though Expanded Hot Spot remediation is defined in part by the use of 3 g/m^2, the Expanded Hot Spot remediation would address a substantial portion of the sediment contained within an MPA of 1 g/m^2 or more. This is illustrated in Figure 3-22. In each diagram contained in the figure, the selection criterion is noted on a histogram of the 1984 sample data. The 1984 data are tallied in the diagram as individual measurement locations. In each diagram, it is clear that the selection process has captured the majority of the 1984 locations exceeding the Expanded Hot Spot remediation criteria. Notably, the Hot Spot remediation addresses 75 percent of the total PCB inventory in River Section 1 (see Table 3-4). Within River Section 1, 92 percent of the total PCB inventory is contained in sediments with MPA of 3 g/m^2 or higher. Therefore, the capture efficiency of Hot Spot remediation is calculated as the 75 percent addressed divided by the 92 percent included in the applicable criterion (3 g/m^2), for a capture efficiency of 82 percent (75/92). This mass of PCBs captured under Hot Spot remediation (82 percent) compares well with the sediment areas addressed under this threshold (86 percent of the area with MPA of 3 g/m^2 or greater).

The Hot Spot remediation captures 73 percent of all locations with an MPA of 10 g/m^2 or greater and 76 percent of all locations with a "surface" concentration of 32 mg/kg or higher. This is illustrated in Figure 3-23. The approach captures the majority of the 1984 locations exceeding the MPA and "surface" concentration criteria. The lower capture efficiency compared to the Expanded Hot Spot remediation results from a number of relatively small isolated areas with MPA values greater than 10 g/m^2 that are not selected due to their isolation and size (<50,000 sq ft; these areas are small, disconnected segments). The areas created using the Expanded Hot Spot remediation criteria are generally more contiguous with fewer isolated areas than the Hot Spot remediation, as can be seen in the examples previously presented. Notably, the Hot Spot remediation addresses 56 percent of the total PCB inventory in River Section 1 (see Table 3-4), out of a possible 66 percent of the PCB inventory which is contained in sediments with MPA of 10 g/m^2 or higher. This represents about 85 percent (56 percent divided by 66 percent) of the theoretical limit. This capture of 85 percent of the PCB mass included under Hot Spot remediation is relatively high compared to the capture of about 73 percent of the areas meeting the 10 g/m^2 criterion. This difference (85 percent capture on a mass basis, as compared to 73 percent capture on an area basis) is attributed to the observation regarding the distribution of 10 g/m^2 areas noted above (*i.e.*, the occurrence of small isolated areas with MPA values greater than 10 g/m^2 that are not selected due to their isolation and size).

3.5.4.4 Other Considerations

Application of the PCB contamination and engineering criteria described above served to create three thresholds focused on reducing both sediment PCB inventory as well as sediment "surface" concentrations. These criteria were best applied in River Section 1 where data were relatively plentiful, as compared to locations downstream. River Section 2 also had a fairly robust data set against which to apply the selection criteria. The River Section 3 data set was the most limited of the three sections and as a result, USEPA also considered other observations besides direct sediment measurements in selecting possible remediation areas. In particular, the 1993 USEPA water column study observed a substantial resuspension event associated with a one-in-three to one-in-five-year flow event on the Hoosic River. During this event, resuspension from the Hudson River sediments significantly raised water column PCB concentrations and loads. This is discussed in the DEIR (USEPA, 1997a) and LRC Responsiveness Summary (USEPA, 1999b). Water column loads were equivalent to the peak GE-related discharges from Hudson Falls seen that year (18 kg/day total PCB).

Given the frequency with which such flow events can occur (once every three to five years), these events will serve to resuspend and transport contaminated Hudson River sediments from the vicinity of the Hoosic River on a regular basis, contaminating downstream areas. While the exact source area of the resuspended sediments is unknown, *Hot Spot* 37, immediately downstream of the Hoosic River confluence, is a likely candidate. This area *hot spot* has lost a substantial portion of its 1976-1978 sediment inventory (USEPA, 1998b), although it still retains a significant PCB inventory. For this reason, this *hot spot* is likely to be selected regardless of remediation approach. Similarly, *Hot Spot* 36 lies in a relatively unsheltered region of the river and is also likely to be subject to regular scour events (although not from the Hoosic River, whose confluence is further downstream). Concern over its contributions to PCB resuspension would dictate its selection for remediation as well.

An additional consideration in the identification of target areas is centered on *Hot Spot* 39, located in River Section 3. This *hot spot* represents a unique condition in the Upper Hudson River. Specifically, several of the core profiles obtained from this *hot spot* as part of the 1994 USEPA investigation indicated very high rates of sediment deposition. As noted in the LRC (USEPA, 1998b), many of the cores from this *hot spot* were incomplete, in that the typical 3-foot core length did not extend through the entire thickness of contaminated sediments. Based on these results, it was concluded that the historical PCB inventory was undergoing burial in part of the *hot spot.* The areas within *Hot Spot* 39 undergoing significant burial were identified by those cores whose PCB maximum occurred below 24 inches. This criterion identified the central portion of the *hot spot* as undergoing significant burial. For this reason, this portion of *Hot Spot* 39 was excluded from consideration under the Select remediation delineations. (Note that the Select remediation delineations for this reach are developed in Chapter 6 of the FS.) In this portion of the *hot spot* it is believed that the bulk of sediment contamination lies sufficiently below the surface and would not be expected to pose a future problem. Additionally, the high rate of deposition in this area should further isolate the contaminated sediments. It should be noted that the portion of *Hot Spot* 39 excluded from Select remediation was included in the target areas identified under Hot Spot and Expanded Hot Spot remediation.

Other areas within, or in the vicinity of, the NYSDEC delineation of *Hot Spot 39* had core profiles more typical of Upper Hudson sediment contamination, with PCB maximum concentrations occurring in the uppermost layers of complete cores. As a result, these areas were considered in the selection of remedial target areas. These areas are all within the southern portion of *Hot Spot* 39, or just south of the NYSDEC delineation, and are referred to in the Select remediation as "the southern portion of *Hot Spot* 39".

3.6 Identification of General Response Actions

General response actions (GRAs) are categories of actions that may be implemented to achieve the project-specific RAOs. GRAs may include (but are not limited to) such categories as treatment, containment, disposal, or combinations of these categories. General response actions identified for remediation of the Hudson River PCBs Site include the following:

- No Action;
- Monitored Natural Attenuation;
- Institutional Controls;
- Containment;
- *In situ* treatment;
- Removal;
- *Ex situ* treatment;
- Beneficial Use; and
- Disposal.

The GRAs listed above represent only actions that would be applied directly to the contaminated sediments. Implementation of additional remedial activities, such as habitat replacement, water treatment, backfill, and the like are considered part of the general actions listed above. These additional remedial activities are considered in the technology screening, alternative development, and detailed analysis chapters that follow.

A brief description of each of the general response actions is provided below.

3.6.1 No Action

No Action will be considered throughout each phase of the FS, as required by the NCP. Under the No Action alternative, contaminated river sediments will be left in place without treatment or containment. The effectiveness of this alternative is assessed as though there are no controls in place, and existing upstream PCB loads (averaging 13 ng/L Tri+ PCBs, as previously discussed) are assumed to continue indefinitely. No additional institutional controls or monitoring would be implemented as part of the No Action alternative. No Action is appropriate if the site poses no current or potential threat to human health or the environment.

3.6.2 Monitored Natural Attenuation (MNA)

Monitored Natural Attenuation includes monitoring and may include modeling to assess the status and future of contamination at the site, but does not include active remedial measures. This response action may be appropriate if *in situ* processes would achieve site-specific RAOs in a time frame that is reasonable compared to active remedial measures. For the Hudson River Reassessment RI/FS, MNA includes the assumption that upstream remedial actions currently planned or underway (*e.g.*, such as the separate Non-Time Critical Removal Action [NTCRA] in the vicinity of the GE Hudson Falls plant, conducted outside the scope of this FS) will reduce the upstream Tri+ PCB load to about 0.0256 kg/day, corresponding to a concentration of about 2 ng/L, by January 1, 2005. MNA may be used as one component of a total remedy, either in conjunction with active remediation, or as a follow-up measure.

3.6.3 Institutional Controls

Institutional controls are administrative or legal controls intended to prevent or reduce human exposure to on-site hazardous substances, processes established to reduce exposure to contaminants of concern (*i.e.*, PCBs) on a community and regional basis. For example, institutional controls for the Hudson River PCBs site may include fish consumption advisories or fishing restrictions. Institutional controls are typically utilized in conjunction with other remedy components, and not as a stand-alone remedy.

3.6.4 Containment

Containment involves the physical isolation or immobilization of contaminated sediment without treatment, for example, by an engineered cap. Containment technologies can be used to isolate contaminated sediment, thereby limiting the potential exposure to, and mobility and bioavailability of, contaminants in the sediments.

3.6.5 *In situ* Treatment

In situ treatment technologies may be used to reduce contaminant concentrations without removal or containment of the contaminated sediments. Also, some *in situ* processes such as stabilization or solidification may reduce contaminant mobility or bioavailability.

400428

3.6.6 Removal

Removal of sediments from the river consists of dredging or excavating contaminated sediments for subsequent treatment or disposal. Contaminants (PCBs) are removed from the river bed by this response action.

3.6.7 *Ex situ* Treatment

Ex situ treatment is treatment of PCB-contaminated sediments prior to removal (subsection 3.6.6) of the contaminated sediments. Numerous *ex situ* treatment options are available. Sediments may be disposed of on land after treatment to meet disposal criteria; or offered for beneficial use after treatment (including reuse as backfill for excavated sediments in the river) to meet beneficial use criteria.

3.6.8 Beneficial Use

Beneficial use means that sediments removed from the river and meeting relevant criteria (either with or without treatment) are used or placed in a manner that provides some benefit to the public.

3.6.9 Disposal

Disposal is the placement of material (after removal) into a site, structure, or facility on a temporary or permanent basis. Depending on the type of disposal, the excavated material may undergo limited or extensive treatment prior to disposal. The disposal options vary depending upon the characteristics of the excavated material (*e.g.*, PCB concentration) and the degree and type of treatment of the material prior to disposal. Disposal, as a GRA, is differentiated from beneficial use in that the contaminated material is assumed to require isolation from human and ecological receptors to prevent adverse health or environmental effects.

Chapter 4

4. IDENTIFICATION AND SCREENING OF REMEDIAL TECHNOLOGIES

Previous studies of the Hudson River have been reviewed as part of the process of identifying technologies for consideration in this FS, including the NUS Feasibility Study (USEPA, 1984b) and the Hudson River PCB Reclamation/Demonstration Program report by Malcolm Pirnie, Inc. (NYSDEC, 1985), prepared as part of the Hudson River PCB Reclamation/Demonstration Project. The majority of the treatment technologies reviewed at the time of publication of the NUS and MPI reports were in the early stages of development, and little was known about their environmental effects and costs. In addition, in some cases technologies had undergone preliminary testing but were not developed further, or the process developers had since left the market. The Phase I Report for this Reassessment RI/FS (USEPA, 1991a) provides a preliminary technology screening.

Various databases, technical reports, and publications, discussed in Section 4.1 below, were used in conducting an updated search to identify and evaluate remedial technologies for use at the Hudson River PCBs site. These and other resources were used to identify a number of potentially applicable remedial technologies or process options for dealing with Upper Hudson River sediments contaminated with PCBs. As an initial screening, each of the potentially applicable remedial technologies was evaluated in terms of effectiveness and technical implementability at the site. A brief description of the remedial technologies considered and the initial screening process is presented in Section 4.2, and a summary of the screening process is presented in Table 4-1. Technologies that were retained after the initial screening were submitted to a second screening process and evaluated in terms of effectiveness, implementability, and costs. The second screening process is presented in Section 4.3 and summarized on Table 4-16. Technologies that were retained after the second screening were then used to develop remedial alternatives for the site as discussed in Chapter 5.

4.1 Sources and Methods for Identification of Potentially Applicable Technologies

Among the databases, technical reports, and publications used in the search, of particular note are the USEPA sources as follows:

- Superfund Innovative Technology Evaluation (SITE) Program (USEPA, 1999g);
- *Selecting Remediation Techniques for Contaminated Sediment* (USEPA, 1993b);
- *Assessment and Remediation of Contaminated Sediments (ARCS) Program Remediation Guidance Document* (USEPA, 1994);
- USEPA Hazardous Waste Clean-up Information (CLU-IN) web site (USEPA, 2000e);
- USEPA Remediation and Characterization Innovative Technologies (USEPA REACH IT) database (USEPA, 2000f);
- Federal Remediation Technologies Roundtable (FRTR, 1999) web site; and
- Remediation Technologies Network (RTN) Remediation Information Management System (RIMS, 2000) Database.

The SITE Program was created by USEPA to encourage the development and use of innovative treatment and monitoring technologies. Under the program, USEPA works with and supports technology developers who research, refine, and demonstrate innovative technologies at hazardous waste sites. SITE demonstration project information is compiled and can be used as a reference guide on innovative treatment technologies.

The ARCS Program was initiated in 1987 by USEPA's Great Lakes National Program Office (GLNPO) to address sediment contamination in the Great Lakes. The ARCS program consisted of a five-year study and demonstration projects relating to the treatment of contaminated sediments. The ARCS remediation guidance document is a product of the ARCS Program, and was prepared by the Engineering/Technology Work Group (ETWG), a working committee under the ARCS Program. The guidance document provides information on the selection, design, and implementation of sediment remediation technologies, including feasibility evaluation, testing technologies, and effectiveness at past site projects.

The USEPA CLU-IN web site provides information about innovative treatment technologies and includes descriptions of and contact information for relevant programs and organizations. It also provides access to publications (*e.g.*, *Tech Trends*) and other tools useful in technology review and evaluation.

The USEPA REACH IT database combines information from three established USEPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT) database, the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS) database, and the Innovative Treatment Technologies (ITT) database. This database combines vendor-supplied information with information from the USEPA, the US Department of Defense (DOD), the US Department of Energy (DOE), and state project managers regarding sites at which innovative technologies have been implemented, and provides information on over 1,400 remediation technologies and 750 vendors.

The FRTR describes itself as an interagency group seeking to improve the collaborative atmosphere among federal agencies involved in hazardous waste site remediation. Member agencies include the DOD, DOE, US Department of the Interior (DOI), US Department of Commerce (DOC), US Department of Agriculture (DOA), and the USEPA. Its web site contains such information as cost and performance of remedial technologies, results of technology development and demonstration, and technology optimization and evaluation.

The RIMS 2000 database, owned and operated by the Research Technologies Network, L.L.C., contains remedial technology information on nearly 900 technologies. It includes technical paper abstracts, summaries, and components of remediation efforts undertaken since the inception of CERCLA in 1980. This information is verified and updated by RTN on a monthly basis to provide current and objective information on the status of innovative technologies.

4.2 Technology Identification and Technical Implementability Screening

Technologies are presented here grouped by general response action type in the same order as presented in Section 3.6:

- No Action
- Monitored Natural Attenuation (MNA)
- Institutional Controls
- Containment

- *In situ* treatment technologies
- Removal methods
- *Ex situ* treatment techniques
- Beneficial use
- Disposal.

Additional remedial activities (*e.g.*, sediment dispersion controls and sediment pretreatment methods) are not discussed or evaluated in detail in this chapter. Some feasibility evaluation of a number of these technologies will be conducted in Chapter 5 so that remedial alternatives can be conceptualized sufficiently for detailed analysis. No Action is presented to provide a baseline for comparison in accordance with the NCP. MNA is included as an option that provides extensive continued monitoring of the river in accordance with USEPA guidance (USEPA, 1999j). Technology identification and technical implementability screening comments are provided in Table 4-1.

4.2.1 No Action

Under No Action, no remedial action, including removal or containment of contaminated sediment, treatment, engineering controls, or institutional controls, is implemented. According to USEPA's 1988 RI/FS Guidance, No Action may include monitoring of conditions in the river in order to verify that no unacceptable exposures to hazardous substances occur in the future. However, for this FS, No Action does not include any monitoring; only the five-year reviews will be performed. The No Action alternative is generally appropriate in situations where contamination at a site presents no current or potential threat to human health or the environment, when CERCLA does not provide the authority to take remedial action (for example, if the site contamination consists only of a pure petroleum product), or when a previous response action has eliminated the need for additional remedial action at a site. The NCP requires the No Action alternative to be developed as one of the potential remedial actions to be considered in the Feasibility Study. The complete deferral of remedial action is easily implemented technically and administratively. No Action will be retained for further evaluation.

4.2.2 Monitored Natural Attenuation

Monitored natural attenuation refers to the reliance on natural attenuation processes, within the context of a carefully controlled and monitored site cleanup approach, to achieve site-specific remediation objectives (*e.g.*, reduction of volume and toxicity of contaminants) within a time frame that is reasonable as compared to that offered by other more active methods. Natural attenuation processes may include biodegradation, biotransformation, bioturbation, diffusion, dilution, adsorption, volatilization, chemical reaction or destruction, resuspension, downstream transport, and burial by clean material. Some or all of the processes may be occurring at any given time and location within the river. In some cases, these processes transfer some or all of the mass of contaminants (or derivative end-products) to and from the sediment and overlying water. The net result of such processes is attenuation of the concentration of the contaminant within the sediment. MNA can be implemented alone, along with an active remedial action, or after an active remediation is completed. In addition, institutional controls (*i.e.*, site use restrictions) may be implemented as long-term control measures as part of an MNA alternative.

Extensive site monitoring and modeling are performed as part of monitored natural attenuation to demonstrate that contaminant reduction is occurring, and that the reduction is achieving cleanup goals (RAOs or PRGs). Long-term monitoring will be conducted in sediments, in the water column, and in biota. Monitoring may include measurements of sediment accumulation rates, contaminant levels in the sediment by depth, bioaccumulation by benthic organisms, and the migration or harvesting of contaminated organisms. Loss of contaminants can be documented by historical trends or contaminant concentration distribution showing a reduction in the total mass of contaminants in sediments, water, and/or biota, or by the presence of degradation products in sediments. The monitoring data can also be used as input parameters in mathematical models to evaluate progress of the natural attenuation processes against the original predictions.

A significant limitation of natural attenuation, particularly where burial by cleaner sediments is the primary attenuation process, is that burial occurs only in depositional areas. In addition, because natural attenuation depends upon maintenance of the uncontaminated sediment layer, anthropogenic processes, or long-term or cyclical changes in weather or severe storms, may result in erosion and scouring of the sediments and redistribution of the contaminants over wide areas, even when burial is achieved.

Monitored natural attenuation is most appropriate as a remedy for sites where natural processes have been observed or are strongly expected, and where there are no adverse impacts on potential human or ecological receptors. Where there is a source present, USEPA guidance (USEPA, 1999j) recommends that natural attenuation should be considered only when source removal or control is also implemented. Natural attenuation that depends primarily on sediment burial may not be appropriate in navigation channels where dredging is required for maintenance of the channels. MNA will be retained for further evaluation.

4.2.3 Institutional Controls

Institutional controls are defined as non-engineering, administrative, and/or legal controls at a site, intended to prevent or reduce human exposure to hazardous substances. Site use restrictions may be applied to control use or disturbance of sediments or resources impacted by the sediments (*e.g.*, surface water and fish) that would otherwise pose danger to human health or the environment if not addressed by remediation. Restrictions may include continuation or extension of existing fish consumption advisories, limitations on recreational use, restrictions on private sediment disturbance activities such as waterfront improvement or small craft access, and controls on sediment removal (*i.e.*, dredging). These restrictions are enforceable by NYSDEC or the USACE. While there may be gaps in compliance, implementation of such restrictions is not problematic from a technical standpoint; therefore, institutional controls are retained for further evaluation. Institutional controls may also be implemented at the site by USEPA.

Monitoring is not an institutional control (USEPA, 2000r); however, it is necessary in order to implement and evaluate certain institutional controls, *e.g.*, fish consumption advisories. Monitoring of various media will allow ongoing evaluation of the concentrations and effects of PCBs in the vicinity of the river. Monitoring may include sediment sampling, water column sampling, fish/biota sampling, and/or air monitoring in the vicinity of the river. All of these are potentially applicable and technically implementable; therefore all are retained for further evaluation. Air monitoring may not be necessary with a well-designed water column monitoring program.

It should be noted that both monitoring and site use restrictions are required to prevent or reduce human exposures to hazardous substances.

4.2.4 Containment

In situ control and containment measures are intended to reduce dispersion and leaching of contaminated sediments to other areas of a water body, and to reduce direct human and ecological exposure to contaminants. Sediment containment measures evaluated here are long-term remedial options. They are different from the temporary sediment control options implemented during dredging or excavation that are discussed in subsection 4.2.6 and evaluated in Table 4-8. Long-term sediment control and containment methods evaluated include capping and use of retaining dikes and berms.

4.2.4.1 Capping

Caps may be engineered for placement in subaqueous (*i.e.*, fully inundated) locations and in the flood zone where alternate cycles of wetting and drying may occur, as is the case at the remnant deposit sites. Caps may be used *in situ* or to cover excavated or dredged materials consolidated for disposal in subaqueous or near-shore areas. Capping would also be necessary for closure of upland disposal sites. For purposes of this evaluation, the discussion is focused on *in situ* containment of sediments. This typically involves the placement of a low permeability material on top of the contaminated sediment. A low permeability material prevents or slows down the movement of contaminated pore water into the water column. Caps can also provide for sorption and attenuation of contaminants. In addition, placement of a cap on top of the contaminated sediments prevents direct human contact and exposure of benthic organisms and demersal (bottom dwelling) fish to contaminated material.

There are practical limits to the application of engineered capping to the Upper Hudson River due to its geometry (water depths) and navigational needs. Large tracts of the river are occupied by fairly shallow shoal areas, in many places bordered by permanent or seasonal homes with waterfront access. In these areas, installation of a cap of any significant thickness could move the shoreline as much as 20 to 50 feet toward the channel, changing both the character of the waterfront and hydraulic features of the shoals. Thus, in-river capping in shallow shoal areas (water depth less than 6 feet) may be impractical unless removal of an equivalent thickness of sediment has been accomplished first. Capping is also inappropriate in the channel of the Champlain Canal, for which a navigational draft of 12 feet must be maintained.

For purposes of this FS, water depths in River Sections 1 and 2 are defined by bathymetric data gathered in 1992. The flow rate at the time of this survey was approximately 3,090 cfs. The 6- and 12-foot contours were mapped using a Triangulated Integrated Network (TIN) accessible to both CADD and GIS software. In River Section 3, *i.e.*, downstream of the Northumberland Dam, contours displayed on the NOAA navigation chart for the Hudson River were digitized into the project mapping. Use of the term "water depth" in subsequent descriptions of technologies, remedial alternatives, and engineering analyses is referenced to these mapped contours, particularly as they describe areas and action boundaries on the river bottom.

It is recognized that the bathymetry may have changed somewhat since 1992, particularly as demonstrated by the annual "canal sweeps" conducted by the Canal Corporation for estimating the extent of dredging necessary to maintain the navigation channel. New York State Thruway Authority data for 1999 is an example of such data. While the methods used to obtain the data are not as sophisticated as those used to perform the bathymetric survey for the Reassessment RI/FS, the results do indicate those areas where the channel has become shallower than the required 12 feet.

Because of the need to maintain at least 12 feet of draft in the Champlain Canal, the 12-foot contour was used as a surrogate for the navigation channel. The 12-foot contour usually results in a wider section than the defined channel (for which no digital mapping coordinates are available to the project), thus likely providing a somewhat conservative estimate of its influence on removal schemes. That is, calculations of volumes for removal will likely be larger than the actual volumes.

Conversely, the areas amenable to capping may be calculated as somewhat smaller than the actual areas. The net effect may be to marginally increase the costs of all active remediation alternatives, since the cost of removal (and subsequent disposal) is greater than the cost of capping. This should not have an effect on relative comparisons among active alternatives.

A wide variety of materials can theoretically be used to cap contaminated sediments in order to minimize or reduce leaching (soluble diffusion), bioturbation, and erosive (convective) transport. Capping materials may be divided into three basic categories: inert materials; active materials; and sealing agents. Capping options evaluated for use in the Upper Hudson River are presented in Table 4-2. Options that are highlighted on the table have been tested for or applied to freshwater sediments or PCB-contaminated sediments.

The USACE has performed extensive research on the placement of capping systems over river sediments. The primary considerations for the design of any capping system are:

- Cap thickness required to isolate sediment from the effects of bioturbation;
- Extent of consolidation of the sediment and/or capping material during and after cap placement;
- Geometry of the sediment surface;
- Potential for cap erosion after installation;
- Operational concerns; and
- Cap thickness required to control chemical flux from sediments to the water column.

The basic criterion for a successful capping project is simply that the cap required to perform some or all of the intended functions identified above be successfully designed, placed, and maintained (Palermo *et al.*, 1998).

Bioturbation is defined as the movement and mixing of sediment as a result of the activities of burrowing benthic organisms. Evaluation of bioturbation is important, as benthic activity may result in mixing capping materials with underlying contaminated sediment, thereby reexposing the contaminants to the water column. Bioturbation also provides mechanisms for contaminant uptake by burrowing organisms with subsequent transfer up the food chain. The extent of benthic activity needs to be defined in order to select a cap thickness that minimizes or prevents mixing of the cap materials with the underlying sediment. Fish nesting behavior is another example that may also result in mixing of capping materials with underlying contaminated sediments.

Contaminated sediments are usually fine-grained and they are often susceptible to large amounts of consolidation. Consolidation of the cap and underlying sediment may result in expulsion of sediment pore water containing chemical constituents into the cap. Additionally, consolidation can be mistaken for erosion during post-cap placement monitoring.

Geometry of the sediment surface is important. Placement of capping material on sloped surfaces may result in uneven distribution because capping materials could migrate over steep slopes soon after placement.

Erosion of the cap may occur due to the action of normal currents or eddies, or due to the effects of storm events. The cap design should include measures to stabilize the contaminated sediments and prevent resuspension and transport to other portions of the river bed. The design should also include measures to mitigate erosion, if deemed necessary.

Operational concerns include factors that may impact the ability to accurately place the cap at the desired thickness under site-specific conditions (including current, flow patterns, and climate), and physical disturbance of the cap (*e.g.*, ice-rafting or boat anchors or running aground).

Chemical flux from sediment through the cap may occur due to diffusion or groundwater advection.

In Situ Capping Using Inert Materials

Inert materials include clay, silt, sand, geosynthetic clay liners (GCLs), geomembranes, and AquaBlok™. Cleaner, less contaminated dredged sediments are often used for subaqueous capping in estuarine and ocean dredging projects. However, the use of less contaminated sediments for this project was eliminated as an option, as the placement of additional contaminants in the river would hinder achievement of RAOs/PRGs. Although, in actual practice, inert material caps would not be all clay, all silt, or all sand as described below, the smaller proportions of other particle size fractions would not materially alter the properties of the primary capping material (clay, silt, or sand). A more detailed discussion of these inert capping materials is outlined below:

Clay. A clay cap consists of a layer of clay placed on top of the existing sediments. Clay, when placed in lifts, at or near the optimum moisture content and subsequently compacted to a predetermined density, such as a Modified Proctor density of 90 to 95 percent, will form a low permeability (1×10^{-7} cm/sec or less) cap. However, bulky clay is very difficult to place and compact in a river environment. Clay caps are usually used to contain waste in landfills, not in rivers. In addition, a clay cap may also be subject to erosion in the river. Thus, a clay cap is eliminated from further evaluation.

Silt. A silt cap is a layer of silt placed on top of the existing sediments. Silt consists of fine-grained sediments that have a relatively low permeability (on the order of 1×10^{-5} cm/sec). The placement of a silt cap is also difficult, as the silt may disperse and float downstream with the current. Further, a silt cap may also be subject to erosion in the river. Thus, a silt cap is eliminated from further evaluation.

Sand. A sand cap is a layer of sand placed on top of the existing sediments. The placement of clean material on top of the existing contaminated sediments means that the benthic organisms repopulate clean sediments. However, the placement of a sand cap does not prevent recontamination of the new sand material by movement of potentially contaminated pore water. In addition, a sand cap is subject to erosive forces that may eventually expose the contaminated sediments. Thus, a sand cap is also eliminated from further evaluation.

Geomembrane. A geomembrane is a polyethylene sheet usually manufactured using either high-density polyethylene (HDPE), very low density polyethylene (VLDPE), or polyvinyl chloride (PVC). Geomembranes have been extensively used in landfills as a low permeability material to prevent the migration of leachate from the landfill into the groundwater. They have also been used to waterproof tunnels and as caps on hazardous waste sites. However, there are some technical difficulties associated with the membrane placement process in a riverine environment. During placement, the river current can carry the membrane or the barge performing the installation, thus making accurate placement of the membrane difficult, if not impossible. The membrane could tear, or the roll could spin quickly, causing a pile of clay that would then have to be removed. In addition, sheets of geomembrane must be hot-welded together to provide a continuous impermeable layer. Further, the fact that this process must occur "in the dry" adds to the difficulty of installation. The use of a geomembrane as a capping material was therefore eliminated from further consideration.

The use of bentonite as a material that is relatively impermeable and that serves as physical, hydraulic, and chemical barrier or liner is proven and well established (Daniel, 1993). In a riverine environment, the technical difficulty lies in finding a suitable method for the placement of this proven material over the contaminated sediments to isolate them from the overlying sensitive ecosystem.

Geosynthetic Clay Liner (GCL). A GCL consists of a layer of bentonite clay sandwiched between two needle-punched geotextiles. The engineering function of GCLs is as a hydraulic barrier to water, leachate, or other liquids. Bentonite is manufactured in a dry powder form. When exposed to water, it hydrates and forms a low-permeability clay with a permeability value of less than 1×10^{-7} cm/sec. GCLs have been used in the cover of landfills as an alternative to the three feet of clay typically required. There has been very limited experience with the placement of GCLs in a riverine environment. If it were possible to place a GCL in the river successfully, the GCL would act as a low-permeability barrier and would prevent the migration of the potentially contaminated pore water into the water column. Many of the problems associated with the installation of the geomembranes are also applicable to the installation of a GCL in a river. Further, adjacent sheets must be overlapped at least 12 inches in order to prevent seepage between sheets. Due to such installation difficulties, the use of a GCL was eliminated from further consideration.

AquaBlok™. AquaBlok™ is a capping system consisting of gravel particles to which bentonite clay is bonded. The composite particle (gravel and bentonite) is created by a special manufacturing process. Gravel or crushed stone is obtained from a local quarry and is initially coated with a polymer. The bentonite is then added, forming a dry, hard aggregate. The composite particles, herein referred to as AquaBlok™, are spread from the surface of the water and sink quickly to the bottom of the river on top of the sediment. As the bentonite hydrates, a uniform, continuous, cohesive low permeability cap (1×10^{-8} cm/sec) is formed over the contaminated sediments. Standard construction equipment such as front-end loaders, conveyors, and barges is used to place AquaBlok™. The hydrated particles are cohesive and are more resistant to erosion than sand. In laboratory flume tests there was little loss of AquaBlok™ particles at a current velocity of 3 ft/sec when compared with the amount of sand lost at the same velocity. The potential success and innovative aspect of the AquaBlok™ composite particle system is as follows:

- It overcomes the technical difficulty of sub-aqueous placement by using the innovative delivery system and
- It utilizes readily available materials such as bentonite and gravel or aggregate.

The use of AquaBlok™ is retained for further consideration.

Other Considerations. Gravel, stone, and riprap may be used as armoring to protect the cap from erosion and to minimize scouring of the underlying cap. The cap thickness must also account for the activity of burrowing animals and benthic organisms.

Engineered caps using other inert materials similar to those employed for landfill or land-based hazardous waste site closure may also be used in near-shore and subaqueous situations. For example, the remnant deposit sites were capped using a combination of natural soils, GCLs, and riprap for scour and erosion protection. However, the cap placed on top of the remnant deposit sites was placed in a dry environment, above the normal level of the water in the river.

Conclusion. Capping using inert materials is retained for further evaluation, with AquaBlok™ as the selected process option.

400443

In Situ Capping Using Active Materials

Active materials such as activated carbon can be applied to the surface of subaqueous sediment or mixed with the sediment in an attempt to limit contaminant mobility. Active materials need to be combined or covered with inert materials to provide stability, erosion resistance, and, in some cases, protection for benthic organisms (Cullinane *et al.*, 1986). For some contaminated sediments, chemically active materials may be added that neutralize or reduce toxicity of the contaminants. However, the literature reviewed provides no indication that chemicals used in *ex situ* treatment systems (see subsection 4.2.7) to dechlorinate or otherwise detoxify PCBs in saturated sediments have been successfully applied *in situ* as part of capping systems. Capping using activated carbon or other active materials can be effective, but has the disadvantage of potential future release of capped (adsorbed) contaminants due to breakthrough in the active materials. The use of active materials in the application of capping is not retained for further evaluation.

In Situ Capping Using Sealing Agents

Sealing agents such as cement, quicklime, or grout may be applied to the surface of subaqueous sediments or mixed with the uppermost layer to form a crust upon curing. This technique stabilizes the surface, preventing erosion and resuspension of the contaminated material, and reduces or eliminates leaching of contaminants into the water column. Mobile (barge-mounted) concrete pumps may be used to apply the material in order to minimize sediment disturbance (Sirrine, 1990). Diversion of stream flow may be required for effective application of a cap composed of sealing agents, but is not considered generally feasible in the Upper Hudson River. Also, the crusty surface is not a desirable habitat for biota. Therefore, capping with sealing agents is not retained for further evaluation.

Thin-Layer Capping

Thin-layer capping, or "particle broadcasting," is a remedial technology that consists of placing a thin cap over contaminated sediments. For purposes of this FS, thin-layer capping refers to cap thicknesses of six inches or less. A cap placed over contaminated sediments can serve three primary functions:

- Physical isolation of the contaminated sediments from the benthic environment;
- Stabilization of contaminated material, preventing resuspension and transport to other sites; and
- Reduction of the flux of dissolved contaminants into the cap and the overlying water column.

Laboratory studies at Louisiana State University (LSU) found that caps as thin as five to seven millimeters (0.2 to 0.3 inches) drastically reduce the flux of 2,4,6-trichlorophenol (TCP) from sediment to water. The LSU study demonstrated that "the most significant factor in determining the time it takes for the contaminant to emerge is the chemical sorptive capacity of the capping sediment. The caps with the lowest organic carbon content were the least effective in slowing down the rate of breakthrough" (Hazardous Substance Research Center, 1995). However, for real-world situations, especially riverine environments like the Upper Hudson River, the LSU laboratory studies are of little value; it would be difficult even to measure sediment thickness variations of 0.2 to 0.3 inches in the river, let alone address the difficulty of uniform placement of caps with such thin layers.

At Pier 64 in Seattle, Washington, a 4-acre area was capped with a design thickness of one foot in waters ranging from 20 to 60 feet deep. This thin-layer cap was intended to "enhance the natural recovery, immediately isolate biota from contaminants (including lead, mercury, zinc, PAHs, benzoic acid, bis (2-ethylhexyl)phthalate, dibenzofurans, and PCBs), reduce resuspension during pile driving, and not unduly reduce navigation depths" (Sumeri, 1996). The cap was designed to withstand the 0.02- to 0.16-ft/sec current measured in the area and attributed to tidal cycles. Physical monitoring of the cap showed that while most of the cap had maintained its design thickness, the western portion of the cap showed a reduction in cap thickness from 0.7 feet during placement to 0.4 feet six months later. It has not been determined whether this reduction is attributed to erosion or to localized consolidation/settling. Post-capping chemical monitoring of the water column has shown that concentrations of metals and organic compounds are below pre-capping non-zero concentrations.

At Eagle Harbor West in Seattle Sound, Washington, 6 acres of surface sediments exceeding the minimum cleanup level of 0.59 ppm mercury were thinly capped (6 inches) using 22,600 tons of quarry sand to enhance natural recovery. Water depths in the capping area ranged from zero to 45 feet. Post-implementation surveys identified 16 discrete cap areas lacking in minimum thickness. To correct this deficiency, an additional 1,000 cubic yards of material was placed. Post-implementation monitoring was still ongoing (GE, AEM, and BBL, 1999).

The results from these larger scale projects over relatively short time periods demonstrate that thin-layer capping does not appear to be very effective or reliable. Other particle broadcasting laboratory studies conducted by ALCOA for the Grasse River sediments have yielded questionable results (ALCOA, 1999). The ALCOA report expressed doubts about the test results obtained during its cap application and cap stability tests. ALCOA questioned the elevated turbidity and TSS concentrations recorded in the water column studies and stated that such observations are not considered to be representative of the solids response expected in the Lower Grasse River. ALCOA also stated that TSS concentrations measured during evaluation of the resuspension potential of fine sand during shaker tests may not have accurately represented the resuspended sediment, and that the shaker tests have limited applicability for evaluating non-cohesive sediments.

It is believed that the conditions in the Upper Hudson River, including the known site-specific hydrodynamic forces, hydrologic conditions, PCB concentrations, and bioturbation caused by native biota (approximately top four inches of the surface sediments) make the site inappropriate for the use of thin-layer capping as a containment technology. A thin-layer cap typically has a thickness of six inches or less. After considering the potential for scouring of sediments due to major storm events, ice-rafting, boat anchors, and the mixing of the upper four inches of the cap material due to bioturbation, it appears that there would be insufficient thickness for such a cap to contain the potential migration of PCBs from the contaminated sediments to the water column. Therefore, thin-layer capping will not be considered further in this FS.

4.2.4.2 Retaining Dikes and Berms

These types of structures include subaqueous or full-depth compacted earth (or sediment) embankments, bulkheads, sheet piling, earth-filled sheet-pile cells, and armored spur dikes used to minimize downstream transport of suspended contaminated sediments. These structures are implemented as long-term sediment containment options, and are different from sediment barriers set up temporarily to control resuspended sediments during sediment removal activities. Dikes and berms may be constructed as components of in-river, near-shore, or upland confined disposal facilities. These are addressed in subsection 4.2.9. Dikes and berms may also be constructed in the river perpendicular to stream flow to impede downstream sediment movement, or parallel to the shore to isolate contaminated sediments from the river channel flow.

When constructed perpendicular to the river bank, retaining dikes and berms may be effective in trapping and increasing deposition of sediments suspended in the water column, thereby interrupting downstream transport and scour. To some degree, existing dams serve this function. However, this role could be enhanced by excavating sediment sinks behind the dams to allow greater capture of waterborne sediments. Such an approach could also serve a secondary purpose in alleviating the buildup of sediment deposits behind the dams, hence maintaining habitat conditions and reducing the necessity of navigational dredging in some areas. Dikes and berms constructed parallel to the shoreline may be used to isolate contaminated sediments left in place in depositional areas from the convective forces of the stream. This technique could be used to prevent or reduce the erosion of materials from depositional areas during periods of high flow and flooding. Retaining dikes and berms are technically implementable and are retained for further evaluation.

4.2.5 *In Situ* Treatment

In situ technologies involve the treatment of contaminated sediments without removal from rivers, lakes, or harbors. The primary advantages of *in situ* treatment over alternatives involving removal of contaminated sediments are the potentially lower release of sediment-borne contaminants to the surrounding environment and the minimal sediment handling requirements. The main limitation of *in situ* treatment is the lack of process control during treatment, which can lead to incomplete or ineffective treatment and release of treatment by-products to the water column. *In situ* treatment technologies are most effective in low-flow streams or embayments where flow can be diverted during treatment (USEPA, 1993b).

In situ treatment technologies include biological and physical/chemical methods. Potential *in situ* bioremediation approaches for treating PCBs in the Hudson River sediments are discussed first, followed by a discussion of physical/chemical treatment technologies including solvent extraction, chemical dechlorination, and solidification/stabilization. *In situ* thermal techniques such as vitrification are not known to have applicability to subaqueous riverine sediments and are thus not discussed.

4.2.5.1 Bioremediation

Bioremediation is a technique in which the physical, chemical, and biological conditions of a contaminated medium are manipulated to accelerate the natural biodegradation and mineralization processes. Biodegradation is the process whereby microorganisms alter the structure of a chemical (which may include other organic and inorganic compounds as intermediate or final byproducts), while mineralization is the complete biodegradation of a chemical to carbon dioxide, water, and simple inorganic compounds (*e.g.*, salts). In nature, both partial biodegradation and complete mineralization take place; the processes, however, are frequently slow.

Bioremediation has been used in the treatment of municipal wastewater for a number of years. It has been used fairly successfully under some conditions to treat petroleum products, creosote, and pesticide contamination. PCBs, however, pose greater challenges to bioremediation than many other types of contamination. Additional research is necessary before effective full-scale biological treatment is available for these compounds.

Paramount to successful PCB bioremediation is the identification of a microbial population capable of degrading a large number of different PCB congeners. Various microbial strains have been identified that have the ability to degrade many PCB congeners (Abramowicz, 1990). Aerobic biodegradation is generally limited to the less-chlorinated PCB congeners (Garvey *et al.*, 1999). On the other hand, anaerobic organisms have shown the ability to reductively dechlorinate the heavily chlorinated PCB congeners. Anaerobic dechlorination generates less-chlorinated biphenyls as degradation products, but does not change the total molar concentration of PCBs. Anaerobic dechlorination does, however, yield products that can be degraded by aerobes. Thus, sequential anaerobic/aerobic treatment may enable treatment of more-chlorinated PCB mixtures.

In addition to the identification of PCB-degrading microbes, successful bioremediation requires identification of the environmental factors controlling biodegradation. Results from research sponsored by General Electric to define the environmental conditions most conducive to PCB biodegradation indicate that optimum aerobic microbial activity requires:

- Microbial growth on biphenyl or chlorobiphenyl (Bedard, 1990; Unterman *et al.*, 1988);
- Temperatures elevated above those that would be characteristic of Hudson River sediments (McDermott *et al.*, 1989);
- Aeration (McDermott *et al.*, 1989); and
- Sufficient PCB bioavailability.

Optimum anaerobic activity for Hudson River strains or consortia appears to require:

- The absence of inhibitors, such as sulfate (Tiedje *et al.*, 1989);
- Elevated PCB concentrations, *i.e.* greater than 50 ppm (Tiedje *et al.*, 1987);
- The presence of certain inorganic nutrients (Abramowicz *et al.*, 1989);
- A supplemental carbon source (Tiedje *et al.*, 1989; Nies *et al.*, 1990; Alder *et al.*, 1990); and
- Temperatures elevated above those that would be characteristic of river sediments (Tiedje *et al.*, 1989).

Once an acceptable microbial consortium and proper environmental variables have been identified, one of two different engineering approaches to bioremediation can be taken, an *in situ* approach or an *ex situ* (land-based or bioreactor) approach. *In situ* bioremediation is discussed here and the remaining approaches are discussed in subsection 4.2.7, *Ex Situ* Treatment. Table 4-3 presents those bioremediation process options (both *in situ* and *ex situ*) evaluated for use at the

400449

Hudson River PCBs site. Options that are highlighted on the table have been tested for or applied to freshwater sediments or PCB-contaminated sediments.

For *in situ* treatment, the contaminated sediments are left in place. This approach obviously limits the amount of control that can be exercised over environmental variables during bioremediation, and can pose significant engineering difficulties in the uniform introduction and mixing of any microbes or nutrients that may be required. Additionally, mixing requires a containment system to prevent suspension and transport of contaminated sediments. Regular monitoring of sediment conditions and PCB concentration is necessary to assess remedial progress.

An *in situ* PCB bioremediation experiment was conducted by GE on sediments in the Upper Hudson River between August 9 and October 21, 1991 (Harkness *et al.*, 1993). Six self-contained steel caisson reactors were driven into the river bottom in the vicinity of Fort Edward, New York. The sediments within the caissons were mixed and used as experimental units subjected to varying addition of oxygen, inorganic nutrients, a co-metabolite, and known PCB-degrading bacteria. Test results showed increases in the numbers of indigenous biphenyl-metabolizing microorganisms in all experimental caissons. In addition, PCB concentrations, normalized to total organic carbon (TOC) content, decreased by about 50 percent in all experimental caissons. However, biodegradation of the remaining PCBs was not observed. Harkness *et al.* (1993) attribute this result to desorption kinetics, with the resistant fraction likely to become available only over long periods of time. Garvey and Thomchuk (1997) used the molar dechlorination product ratio (MDPR; see definition in subsection 3.5 of this FS) to demonstrate the infeasibility of complete PCB biodegradation.

Based on results of the field study and in the absence of other evidence of the effectiveness of this option, there is insufficient information to indicate that *in situ* bioremediation is technically feasible for sediments in the Upper Hudson River, or that it would achieve RAOs/PRGs within a reasonable time frame. Thus, this technology will not be evaluated further.

4.2.5.2 Solvent Extraction

Solvent extraction involves the dissolution of contaminants from the sediment matrix followed by recovery and treatment of the solvent. This technology first reduces the volume of contaminants in the sediment, PCBs in this case, and then reduces the toxicity by treatment or destruction of the contaminant-bearing solvent. For *in situ* extraction, necessary system components include an injection system for delivery of the solvent, a recovery system for the contaminant-bearing spent solvent, and containment structures to prevent uncontrolled migration of the solvent. Treatment or destruction of the spent solvent would be accomplished *ex situ*.

Types of solvent potentially applicable to PCB removal are discussed under *ex situ* solvent extraction options in subsection 4.2.7. Table 4-4 presents solvent extraction technologies evaluated for treating the Hudson River sediments; however, none of the technologies has been implemented *in situ* in sediments. *In situ* solvent extraction is not considered applicable to the Hudson River sediments for several reasons. Specifically, non-homogeneous materials may result in uneven solvent application and potential short-circuiting, and monitoring of extraction effectiveness would be difficult. Also, the potential for incomplete recovery of solvents is substantial. Failure of the containment system would have potentially deleterious results on surrounding sediments and water quality. *In situ* solvent extraction will not be evaluated further.

4.2.5.3 Chemical Dechlorination

This technology is somewhat similar to solvent extraction. Reagents are injected into the sediment, and PCBs are solubilized into the reagent/liquid phase where dechlorination occurs, resulting in a reduction in toxicity. Like solvent extraction, the process requires an injection system for delivery of reagents and a containment system or diversion of stream flow to control the process. USEPA (1993b) indicates conceptual applicability of the APEG (alkali metal hydroxide-based polyethylene glycol) reagent dechlorination process (discussed further in subsection 4.2.7) to sediments *in situ*. Table 4-5 presents chemical dechlorination technologies evaluated for treating the Hudson River sediments. None of the technologies, however, have been implemented *in situ*.

400451

In the dechlorination process, an alkali metal hydroxide base and polyethylene glycol reagents react with PCBs to produce glycol ether and a chloride salt, which are water soluble and of low toxicity. However, drawbacks similar to those for solvent extraction render this technology unsuitable for Hudson River sediments *in situ*. Specifically, non-homogeneous sediments may result in uneven application of reagents and short-circuiting and, again, monitoring of process effectiveness *in situ* would be difficult. USEPA (1993b) reports that the degradation process is temperature-dependent and may proceed slowly at ambient temperatures, especially in the winter. Also, the amount of water tolerated by the process has not been established; this is of critical importance in a subaqueous setting. Constructing a completely reliable containment system is problematic, and diversion of stream flow for long inter-seasonal time periods is impractical on this large scale. *In situ* chemical dechlorination will not be evaluated further.

Dechlorination in combination with solidification (discussed below) is a process that combines the addition of setting agents to immobilize contaminants, and appropriate reagents to dechlorinate contaminants. This process has not been demonstrated for PCB-contaminated sediments. Furthermore, this process has been inactive since 1994, with no new advances or tests (Funderburk, 1999; dePercin, 1999). Combined dechlorination/solidification is not retained for further evaluation.

4.2.5.4 Immobilization

Immobilization refers to a broad class of treatment processes that physically or chemically reduce the mobility of hazardous constituents in a contaminated material. Immobilization includes solidification, stabilization, and encapsulation processes, described below. In solidification, the contaminants are physically rather than chemically bound within a solidified matrix. Stabilization is a process by which a contaminated material is converted to a more chemically stable form. The process entails the use of a chemical reaction to transform the contaminant to a new non-toxic compound or substance. In many applications, both solidification and stabilization occur simultaneously to varying extents. Encapsulation involves complete coating or enclosure of a contaminant particle with an additive or binder.

In situ immobilization methods involve mixing solidification/stabilization agents such as cement, quicklime, grout, and pozzolanic materials, as well as reagents, with sediments in place to solidify/stabilize contaminants in the matrix. The solidification/stabilization agents are mixed throughout the zone of contamination using conventional excavation equipment or specially designed injection apparatus such as mixing blades attached to vertical-drive augers.

Solidification/stabilization technologies evaluated for use at the Hudson River PCBs site are presented in Table 4-6. The processes in Table 4-6 include both *in situ* and *ex situ* applications; however, *in situ* immobilization is considered in this section and *ex situ* immobilization is evaluated in subsection 4.2.7.8.

The effectiveness of stabilization/solidification technologies is variable depending on the characteristics of the contaminated soil and the particular additives used. In general, this technique is more effective for inorganic constituents (metals) than for organic constituents. Although stabilization/solidification can potentially be effective in reducing the mobility of PCBs because PCBs have characteristics of strong adsorption to sediments, the technology would not reduce their toxicity.

As typically performed, *in situ* solidification/stabilization has several limitations: reagent mixtures may be difficult to adjust and place accurately in a subaqueous setting; the use of augers or circular caissons requires substantial overlap for continuous coverage; some volume increase of the river bed is to be expected; and release of free solidification agents to the water column during mixing may be difficult to control. Long-term monitoring of the cured mass could be problematic, but a properly designed water column monitoring program may be sufficient. The technique is not feasible in areas where the solidified mass will interfere with future dredging activities (*i.e.*, the navigational channel). Further, solidification/stabilization may not be appropriate for shallow areas of the river, where volume expansion of the treated sediments may interfere with small craft navigation in these areas. Finally, a solidified mass may present problems as habitat for biota in the river.

400453

Even though solidification/stabilization may be effective in reducing PCB mobility in sediments, *in situ* immobilization is not retained for further evaluation because of potential implementability and future use issues.

Solidification in combination with dechlorination was discussed and evaluated previously in subsection 4.2.5.3, Chemical Dechlorination. Combined dechlorination/solidification is not retained for further evaluation because of lack of demonstrated effectiveness for PCB-contaminated sediments.

4.2.6 Removal Technologies

Removal technologies are employed in those cases where contaminated sediments are to be withdrawn for *ex situ* treatment, confinement, or disposal. Sediment removal can be conducted "in the dry," *i.e.*, by excavation methods, or by dredging techniques. Numerous excavation and dredging technologies are available to address site-specific conditions and constraints likely to be encountered at the Hudson River PCBs site. Factors that influence equipment selection for projects involving riverine sites include river bed characteristics, water depth, sediment characteristics, volume of material being removed, the hydrodynamic environment, accessibility, availability of upland areas for sediment processing and storage, and ultimate disposal options. Sediment removal technologies evaluated are presented in Table 4-7. Technologies that are shaded on the table are potentially applicable for use at the Hudson River PCBs site and are described in the following discussion; thus, the "shading" on Table 4-7 has a different meaning than on other tables.

Debris removal may be required prior to dredging to remove over-sized material from target areas. Over-sized material, *e.g.*, boulders, timbers, and man-made debris, can interfere with proper operation of dredges, thereby causing increased sediment resuspension during dredging. Debris removal can be achieved by mechanical means using construction equipment or a mechanical dredge.

A recent debris survey conducted in the Upper Hudson River (November, 1999; Appendix H) indicated that both woody materials and rock may be encountered during removal work. The wood materials appear to consist of both tree fragments and cut shapes such as boards and pilings.

Rock was found in piles at various locations throughout the river system. It is expected that the rock piles will either be avoided or removed prior to dredging work. Most wood debris would not be expected to impact removal operations; however, larger tree fragments can also be removed prior to the start of work in a particular area.

Sediment removal activities will likely result in an increase in suspended matter in the water column. It should be noted that control of the dredging operation itself is the primary means of control of sediment resuspension. Other suspended sediment control measures, listed in Table 4-8, may be implemented as needed to control the amount of sediment resuspension and transport expected from a particular remedial alternative. Some of these potential suspended sediment control options are intended to block suspended sediment movement, while others are intended to limit or redirect water currents at the work site during sediment removal activities. To be effective, barriers are deployed around the dredging operation and must remain in place until the operation is completed at that area, while at the same time minimizing, to the extent practicable, interference with navigational traffic.

The most common method of containing suspended sediments involves the use of silt screens and curtains. These barriers generally consist of vertically hung geotextile fabrics that may either be impermeable (curtain) or porous (screen). The barriers are installed around the work area and secured by anchoring to the river bed or by fastening to existing bulkheads or piers. Effectiveness rests on a number of site conditions that may disrupt the securing process, including local currents (barriers will have diminished effectiveness at currents exceeding 1.5 ft/sec as described in Appendix E), water depth, wind, tides, boat wakes, waves, presence of extremely hard bed surfaces such as bedrock in critical points, and the presence of debris.

Another suspended sediment control method, applicable to shallow or near-shore locations, involves physical isolation of the work area from the rest of the river. Isolation can be accomplished using various physical barriers (Table 4-8), although steel sheet piling and cofferdams have been the most commonly used methods to date. Use of sheet piling is not known to be feasible due to presence of shallow bedrock in many areas. "Porta-dams," which are braced steel walls in sections, can be used where sheet piling is impractical. Once installed, barge-mounted dredging can be performed inside the isolated area, or the area can be dewatered and its sediments excavated "in the dry."

4.2.6.1 Excavation

Excavation methods would apply to sediment removal from shallow, near-shore areas where the work zone can be isolated from the adjacent water body and dewatered to the point where the contaminated sediments are exposed for removal. Excavation technologies can also be employed in shoal areas of the river that may be exposed during low-flow periods. Table 4-7 identifies equipment commonly employed during excavation operations. Excavation methods can also be effective for removal of contaminated sediments that have been deposited within shallow side channels where access by dredging equipment may be difficult. In such cases, the excavation equipment would be coupled with one of the containment technologies identified on Table 4-8 so that the work can be accomplished in relatively dry conditions. Excavation is technically implementable and is retained for further evaluation.

4.2.6.2 Dredging

As the Upper Hudson's sediment contamination problems have become better understood, dredging alternatives, including bank-to-bank dredging of the river, full-scale dredging of the 40 NYSDEC-defined PCB *hot spots* in the river, and reduced-scale dredging of the most contaminated *hot spots* have been considered. Due to limited funding under the CWA, a reduced-scale dredging program had been considered by USEPA and NYSDEC in earlier studies. The NYSDEC at one time proposed dredging and encapsulation of river sediments at a near-river site (NYSDEC, 1985).

Dredging technologies have been evaluated extensively by the USACE and by USEPA for their applicability to specific Superfund projects. With the growing demand for equipment tailored to the specific needs of remedial projects, a wide variety of specialty dredging equipment has been developed. Classifying this equipment is complicated by the fact that hybrid machines are now being fabricated with the characteristics of both mechanical and hydraulic dredges. Table 4-7 provides an approach to classifying dredging equipment that is based, in part, on the particular requirements and constraints of the Hudson River. A description of the principal systems follows.

Dredging Using Conventional Dredges

Both conventional hydraulic and mechanical dredges have applicability to remove Hudson River sediments. These machines come in a range of capacities and are currently being fabricated at a scale that is consistent with the access limitations of the Upper Hudson. Historically, maintenance of the Champlain Canal navigation channel has been accomplished by both conventional mechanical and hydraulic equipment.

Mechanical systems can conveniently be categorized into two types: those that use various types of buckets suspended from barge-mounted derricks ("bucket-on-rope" systems), and those systems that are hydraulically actuated (*e.g.*, backhoes). An advantage of a hydraulically actuated machine is the positive action that allows for greater removal precision and permits handling of a wide range of sediment types and debris. On the other hand, "bucket-on-rope" systems may be preferable when dredging softer contaminated sediments overlying a harder or impermeable non-contaminated layer. Both "bucket-on-rope" and hydraulically actuated machines have been fitted with various types of covers, enclosures, and seals to minimize the release of sediments during removal operations. Should mechanical dredges be used for removal of river sediments, use of buckets with such "environmental" modifications may be necessary.

Hydraulic dredges use pump suction to withdraw sediments. When a hydraulic dredge is fitted with a rotating cutting head, it acquires the ability to remove a wide range of sediment types including, in some cases, consolidated materials. Hydraulic cutterheads come in numerous configurations, depending on the manufacturer, and can be sized to conform to the spatial constraints of the river. One disadvantage of these machines is that they tend to entrain substantial quantities of water, thereby requiring dewatering of sediments before further processing is possible. In addition, relatively cumbersome and costly slurry lines and pumping stations may be needed to convey sediments to shore-side processing facilities. This disadvantage of hydraulic methods may be outweighed by cost savings if sufficient bank area is available for near-shore passive dewatering of the dredged slurry and disposal of dewatered sediments with overland transportation. The resuspension potential of mechanical and hydraulic dredges is discussed in Appendix E.

Both mechanical dredges and hydraulic units are retained for further evaluation in this feasibility study. The equipment in this category that will be given further consideration includes "bucket-on-rope" and hydraulically actuated mechanical dredges and suction and cutterhead hydraulic machines.

Dredging Using Large-Scale Dredges

Table 4-7 also lists a number of dredges that receive some attention when dredging equipment is evaluated, but usually are found to be unsuitable upon final analysis. These relatively large machines (often mounted on ocean-going vessels) are most often used to obtain borrow materials or for maintenance and new work navigational dredging. While it is theoretically possible to scale such equipment to river conditions, various alternative conventional and specialty dredges (discussed below) are both available and better suited to conduct removal operations within the Hudson River. For these reasons, these large-scale dredges are not retained for further evaluation.

Dredging Using Specialty Dredges

Numerous specialty dredges have been configured to address project-specific needs. Most of these have had their origins in non-Superfund activity and have been adapted to removal of contaminated sediments. However, as the scale and complexity of remedial programs increased, manufacturers began to assemble equipment to address the specific constraints of Superfund work, including precision removal of sediments and the need for low sediment resuspension rates. Several of the specialty dredges that appear to have applicability to conditions represented by the Upper Hudson River are listed in Table 4-7 and are described below.

Amphibious Excavators. Amphibious excavators are readily transportable units that have the potential to specifically remove contaminated sediments along the river shorelines and within shallow secondary channels. One of the unique characteristics of these machines is that they have hydraulically actuated arms that can be fitted with any of several heads, including a bucket, a rake, or a cutterhead pump bucket. While the production rate of such equipment is expected to be relatively low, its versatility, particularly in shallow areas, warrants continued consideration of the excavators. Amphibious excavators will be retained for further evaluation.

Ham Visor Dredge. A Dutch contractor has modified a backhoe with a unique bucket geometry that fully encloses captured sediments by means of hydraulically operated flap gates. The gates are closed before the bucket is raised. Potentially, the Ham Visor Dredge reduces sediment resuspension in comparison to non-enclosed buckets. Although it has some of the same applicability as the conventional backhoe, its capability to limit resuspension may be impeded when debris is present in the work area. The Ham Visor Dredge is retained for further evaluation.

Horizontal Auger Dredge. A number of manufacturers fabricate these compact units, which have seen wide application on non-Superfund projects. Auger dredges tend to function best in quiescent waters where relatively fine-grained materials have accumulated. Several manufacturers have enhanced their auger equipment by adding cutters to the auger flights to give the equipment greater applicability. Augers use pump suction to withdraw sediments (in this sense they function as hydraulic dredges) that are then conveyed as a slurry for further processing. Due to the relatively low production rates expected from auger systems, and their propensity to become fouled when debris is present, these systems are not retained for further evaluation.

Clean-up Dredge. The clean-up dredge is an auger-type system developed in Japan for removal of highly contaminated sediments (Palermo and Pankow, 1988). The auger is shielded with pivoting wings covering the sediment during collection and with shrouds for collecting gas for venting in order to minimize resuspension. An underwater television camera is used to monitor resuspension, while sonar devices are used to monitor the depth of the cut. It is expected that this unit has some of the same limitations as the conventional horizontal auger dredge. In addition, there is little US experience with the dredge and, therefore, it is not retained for further evaluation.

Refresher System. This is another Japanese design wherein a helical cutterhead is shrouded to minimize sediment resuspension, reportedly generating only a fraction of the suspended solids

400459

produced by a conventional cutterhead. Like the clean-up dredge, this system also includes underwater video monitoring and gas collection capability. Given that there is no US experience with this equipment, it is not retained for further evaluation.

Submersible Pumps. Submersible pumps have been variously configured for the removal of sediments. The sediments are conveyed in slurry form to either barge-mounted or shore-side processing facilities. Some manufacturers have begun to fit their pump systems with a form of cutting head to expand the range of applicability. In addition, one manufacturer has configured the submersible pump inlet so as to create an eddy effect that enhances movement of sediments into the pump suction. In addition to being mounted on a floating platform, submersible pumps can also be hung from a land-based boom or crane, thereby permitting landside access to the work area. These units are most applicable to removal of fine-grained sediments that may have been deposited within secondary channels and along the river's shoreline. Submersible pumps are retained for further evaluation in this FS.

Matchbox Suction Dredge. The Matchbox Suction Dredge was developed in Holland as an alternative to the conventional cutterhead, specifically for use with contaminated sediments (Palermo and Pankow, 1988). A large plate covers the top of the plain suction dredge head to avoid excessive water movement and escape of gas bubbles. A flap on the side of the dredge head is opened in the direction of swing, while the opposite flap is closed, with the intent of maximizing capture of sediment at near *in situ* density while minimizing resuspension. Also, the angle of the dredge head is adjustable to maintain the optimum position relative to the bottom. This type of dredge was evaluated in the New Bedford Harbor Superfund Pilot Study along with the conventional cutterhead and horizontal auger dredges. Operational problems encountered with the Matchbox were considered more severe than for the cutterhead dredge (USACE, 1990). The Matchbox suction dredge is not retained for further evaluation.

Diver-Assisted Dredging. In this technology, divers hold small-diameter suction hoses or guide submersible pumps to manually remove sediments. In some cases, sediments have been manually removed by vacuum lines connected to awaiting trucks. This labor-intensive, low-production dredging method, which is typically used only for small, inaccessible areas, was used to remove sediments from a water intake flume in Indiana Harbor and for a limited part of the Manistique Harbor project. Diver-assisted dredging could be used in limited areas of the Upper Hudson River where the primary dredging technology has been applied, but does not achieve RAOs/PRGs due to inaccessibility of the sediments. Diver-assisted dredging is retained for further evaluation.

Pneumatic Dredges. Unlike hydraulic dredges, these systems use compressed air and hydrostatic pressure differential to dislodge sediments that are then pumped as a slurry. Generally, the pneumatic cover or chamber is lowered into the sediment using a crane and suspension cable; once in place, the chamber's pressurized air is released, bringing the chamber back to atmospheric pressure. The difference in surrounding hydrostatic pressure forces sediment into the chamber through an entrance valve. The valve is closed and compressed air is forced into the chamber, displacing sediment slurry out the discharge valve and to the surface through a discharge hose or pipe (Palermo and Pankow, 1988). Pneumatic dredges have largely been applied outside the US to projects involving fine-grained sediments, but because they typically have minimum water depth requirements for effective operation, they are not appropriate for use in shallow shoal areas of the Upper Hudson. In the channel, where sufficient depth may exist, their use is unsuitable due to the sediment characteristics. Therefore, pneumatic dredges will not be given further consideration.

4.2.6.3 Removal by Soil Freezing

A derivative of soil freezing technology has been given some consideration for possible applicability to contaminated sediments. According to initial reports from a project in Canada (OCETA, 1999), a sediment freezing demonstration was undertaken to remove contaminated sediment, under water, in two-square-meter blocks. The sediment blocks were frozen by injecting a refrigerant into a series of cells that had been lowered into the target material. Final evaluation of the demonstration effort is not yet available. However, it is expected that the process would be costly, provide relatively low removal rates, and apply only to fine-grained sediments where hydrodynamic conditions would permit freezing to occur. In addition, due to the factors such as high energy consumption and potential leakage of refrigerant (OCETA, 1999), sediment freezing technology will not be retained for further evaluation.

4.2.7 *Ex Situ* Treatment

To date, incineration and disposal in landfills are the most widely practiced and permitted methods for management of PCB-contaminated soils and sediment. However, other technologies have now emerged and are considered technically and economically feasible alternatives to incineration and landfilling in certain circumstances. In this section, a range of *ex situ* treatment technologies is presented, with a discussion of their general applicability to the Hudson River site and their level of development.

Treatment can be performed at a facility located near the river using mobile units or more permanent treatment plants contained within buildings, or located off site at a treatment facility. Although the same remedial technologies are applicable for both near-river and off-site treatment of contaminated sediments, near-river treatment is considered first because it would minimize transportation and handling costs. For the purpose of this FS, near-river is defined as a corridor that includes the river and extends two miles landward from either bank. A two-mile width of corridor is used because it encompasses a wide variety of locations that could be considered for a local processing, treatment, or disposal facility within a reasonable hauling distance from the river. The applicability of complete or partial near-river treatment depends primarily on the availability of land for such a facility.

Biological, physical, chemical, thermal, and solidification/stabilization processes are considered for treatment of PCB-contaminated sediment in the Upper Hudson River. In this instance, treatment is defined as those processes that destroy, detoxify, isolate, immobilize, or otherwise render the contaminant environmentally unavailable. Processes considered for treatment of PCB-contaminated sediments include bioremediation, sediment washing, solvent extraction, dechlorination, thermal desorption, thermal destruction, thermal destruction/beneficial use, and solidification/stabilization. The processes considered are at different stages of development. Each, however, has potential value in treatment of the PCB-contaminated sediment. To be retained for further evaluation, a technology must have undergone preliminary testing for its environmental compatibility and technical implementability.

Sediment pretreatment technologies, which refers to processes that modify or condition dredged or excavated sediments prior to final treatment or disposal, are described first, followed by a discussion of *ex situ* treatment technology.

4.2.7.1 Sediment Pretreatment

Sediment pretreatment, including such technologies as dewatering and solids classification, is typically utilized to facilitate the efficacy of subsequent sediment treatment processes. These pretreatment technologies are not, in themselves, generally effective in removing or reducing contamination levels in the sediment. However, by improving the sediment characteristics or reducing the volume of the material to be treated, such technologies may reduce the overall cost of *ex situ* treatment alternatives. While they are not screened in this chapter, these supporting technologies are briefly discussed below. More detailed descriptions and evaluations are provided by Cullinane *et al.* (1986) and USEPA (1991b, c, 1993b, and 1994).

Dewatering

Dewatering is used to reduce the moisture content of a sediment, thereby improving its handling characteristics. The extent to which dewatering is necessary is dependent on the method(s) used in dredging the sediment, as well as the subsequent treatment/disposal of the sediment. Mechanically dredged sediment will have a moisture content comparable to its *in situ* moisture content, which for Hudson River sediments is approximately 50 to 60 percent by weight (*i.e.*, a geotechnical water content of 100 to 150 percent). This statement generally applies to "virgin" or relatively consolidated sediments. Sediments previously disturbed by dredging or other activities may have a much higher moisture content (70 to 80 percent by weight). This can become important if a second pass is necessary to remove additional material at a later time or if the dredging operation is not well controlled. In contrast, hydraulically dredged sediment could potentially have a moisture content on the order of 85 percent by weight or more (*i.e.*, a geotechnical water content of 500 percent or more). Such material is a slurry or suspension, and retains no structural soil properties.

Dewatering reduces the costs of transportation and ultimate disposal by reducing the weight and volume of the sediments. In addition, many treatment processes have an optimum moisture content range outside of which the process is either not effective or not economical, or perhaps both. A variety of dewatering processes is available, the selection of which is dependent on the volume of the sediment, the amount of available land space, the moisture content of the influent, and the desired moisture content of the effluent. The ARCS Remediation Guidance Document (USEPA, 1994) has classified dewatering technologies into three general types: passive dewatering technologies; mechanical dewatering technologies; and active evaporative technologies.

Passive dewatering of sediments is typically accomplished in tanks, lagoons, or other surface impoundments and relies primarily on processes such as settling, surface drainage, consolidation, and evaporation to remove water from sediments. Disadvantages of passive dewatering technologies are potentially significant land and time requirements for effective dewatering compared to mechanical and active evaporative technologies, particularly if conditioners to aid in dewatering are not used. The process can achieve high solids in surface crust, but has the disadvantage of potential PCB emissions into the air.

Mechanical dewatering processes are based on the input of energy to squeeze, press, or draw water from sediments. Most mechanical dewatering processes can increase the solids content of a feed material to a level comparable to that of *in situ* sediment deposits (about 50 percent solids). Common mechanical dewatering processes include belt filter presses, plate filter presses, vacuum filters, centrifuges, and gravity thickeners. Mechanical dewatering is most suitable where land is not available for a passive dewatering facility. Disadvantages of mechanical dewatering processes are the potentially high operation and maintenance costs.

Active evaporative processes rely on artificial energy sources to heat sediments and remove moisture. Active evaporative dewatering can achieve the highest solids, approximately 90 percent, of the three types of dewatering discussed here. Common active evaporative technologies include flash dryers, rotary dryers, and modified multiple hearth furnaces. Active evaporative technologies would only be employed where subsequent processes (*e.g.*, incineration) require extremely dry materials. Disadvantages of active evaporative processes are high operating costs due to high energy requirements, and capture and treatment of potential air emissions.

Solids Classification

Solids classification is used to separate the sediment solids based on such characteristics as size, density, and mass, and can be important in managing contaminated sediments because PCBs tend to preferentially adsorb to the fine-grained sediments. Therefore, separation of the relatively non-contaminated coarse-grained fraction can significantly reduce the volume of material that requires additional treatment. The effectiveness of solids classification is dependent on such factors as the volume of contaminated sediments, the particle size distribution of the material, and the characteristics of the contaminants. Typical solids classification processes include stationary screens and sieves, vibratory screens, hydraulic classifiers, spiral classifiers, and cyclones/hydrocyclones.

Selection of a solids classification technology depends on the objective of the pretreatment. Besides minimizing the volume of material for subsequent treatment, solids classification can be used to remove oversized material that may interfere with subsequent treatment processes.

Grizzlies and trommels are used to remove the coarsest material from dredged sediments. Grizzlies typically remove rocks and debris five cm or larger in diameter. Trommels are used to remove gravel, rocks, or trash one to ten cm in diameter. Either is usually the first step in any treatment train. The purpose of this equipment is to remove over-sized material that may damage other processing equipment. Vibratory screens and hydrocyclones are typically used to cull out particles larger than about 2 cm and 100 μm, respectively, in diameter. Vibratory screens are more effective than hydrocyclones for sediments with solids content greater than 25 to 30 percent and for variable feed rates. Mechanical classifiers can also be used for separation in the same size range as hydrocyclones. However, classifiers are even more sensitive than hydrocyclones to variations in solids content and feed rate (USEPA, 1994).

A hydrocyclone was used in a pilot scale demonstration of sediment particle size separation technologies conducted at the Saginaw River. Results of the demonstration project showed that approximately 80 percent of the PCB mass in the sediment samples was associated with the finest-grained sediments, which composed 20 percent of the original sediment mass. Preliminary toxicity testing of the separated coarser-grained fraction indicated that this material may be suitable for unrestricted disposal.

4.2.7.2 Bioremediation

As discussed in subsection 4.2.5.1, bioremediation is a technique in which the physical, chemical, and biological conditions of a contaminated medium are manipulated to accelerate the natural biodegradation and mineralization processes. Bioremediation can occur *in situ* or *ex situ.* The advantage of *in situ* bioremediation is that it avoids materials handling by enhancing biological activity of the contaminated sediment in place. However, *ex situ* bioremediation allows for stricter control of environmental conditions that impact biological activity. Two approaches to *ex situ* bioremediation are evaluated below: a bioreactor approach and a land-based approach. In the bioreactor approach, slurry phase bioremediation is considered, while in the land-based approach, land farming and composting are considered. Table 4-3 presents bioremediation process options evaluated for use at the Hudson River PCBs site. Options that are highlighted on the table have been tested for or applied to freshwater sediments or PCB-contaminated sediments.

Slurry Phase Bioremediation

In an *ex situ* bioreactor approach, the sediments are completely contained, so a bioreactor approach offers greater control over environmental variables than either an *in situ* or land-based system. Furthermore, this approach is conducive to the sequential anaerobic/aerobic treatment that may be required to treat more heavily chlorinated PCBs. Remediation in a bioreactor, however, may provide little advantage over alternative remedial techniques in terms of sediment handling requirements and destruction efficiency.

In slurry phase bioremediation, the excavated contaminated sediment is combined with water to create a slurry and is then aerobically biodegraded using either a self-contained reactor or a lined lagoon; if already in a slurry form, the excavated sediment would possibly be dewatered to achieve an optimum water content. Aeration is provided by floating or submerged aerators, or by compressed air and spargers. Aeration tends also to mix the sediment slurry; however, this mixing action is often supplemented by mechanical mixers to enhance contact between the microorganisms and the contaminants. Nutrients and neutralizing agents are added as appropriate, as are surfactants, dispersants, or other agents, to improve bioavailability of the contaminants. The reaction time is dependent on such factors as the physical/chemical nature of the contaminant as well as its biodegradability. Once biodegradation is complete, the slurry is dewatered and the solids are recovered for disposal or additional treatment as necessary. Process water is typically recovered and reused.

Reactor-based slurry biodegradation of PCB-contaminated sediment has not been demonstrated in full-scale capacity. In addition, the lengthy time necessary to achieve significant PCB degradation in pilot-scale tests indicate that this method is not yet appropriate for treating the potentially large volume of Hudson River sediment in a realistic time frame. Slurry-phase bioremediation is not retained for further evaluation.

Bioremediation by Composting and Landfarming

Two types of land-based biological treatment approaches, composting and land farming, can be used for bioremediation of sediments. Implementation of either treatment for the Hudson River site may require dewatering of the dredged sediments. Since anaerobic conditions would be difficult to maintain in both composting and landfarming approaches, these systems are appropriate only for aerobic bioremediation application.

In composting, sediments are placed in large piles. A typical compost pile may be six to eight feet in height and contain from 4,000 to 10,000 cubic yards of sediment. Sediments are placed on top of a prepared clay or plastic liner with a leachate collection system in compliance with RCRA minimum technology requirements. Oxygen is supplied to the material through a piping system. Alternatively, the compost piles can be tilled to facilitate the transport of oxygen through the system.

Installation of a watering system to maintain appropriate moisture levels and to deliver nutrients and microbes to the piles may be necessary. In cool weather, steam or heated water may be delivered to the piles to maintain elevated temperatures. Collected leachate can be recirculated. In some cases, the compost piles are covered to provide insulation as well as to minimize particulate emissions and surface runoff. Depending upon the permeability of the sediments, they may require mixing with a bulking agent prior to piling to develop a permeability that will allow penetration of nutrients, water, air, and microbes. In a typical static pile system, the bulking agent consists of wood chips that are mixed with the sediments (NYSDEC, 1991). Regular monitoring of both pile conditions and changes in PCB concentration is necessary to assess remedial progress.

In land farming, sediments are spread over liners and leachate collection systems in 9- to 18-inch layers, or lifts, for treatment. Although land farms require more space for treatment than compost piles, a number of lifts can be land-farmed sequentially over the same surface area. A sprinkler system is used to deliver microbes, nutrients, and moisture to the land farm. Oxygen can be supplied through periodic tilling. As land farms are generally not covered, there is the potential for loss to the air of more volatile congeners, especially during initial spreading and tilling.

Compost piles and land farms have been used to treat soil contaminated with solvents, petroleum products, or creosote at a number of sites, with varying degrees of success. These contaminants, however, are generally more readily biodegraded than PCBs. No full-scale PCB bioremediation projects using these techniques have been completed to date, and few vendors have experience treating any compounds in soil or sediment volumes greater than 10,000 cubic yards. Land-based bioremediation options will not be retained for further evaluation.

Phytoreclamation of Dredged Sediments

Sediments are essentially displaced topsoils from the watershed that enter and are eventually deposited in the Upper Hudson River. Dredged sediments are therefore topsoils that have been removed from the river. One possible beneficial use of contaminated dredged sediments is to make them suitable for reuse off site as a soil material by reducing contaminant concentrations to within regulatory compliance limits. Phytoreclamation is the use of plants to reduce contaminant concentrations in dredged material.

The application of phytoreclamation to dredged sediments presents some challenges that are unique to sediments. Since these sediments come from an aquatic environment, they are initially wet and anaerobic after placement in a confined disposal facility (CDF). Subsequent drying and oxidation depend on dewatering and management techniques, which vary from site to site. Drying and oxidation of surface layers may result in physicochemical changes that may affect plant establishment and contaminant mobility. Although the surface layer of dredged sediments in a CDF may be dry and aerobic, deeper layers may remain anaerobic due to the physical design of CDFs and limited air penetration of surface layers. The depth of dredged sediments in a CDF may vary from only a few feet to as much as 90 feet. Management of dredged sediment is further complicated by the potential of elevated concentrations of multiple contaminants. The selection of plant species and methods of plant establishment is determined by these factors.

A number of factors must be considered prior to initiating a phytoreclamation process in the field. The age and condition of dredged sediments in existing CDFs may determine the process selection. Freshly deposited sediments and sediments in some older CDFs will require dewatering prior to plant establishment. The selection of plant species is contaminant- and site-specific, as plants that are noted as effective in reducing certain contaminants may not grow sufficiently in certain climates or soil types. Other difficulties may include the patent and/or licensing requirements to use some phytoreclamation processes and the ability to obtain certain germplasms. The phytoreclamation framework described in Price and Lee (1999) provides guidance in determining the most effective phytoreclamation approach, if one is available.

Reclamation goals or acceptable concentrations in the final soil product are typically determined by the local authority in which the site is located, or where the soil material will be used if transported off the site. For phytoreclamation of freshly dredged sediment or in a ponded CDF, removal of water to support establishment of upland plants and other bioreclamation processes may be required. Lee *et al.* (1976) determined that certain plants can facilitate dewatering and consolidation of fine-grained dredged material. Transpiration by plants can remove significantly larger quantities of water than simple evaporation of unvegetated dredged material. Plants that can be easily established on loosely consolidated dredged material and have large root systems that will reach anaerobic zones to facilitate water removal are necessary. Examples of such suitable plants include Eastern gamma grass (*Tripsacum dactyloides*) and hybrid poplar trees (*Populus* spp.). Under certain conditions, anaerobic dredged material may be blended with cellulose and biosolids to produce a manufactured soil product. The resulting soil product will have less free water and will be ready for immediate establishment of plants for the phytoreclamation process.

The cleanup goals for each contaminant may be based on a soil concentration threshold or a bioavailability threshold. In situations where two or more contaminants require some form of reduction, phytoreclamation may have to occur sequentially or concurrently with other phytoreclamation, bioreclamation, or chemoreclamation processes.

Phytoreclamation of PCBs is not an effective technology at present. Some studies are being conducted using mulberry (*Morus* spp.) and hackberry (*Celtis occidentalis*) trees (for Aroclors and PCB congeners, respectively), utilizing sequential wet/dry soil conditions and inoculation with specific microbes. The degradation of PCBs by phenol-like root excretions has been identified as a likely process (Fletcher *et al.*, 1995). Phytoreclamation may be more effective on PCBs in conjunction with a bioreclamation process such as biomounds. Data concerning phytoreclamation of PCBs, dioxins, and other such compounds are inconclusive at present; further research and testing is required (Price and Lee, 1999). Therefore, phytoreclamation of PCB-contaminated sediments will not be retained for further consideration in this FS.

4.2.7.3 Sediment Washing

Sediment washing is a water-based volume minimization process in which the sediment is mechanically scrubbed to remove such contaminants as halogenated solvents, aromatics, fuel oils, PCBs, and chlorinated phenols (USEPA, 1993b). Sediment washing is based on the same principle as solids classification; that is, organic and inorganic contaminants tend to preferentially bind, either chemically or physically, to smaller-sized particles such as clay and silt. Sediment washing separates the fine fraction of sediments from the coarser particles, thereby concentrating the contaminants and reducing the volume of material requiring additional treatment or disposal. Consequently, sediment washing has limited effectiveness in treating sediments with large fractions of fine-grained particles. Typical soil washing solutions are water or water in combination with organic solvents, chelating compounds, surfactants, acids, or bases. Extraction technologies using organic solvents will be discussed in subsection 4.2.7.4, Solvent Extraction. Modification of the soil washing solution adapts the process to most effectively remove and concentrate the contaminant(s) of concern.

Sediment washing technologies evaluated for use at the Hudson River site are presented in Table 4-9. Options that are highlighted on the table have been tested for or applied to freshwater sediments or PCB-contaminated sediments. Sediment washing is technically implementable and can be potentially effective in treating the PCB-contaminated sediment at the site. Sediment washing will be retained for further evaluation.

4.2.7.4 Solvent Extraction

Solvent extraction, discussed in subsection 4.2.5.2, involves the dissolution of contaminants from the sediment matrix and recovery and treatment of the contaminant-bearing solvent. Multiple extraction cycles are often required to achieve high removal efficiencies. The most common solvents used for PCB extraction are kerosene, propane, methanol, ethanol, dimethylformamide, ethylenediamine, triethylamine, and freon mixtures. Solvent extraction processes evaluated for use at the Hudson River PCBs site are presented in Table 4-4. Options that are highlighted on the table have been tested for or applied to freshwater sediments or PCB-contaminated sediments.

As shown in Table 4-4, *ex situ* solvent extraction has been demonstrated to be effective in treating sediments contaminated with PCBs at pilot scale and full scale. Furthermore, solvent extraction would be technically implementable for the Upper Hudson River. It should be noted that the liquid waste stream would require further treatment, *e.g.*, other chemical or physical separation processes, to separate the contaminants and recover the solvent. The concentrated PCB residuals would require ultimate disposal either by incineration or another suitable method. The treated sediments may also require further processing prior to ultimate disposal. Solvent extraction will be retained for further evaluation.

4.2.7.5 Chemical Dechlorination

Dechlorination processes remove chlorine atoms from chlorinated contaminants such as PCBs through the addition of a chemical reagent under alkaline conditions at increased temperatures. Dechlorination processes evaluated for treating Hudson River sediments, including the APEG process, the base-catalyzed decomposition (BCD) process, dechlorination in combination with thermal desorption, and dechlorination in combination with solidification, are described briefly in the following section and evaluated further in Table 4-5. Options that are highlighted on the table have been tested for or applied to freshwater sediments or PCB-contaminated sediments. Processes combining dechlorination and thermal desorption are included both in this section and in subsection 4.2.7.6, Thermal Desorption. Processes combining dechlorination and solidification are also included in subsection 4.2.7.8, Immobilization.

Chemical Dechlorination Utilizing Alkali Metal Hydroxide-based Polyethylene Glycol Reagent (APEG)

This process detoxifies PCBs by heating and mixing the contaminated sediment with the APEG reagent. Potassium hydroxide is the most commonly used alkali metal hydroxide in this process; the resulting product is potassium polyethylene glycol (KPEG). Sodium hydroxide is another commonly used alkali metal hydroxide. During the process, the PCBs are decomposed into glycol ether and chloride salt, which are water-soluble, low-toxicity compounds.

The dechlorination process requires from 0.5 to 5 hours per batch, depending on such factors as the contaminant concentration, water content, humic and clay content, and the level of treatment required. Once dechlorination is complete, the treated sediment is washed to remove excess reagent and treatment by-products. Spent reagent and washwater may require additional treatment.

Toxicity of the technique's reaction products and their long-term effect on environmental conditions remain to be confirmed. The APEG process often results in partial dechlorination, with residual compounds that are water-soluble and slightly toxic. Furthermore, the APEG process can sometimes form dioxins and furans (USEPA, 1993c). Due to the potential for the latter, this process is not retained for further evaluation.

Chemical Dechlorination by the Base-catalyzed Decomposition (BCD) Process

The BCD process combines chemical addition with thermal input to dechlorinate organic compounds without the use of polyethylene glycol. The process, which was developed by USEPA, is partly a thermal desorption process (discussed below) and partly a dechlorination process. The first step of the process involves the addition of sodium bicarbonate to PCB-contaminated sediments to lower the temperature at which thermal desorption occurs and to partially destroy the PCBs. The sediment-sodium bicarbonate mixture is heated to temperatures ranging from 600° to 950° F, which results in PCB dechlorination and volatilization. The vapor condensate is then passed into another reactor, where sodium hydroxide, a high-boiling hydrocarbon oil, and a catalyst are added. The mixture is heated to 600° to 950° F for three to six hours, during which further PCB dechlorination occurs. The BCD process produces residual compounds that are not water-soluble and not toxic. Laboratory tests have demonstrated that BCD treatment of PCBs does not produce dioxins and furans.

In 1996 and 1997, a thermal desorption/BCD unit was used in a full-scale project at Naval Station Guam to treat PCB-contaminated soil. The system averaged 1.3 tons per hour and treated the soil to an average total PCB concentration of below 2 ppm.

The BCD process can be effective in the treatment of PCB-contaminated sediments. It does not have the same limitation as the APEG process in terms of producing dioxins and furans. The BCD process is technically implementable at the site. Base-catalyzed decomposition is retained for further evaluation.

Combined Thermal Desorption/Dechlorination Processes

As discussed above, dechlorination processes, particularly BCD, rely on thermal desorption to extract PCBs from sediments before dechlorination can occur. Combined thermal desorption/dechlorination processes have an advantage over simple thermal desorption processes in that the organic contaminants are chemically destroyed rather than just concentrated after being desorbed from the sediment solids. Combined thermal desorption/dechlorination processes are evaluated in Table 4-5. Options that are highlighted on the table have been tested for or applied to freshwater sediments or PCB-contaminated sediments.

Combined thermal desorption/dechlorination processes have been demonstrated to be effective in treating PCB-contaminated sediments in pilot and full-scale projects. This technology is technically implementable and is retained for further evaluation.

Combined Dechlorination/Solidification

Dechlorination in combination with solidification (discussed below) is a process that combines the addition of setting agents to immobilize contaminants, and reagents to dechlorinate contaminants. This process has not been demonstrated for PCB-contaminated sediments. Furthermore, this process has been inactive since 1994, with no new advances or tests (Funderburk, 1999; dePercin, 1999). Combined dechlorination/solidification is not retained for further evaluation.

4.2.7.6 Thermal Desorption

Thermal desorption involves the application of heat to below-combustion temperatures, typically 200° to 1,000° F, to volatilize water and organic contaminants. Dewatering prior to treatment is often appropriate to avoid excess costs associated with thermally driving off moisture. Thermal desorption processes take place under anoxic conditions to prevent combustion. The vaporized organics are then recovered by condensation or carbon adsorption for additional treatment, *e.g.*, dechlorination. Alternatively, the vaporized organics can be incinerated in a high-temperature, secondary-combustion chamber (USEPA, 1993c). By desorbing the contaminants from the sediment matrix, the volume of material subject to additional treatment is greatly reduced.

Thermal desorption processes can be categorized into two groups based on the operating temperature of the desorber: high-temperature thermal desorption (HTTD) or low-temperature thermal desorption (LTTD). These relative terms should not be confused with terms used when thermal desorption is being compared with incineration processes. In such comparison, thermal desorption is referred to as a low-temperature thermal process, while incineration is considered a high-temperature process, in which temperatures are generally 2,000° F or higher. HTTD processes operate at 600 to 1,000° F and are frequently used in combination with incineration or dechlorination. LTTD processes operate at 200 to 600° F and have been most successful for remediating petroleum hydrocarbon contamination in soil (FRTR, 1999).

A temperature below 800° F is generally not sufficient to release PCBs from soils or sediments unless air flow is severely restricted. However, in a restricted-oxygen atmosphere, PCBs may react (by pyrolysis) to form other compounds such as dibenzofurans, some of which are considered more toxic than PCBs. This problem must be addressed in order for a particular thermal desorption technology to be appropriate for PCB-contaminated sediments.

There are many commercially available thermal desorption processes. Those evaluated for use at the Hudson River site are presented in Table 4-10. Options that are highlighted on the table have been tested for or applied to freshwater sediments or PCB-contaminated sediments.

Thermal desorption has been demonstrated to be effective in removing PCBs from sediments, and is technically implementable at the site. The desorbed PCBs would require further treatment or disposal. As discussed previously, thermal desorption is often combined with dechlorination processes so that organic contaminants are chemically destroyed rather than just concentrated after being desorbed from the sediment solids. Combined thermal desorption/dechlorination processes are also evaluated in Table 4-10. Thermal desorption is retained for further evaluation.

4.2.7.7 Thermal Destruction

Thermal destruction is a controlled process that uses high temperatures to destroy hazardous contaminants. The specific products of thermal destruction vary depending on the types of wastes that are burned and the operating parameters. Most thermal destruction units consist of a waste feed system, an air or oxygen-fed burner system, a combustion chamber, a combustion monitoring system, and equipment for air pollution treatment and control and ash removal.

Thermal destruction systems can be fixed, mobile, or transportable. Fixed systems are off-site TSCA-permitted incineration facilities. The use of these facilities requires that sediments be dewatered prior to transportation to the facilities. Mobile thermal destruction systems are brought to a site and then removed at the conclusion of the remediation. They normally include all of the equipment and supporting systems necessary for operation of the facility, such as electric-power generation equipment, a fuel supply, and equipment to collect and dispose of wastewater. Transportable equipment differs from mobile equipment in that it requires a significant installation effort. This equipment is provided in modular components and must be assembled before use. Transportable systems are designed so that they can be dismantled, removed, and re-installed at another site. The potentially large load for this project would probably necessitate installation of one or more near-river thermal destruction systems if mobile or transportable systems are selected.

The thermal destruction processes/options evaluated for Hudson River sediments are presented in Table 4-11. Options that are highlighted on the table have been tested for or applied to freshwater sediments or PCB-contaminated sediments. Thermal destruction has been demonstrated to be very effective in destroying PCBs in soils and sediments and is technically implementable; thermal destruction is therefore retained for further evaluation.

4.2.7.8 Immobilization

Immobilization refers to a broad class of treatment processes that physically or chemically reduces the mobility of hazardous constituents in a contaminated material. Immobilization treatment of contaminated sediments improves material handling characteristics, decreases the area through which contaminant transport can occur, and limits the contaminant solubility and toxicity. Immobilization includes solidification, stabilization, and encapsulation processes (subsection 4.2.5.4).

Ex situ immobilization methods involve mixing setting agents such as cement, quicklime, grout, pozzolanic materials, and reagents with sediments in a treatment unit. A treatment unit typically consists of a materials feed system, a reaction vessel equipped with mixing equipment, and an area for curing. Sediments may require some pre-processing, such as screening of oversized material, prior to solidification/stabilization treatment.

Solidification/stabilization processes evaluated for use at the Hudson River PCBs site are presented in Table 4-6. Options that are highlighted on the table have been tested for or applied to freshwater sediments or PCB-contaminated sediments.

The effectiveness of solidification/stabilization technologies is variable depending on the characteristics of the contaminated soil and the particular additives used (subsection 4.2.5.4). This technology is technically implementable at the site because PCBs have characteristics of strong adsorption to sediments. *Ex situ* immobilization technologies are retained for further evaluation.

Solidification in combination with dechlorination was discussed and evaluated previously (subsection 4.2.7.5, Chemical Dechlorination). Combined dechlorination/solidification is not retained for further evaluation because of lack of demonstrated effectiveness for PCB-contaminated sediments.

4.2.8 Beneficial Use

Beneficial use of dredged contaminated sediments includes two main options, using the dredged sediment in their original form, or treating the sediments to destroy the PCB contaminants and processing the treated material to create a useable product.

4.2.8.1 Landfill Cover Material, Construction Fill, Mine Land Reclamation

Beneficial use options discussed in this subsection involve using dredged sediment in its original form, *i.e.*, the sediment may be treated to remove contaminants prior to being put to use, but its essential form will still be that of a sediment material. These beneficial use options are presented in Table 4-12, and differ from those discussed in subsection 4.2.8.2, Manufacture of Commercial Products, where thermal treatment processes actually form a useable product that is no longer sediment.

400477

Beneficial Uses of Dredged Material, Engineer Manual 1110-2-5026 (USACE, 1987a), provides evaluation of and conceptual design criteria for several potential beneficial use options. The physical location of the site and character of the surrounding region, as well as the nature of the contaminant problem, limit the beneficial options that can be considered. It is unlikely that options that bring exposed sediments - even if treated - into close physical proximity to humans, domestic animals, or wildlife would be acceptable for consideration due to the perception of risk. For these reasons, beneficial use options such as habitat (*e.g.*, wetlands) development, park and recreational uses, and agricultural uses are not evaluated for this project. The creation of made land, with proper isolation and engineering controls, is a possible exception; this is discussed below in subsection 4.2.9. Beneficial use options discussed in this subsection include using dredged sediments for solid waste landfill cover, construction fill, and abandoned strip mine reclamation.

As a practical matter, it is unlikely that private parties would accept treated sediment for construction purposes due to the nature of the contamination. Moreover, the sheer volume of material potentially involved makes the logistics of beneficial use schemes a challenge. Potential beneficial use, other than made land, is therefore likely to be limited to solid waste landfill cover material, fill material for large government construction projects, such as highways and airports, and strip mine reclamation fill material.

Beneficial use may be applicable to raw sediments, to coarser-grained sediments separated from fine-grained sediments through solids classification pretreatment or soil washing treatment, or to treated sediments. It is likely that beneficial use options will require meeting certain appropriate criteria for the specific use.

Solid Waste Landfill Cover

Soils are used in the operation of solid waste landfills to provide daily cover, interim cover, and final cover. This material must be amenable to handling by typical earth moving equipment such as front end loaders and dump trucks; must be spreadable; and must be able to be compacted under the wheels or tracks of trucks and bulldozers. The sediments of the Upper Hudson River are largely silty sands and sandy silts which, if dry enough, would serve as satisfactory cover material.

Hydraulically dredged sediments would require settling with subsequent drying prior to use at a landfill.

There are several solid waste landfills within 100 miles of the site. However, because of the potentially large volume of dredged material that could be generated, and because some landfills may not accept dredged material as landfill cover even if treated, the total combined capacity of these landfills may not be sufficient. However, if smaller components of the total sediments are considered (*e.g.*, separated coarse-grained material), or if this option were to be combined with another beneficial use option, use of the material as landfill cover may be feasible. This beneficial use option may be suitable for sediments with low concentrations of total PCBs (typically four to ten mg/kg), especially if these sediments have already undergone a relatively low-cost treatment such as solidification/stabilization with pozzolanic materials. Beneficial use of sediments as solid waste landfill cover, therefore, is retained for further evaluation.

Construction Fill

Utilization of barge canal sediments as fill for construction projects is a sediment reuse historically practiced in the Mohawk Region (Malcolm Pirnie, Inc., 1984). As noted above, current knowledge of the PCB contamination of Hudson River sediments, or even association with the remediation project, would likely restrict potential demand for these materials to state or federal government projects. However, treated solidified/stabilized sediments from Newark Bay were used as construction fill at the Jersey Gardens Mall project, which is privately owned. Treated or minimally contaminated sediments can also be used in major highway or airport construction where they would be encapsulated safely within pavements or beneath structures.

Dredged sediments from the Hudson River likely do not have sufficient coarse materials (gravel) to be utilized as highway or runway subbase without amendment. In addition, as discussed previously with regard to landfill cover, there likely would not be sufficient capacity at potential construction projects in the vicinity of the site to accept the total volume of dredged material, given that it is potentially so large. Again, however, if smaller components of the total sediments are considered (*e.g.*, separated coarse-grained material), or if this option were to be combined with another beneficial use option, the construction project option may be feasible. This beneficial use option may be suitable for sediments with low concentrations of total PCBs (typically four to ten mg/kg), especially if these sediments have already undergone a relatively low-cost treatment such as solidification/stabilization with pozzolanic materials. Beneficial use as construction fill is retained for further evaluation.

Abandoned Mine Reclamation

This beneficial use option involves using dredged sediments to reclaim abandoned mine lands. The focus of abandoned mine reclamation is to reduce health and safety issues related to the unreclaimed mines. Pennsylvania, for example, which in the past was a leading coal producer, has many abandoned mines statewide that could potentially use dredged sediments for reclamation. Reclamation can involve filling open mine pits, open shafts, and undermined areas with subsidence problems, and grading surface mine areas to minimize erosion. Prior to use as mine reclamation material, the dredged sediments may be blended with other materials such as biosolids, paper waste, and coal ash to provide products that inhibit acid mine drainage production and facilitate enhanced reclamation and revegetation of abandoned mine lands.

Abandoned mine reclamation has many benefits, including elimination of physical hazards to people living and working near these sites. The environmental benefits of abandoned mine reclamation include restoration of land for future use and improvement of water quality. Restoration of the land can result in increased pasture land and recreational areas, and enhanced wildlife habitat.

Currently, the use of dredged sediments as mine reclamation material is being evaluated at an abandoned surface mine in the central part of Pennsylvania in a pilot project sponsored by the Office of New Jersey Maritime Resources (USEPA, 1999m). Pending evaluation of groundwater monitoring results from this project, which may require several years, the Pennsylvania Bureau of Abandoned Mine Reclamation is not authorizing other reclamation projects using dredged material. In addition, dredged sediments with PCB concentrations greater than 4 ppm will not be accepted as abandoned mine reclamation material (Linanne, 1999). However, because this beneficial use option can potentially accept large quantities of sediments (in the TI Pool, for example, it is estimated that more than 11 percent of the sediments potentially targeted for remediation under a full section effort have PCB concentrations below 4 ppm), it will be retained for further evaluation.

4.2.8.2 Manufacture of Commercial Products

The technologies discussed in this subsection combine treatment processes to destroy organics in the sediments with some further physical/chemical processing to convert the decontaminated sediment into a useable commercial product. The treatment processes are thermal destruction processes that may involve oxidation and destruction of organic contaminants in an oxygen-rich environment, or pyrolysis and destruction of organic contaminants in an oxygen-poor environment. Along with contaminant destruction, the three technologies evaluated in this group all include further processing such as heating the sediment matrix to the melting point to fuse the matrix into a homogenous glassy liquid, then quenching the melt to make a glass tile product or glass fibers for use in the manufacturing of construction grade cement. These processes are presented in Table 4-13. Options that are highlighted on the table have been tested for or applied to freshwater sediments or PCB-contaminated sediments.

Thermal destruction has been demonstrated to be very effective in destroying PCBs in soils and sediments. Thermal destruction, combined with further processing to manufacture a useable product, has an advantage over simple thermal destruction processes in that there is no final product for disposal. Furthermore, processing costs may be recovered when the useable product can be sold commercially. Combined thermal destruction/beneficial use processes are technically implementable and will be retained for further evaluation.

4.2.9 Disposal Technologies

Some means must be employed to provide final disposal of any sediments that are physically removed from the river through environmental dredging. Some disposal technologies may require dewatering prior to implementation and, depending on the particular technology and contaminant concentrations, some form of *ex situ* treatment as discussed in subsection 4.2.7 may also be required. Disposal technologies considered include land disposal and aquatic disposal.

400481

4.2.9.1 Land Disposal

Land disposal of PCB-contaminated sediments may be accomplished in CDFs or in landfills. Confined disposal facilities can accommodate hydraulically dredged sediments and are designed and operated to accomplish both dewatering and encapsulation. Confined disposal facilities include both upland facilities and near-shore facilities. Near-shore facilities are those located within the influence of the water body, whether within the floodplain or within the water course proper; the lower zones of the facility are below the groundwater table. USEPA (1993b) notes that CDFs are cost-effective, and with proper location, design, and construction can perform well in isolating contaminants from the environment.

The use of landfills requires that sediments be dewatered prior to placement. Since the most economical means of dewatering bulk dredge spoils utilizes diked impoundments, near-river landfills with separate dewatering facilities will not be considered; the confined disposal facility is an equivalent and more cost-effective method. The use of off-site landfills is also considered. However, the additional handling and transportation of the material to an off-site landfill may add significantly to the cost.

Off-Site Landfill

Dredged material with PCB concentrations less than 50 ppm can legally be disposed of in a municipal or solid waste landfill. Dredged material with PCB concentrations greater than 50 ppm requires disposal at a TSCA-permitted landfill. Because commercial solid waste facilities may impose a more stringent limit of 30 to 35 mg/kg PCBs as an acceptance criterion, however, for management and final disposition of dredged sediments for purposes of this assessment, a trigger level of 33 ppm, not 50 ppm, will be used as the PCB concentration in sediment that would differentiate between TSCA-permitted and non-TSCA-permitted disposal. A list of solid waste landfills evaluated and screened for Hudson River PCB sediment disposal is presented in Table 4-14. A list of TSCA-permitted landfills is presented and screened in Table 4-15. In both cases, these landfills are screened on the basis of potential capacity to accept PCB-contaminated sediments.

Depending on the degree of unavoidable mixing expected during the removal, treatment, or dewatering process, use of both non-TSCA-permitted and TSCA-permitted disposal facilities may be necessary. Further, off-site landfill disposal would require transportation, potentially to great distances. Some disposal facilities may be accessible by rail. Using unit trains, the cost of transportation for large quantities of material, if planned in advance, may be significantly lower than use of trucks. This option is technically implementable and is retained for further evaluation.

Upland Confined Disposal Facility

The fundamental characteristic of a CDF is a diked area into which dredged materials are placed hydraulically. The facility must be large enough to provide adequate capacity to meet dredging requirements and must efficiently retain solids while allowing supernatant to be released. Coarse material such as gravel, sand, and perhaps clay balls, falls out of suspension rapidly near the inlet pipe. The fine-grained material such as silt and clay particles gradually settles out as the suspension water moves toward the overflow weir.

In this case, the CDF is also intended to provide long-term disposal of the contaminated dredged material, essentially as a secure lined landfill. This necessitates siting, design, construction, operation, closure, post-closure monitoring, and maintenance. The facility must meet regulatory requirements, including effluent discharge limits and groundwater standards, for landfills in which PCB-contaminated materials will be stored. A secure, lined CDF provides a high degree of isolation of the contaminated material with a low probability of subsequent discharge.

Siting a location for a CDF in the vicinity of the Upper Hudson River will be the primary consideration in evaluation of this technology (USEPA, 1997b). Although local and political issues have historically made the siting of land disposal facilities problematic (see subsection 1.2.2), this technology is technically feasible and will be retained for further evaluation.

400483

Near-shore Confined Disposal Facility

This term is normally used for a diked disposal area within the tidal zone employed for harbor and waterfront dredging projects. For the purposes of this project, it refers to a CDF located within the 100-year floodplain or in shallow, non-navigation areas of the river. A potential floodplain location large enough to accommodate the volume of dredge spoils anticipated is the remnant deposit area north of Fort Edward. Use of this area would probably require initial removal and stockpiling of the remnant material to allow installation of a liner below significant contamination. The remnant material could then be disposed of in the newly created cells along with dredged material. Location of CDFs in shallow river areas would result in made land, creating or extending islands, or connecting islands to the river bank. While there is no single location that could accommodate the volume of dredged material anticipated, there are several potentially suitable areas between Fort Edward and Schuylerville which, taken together, could provide sufficient capacity.

The layout and operation of a near-shore CDF are, in many respects, similar to those for an upland facility. However, whether in the floodplain or in shallow river areas, construction must take place in wet conditions and the design and operation must account for high-flow periods and floods. Since in both cases the areas to be filled are not necessarily contiguous, the dredging sequence may be matched to filling and closure of individual cells in a single season, thereby avoiding washout during floods. With proper capping and isolation, such areas could be developed for habitat, parkland, commercial uses, or waterfront access. Advantages of near-shore CDFs are that in some cases no purchase of land is necessary (except possibly for construction access), and the permit exemption of CERCLA Section 121(e)(1) would apply to any CDFs that are located within the Hudson River PCBs Site. The construction of near-shore CDFs for disposal is technically feasible and this option will be retained for further evaluation.

4.2.9.2 Contained Aquatic Disposal

Contained aquatic disposal of dredged material in open waters has been practiced for many years. Restricted disposal involves controls beyond those applied in conventional projects in order to address the risks or uncertainties associated with contaminated sediments (Cullinane *et al.*, 1986). Unrestricted disposal is not appropriate in the Upper Hudson River because of the nature of the contamination and the need to avoid interfering with navigation. For the purposes of this FS, the principal restriction to be considered is containment of the sediments to avoid subaqueous material transport or release of contaminants.

Contained aquatic disposal involves subaqueous covering or capping of dredged sediments, whether they are simply placed on the bottom or deposited in depressions or excavated pits. Subsection 4.2.4 contains a discussion of capping sediments in place. Over the last two decades, millions of cubic yards of sediments have been disposed of in this manner, mostly in harbor and estuarine locations.

Contained aquatic disposal has not been used previously in the Upper Hudson River. However, numerous uncapped "wet dump grounds" have historically been used for temporary storage or disposal of sediments during navigational maintenance dredging. At least seven such areas between Fort Edward and Schuylerville have been documented (Malcolm Pirnie, Inc., 1984). Typically, these areas resulted from storage of material dredged by the slower but more available clamshell dredges. When available, faster cutterhead dredges were used to redredge the wet dump grounds to retrieve the material for upland disposal. Some of the wet dump grounds are coincident with *hot spots*.

Cullinane *et al.* (1986) suggest that the most important physical goal in selecting a site for aquatic disposal is long-term stability, which is influenced by at least six factors, including currents, water depth, salinity/temperature stratifications, bathymetry, dispersion and mixing, and navigation and positioning. There are locations in the Upper Hudson River where currents may cause difficulties for the disposal operation, particularly during periods of high flow. However, the major reaches of the river in which the largest amounts of the contaminated sediments exist are relatively calm. In the short term, the major concern with currents is simply accurate positioning of the disposal device (USEPA, 1993b). The bulk of the material will settle out close to the point of deposition with only small amounts of the sediment remaining suspended. In order to address long-term stability issues with regard to currents, sufficient armoring would be required to avoid transport of the cover material.

The water depth for typical aquatic (open water) disposal projects in marine environments is about 70 feet (USEPA, 1993b). Except for a single deep hole immediately south of TI Dam on the west side of Thompson Island, no other part within the area under consideration approach this depth. The navigation channel is maintained at a minimum depth of 12 feet, while non-channel areas may be considerably shallower. Unless large subaqueous pits are excavated specifically for disposal, there is insufficient area in which to place the anticipated quantities of material without significantly changing the nature and hydraulics of the watercourse in disposal locations.

Due to the extremely limited potential areas for disposal, this technology is not appropriate for the Upper Hudson and will not be evaluated further.

4.2.10 Summary of Initial Screening of Technologies

Aside from No Action, MNA, and institutional controls, there are six categories of general response actions appropriate to remediation of PCB-contaminated sediments of the Upper Hudson River. These are containment, *in situ* treatment, removal, *ex situ* treatment, beneficial use, and disposal. In connection with these six general response actions, 20 technologies with various process options have been evaluated as described above for effectiveness and technical implementability; four of these technologies were evaluated for both *in situ* and *ex situ* application. The results of this screening evaluation are summarized in Table 4-1.

Of the 20 technologies considered, seven were not retained for further evaluation. These include bioremediation (both *in situ* and *ex situ*), *in situ* solvent extraction, *in situ* chemical dechlorination, *in situ* immobilization, soil freezing, and aquatic disposal. There are various supporting technologies that may be required in order to implement certain of the primary technologies. A discussion of these supporting technologies can be found in subsection 4.2.11.

Containment of the sediments in place is the remedial response least invasive to the sediment environment. Containment systems such as capping and retaining structures are methods for controlling sediment resuspension under the range of expected river hydraulic conditions. While retaining dikes and berms may be used as part of a containment scheme, it is most likely that capping with inert materials or sealing agents would provide more long-term effectiveness and stability than dikes or berms alone.

Technologies applicable to treating the Hudson River sediments *in situ* have also been considered. *In situ* treatment technologies would be somewhat more invasive than containment but less so than removal. The main limitation of *in situ* treatment is the lack of process control during treatment, which can lead to incomplete or ineffective treatment and contaminant release to the water column. All *in situ* treatment technologies were eliminated in this first stage of screening for these reasons.

Bottom sediments may be removed if other less invasive technologies are not cost-effective or protective. Excavation and environmental dredging using conventional or specialty dredges has been retained for further evaluation. Equipment modifications and operational controls to reduce sediment dispersion during dredging, such as using cutterhead dredge shrouds, adjusting cutterhead rotational speed, employing scow-filling controls, and setting limitations on cutterhead swing speed, are important considerations. Excavation may generate less sediment resuspension than dredging because the work zone can be isolated from the adjacent water body or dewatered prior to removal of contaminated sediments.

Should a decision be made to remediate the Hudson River PCBs site by removing some or all of the contaminated bottom materials, it would be necessary to dispose of the removed materials directly or to treat those materials and dispose of the treated residuals. Physical, chemical, biological, and thermal processes or technologies, or combinations thereof, have been proposed for treatment of PCB-contaminated solids. Of the treatment technologies evaluated, all were retained for further consideration except for bioremediation because, based on results from other sites, complete biodegradation of PCBs may be difficult to achieve within a reasonable time frame for the potentially large volume of dredged sediments for the Upper Hudson.

Beneficial use options of either using the dredged sediment in its original form, or treating the sediments to destroy the PCBs and processing the treated material to create a useable commercial product, were evaluated and retained.

The final category of remedial technologies considered here involves disposal of either untreated contaminated sediments or the residuals from treatment of contaminated sediments. Land disposal options have been retained for further assessment. While there are no nearby landfills permitted to receive PCB-containing sediments, transportation and disposal at landfills more distant from the river but permitted to receive PCB sediments is technically feasible and is an option. Upland disposal, which would involve obtaining approval to construct a proximate CDF specifically for contaminated sediments removed from the Upper Hudson River, and near-shore disposal in a facility located within the 100-year floodplain or in shallow, non-navigation areas of the river, are two other land disposal options. Aquatic disposal has been ruled out based on the lack of suitable area to accommodate the quantity of material expected.

4.2.11 Supporting Technologies

Supporting technologies are mentioned in this chapter in relation to their potential applicability in concert with some of the primary technologies that were evaluated. None of these supporting technologies has been evaluated or screened to this point. Such technologies include:

- Sediment dispersion controls to maintain water quality, described briefly in subsection 4.2.6, Removal Technologies;
- Passive, mechanical, and active evaporative dewatering technologies and solids classification processes (stationary screens and sieves, vibratory screens, hydraulic classifiers, spiral classifiers, and cyclones/hydrocyclones), described in subsection 4.2.7, *Ex Situ* Treatment;
- Wastewater treatment subsequent to application of some *ex situ* treatment technologies; and
- Transportation, whether by truck, rail, or barge.

Evaluation and selection of supporting technologies is appropriate in the detailed evaluation and conceptual design phase.

Some consideration of habitat replacement is also appropriate here. Sediment removal and sediment containment involve primary technologies that result in potential impacts to or disturbance of aquatic and wildlife habitat, potentially resulting in the need for restoration measures that involve application of supporting technologies. Details pertaining to the habitat replacement concepts appear in Chapter 5 and Appendix F. The major objectives of habitat replacement are:

- Restoration of fish habitat;
- Restoration of benthic habitat;
- Replacement of vegetation communities;
- Restoration of wetlands; and
- Stabilization of shorelines.

The following potentially applicable supporting technologies would address these objectives:

- Placement of suitable substrate and limited deployment of boulder clusters in deep river areas;
- Planting of rooted submerged and floating aquatic vegetation in shallow river areas, excluding emergent wetlands and riverbanks;
- In emergent marsh areas, establishment of vegetative species that are valuable to fish and wildlife; deep pools vegetated with rooted and floating vascular plants; and shrub-scrub wetlands along the shoreline fringes; and
- Stabilization of riverbanks utilizing both vegetative and structural-vegetative methods.

4.3 Effectiveness, Implementability, and Cost Screening of Technology Process Options

Technologies and process options that pass the initial technical feasibility screening are subjected to a further screening based on the three criteria of effectiveness, implementability, and cost. Results of this screening are discussed below and are summarized on Table 4-16. It should be noted that the numbering of subsections for this screening does not directly match the numbering of the initial technology screening discussion (subsections 4.2.1 through 4.2.10), since one general response action category (*in situ* treatment, subsection 4.2.5) was not retained for further evaluation in this section.

Effectiveness focuses on the degree to which a process option reduces the toxicity, mobility, or volume of hazardous substances through treatment and achieves long-term protection. The effectiveness criterion also considers the degree to which the process options complies with the ARARs and minimizes short-term impacts, and also how quickly it achieves protection.

Implementability includes both the technical and administrative feasibility of implementing a technology process. Technologies that were clearly ineffective or unworkable for this site were previously screened in Section 4.2. Therefore, consideration of implementability with respect to process options focuses on the administrative implementability of technology processes, including necessary permits for off-site actions; the availability of treatment, storage, and disposal facilities; and the availability of necessary equipment and skilled workers to implement a technology process.

Cost plays a limited role in this screening stage; only order-of-magnitude costs (*i.e.*, low, moderate, or high cost) are developed. For the purposes of this discussion, processing costs of less than $100/ton of sediments were considered low; $100 to $500/ton were considered moderate; over 500 to $1,000/ton were considered high, and processing costs over $1,000/ton were considered very high. For treatment technologies, processing costs were assumed to include all the costs associated with the treatment other than capital and mobilization costs. Technologies or process options that may be significantly more costly without any offsetting benefit over comparable options may be screened out at this point.

4.3.1 No Action

Under No Action, no active remediation of any kind is implemented. In this FS, the No Action alternative excludes implementation of ongoing monitoring programs and any institutional controls/administrative actions; only five-year reviews will be performed.

4.3.1.1 Effectiveness

Under the No Action scenario, ecological and human health risks at the site exceed acceptable levels (USEPA 2000q, and USEPA 2000p) and are likely to remain at unacceptable levels for several decades. The No Action alternative is not effective in reducing these risks because it does not include any remedial activities to reduce human or ecological exposure to hazardous substances at the site.

4.3.1.2 Implementability

No Action is easily implemented from a technical and administrative perspective.

4.3.1.3 Costs

There are no short-term costs for No Action. Long-term costs are limited to periodic reassessment at five-year intervals.

4.3.1.4 Conclusion

The No Action option is retained as a baseline for comparison to other alternatives.

4.3.2 Monitored Natural Attenuation

As discussed in subsection 4.2.2, monitored natural attenuation refers to the reliance on natural attenuation processes to achieve remedial action objectives within a time frame that is reasonable compared to other more active methods. It is not considered to be a No Action remedy. Natural attenuation includes the reduction of volume and toxicity of contaminants in sediments by natural biological, chemical, and physical processes. Extensive site monitoring and modeling would be performed as part of monitored natural attenuation for the Hudson River PCBs site. Institutional controls also may be a component of the MNA alternative.

4.3.2.1 Effectiveness

The effectiveness of MNA depends on how well naturally occurring processes such as biodegradation and burial reduce PCB levels in the river. Biodegradation of PCBs in the Upper Hudson River sediments has resulted in partial reduction of highly chlorinated congeners, but little or no reduction of less chlorinated congeners (USEPA, 1997a). More importantly, the degree of dechlorination varies directly with the level of contamination but only becomes important at higher concentrations (greater than 100 mg/kg and higher). Additionally, dechlorination does not appear to continue indefinitely with time. Finally, full dechlorination can only reduce the total mass of PCBs by 26 percent and this has been only rarely observed. Thus much of the sediment PCB inventory remains largely intact with regard to dechlorination, having only been subject to minor dechlorination losses, estimated at less than 10 percent of mass (USEPA, 1997a, and USEPA, 1998b).

Notably, dechlorination, when it is able to proceed to its fullest extent, is expected to reduce the carcinogenicity of PCBs although this has not been directly verified. However, less than full dechlorination, more typical of Hudson conditions, is expected to increase PCB mobility, potentially increasing migration from the sediments and bioavailability. Additionally, lower chlorinated congeners have been ascribed higher neurological and developmental impacts in humans so that the ultimate impact of the dechlorination levels typically seen in Hudson River PCBs is unclear. Thus, dechlorination is not expected to improve the effectiveness of MNA through reduction of mobility or toxicity.

Burial of contaminated sediment by deposition of less-contaminated sediment does occur in the Upper Hudson, but varies significantly along the river and is difficult to quantify at a specific location. Additionally, the USEPA found evidence for statistically significant PCB mass loss from the sediments, indicating that re-release of the PCBs in the river sediments is occurring over time. Indeed, the water column monitoring records obtained by GE suggest that sediment release of PCBs from the TI Pool has diminished little over the ten-year period of record. Monitoring of PCB levels in fish indicates that some reduction has occurred historically, but the current rate is such that will not reach RAOs or PRGs for several decades (USEPA, 2000a). Extensive monitoring and analysis required as part of MNA/recovery are effective in tracking trends in PCB dynamics, but will not, in themselves, meet RAOs. Indeed, the gradual downward declines of PCB levels in fish and in sediments are consistent with much slower rates of recovery than those estimated by the modeling analysis. These issues raise significant concerns about the effectiveness of MNA.

4.3.2.2 Implementability

Monitored natural attenuation is considered to be readily implementable technically and administratively.

4.3.2.3 Costs

Short- and long-term costs for site monitoring and data analysis and modeling are relatively low compared to active remedial actions.

4.3.2.4 Conclusion

Monitored natural attenuation can be implemented alone, along with an active remedial action, or after an active remediation is completed. MNA timing and efficiency can vary by river section depending on whether active remediation is planned for that section. This option is retained for further evaluation.

4.3.3 Institutional Controls

Institutional controls are non-engineering, administrative, and/or legal controls intended to prevent or reduce human exposure to on-site hazardous substances. For example, institutional controls for the Hudson River PCBs site may include fishing bans or advisories, site access/deed restrictions, water use restrictions, or restrictions on sediment disturbance.

400493

4.3.3.1 Effectiveness

The effectiveness of institutional controls if implemented with no remedial action is low, because RAOs are not met. Site use restrictions may prevent exposure to PCBs from a human health standpoint, but will not reduce or alleviate ecological impacts. Also, since some people may not comply with fish consumption advisories, it is possible that some exposure to PCB contamination may occur.

4.3.3.2 Implementability

Site use restrictions are easily implemented. Effective enforcement of site use restrictions, including fish consumption advisories, may be difficult to maintain in the long term.

4.3.3.3 Costs

Costs for institutional controls including any associated monitoring are relatively low compared to active remedial actions.

4.3.3.4 Conclusion

Institutional controls are retained for further evaluation in this FS.

4.3.4 Containment

Both containment technologies evaluated, subaqueous capping and retaining berms and dikes, were retained in the initial screening.

4.3.4.1 Subaqueous Capping

A wide variety of materials can theoretically be used to cap contaminated sediments in order to minimize or reduce leaching, bioturbation, and erosive transport of contaminants. Capping using inert materials or sealing agents was retained after the initial screening.

Effectiveness

Capping is expected to be effective in containing PCBs in the sediments and meeting RAOs if the cap is properly designed, constructed, and maintained. Given sufficient thickness and armoring, capping using inert materials or sealing agents can minimize leaching of PCBs to the water column, prevent bioturbation, and withstand hydraulic conditions such as scour events associated with extreme floods. However, a large groundwater flux component may significantly impair the effectiveness of a subaqueous cap. Other factors that may affect the effectiveness of a subaqueous cap include scour due to movement of ice chunks during spring thaw (ice rafting), possible damage due to watercraft navigation, and drying/cracking of or result of freeze/thaw cycles on cap areas exposed during low-flow periods.

Implementability

While technically feasible, implementation of this technology would require consideration of several factors. Due to the thickness of material layers needed, the cap would penetrate the water surface in many locations and make other locations so shallow that the parameters for recreational craft navigation would change. Unless sediments are removed prior to placement of the cap, these changes may result in extensive modifications to the shoreline and bathymetry. In addition, implementation of a cap in shallow areas may be limited due to reasons stated above (*i.e.*, drying/cracking, freeze/thaw cycles, scour due to ice chunks, etc.). A subaqueous cap will likely not be implemented in the canal navigation channel, which is subject to maintenance dredging. Finally, this approach will substantially eliminate the benthic population in the extensive areas capped.

Costs

Construction costs are expected to be low to moderate depending on the type of capping material, the thickness of the cap, and the method of construction. For a typical cap design and most capping materials, cap construction costs are expected to be less than $10 per square foot. Long-term costs include periodic monitoring of the cap and cap maintenance, as required.

Conclusion

Capping has been effectively implemented at other sites with contaminated sediments. Capping presents a viable *in situ* remedial alternative compared to sediment removal. Capping may be considered where sediment removal is implemented but contamination is left in place. It can be used to cover areas where sediment removal has been implemented, although it is not practicable for the navigation channel. Capping using inert materials or sealing agents is retained for further evaluation.

4.3.4.2 Retaining Dikes and Berms

This evaluation considers dikes and berms only in the context of long-term stand-alone structures within the river to minimize downstream transport of suspended contaminated sediments. When used as components of CDFs or subaqueous capping system, evaluation of retaining dikes and berms is inferred in the discussion of the primary technology. These structures are intended for implementation as long-term sediment containment options, and are different from sediment barriers set up temporarily to control resuspended sediments during sediment removal activities.

Effectiveness

Retaining dikes and berms may be engineered to be effective in minimizing downstream transport. This can be accomplished by trapping or increasing deposition of suspended sediments or by isolating already deposited sediments from scouring forces. With proper understanding of each local hydrodynamic situation, dikes or berms may be engineered to withstand and provide effectiveness during extreme scour events or under routine water levels and current velocities. Regardless of their effectiveness against erosional transport, however, these structures by themselves will have no effectiveness in reducing diffusion of PCBs to the water column from the contaminated sediments, except insofar as they allow or enhance deposition of clean suspended material over contaminated sediments. This process, though, would be slow and unreliable. This technology will, therefore, not be effective in achieving RAOs.

Implementability

Implementation of this technology requires less backfill or armoring material than subaqueous capping. The necessary resources, regardless of the particular design, are readily available. The presence of rocky soils may impede construction of some containment options. Less disruption of shorefront property and small-craft navigation would occur than for shallow area subaqueous capping. However, depending on location of the retaining dikes and berms, some interference with navigation activities may occur. Due to the smaller amounts of resources needed and less construction activity required, this technology is expected to require less time to implement than subaqueous capping.

Costs

Construction costs are expected to be low and to depend on the type of construction material and the method of construction. Long-term costs include periodic monitoring and maintenance of the retaining structures, as required.

Conclusion

Retaining dikes and berms are eliminated from further consideration due to their ineffectiveness in achieving RAOs compared to other technologies.

4.3.5 Removal

Two sediment removal technologies, *i.e.*, excavation and dredging, were retained in the initial screening.

4.3.5.1 Excavation

Excavation technologies are sediment removal technologies that would be used after a particular work area has been isolated from the river and then dewatered to expose the target material. Contaminated sediment in shoal areas of the river that may be exposed during low-flow periods can also be excavated.

Effectiveness

Excavation technologies are effective and most applicable to removal of those sediments that have been deposited along the river's shallow shoreline areas and within secondary channels. Excavation is most effective when used in combination with any one of several containment or isolation systems (see Section 4.2). Excavation is effective in removing the targeted contaminated sediments from shallow areas.

Implementability

Excavation technologies are conventional systems and are readily available in configurations and sizes that conform to the access limitations and other constraints of the Upper Hudson. While excavation technologies are not likely to be suitable for removing all the river's contaminated sediments, they can be used to manage a portion of the removal requirements. It appears that landside access to contaminated sediments in the Upper Hudson River would require significant disruption of some private properties. Therefore, it is likely that excavation activities would usually be conducted from the water side.

Costs

Costs associated with implementation of typical excavation methods are expected to be in the low to moderate range. As the volume of material being removed increases, the unit cost for excavation work will decrease.

Conclusion

Excavation technologies are applicable for removal of contaminated sediments in shallow areas of the river and therefore are retained for further evaluation.

4.3.5.2 Dredging

The dredging technologies that have been retained to this point in the analysis include conventional dredges and specialty dredges. Actual dredging technologies selected for removal of Upper Hudson contaminated sediments would need to function effectively in light of the wide range of physical conditions that would be encountered, including access limitations, varying river conditions, sediments ranging from fine- to coarse-grained, the presence of debris, cobbles, or boulders in some locations, and navigational conflicts, among others. In light of the many constraints, it can be expected that several different dredging technologies may need to be applied to complete removal of the targeted sediments.

For this FS, dredging technologies were placed into three categories: conventional dredges; large-scale dredges; and specialty dredges (subsection 4.2.6.2). Both large-scale dredges and certain specialty machines were eliminated from further evaluation. The type of equipment that have been retained are evaluated below for potential effectiveness, implementability, and cost.

Mechanical Dredges

Mechanical dredges can be placed into two principal categories, "bucket-on-rope" systems and hydraulically-actuated buckets.

Effectiveness. The "bucket-on-rope" units are now being designed with covers and enclosures that significantly reduce the quantity of material resuspended during removal operations. In addition to enclosures, in some cases the actual digging action of the bucket has been modified to achieve greater sediment removal precision. This technology can be effective for the removal of fine- and coarse-grained sediments, provided excessive debris is not present to prevent complete bucket closure.

The hydraulically actuated bucket dredge is essentially an excavator that has been adapted to dredging operations. These machines, particularly in a backhoe configuration, have been used in European dredging projects for some time. Recently, backhoes have seen utilization in US dredging projects, including deepening of the Kill Van Kull in New York Harbor. Advantages of the hydraulically actuated bucket include its removal precision and production efficiency. Both clamshell and backhoe buckets are now being fitted with covers to reduce resuspension and can remove fine- and coarse-grained sediments at nearly *in situ* water content. These machines can remove most bulky debris encountered during dredging operations with less impairment to productivity than hydraulic dredges operating under comparable conditions.

Implementability. "Bucket-on-rope" systems that are compatible with the Upper Hudson's physical constraints are readily available. Hydraulically actuated machines are also readily available in configurations that are compatible with the physical limitations of working on the river. Since mechanical dredges can be expected to remove sediments at nearly *in situ* conditions, these systems have the advantage of minimizing the volume of water removed from the sediments.

Costs. Costs associated with "bucket-on-rope" systems and hydraulically actuated bucket dredges are expected to be in the low to moderate range, even when consideration is given to the use of turbidity curtains or other suspended sediment control systems. Since mechanical dredges would remove sediments at nearly *in situ* densities, dewatering costs would be minimized with these types of equipment.

Conclusion. Mechanical dredges, in particular "bucket-on-rope" systems and hydraulically actuated bucket dredges, are potentially effective and implementable for removal of Upper Hudson sediments. Thus, these types of equipment are being retained for further evaluation in this feasibility study.

Hydraulic Dredges

This is a broad category of dredges that ranges in size from high-volume production machines to dredges designed to address specific remedial action situations. The units being considered here are those that are mounted on floating platforms and require at least several feet of water for maneuvering. When a hydraulic dredge is fitted with a cutting head it is often referred to as a cutterhead dredge. Given the wide range of bottom conditions that would be encountered in the river, it is expected that the hydraulic cutterhead machine would have greater applicability than would a conventional suction dredge.

Effectiveness. The cutterhead unit can be expected to efficiently remove either coarse or fine grained sediments. Also, it has been the historic view that hydraulic dredges are less prone to resuspend sediments than mechanical systems; however, it should be noted that much of the comparative evaluation of these systems comes from navigational projects where conventional open buckets were employed for removal work. It is not expected that the historic comparisons will be applicable to the equipment and operating philosophy that would be utilized for dredging of the Upper Hudson River. Finally, it is expected that productivity of hydraulic equipment is somewhat more apt to be impacted by the presence of debris than that of a mechanical system.

Implementability. Hydraulic cutterhead dredges are readily available in configurations and capacities that are compatible with working conditions on the Upper Hudson River. However, implementation of a complete hydraulic dredging system will entail addressing several important constraints imposed by the river. In order to carry out hydraulic dredging operations, a lengthy slurry line will need to be installed to convey dredged solids to a shoreside processing facility. That line and the associated pumping system have the potential to impede river navigation. In addition, as slurry line length increases, reliability of the overall dredging system can be reduced. It is expected that considerations such as these will be addressed, in detail, during the project's design phase.

Costs. Costs for dredging with a cutterhead are expected to be in the low to moderate range. However, since these machines pump the removed sediments in a relatively low-density slurry form, there could be substantial cost associated with dewatering the dredged material prior to its final disposition.

Conclusion. Given their versatility to handle a wide range of sediment types, hydraulic cutterhead systems are retained for further evaluation in this study.

Specialty Dredges

The types of equipment that have been retained in this category include submersible pumps and various amphibious excavators that can be fitted with several different types of removal heads.

Effectiveness. Specialty dredges may offer an advantage where the target material is difficult to access because water depth is not sufficient to enable use of any of the conventional dredges. A substantial fraction of the contaminated sediments in the Upper Hudson River is found in shallow shoreline areas or within secondary channels. Amphibious excavators, and possibly submersible pumps, may provide an alternative to excavation for removal of these sediments.

Implementability. Specialty dredges are available in a wide array of configurations and are supplied by numerous manufacturers. In general, these machines function best when fine-grained materials are targeted for removal. However, some of the units are being fitted with cutting-action attachments to extend their range of applicability. The specialty units can be expected to attain relatively low production rates and there may be a need to employ suspended sediment control barriers when removal operations are being conducted. Furthermore, depending on the type of removal head selected, use of the specialty machines may entail dewatering of sediments, as would be the case when conventional hydraulic dredges are used.

Costs. Because of their low production rate, it is expected that costs associated with the use of these specialty dredge systems will be moderate.

Conclusion. Amphibious excavators and submersible pumps are specifically designed to access sediments in shallow areas and are therefore applicable to removal of Upper Hudson River sediments. Speciality dredges will be retained for further evaluation.

4.3.6 *Ex Situ* Treatment

For the following evaluation of *ex situ* treatment technologies, it will be assumed that a location for the treatment facility in the site vicinity is equally available for all technologies and options. However, a near-river treatment facility would likely be limited by land area availability, and therefore, technologies and process options with large land area requirements would be at a disadvantage in terms of implementability. *Ex situ* treatment at an off-site facility is potentially an option; however, this involves transportation of large volumes of untreated sediments, with associated costs. The economics of off-site transportation would have to be balanced with the potential effectiveness of the treatment process during evaluation of the treatment technology. Federal and state permits, including TSCA permits, may be required for most, if not all, of the treatment options evaluated in this section. For purposes of this analysis, it is assumed that permitting will be administratively feasible for all technologies, with the possible exception of incineration, for which permitting may prove difficult.

4.3.6.1 Sediment Washing

Sediment washing is a water-based volume minimization process in which the sediment is mechanically scrubbed to remove contaminants.

Effectiveness

The effectiveness of this technology for treating PCB-contaminated sediments has been demonstrated at pilot scale, where PCB removal efficiency up to 95 percent has been reported. When the appropriate equipment and washing solution are used, sediment washing can effectively concentrate contaminants into a fine-particle fraction for secondary treatment. Sediment washing may have limited effectiveness in treating sediments with large fractions of fine-grained particles such as clay and silt. For example, a representative soil washing process has been demonstrated to be most effective for soil/sediment with less than 40 percent silt, and clay material smaller than 45 μm (see Table 4-9, page 2). The contaminated sediments of the Upper Hudson River that would potentially be removed in dredging are largely silty sands and sandy silts. Based on Phase 2 confirmatory sampling, fine-grained material averaged about 30 percent of the sediment by weight. However, the median value was about 20.5 percent, and since the samples were not collected randomly within contaminated areas, this is perhaps a more representative value. Therefore, sediment washing is potentially effective for treating the Hudson River sediments.

Implementability

Sediment washing is technically and administratively implementable, and the appropriate equipment and services are available from various vendors. Existing full-scale commercial systems can operate at rates up to 300 tons per hour. Sediment washing produces a liquid waste stream along with the contaminated fines fraction that will require further treatment. The final disposal of different phases of contaminated materials could present implementability and space problems in terms of materials handling and temporary storage.

Costs

Separation of the contaminated fine-grained fraction from coarse-grained material can result in reduced disposal cost and volumes requiring handling as hazardous waste. The relative costs of this technology are variable and depend on the type of washing reagents, level of contaminant in the sediments, and the fraction of fine-grained material in the sediments. In general, the costs can be classified as low to moderate compared to other technologies.

Conclusion

Because of its potential effectiveness in separating the more contaminated fine-grained fraction from coarse-grained material, sediment washing is retained for further evaluation.

4.3.6.2 Solvent Extraction

Solvent extraction involves the dissolution of contaminants from the sediment matrix; the contaminant-bearing solvent is then recovered and treated.

Effectiveness

When the appropriate solvent is used, solvent extraction can effectively concentrate contaminants into a residual byproduct waste stream for secondary treatment. However, multiple extraction cycles are often required to achieve high removal efficiencies. The effectiveness of this technology for treating PCB-contaminated sediments has been demonstrated at pilot scale, where PCB removal efficiency up to 99.9 percent has been reported, and at full scale, where removal efficiencies of greater than 98 percent have been reported.

Implementability

Solvent extraction is technically and administratively implementable, and appropriate equipment and services are available from various vendors. However, the capacity of existing equipment may not be sufficient to handle the potential volume of dredged sediments from the river within a reasonable time frame. Existing full-scale continuous treatment systems can operate at rates up to 10 tons per hour. One batch treatment system evaluated can be configured to treat varying soil volumes (1 to 1,000 cubic yards per batch); however, the treatment time for each batch is not known. Final disposal of different phases of contaminated materials such as sediments, solvent, and water could present implementability and space problems in terms of handling and temporary storage.

Costs

The relative costs of this technology are variable and depend on the type of solvent and level of contaminant in the sediments. In general, the costs can be classified as moderate to high compared to other technologies. Costs for further treatment and/or ultimate disposal of the solvent containing PCBs may be incurred in addition to the solvent extraction costs noted above.

Conclusion

Because of its relatively widespread use and treatment effectiveness, solvent extraction is retained for further evaluation. Reliable vendors of this technology are available, and the technology has successfully treated materials containing PCBs at full scale on a limited basis.

4.3.6.3 Chemical Dechlorination

The BCD process was retained out of the two dechlorination options evaluated. It is partly a thermal desorption process and partly a dechlorination process. Dechlorination reagents can be sprayed on contaminated soil/sediment before it enters a thermal desorption unit to allow for dechlorination in the desorber, or the condensed liquids from the desorption process can be dechlorinated in a separate reactor.

Effectiveness

The BCD process is potentially effective in treating PCB-contaminated sediments. BCD, in combination with thermal desorption, has been demonstrated at full scale to treat PCB-contaminated soil to an average total PCB concentration of below 2 ppm from a high of near 3,000 ppm.

Implementability

Chemical dechlorination, with and without thermal desorption, is technically and administratively implementable. However, the number of vendors offering this technology may be limited. Furthermore, the capacity of existing equipment may not be sufficient to handle the potential volume of dredged sediments from the Upper Hudson River within a reasonable time frame. One existing BCD/thermal desorption system has a reported treatment rate of only about 20 tons per day. Additional treatment capacity may be available in the future if the need arises.

Costs

The relative costs of this technology depend on the sediment properties and volume to be treated. In general, they can be classified as moderate to high compared to other technologies.

Conclusion

Dechlorination is effective and retained for further evaluation, most likely implemented in combination with thermal desorption; the combined process, also effective, is retained for evaluation.

4.3.6.4 Thermal Desorption

Thermal desorption involves application of heat at below-combustion temperatures, typically 200 to 1,000° F, to volatilize water and organic contaminants. The vaporized organics are then recovered via condensation or carbon adsorption for additional treatment, *i.e.*, dechlorination or incineration in a high-temperature secondary combustion chamber.

Effectiveness

Thermal desorption can effectively separate PCBs from sediments for subsequent removal of the contaminant. Thermal desorption has been demonstrated at pilot and full scale for treating PCB-contaminated sediments, where PCB removal efficiency of more than 99 percent has been reported.

Implementability

Thermal desorption is technically and administratively implementable, and the appropriate equipment and services are available from various vendors. Existing commercially available, full-scale systems can operate at rates up to 90 tons per hour. Depending on the water content of the dredged material, sediment dewatering may be required prior to thermal desorption treatment. The final treatment or disposal of desorbed PCBs would be required as part of this process. Thermal desorption can be combined with dechlorination as described in the previous section.

Costs

The relative costs of this technology can be classified as moderate to high compared to other technologies. Costs for further treatment and/or ultimate disposal of the desorbed PCBs would be incurred in addition to the thermal desorption costs.

Conclusion

Because of its relatively widespread use and treatment effectiveness, thermal desorption is retained for further evaluation. Reliable vendors of this technology are available.

4.3.6.5 Thermal Destruction

Thermal destruction is a controlled destruction process that uses high temperatures to destroy hazardous contaminants in sediments.

Effectiveness

Thermal destruction can be very effective for treating PCB-contaminated sediments. Proper operation, however, is essential to achieve the complete breakdown of PCBs and to avoid the formation of incomplete combustion products. For incineration of TSCA-regulated PCB wastes, a minimum destruction and removal efficiency (DRE) of 99.9999 percent is required.

Implementability

Implementability issues are similar to those of other technologies. Unit throughput, timeliness of completing the treatment, and availability of sufficient capacity are important concerns. Various mobile and transportable thermal destruction systems of different capacities, manufactured by a number of firms, are widely available. The primary implementability issue for a near-river incineration system as opposed to using existing incineration systems that are farther away is the ability to obtain the necessary federal and state (TSCA) permits. Permitting is theoretically feasible but numerous on-site incineration projects have experienced long delays, and local opposition to an incinerator can significantly delay and possibly prevent issuance of a permit. Off-site contract incineration would avoid permitting concerns but would require transporting the material. Four TSCA incinerators are currently capable of treating PCB-contaminated sediments and are located at various distances from the Hudson River PCBs site. Dewatering is required before any thermal destruction treatment can be conducted. For near-river incineration, flue gases must be treated prior to discharge, and treatment of residual ash may be required prior to disposal. In accordance with CERCLA Section 121(e)(1), federal, state, and local permits are not required for remedial actions undertaken entirely on-site, including incineration, although an on-site incinerator would still need to comply with substantive requirements of federal and state permitting laws.

Costs

Thermal destruction costs are moderate to very high compared to other technologies. The high energy requirements and necessary emission controls inherent to thermal destruction processes, particularly incineration, are the primary contributors to the elevated costs. For disposal at an off-site incinerator, significant transportation costs may be incurred in addition to treatment costs.

Conclusion

Near-river thermal destruction processes will be eliminated from further consideration because of potential permitting and public acceptance difficulties. Off-site incineration is eliminated from further consideration because of prohibitively high costs compared to other off-site treatment and disposal options.

4.3.6.6 Immobilization

Immobilization refers to a broad class of treatment processes that physically or chemically reduce the mobility of hazardous constituents in a contaminated material through the addition of binding agents.

Effectiveness

Immobilization, in particular solidification and stabilization, can potentially be effective for treating PCB-contaminated sediments depending on the characteristics of the sediments and the type of binding agent used. Solidification/stabilization can also be implemented for water absorption in dredged sediments for transport and landfill disposal. This technology is generally more effective for immobilizing metal contamination but can also be effective for PCBs because of strong adsorption characteristics of PCBs to soil and sediments. This technology does not destroy or remove PCBs; consequently, determination of the effectiveness of solidification/stabilization requires measurement by an appropriate extraction or leaching procedure. However, because of the tendency of PCBs to adsorb to soil and sediment, typical leach test results may not show significant differences between the leachability of PCBs in the untreated and treated matrix.

Solidification/stabilization was used to treat PCB-contaminated soil at the Pepper Steel Alloy Superfund site. Soil containing PCBs at concentrations ranging from 1.4 to 760 ppm was treated with cement and fly ash. Analysis of leachate from the solidified mass showed no PCBs at a detection limit of 1 ppb.

Implementability

Solidification/stabilization is technically and administratively implementable, and the appropriate equipment and services are available from various vendors. Most binding agents and additives are also widely available. However, treatability studies to determine the appropriate amount and type of binding agent for effective PCB immobilization must be performed prior to full-scale implementation. The volume and weight of treated material can increase significantly after solidification/stabilization depending on the amount of binding agent used. Because PCBs are not removed or destroyed, the solidified/stabilized material may still require disposal at a landfill.

Costs

The relative costs of this technology are variable and depend on sediment characteristics, the type of binders and additives used, and the level of contaminant in the sediments. In general, the costs can be classified as low to moderate compared to other treatment technologies.

Conclusion

Because solidification/stabilization using pozzolanic materials can effectively immobilize PCBs in sediments, and because such treated sediments have a potential beneficial use as landfill cover materials or as construction fill, this treatment technology will be retained for further consideration in the development of remedial alternatives.

4.3.7 Beneficial Use

Beneficial use of dredged contaminated sediments includes two main options: using the dredged sediment in its original form, or treating the sediments to destroy the PCB contaminants and processing the treated material to create a useable commercial product. Both were retained after the initial evaluation and screening.

4.3.7.1 Landfill Cover Material, Construction Fill, Mine Land Reclamation

Beneficial use options discussed in this section include using dredged sediments for solid waste landfill cover, construction fill, and abandoned strip mine reclamation.

Effectiveness

Beneficial use options that involve the use of dredged sediment in its original form are potentially effective methods for final disposal of dredged material. These beneficial use options may be implemented with or without preprocessing or treatment to remove PCBs, although any beneficial use must take into account the potential exposure of human health and environment to PCBs in the dredged material.

Implementability

The beneficial use options evaluated are technically and administratively implementable. The capacity available to accommodate these options may not be sufficient to handle the potential volume of dredged material unless smaller components of the total sediments are considered (*e.g.*, separated coarse-grained material) or the options are used in combination. Currently, the use of

400511

dredged sediments as mine reclamation material is being evaluated in Pennsylvania. Pending completion of ongoing groundwater monitoring, the Pennsylvania Bureau of Abandoned Mine Reclamation is not authorizing similar reclamation projects using dredged material. In addition, dredged sediments with PCB concentrations greater than 4 ppm would not be accepted as abandoned mine reclamation material (Linanne, 1999).

Costs

For the beneficial use options evaluated, costs are variable and depend on degree of preprocessing or treatment required, transportation costs to the disposal destination, and potential fee for disposal. These costs are estimated to be low compared to other disposal options.

Conclusion

Because of the potential beneficial use of dredged sediments as compared to disposal options such as landfilling, these options are retained for further evaluation.

4.3.7.2 Manufacture of Commercial Products

The technologies evaluated in this section combine treatment processes to destroy organics in the sediments with some further physical/chemical process to convert the decontaminated sediment into a useable commercial product.

Effectiveness

Beneficial use options are potentially effective methods for final disposal of dredged material. Beneficial use options that involve the manufacture of useable commercial products are particularly effective because the treatment processes used are thermal processes that destroy organic contaminants. All three options evaluated (*i.e.*, production of cement, light weight aggregate, and glass tile) have been demonstrated at pilot scale and are in the process of being, or will be, demonstrated at full scale in the immediate future as part of the New York/New Jersey Harbor Decontamination Demonstration Project (see Table 4-13).

Implementability

These beneficial use options are technically and administratively implementable. The technologies evaluated are process-specific and are only offered by certain vendors. Large-scale equipment with high throughput rates are either being constructed or planned for all three beneficial use options evaluated. As the products are manufactured, it is assumed that there will be potential demand and market for the products.

Costs

Costs of thermal treatment and manufacture of useable products varies widely and range from low to very high depending primarily on the thermal process option used. A primary benefit of these beneficial use options is that some of the processing costs may be recovered when the useable products are sold commercially.

Conclusion

Because of the beneficial use options and the effectiveness in PCB removal and potential recovery of processing costs from these useable product manufacturing options, they will be retained for further evaluation.

4.3.8 Disposal Technologies

Disposal technologies evaluated in Section 4.2 include land disposal and aquatic disposal. Only land disposal, either at off-site landfills or in upland or near-shore confined disposal facilities, was retained after the initial screening.

Effectiveness

Land disposal options are potentially effective methods for final disposal of dredged material. Off-site landfill facilities would be permitted to handle PCBs. Upland or near-shore CDFs must be designed and constructed to meet regulatory requirements, including effluent discharge limits and groundwater standards, for landfills in which PCB-contaminated materials will be disposed.

Implementability

Off-site landfill disposal is technically and administratively implementable. Several landfills have been identified that can accept PCB sediments (both TSCA- and non-TSCA regulated material) from the river and that have sufficient capacity for the potentially large volume of dredged material. Sediments to be disposed of at an off-site landfill would likely require dewatering and/or stabilization prior to being transported from the site.

Disposal in upland or near-shore CDFs is also technically implementable. However, siting a location for a CDF in the vicinity of the Upper Hudson may not be administratively feasible given local opposition to a dredged material disposal facility in this area and the need to obtain New York State Hazardous Waste Facility Siting Board approval for a new facility in New York State that is not within the Hudson River PCBs site. At the very least, administrative issues to obtain approval and to construct a near-river CDF could significantly delay implementation of any remedial action that includes this disposal option. In addition, given the volume of dredged material anticipated, more than one disposal area could be required to provide sufficient capacity.

Costs

Costs for off-site landfill disposal are expected to be low for dredged sediments with PCB concentrations less than 50 ppm and moderate for sediments with PCB concentrations greater than 50 ppm. Although TSCA regulates PCBs at concentrations greater than 50 ppm, most commercial solid waste facilities impose a more stringent limit in order to provide them with a margin of safety, as discussed in subsection 4.2.9.1. Dewatering and transportation costs are additional costs that would be incurred for off-site landfill disposal options. Costs for construction and disposal at upland or near-shore CDFs are expected to be low.

Conclusion

Because of their effectiveness, off-site land disposal options will be retained for further evaluation. However, disposal in upland or near-shore CDFs will not be retained for further evaluation because of the potential administrative infeasibility of such options.

4.3.9 Summary of Effectiveness, Implementability, and Cost Screening of Technologies

Based on the effectiveness, implementability, and cost screening performed as described above, the following remedial options have been retained for further evaluation:

- No Action
- Institutional Controls (monitoring and site use restrictions)
- Monitored Natural Attenuation
- Containment by capping
- Removal by excavation and dredging
- *Ex situ* treatment by sediment washing
- *Ex situ* treatment by solvent extraction
- *Ex situ* treatment by chemical dechlorination
- *Ex situ* treatment by thermal desorption
- *Ex situ* treatment by immobilization (Solidification/stabilization)
- Beneficial use (re-use and manufactured products)
- Off-site disposal (excluding CDFs and upland facilities)

Based on the effectiveness, implementability, and cost screening performed as described above, the following did not pass the screening and have not been retained for further evaluation:

- Containment by retaining dikes and berms
- *Ex situ* treatment by thermal destruction (incineration)
- Off-site disposal in CDFs or upland facilities
- *In situ* treatment

400515

4.4 Selection of Representative Process Options

For various technologies screened in this chapter, there may be more than one process option approach that may be applicable to the Hudson River remedial alternatives. Those process options will be identified and discussed as necessary for the development and screening of the alternatives presented in Chapter 5 and Chapter 6.

Chapter 5

5. DEVELOPMENT OF REMEDIAL ACTION ALTERNATIVES

In this chapter, categories of potential remedial alternatives for the contaminated sediments in the Upper Hudson River are developed by grouping the potential remedial technologies identified in Chapter 4. These alternative categories are described in detail and specific remedial alternatives within each of these categories are developed for screening in Chapter 6. This development was performed based on an evaluation of alternative scenarios to narrow the field of potential alternatives while preserving an appropriate range of options.

As stated in Section 3.2, the RAOs and PRGs determined for this FS are:

- Reduce the cancer risks and non-cancer health hazards for people eating fish from the River by reducing the concentration of PCBs in fish. The risk-based PRG for protection of human health is 0.05 mg/kg total PCBs in fish fillet based on the RME adult fish consumption rate of one meal per week. Other target concentrations are 0.2 mg/kg total PCBs in fish fillet, which is protective at a fish consumption rate of about one meal per month, and 0.4 mg/kg total PCBs in fish fillet, which is protective of the average (CT) angler, who consumes about one fish meal every two months. These targets of higher concentrations in fish represent points at which fish consumption advisories might become less stringent (*e.g.*, the "eat none" advisory for the Upper Hudson could be relaxed) as conditions improve.

- Reduce risks to ecological receptors by reducing the concentration of PCBs in fish. The risk-based PRG for the ecological exposure pathway is a range from 0.3 to 0.03 mg/kg total PCBs in fish (whole fish), and is based on the LOAEL and NOAEL for consumption of whole fish by the river otter, an upper trophic level piscivorous mammal that was found to be at greatest risk ($TQ_{[LOAEL\ or\ NOAEL]\text{-}DIET} = 1$). Consideration was also given to use of TEQ-based NOAEL 0.015 mg/kg dioxin-like PCBs as the PRG; however, use of this criterion requires congener-specific data that are not routinely available, and would not necessarily achieve greater protection of wildlife. Furthermore, there is more uncertainty associated with the TEQ-based NOAEL than with the PCB-based NOAEL.

- Reduce concentrations of PCBs in river (surface) water that are above ARARs. The surface water ARARs are 1×10^{-6} µg/L (one part per quadrillion) total PCBs, the NYS ambient water quality standard for protection of human consumers of fish; 1.2×10^{-4} µg/L, the NYS standard for protection of wildlife; 1×10^{-3} µg/L, the federal Ambient Water Quality Criterion; 0.09 µg/L, the NYS standard for protection of human health and drinking water sources; and 0.5 µg/L, the federal MCL.

- Reduce the inventory (mass) of PCBs in sediment that are or may be bioavailable.

- Minimize the long-term downstream transport of PCBs in the river.

In order to meet these objectives, this FS considers various containment, removal, treatment, and disposal options for remediation of contaminated sediments in three sections of the Upper Hudson River. The three river sections, as defined in subsection 1.2.1, are:

- Section 1: the TI Pool;
- Section 2: the TI Dam to the Northumberland Dam; and
- Section 3: below the Northumberland Dam to the Federal Dam.

The contaminants of concern in both sediments and surface water are PCBs.

The primary sources of the PCB contamination in the Upper Hudson River are the historical discharges from the GE facilities in Fort Edward and Hudson Falls, New York. Chapter 1 contains a summary of site history and contains a review of historical sources of PCBs. During the past 50 years, these PCBs have adhered to the sediments, and these sediments now serve as the dominant source of PCB contamination for the water column and biota. Benthic organisms are directly exposed to the PCB-contaminated sediments of the Hudson River, thus introducing PCBs into the food chain. PCBs in the sediments also contribute to PCB concentrations in the water column through exchange and movement of sediments, leading to bioaccumulation through water column food chain pathways.

The processes that determine the fate of PCBs in the Upper Hudson River may be divided into two categories: (1) transport; and (2) transfer and reaction. Transport is the physical movement of PCBs caused by the net advective movement of water, mixing, resuspension, deposition, and bed-load transport of solids to which PCBs are adsorbed. Transport is dependent on the flow and dispersion characteristics in the water column and the settling velocity and resuspension rate of the solid particles. Downstream transport for the Hudson River PCBs site refers to the migration of PCBs beyond the Federal Dam at Troy to the Lower Hudson River. Transfer and reaction include movement of PCBs between the water and solid phases of the system, and biological (or biochemical) transformation or degradation of the PCBs. The processes involved in transfer and reaction include adsorption, dechlorination, bioturbation, and biodegradation. The extent to which each of these processes occur varies in different portions of the River at different points in time. PCBs are present in the Upper Hudson River in three phases that interact with each other: freely dissolved; sorbed to particulate matter or solids; and complexed with dissolved (or colloidal) organic matter.

In addition to exchanging PCBs with the water column, contaminated sediments within the Hudson River may move as a result of scour and deposition processes. Sediments and sediment-associated PCBs migrate downstream via both suspended load and bed-load transport. Bed-load transport represents particles that roll or bounce along the river bottom without being brought into resuspension. Since these particles are not transported into the water column, they have no effect on the suspended sediment concentration. However, the effects of bed-load transport are significant in that this transport may change the thickness of the sediment bed and the spatial distribution of PCBs in the river. Bed-load movement of PCB-contaminated sediments may also increase the rate of desorption of PCBs from the transported sediments into the water column.

This FS considers alternatives that can be typically categorized as both source control and management of migration alternatives. Source control alternatives generally consist of remedial actions that prevent or minimize risks by controlling the source of the contamination at or near the area where the hazardous substances were originally located. Management of migration alternatives generally prevent or minimize risks due to the migration of the hazardous substances away from the source. The categories of remedial alternatives developed for sediments are presented in Section 5.1. Alternative development criteria and applicable guidelines are also presented in Section 5.1. The detailed description of these categories of remedial alternatives is presented in Section 5.2, and a list of candidate alternatives for screening (within these alternative categories) is provided in Section 5.3.

The alternatives developed and screened in this FS are conceptual. Any characteristics of these alternatives, *e.g.*, remediation target area boundaries, staging and pretreatment locations, and removal depths and rates, should be considered to be approximate. Specific details would be finalized during remedial design, as appropriate, based on the Record of Decision (ROD).

5.1 Remedial Alternative Development

The criteria for developing alternatives and the subsequent identification of potential remedial alternatives for the Hudson River PCBs site are presented below.

5.1.1 Alternative Development Criteria

Alternative development must conform to the requirements of CERCLA and, to the maximum extent practicable, the NCP. CERCLA Section 121(d) requires that Superfund remedial actions comply with federal and state ARARs, or justify a waiver. Superfund remedial actions must also attain state requirements that are more stringent than federal requirements to the extent that they are also applicable or relevant and appropriate and are identified to USEPA in a timely manner.

CERCLA Section 121(b) identifies the following statutory preferences that must be considered in the development and evaluation of remedial alternatives:

- Remedial actions that involve treatment that permanently and significantly reduces the volume, toxicity, or mobility of the hazardous substances through treatment are preferred over remedial actions not involving such treatment.

- Off-site transport and disposal of hazardous substances or contaminated materials without treatment is considered the least favorable remedial alternative when practicable treatment technologies are available.

- Remedial actions using permanent solutions, alternative treatment technologies, or resource recovery technologies that, in whole or in part, will result in a permanent and significant decrease in toxicity, mobility, or volume of a hazardous substance are preferred.

Based on these statutory preferences and the RAOs developed in Chapter 3, remedial alternatives were developed to meet the following criteria:

- The remedial alternative is protective of human health and the environment.

- The remedial alternative attains chemical-specific ARARs (unless a waiver is justified) and can be implemented in a manner consistent with location-specific and action-specific ARARs.

- The remedial alternative uses permanent solutions and alternative treatment technologies to the maximum extent practicable.

- The alternatives developed are capable of achieving the remedial action objectives (RAOs) in a cost-effective manner.

USEPA's RI/FS Guidance (USEPA, 1988) and the NCP state that the treatment alternatives should range from an alternative that, to the degree possible, would eliminate the need for long-term management (including monitoring) at the site to other alternatives that treat the principal threats posed by hazardous substances at a site but that vary in the degree of treatment employed and the quantities and characteristics of the treatment residuals and untreated waste that must be managed. This guidance and the NCP require that a containment option involving little or no treatment, as well as a no action alternative, should be developed.

Source control alternatives primarily address situations in which hazardous substances remain at or near the areas where they were originally located and are not adequately contained to prevent migration into the environment. The purpose of source control remedies is to prevent or minimize the migration of hazardous substances from the source material. These remedies seek to remove, stabilize, or contain the hazardous substances, and are primarily applied in cases where contaminants are present at significant concentrations in the surface sediments. Hence, source control alternatives have been developed for the Upper Hudson River surface sediments in the three river sections.

For the Upper Hudson River, these remedial alternatives can also be categorized as management of migration actions in that they will eliminate or reduce the migration of PCBs from the Upper Hudson River sediments to other areas of the Upper Hudson River or downstream.

These remedial alternatives have been conceptually designed to prevent or minimize potential short-term and long-term disruptions of recreational and commercial navigation, as well as riverfront access to private and public properties, as they currently exist in the Upper Hudson River. These potential remedial alternatives have also been designed to restore and monitor benthic and fish habitat in areas where short-term impacts to such habitat due to containment or removal actions are unavoidable in order to meet the RAOs.

5.1.2 Combination of Potentially Applicable Remedial Technologies into Remedial Alternatives

The potentially applicable technologies remaining after the initial screening in subsection 4.3.9 have been combined into a number of remedial alternative (general response action) categories, as follows:

Alternative Category 1:	No Action
Alternative Category 2:	Monitored Natural Attenuation
Alternative Category 3:	Containment (Capping) of Target Areas and Monitored Natural Attenuation
Alternative Category 4:	Removal (Dredging) of Target Areas and Monitored Natural Attenuation
Alternative Category 5:	Combined Capping and Dredging of Target Areas and Monitored Natural Attenuation

Alternative Categories 1 and 2 do not include any containment, removal, disposal, or treatment of contaminated sediments. Alternative Category 1 does not assume any source control in the vicinity of the GE Hudson Falls facility (implemented under a separate NTCRA), nor does it include continuation of the current institutional controls such as fish consumption advisories; Alternative Category 1 involves only the five-year reviews required by CERCLA Section 121(c). Alternative Category 2 assumes the separate source control NTCRA in the vicinity of the GE Hudson Falls facility, and includes the continuation of the current institutional controls such as the New York State fish consumption advisories. It also involves monitoring and the five-year reviews required by CERCLA Section 121(c). Alternative Category 2 may also include new (additional) institutional controls. Alternative Categories 3, 4 and 5 all assume the separate source control NTCRA in the vicinity of the GE Hudson Falls facility.

The containment alternatives (containment only, Alternative Category 3, and capping combined with dredging, Alternative Category 5) include placement of an engineered cap and fill suitable for benthic and fish habitat. The removal alternatives (Alternative Categories 4 and 5) include several post-removal option categories for handling of the removed sediments. The removal alternatives also include placement of backfill in target areas from which the sediments are removed. The functions of the backfill material are to isolate any residual PCB contamination in surface sediments and to provide a substrate suitable for benthic and fish habitat.

For the combined capping with dredging alternatives (Alternative Category 5), sediments would be removed from some target areas and an engineered cap would be placed over areas from which sediments are removed, as well as over other target areas. The exceptions with regard to placement of an engineered cap are the channel and very shallow areas, which would not be capped. Definition of "shallow areas" is found in Section 5.2 as part of the discussion concerning detailed development of alternatives. For the combined capping with dredging alternatives, sediments would only be removed from target areas to be capped to the extent necessary to maintain existing water depths in the river suitable for recreational and commercial navigation. In addition, backfill would be placed in target areas from which the sediments are removed or contained. The functions of the backfill material placed over the cap are to provide a buffer layer for erosion protection, to prevent bioturbation of the cap material, and to provide substrate suitable for benthic and fish habitat.

Alternative Categories 3, 4, and 5 also include continuation of the current institutional controls such as the New York State fish consumption advisories and expected improvement in the upstream water quality (and measured PCB fish concentrations) due to ongoing remedial work in Hudson Falls and Fort Edward.

The post-removal option categories for the removed sediment (Alternative Categories 4 and 5) are as follows:

A. Off-site Containment/Disposal of Removed Sediments;

B. Near-river *Ex Situ* Treatment of Removed Sediments followed by Off-site Containment/ Disposal of Treated Sediments;

C. Off-site *Ex Situ* Treatment of Removed Sediments followed by Off-site Containment/ Disposal of Treated Sediments;

D. Abandoned Mine Reclamation/Landfill Cover/Construction Fill;

E. Near-river *Ex Situ* Treatment of Removed Sediments followed by Abandoned Mine Reclamation/Landfill Cover/Construction Fill;

F. Off-site *Ex Situ* Treatment of Removed Sediments followed by Abandoned Mine Reclamation/Landfill Cover/Construction Fill;

G. Near-river *Ex Situ* Treatment of Removed Sediments followed by Manufacture of Commercial Products from Treated Removed Sediments; and

H. Off-site *Ex Situ* Treatment of Removed Sediments followed by Manufacture of Commercial Products from Treated Removed Sediments.

All of the above post-removal handling option categories require dewatering of the sediments. They also include suitable treatment of the water (primarily filtration with polishing by granular activated carbon [GAC] adsorption) to meet NYS Pollution Discharge Elimination System (NYSPDES) discharge requirements before being discharged into the river. Option Category A includes containment/disposal of the removed sediments in an industrial (RCRA Subtitle D) or TSCA-permitted landfill, depending on the concentration of total PCBs in the bulk dewatered sediments. Option Categories B and C are similar except for the location where the *ex situ* treatment (stabilization) is performed. Option Category D is a form of low-value beneficial use of the removed sediments without the need for any *ex situ* treatment (stabilization). This option category is likely suitable for sediments with relatively low concentrations of total PCBs (typically < 4 or < 10 mg/kg depending on the application and local site-specific requirements).

Option Categories E and F are applicable to sediments with similar concentrations of total PCBs (typically < 4 or < 10 mg/kg) that require some *ex situ* treatment (stabilization) to improve the handling and disposal characteristics of the dredged sediments prior to the low-value beneficial use. They are similar except for the location where the *ex situ* treatment is performed. Option Categories G and H are quite different from options A through F because the PCBs are removed by thermal desorption, plasma arc vitrification, or surfactant washing and chemical treatment, and the sediments (clays, silts, and sands) are converted into higher value, useful commercial products such as architectural tiles, fiberglass, cement, light-weight aggregate, or manufactured soils. Option Categories G and H are designed to allow unrestricted use of these products because they no longer contain PCBs; the categories are similar to each other except for the location where the *ex situ* treatment is performed.

Near-river *ex situ* treatment is preferable (if feasible) because it is likely to be more cost-effective due to lower transportation costs. Therefore, Option Categories B and E are preferable to Option Categories C and F. Stabilization typically results in a product with an increased weight and volume. Although other treatment processes such as sediment washing with surfactants and other additives, thermal desorption, vitrification, solvent extraction, and chemical dechlorination are more effective than stabilization, they are also relatively more expensive. Also, stabilization may help to improve the handling and disposal characteristics of the removed sediments. In addition to permanently reducing the toxicity and volume of PCBs in sediments, the choice of thermal desorption, plasma arc vitrification, or surfactant washing treatment may be justifiable when the

400526

sediments are used for the manufacture of higher value commercial products instead of being sent to a landfill.

Abandoned mine reclamation in Pennsylvania coal mines using sediments from the New York/New Jersey harbor containing less than 4 mg/kg of total PCBs is currently being evaluated in a large-scale pilot study, and future use of this option is pending. Sediments with 4 to 10 mg/kg of total PCBs (depending on the application and local site-specific requirements) are considered to be suitable for use as landfill cover or construction fill material.

Based on the discussion above, stabilization is the only form of near-river *ex situ* treatment that may be required (to improve handling and disposal characteristics) prior to off-site containment/ disposal in a landfill or low-value beneficial use. As explained later in subsection 5.2.5.1, the cost of transportation and disposal at a non-TSCA landfill is approximately $50 per ton, and the cost of transportation and disposal at a TSCA landfill is approximately $100 per ton. The cost of stabilization is approximately $19 per ton, whereas the costs of the other treatment processes - thermal desorption, plasma arc vitrification, or surfactant washing and chemical treatment - are $100 per ton or higher. Therefore, the use of other *ex situ* treatment processes described above is not cost-effective or justifiable if the treated sediments are eventually sent to a landfill or used as construction fill material. Thus, near-river *ex situ* treatment for Option Categories B, C, E, and F refers to stabilization. On the other hand, for the manufacture of higher value commercial products, treatment processes like thermal desorption, plasma are vitrification, or surfactant washing and chemical treatment are necessary to remove the PCBs from the sediments. Therefore, Option Categories G and H refer to these *ex situ* treatment processes and not to stabilization.

Due to additional materials handling and transportation steps, Option Categories C, F, and H, which involve off-site treatment, are likely to be relatively more expensive to implement than Option Categories B, E, and G, which involve treatment near the river. However, Option Category H may be preferable to Option Category G in many instances because of the ease of performing all the processing steps necessary to manufacture the commercial product at the same location, thus minimizing requirements for additional loading and unloading of the removed sediments. Similarly, Option Categories B and E, which include treatment (*i.e.*, stabilization), will be relatively more expensive to implement than Option Categories A and D, which do not include treatment; however, Option Categories B and E may be preferable in many instances in spite of the slightly higher transportation costs because of the improvement in the handling and disposal characteristics of the removed sediments.

If mechanical dredging is performed, Option Categories C and F are not selected because near-river ex situ stabilization is required before the sediments are transported. Option Category G is not selected because it requires additional loading and unloading of large quantities of sediments prior to the manufacture of commercial products. Therefore, Option Categories B and E are selected if mechanical dredging is performed, due to the need to stabilize the sediments for transportation to disposal. On the other hand, Option Categories A and D are selected if hydraulic dredging is performed, since stabilization is assumed to be unnecessary following hydraulic dredging. Based on the foregoing comparisons, therefore, only Option Categories A, B, D, E, and H will be retained for further consideration in the development and screening of alternatives in this FS.

As described in subsection 4.2.4.1, there are practical limits to the application of engineered capping to the Upper Hudson River due to its geometry (water depths) and navigational needs. Large tracts of the river contain fairly shallow shoal areas, in many places bordered by permanent or seasonal homes with waterfront access. In these areas, installation of an engineered cap of any significant thickness could move the shoreline as much as 20 to 50 feet toward the channel, changing both the character of the waterfront and the hydraulic features of the shoals. Thus, in-river capping in shallow shoal areas (water depth less than 6 feet) may be impractical unless removal of an equivalent thickness of sediment has been accomplished first. Capping is also inappropriate in the channel of the Champlain Canal, for which a navigational draft of 12 feet must be maintained, as this may require navigational dredging. Further, based on the preliminary modeling for the containment-only scenario described in Appendix D, Alternative Category 3 (Containment of Targeted Areas and Monitored Natural Attenuation) is not effective in meeting the RAOs and PRGs. Therefore, Alternative Category 3 is eliminated from further consideration in the development of remedial alternatives in this FS.

400528

5.2 Concepts for Application of Technologies in Remedial Alternatives

This section of the FS develops concepts for application of technologies in remedial alternatives. A wide range of technologies have been evaluated in Chapter 4 for their applicability to remediating Upper Hudson contaminated sediments. For reasons detailed in Chapter 4, many of those technologies were screened out, while several have been retained for further evaluation. Based on the previous screening, the remaining technologies will be presented here as components of remedial categories that will, in turn, form the basis of specific remedies for the Upper Hudson. The technologies that will be addressed in this section are as follows:

- No Action;
- Institutional Controls;
- Monitored Natural Attenuation (MNA);
- Removal of targeted sediments by mechanical dredging methods;
- Removal of targeted sediments by hydraulic dredging methods;
- Capping of targeted sediments with dredging;
- Site restoration; and
- Monitoring.

5.2.1 No Action, Institutional Controls, Monitored Natural Attenuation (MNA)

As detailed in Chapter 4, No Action, Institutional Controls, and MNA do not involve active remediation of contaminated sediments. No Action consists of refraining from active application of any remedial technology to the Hudson River PCBs site. Under No Action there is no source control of contaminants entering the river at Hudson Falls, no monitoring of environmental media, and no institutional controls.

Institutional controls are non-engineering, administrative, or legal controls intended to prevent or reduce human exposure to hazardous substances. This includes monitoring of environmental media as well as site use restrictions such as fish consumption advisories and bans. Institutional controls do not comprise an independent technology category but, rather, will become a component of all other alternative categories except No Action.

MNA refers to a reduction in sediment contaminant mass and toxicity by naturally occurring biological, chemical, and physical processes as described in subsection 4.2.2 In addition, incorporated within MNA are extensive site monitoring and modeling to demonstrate that contaminant reduction is, in fact, occurring. Finally, both institutional controls and the assumption of a separate source control NTCRA in the vicinity of the GE Hudson Falls plant are elements of MNA. MNA will be a component of all active remedies described below.

5.2.2 Removal of Targeted Sediments by Mechanical Dredging Methods

For purposes of describing a remedy that includes mechanical dredging, it is assumed that the remedial work will be implemented over a five- to seven-year construction period. This duration reflects the magnitude of the program that would need to be accomplished given the volume of targeted sediments (Chapter 3). Knowing the quantity of targeted sediment and the construction duration, it becomes possible to identify the type and scale of systems and facilities that will be incorporated into a mechanical dredging scenario.

This subsection describes, in general terms, the equipment and physical plant that would be needed to mechanically remove, process, and dispose of targeted Hudson River sediments. Actual implementation of an active remedy, however, would not be limited by the equipment and systems described below. Project designs or construction plans may identify alternative means and methods to conduct any particular program. For purposes of this evaluation, mechanical removal of contaminated sediments is considered to involve the following principal steps:

- Dredging targeted sediments;
- Transporting or conveying sediments to a transfer facility;
- Processing dredged sediments; and
- Transporting processed sediments off-site.

400530

5.2.2.1 Mechanical Dredging Technology

As a result of the evaluation presented in Chapter 4, several types of mechanical dredges were retained for further evaluation. These include bucket-on-rope systems and hydraulically actuated excavators. Of these, a dredging system based on the hydraulic excavator, fitted with appropriate auxiliary equipment, appears to be most applicable to Upper Hudson conditions:

- Excavators generate sufficient digging force to remove both cohesive and non-cohesive river sediments;
- These units are less prone to debris-induced equipment breakdowns;
- Auxiliary equipment, in a wide range of capacities and reaches, can be fitted to the machines;
- Excavators can be installed on floating platforms with drafts that are compatible with available water depths at target sediment locations;
- Productivity of these machines is relatively high under conditions likely to be encountered during remedial work; and
- Relatively precise excavator positioning is possible using electronic sensors and digital positioning systems.

Auxiliary equipment that can be fitted to excavators include hydraulically actuated mechanical arms (boom and stick) with sufficient reach to access targeted sediments. In addition, the auxiliary equipment includes hydraulically actuated buckets with capacities compatible with project productivity requirements and in-river working constraints. As described further below, it is expected that the mechanical dredges used on the Upper Hudson will be equipped with state-of-the-art components to limit sediment resuspension and to enable real-time assessment of equipment position and removal status.

Each excavator will be positioned on a floating platform (for example, deck barge or flexi-float) so that it can be towed to the actual work area and then maneuvered, as necessary, during removal operations. The platform-mounted excavator must maintain a draft that is compatible with water depth limitations imposed by the in-river location of targeted sediments. As removal operations proceed, sediments will be placed either into hopper barges (where water depths are adequate) or onto deck barges (in shallow areas) that have been configured for sediment handling.

Barges will be filled to planned limits and towed to one of several waterfront transfer facilities where the sediments will be off-loaded.

Recent innovations to mechanical dredging systems are expected to reduce sediment resuspension and allow more precise removal of targeted material. Several of these developments are listed below:

- Enclosures have been added to both clamshell and backhoe buckets to limit spillage during sediment removal;
- Relief valves or vents have been added to clamshell buckets to limit the hydraulic force exerted by the downward descending bucket and, as well, to improve sediment removal efficiency;
- The cutting profile of clamshells has been substantially modified to enable efficient removal operations when taking shallow sediment cuts;
- Modified cutting profiles also reduce suction forces on sediments as the bucket is lifted;
- Addition of on-board computers tied to various digital positioning systems allow precise removal of targeted sediments and automated, real-time documentation of removal results; and
- Instrumenting the excavator unit and its auxiliary equipment provides operators with status information including completion of bucket closure.

This FS Report is not intended to specify the precise equipment and systems to be used for remediation of the Upper Hudson, which would be determined during remedial design. Rather, the goal here is to present concepts at a sufficient level of detail so that alternative-specific implementability can be evaluated and costs can be estimated. In order to accomplish this objective it is necessary to make assumptions as to equipment and systems. With regard to mechanical dredging equipment, excavators outfitted with auxiliaries such as the profiling grab developed by Boskalis Dolman (Netherlands) appear to incorporate most of the relevant technical innovations that have occurred in recent years. The profiling grab was developed for removal of contaminated sediments in shallow cuts and has recently been demonstrated at the New Bedford Harbor Superfund site. Also, the system of which the profiling grab is a component has been planned with a complete instrumentation package for positioning and operational control. Thus, the analysis that follows assumes that mechanical dredging equipment similar to that demonstrated at New Bedford Harbor will be used.

Several American and international equipment manufacturers were contacted to gather information on their approaches to riverine dredging operations. At least one domestic manufacturer indicated interest in developing an environmental bucket for remedial work. In fact, it is anticipated that both American and international suppliers will continue to make improvements to their equipment in reaction to changing conditions at both remedial and navigational dredging sites. Given the continuing development of new systems and equipment, and the scale of effort represented by sediment projects such as the Hudson River PCBs site, it is anticipated that further equipment innovation will occur over the next several years.

In addition to equipment-specific features, several other aspects of removal operations are worth noting, particularly in regard to sediment resuspension. Hydraulic actuated excavators, when unconstrained by concerns over sediment resuspension, can operate at cycle times of one minute or less (recently a large backhoe dredging within the Kill Van Kull in New York Harbor was observed operating on a 70 second cycle in 30 to 40 feet of water). It is expected that, as cycle time is extended, sediment resuspension will be reduced. Therefore, to some extent, the release rate of sediments is under control of the equipment operator; this is particularly the case where the equipment has, at the outset, been designed to be low-impacting. Thus, sediment resuspension may be limited, in part, by specifying equipment speed or cycle time; the downside of this approach is that productivity suffers as cycle times are lengthened. Appendix E contains a technical memorandum on the subject of resuspension during dredging operations.

Finally, it is expected that removal work will be conducted, to the maximum extent practicable, within an enclosure consisting of a combination of various types of turbidity barriers. The enclosure system will reduce river current speeds within work areas and will limit downstream migration of those sediments that become waterborne. The enclosure system will be deployed each time dredging activity is initiated at a new work area and then re-deployed as work proceeds along the contractor's pre-established dredging pattern. It is not expected, however, that turbidity barriers can be deployed within the navigation channel of the Upper Hudson. Appendix E contains a technical memorandum addressing turbidity barriers.

5.2.2.2 Mechanical Dredging Equipment Capacity

An array of mechanical dredging equipment, configured to meet limitations imposed by site conditions, will be required to remove Upper Hudson River contaminated sediments. Of particular importance in this regard is the water depth available for the dredging equipment to access targeted work areas. Hydraulically actuated excavators and the associated auxiliary equipment (boom, stick, bucket, etc.) are fabricated in a range of sizes, capacities, weights, and working reaches. Equipment combinations selected for any particular project reflect all the particulars of the job; however, there are important constraints on the possible equipment combinations that can be fashioned due to various physical limitations.

In order to provide an overview of sediment removal equipment and operations, it is necessary to establish some general parameters so that one potential set of equipment and facilities can be analyzed. Since available draft (water depth) is such a significant constraint on sediment removal operations, water depth at target material locations is used here as the basis for identifying equipment capacities, which in turn drive removal productivity. In particular, the selection of equipment will be based on the following general work area characteristics:

- Work areas with sufficient water depth to enable use of somewhat larger, higher productivity, equipment;
- Work areas with water depths that require use of relatively shallow draft, lower productivity, equipment; and
- Near shore and extremely shallow areas where specialty systems are required.

One general objective in delineating work areas for deeper draft and shallower draft equipment is to avoid selection of equipment packages that have only limited applicability to Upper Hudson conditions. For instance, while there may be some logic in selecting the largest capacity unit to maximize productivity, in-river access limitations inherent to such equipment can marginalize its overall value. Thus, based on a review of available bathymetric maps and maps of target material locations, as well as an analysis of the range of potentially available excavator equipment packages, a relatively larger, higher productivity equipment package has been selected that is capable of performing in areas with as little as five feet of water.

For areas that provide less than five feet of water, it is necessary to select an alternative equipment package that can remove a significant fraction, if not all, of the remaining target material. Therefore, based on a review of available river data and an analysis of potential equipment, a package has been selected that can conduct removal operations in three feet of water. The principal difference between the two equipment packages is that the lighter package incorporates a smaller hydraulic excavator and a lower capacity bucket.

Deeper Draft Equipment

This equipment package will utilize an excavator fitted with a 4-cubic-yard environmental bucket. The selected machine will be configured to have a 30-foot effective working reach and is expected to maintain an operating cycle of 120 seconds. The alternative-specific productivity analysis presented in Appendix E is based on this system's being used to remove targeted sediments that are within its effective working reach and where there is at least 5 feet of water under post-dredging conditions. The excavator will discharge sediments into a hopper barge that is expected to draw 5 feet of water when loaded with 400 tons of sediment and 8 feet when loaded at 1,000 tons.

While it is expected that the higher productivity machine will draw approximately 5 feet of water when mounted on a floating platform, it is not expected that the hopper barge into which dredged material is discharged can be fully loaded in 5 feet of water (hopper barges loaded with about 1,500 to 1,800 tons of cargo have historically transited the Champlain Canal). Thus it will be necessary to plan the work so that full loading of hopper barges can be achieved as often as possible. The alternative-specific productivity analysis assumes that, on average, hopper barges will be loaded with 1,000 tons of cargo. Appendix E contains alternative-specific productivity calculations.

Once a hopper barge has been loaded, it will be towed from the work area to the transfer and processing facilities established at the northern or southern limits of the site. Transit through the Champlain Canal places a number of constraints (*e.g.*, draft, length, width, overhead clearance) on the scale of equipment that can be used for remediating Upper Hudson sediments. While nominally the canal system can pass vessels drawing 12 feet of water, less draft is actually available since navigational dredging over the last 20 years has been limited to uncontaminated sediments at the confluence of the Hoosic River. Dredging the Champlain Canal's navigation channel to enable passage of loaded barges (1,000 tons of sediment) is a component of each active remedial alternative.

Shallow Draft Equipment

A lower productivity equipment package has been identified that can perform the bulk of remaining removal work, *i.e.*, that which cannot be handled by the selected higher productivity, deeper draft equipment. An excavator with a 30-foot effective working reach and a 2-cubic-yard environmental bucket has been selected for this purpose. This dredge would operate in three feet of water. In addition, it is assumed that the machine will discharge sediments into either a hopper barge or a suitably configured deck barge. Each storage barge would be loaded with up to 200 tons of cargo and would draw about 4 feet of water. The working cycle for this equipment package is expected to be 120 seconds, on average, which is comparable to that of the equipment working in deeper waters.

The alternative-specific productivity analysis presented in Appendix E assumes that the lower productivity package will remove most of the targeted sediments in areas shoreward of the defined working limits for the higher productivity system. It is assumed for conceptual purposes that all loaded barges will be towed to a transfer and processing facility established adjacent to River Section 1. (The southern transfer facility is assumed to be used only for the larger loads generated by the deeper draft dredging.) It has been assumed that no additional material beyond the initial 2,000 tons would be loaded into these barges in order to generate a more economic load. Given the draft of these lightly loaded barges, there will not be substantial limitations on their accessing a transfer and processing facility.

Specialty Equipment

In limited areas, where application of the equipment previously described would not be optimal, it may be necessary to consider use of any one of a number of specialty dredges such as the amphibious excavator or the long reach Ham Visor Grab. These specialty devices are able to function at locations that have little or no available water and are, consequently, out of reach of conventional dredging systems. As described in subsection 4.2.6.2, amphibious excavators employ

400536

pontoons and other means to move through mucky soils/sediments and are able to remove contaminants either in a mechanical mode or hydraulically. The Visor Grab employs a low-capacity, enclosing backhoe bucket (less than two cubic yards) that is mounted on a long-reach excavator system to remove near-shore sediments. Productivity achieved by these machines is expected to be lower than that attained by more conventional dredging equipment.

For purposes of the cost evaluation presented in this FS, it is assumed that the work that would optimally be performed by a specialty dredge is instead conducted by the shallow draft mechanical dredge previously described. Since that equipment package is not optimum for work in areas where the specialty equipment would best be deployed, a penalty has been assigned to account for the loss of efficiency that is likely to result. The penalty consists of extending the operating cycle time for the shallow draft equipment to three minutes from the expected two minutes. For purposes of the analysis presented here, the three-minute operating cycle will apply to all work conducted by the shallow draft equipment.

5.2.2.3 Productivity Analysis (Mechanical Dredges)

In general, the overall rate at which contaminated sediments must be removed to maintain a particular schedule depends on a number of project-specific considerations including the following:

- Volume and depth of targeted material;
- Targeted construction time frame of five to seven years; and
- Seasonal working limits (May through November) due to operation of locks in the canal system.

In the case of mechanical dredging systems, the following were the principal factors used to compute short-term productivity and equipment requirements for implementing removal alternatives:

- Removal work will occur 30 weeks each year and 6 days per week with about 75 hours of productive dredging each week;
- Remaining time is available for equipment relocation, set-up, and maintenance;
- Equipment working in deeper areas will maintain a 2-minute working cycle;

- Equipment working in shallow areas will maintain a 3-minute working cycle;
- Each bucket load will consist of 80 percent target material and 20 percent additional water; and
- A 15 percent efficiency penalty is imposed to account for an overlap between adjacent sediment removal cuts.

Since it has been assumed that two different equipment packages will be employed to carry out removal operations, it is necessary to establish the fraction of target materials that will be handled by each system. This has been accomplished on an alternative-specific basis and the methodology is further detailed in Appendix E. Once the volume that will be handled by each equipment package is known, it becomes possible to determine daily and hourly production rates (*e.g.*, cubic yards removal per day or per hour) as well as the number of dredges, tow boats, and barges that would be needed to implement an alternative.

Daily and hourly production rates are of particular importance to the analysis presented here since these two parameters have a significant influence on the scale of processing equipment that must be provided at each waterfront transfer facility. In addition, daily production will also impact the transportation system that must be configured to haul stabilized sediments to final disposal locations (landfills, beneficial use facilities, etc.).

5.2.2.4 Transfer Facilities (Mechanical Dredging)

Mechanically dredged sediments will be transported via hopper or deck barges to a waterfront transfer facility where they will be off-loaded, processed, and placed into rail cars for off-site disposal. A preferred location for the transfer facility is one that is already being used for such operations and, therefore, has existing wharf facilities at which barges can be secured and unloaded. In addition, a transfer facility needs to have good rail access. It is expected that such locations can be found in the greater Albany area where a number of riverside materials handling terminals, with existing wharf facilities and good rail access, already exist. Therefore, the analysis presented herein is predicated on the use of the Albany area waterfront for sediment transfer and processing operations.

In addition to establishing waterfront operations in the Albany area, it would be desirable to locate a transfer and processing facility at the northern limits of the work area so as to reduce in-river transportation requirements. Since there are essentially no waterfront materials handling operations within River Section 1 or 2, it will be necessary to assume that a location can be found where a temporary facility can be constructed. Characteristics of a suitable location include adequate river frontage for supporting barge operations, sufficient land for materials processing and storage, and access to rail facilities. For purposes of the analysis presented here, it is also assumed that a suitable transfer and processing location can be found adjacent to River Section 1. Figure 5-1 is a conceptual sketch of a transfer facility identifying the principal facilities that would need to be erected to support mechanical dredging operations.

Barges delivering dredged sediments to the processing/transfer facilities will be secured at an existing or newly constructed wharf or dock. Material in the barges will be off-loaded by conventional methods such as a crane or excavator. Prior to unloading barges, excess water that has accumulated above the incoming sediments will be pumped off, treated, and discharged back to the river. Figure 5-2 shows a concept for the treatment of water withdrawn from incoming barges. It is expected that most excess water (*i.e.*, water entrained during dredging operations) will be recovered by this means.

Once the dredged material has been off-loaded, it will be processed to improve its handling and shipping characteristics and to facilitate landfill stacking. The precise nature and degree of processing will primarily depend on sediment characteristics, dredging methods, and particulars of the landfill at which the sediments will be disposed; beneficial use of sediments will also influence the processing concept. As described in Appendix E, processes such as gravity draining, mechanical dewatering, and chemical stabilization are applicable to sediments removed from the Upper Hudson. Of these, chemical stabilization has been selected as the processing technology for purposes of deriving alternative-specific cost estimates. Thus, post-removal Option Categories B, E, and H are applicable to the mechanical dredging concept. Chemical stabilization has been applied to dredged materials generated by other Superfund projects and, as well, by several recent navigational dredging projects. A wide range of stabilizing agents have been used in these cases including cement, fly ash, and cement kiln and lime kiln dust. Specifically, the analysis presented in following sections is based on blending eight percent Portland Cement into the dredged sediments to improve the materials handling properties (Appendix E).

Based on the foregoing, off-loaded sediments will be discharged into a collection hopper through a series of racks and screens that remove larger debris. The dredged material will then be blended with cement in a pug mill, after which the stabilized sediments will be placed into temporary storage prior to being loaded into rail cars by either conveyors or front-end loaders. It is possible that some in-storage residence time will be required before the sediment's handling properties improve sufficiently to allow rail load-out.

Stabilized sediments will be hauled off site in covered rail gondolas that can accept up to 100 tons of bulk material per car. Sufficient rail capacity appears to exist in the Port of Albany area to accommodate the transportation needs of an Upper Hudson River remedial project. However, it is expected that at a northern transfer facility, it will be necessary to develop a small rail yard adjacent to an active rail corridor so that a manageable, project-specific logistics system can be developed for exporting dredged material. Given that opportunities to develop a facility adjacent to River Section 1 are constrained, the alternative-specific productivity analysis places an upper bound on the mass of stabilized sediment that can be processed and shipped from the northern transfer facility. The limit is set at 1,600 tons per day, which equates to 16 rail car loads. All remaining material is assumed to be processed and shipped from a transfer facility situated in the Port of Albany area.

5.2.2.5 Management of Dredged Material (Mechanical Dredging)

As described in Chapter 4, several options for management of sediments removed from the Upper Hudson River have been retained for further analysis. An evaluation of these technologies, as applicable to a mechanical dredging option, is presented in subsection 5.2.5

5.2.3 Removal of Targeted Sediment by Hydraulic Dredging Methods

Hydraulic dredging methods are also applicable to removal of contaminated sediments. Of the several hydraulic systems initially screened in Chapter 4, the conventional cutterhead suction dredge was retained for further consideration. The two principal operating components of a cutterhead suction dredge are a leading suction pipe with attached cutting head and an onboard slurry pump. The pump hydraulically entrains river sediments that have been loosened by action of the cutterhead and discharges the resultant slurry (water and sediment) into a length of trailing pipe.

Using a boom or ladder, the inlet or suction pipe and cutterhead can be extended sufficiently beyond the leading edge of the dredge to reach targeted materials. The slurry pump is sized to meet project productivity requirements and to convey slurried sediments to a processing facility. The entire assembly of suction piping and slurry pump is mounted on a hull that allows the dredging system to be towed to and maneuvered within a particular work area. An illustration of a hydraulic dredge along with a more detailed presentation of an overall concept for an hydraulic dredging system is provided in Appendix H of this report.

5.2.3.1 Equipment and Conceptual Approach (Hydraulic Dredging)

As discussed in Appendix H, the hydraulic dredge selected for evaluation here is outfitted with a 12-inch suction line and 600 HP main pump. It is mounted on a 60 x 28 x 4 foot hull that is expected to maintain a 2.5- to 3-foot draft. The cutterhead for the 12-inch dredge has an approximate diameter of 40 inches and is about 42 inches long. The dredging unit advances by raising and lowering spuds located at the rear of the hull and swings by pulling on anchors positioned off to either side of the hull.

During operation, the hydraulic dredge discharges slurry into a 16-inch, high-density polyethylene (HDPE) pipeline that may approach a maximum length of about 50,000 feet. The length of the pipeline depends on the distance from the dredge to the location where the sediment slurry will be processed. The slurry pipeline is configured in three principal sections. The first pipeline section is about 2,000 feet long, floating immediately behind the dredge on a system of pontoons to enable repositioning of the dredge. The second pipeline section (up to 50,000 feet in length) is submerged to avoid interference with river traffic. Lastly, where the slurry line must bypass several dams, it is anticipated that the line would emerge from the river and run along the shoreline for short distances.

It is expected that all material removed by the hydraulic dredging system will be conveyed by slurry line to the northern transfer facility. The configuration of that transfer facility differs substantially from that described for the mechanical dredging option (subsection 5.2.2.4). In order to convey the sediment/water slurry up to 50,000 feet, a series of booster pump stations are needed. Since booster pumps can be effective over distances of up to 10,000 feet, it is expected that up to 5 stations will be needed when the slurry line is at its maximum working length. The booster pumps are mounted on a series of shallow draft barges outfitted with 1600 to 2000 HP diesel-operated pumps. The practical limit for slurry line length is considered to be about 50,000 feet due to the decreasing reliability inherent in a system composed of multiple booster stations operating in series.

As is the case with mechanical systems, it is expected that the hydraulic dredging system will be fitted with state-of-the-art electronic positioning equipment so that the work is performed as efficiently and precisely as possible. In addition, it is expected that a number of innovations may be developed for this program to further control resuspension of river sediments and to improve the overall productivity of dredging operations. These innovations will most likely be modifications to the geometry of the cutterhead and suction pipe, addition of shrouds, and improved operation of the ladder mechanism from which the suction pipe is suspended. It is also expected that a skimmer boat will be employed to collect floating materials that may be generated during dredging operations.

5.2.3.2 Productivity (Hydraulic Dredging)

Once the overall capacity (size) of the hydraulic dredge has been established, estimating production rates for that unit depends on several principal factors (quantities shown are those used in the alternative-specific productivity analysis):

- Hours of productive dredging per day (14 to 17 hours per day);
- Days of operation per week (6) and weeks per season (30);
- Slurry pumping rate (7,000 to 9,000 gpm);
- Type of cut (production); and
- Slurry solids content (15 to 20 percent by cut volume).

Additional information on production rates (cubic yards of sediment removed per day) for the hydraulic dredging system is provided in Appendix H. In general, it is estimated that the hydraulic system will remove targeted sediments at rates ranging from 266 to 275 cubic yards per hour.

5.2.3.3 Transfer Facilities (Hydraulic Dredging)

The transfer facility configuration applicable to hydraulic dredging operations differs from that needed to support mechanical dredging operations (see Appendix H for a concept sketch). Under the mechanical removal scenario, sediments would be transported to processing facilities by means of hopper and deck barges that will be unloaded by conventional mechanical means. In contrast, for the hydraulic dredging option, sediments will be conveyed in slurry form to the transfer facility via pipeline, and therefore require substantial processing prior to off-site shipment.

Given the location of the bulk of the targeted sediments, as well as slurry pipeline constraints, it has been assumed that all hydraulically removed sediments will be conveyed to a northern transfer/processing site established located adjacent to River Section 1. The incoming slurry will likely undergo three principal stages of processing: coarse solids separation, fine solids sedimentation and dewatering, and water treatment. In addition, depending on overall system efficiency, it may not be necessary to stabilize either the separated coarse solids or the dewatered fine material prior to shipping these materials to off-site disposal or beneficial use facilities. Therefore, for the alternative-specific analysis presented in Chapter 8, it has been assumed that stabilization will not be needed. Thus, post-removal Option Categories A, D, and H are applicable to hydraulic dredging.

Processed sediments will be hauled to ultimate disposal facilities either by direct rail shipment from the northern transfer facility or, as necessary, by barge to a secondary rail trans-shipment location. The need for a secondary trans-shipment location arises because the northern transfer facility is not expected to have adequate rail capacity to handle all sediments removed on a daily basis during the course of remediation. The secondary location is assumed to be in the Port of Albany area and is intended to handle those materials that cannot be shipped from the northern transfer facility due to rail and other capacity constraints.

Since the practical length of a reliable slurry line has been estimated to be 50,000 feet, it is not expected that a processing facility located adjacent to River Section 1 can be utilized for processing slurry generated by dredging operations south of the Northumberland Dam. Consequently, for any remedial alternative that involves removal of sediments in River Section 3, it is assumed that dredging will be accomplished by the mechanical equipment previously described. Mechanically dredged material, in this case, would be transported in hopper barges to a processing facility established in the Port of Albany area, where unloading and stabilization of sediments would be accomplished in accordance with the mechanical dredging concept.

5.2.3.4 Slurry Processing (Hydraulic Dredging)

The initial stage of slurry processing, *i.e.*, solids separation, is intended to take advantage of the fact that a substantial portion of the targeted sediments, particularly those characterized as non-cohesive, are relatively coarse material (60 to 70 percent sands or fine sands). It is expected that the coarse fraction can be effectively separated from the rest of the incoming slurry by physical means. To do this, the slurry will be discharged over several stationary and vibrating screens that remove gravel-sized and larger materials. The slurry will then flow down a series of hydrocyclones in which fine and coarse sands will be separated from the solids stream. Coarse materials separated by these two physical processes will be stockpiled, allowed to drain, and disposed.

The remaining slurry stream will be discharged to a series of circular tanks wherein flocculants or polymers will be added to enhance coagulation and settlement. Settled solids will then be dewatered (using belt presses) and loaded onto rail cars for off-site disposal. The flocculation tank supernatant will be pumped to a water treatment plant that includes a series of settling and filtration steps as illustrated in Appendix H. The treatment plant will be sized to handle the entire flow of incoming slurry as well as any additional waste water incidental to site operation.

Solids generated by the solids separation and water treatment systems will be hauled to either off-site disposal facilities or to off-site beneficial uses (see subsection 5.2.5). Since Hudson River PCB contamination has been associated with fine-grained sediments (predominantly silts), the coarser fraction of the slurry materials separated by physical methods as described above is expected to be relatively free of contamination and may be suitable for beneficial use without further processing.

5.2.4 Capping of Targeted Sediments

As a result of the screening presented in Chapter 4, capping using the AquaBlok™ system has been retained as the representative process option. Capping involves the placement of a low permeability material over contaminated sediment that acts to prevent or slow the movement of contaminated pore water. In addition, exposure of aquatic organisms to contaminated sediments is prevented by an engineered cap, since it isolates the original contaminated substrate and, once in position, allows repopulation to occur in clean materials. AquaBlok™ is a manufactured product consisting of bentonite applied to a gravel substrate, which when placed in water hydrates and expands to form a continuous impermeable mat.

5.2.4.1 Typical Cap Cross-Section

An engineered cap using the AquaBlok™ system is expected to consist of a 12-inch layer of hydrated AquaBlok™ overlain by a 6-inch layer of backfill/benthic substrate. A typical cap cross-section is shown in Figure 5-3. Of the different types of AquaBlok™ materials that can be manufactured, three have been considered for application to the Upper Hudson:

- Type A AquaBlok™ is a mixture consisting of 80 percent stone and 20 percent bentonite, applied at a rate of 55 pounds per square foot (lb/sf). Since Type A is more resistant to mechanical impacts than other formulations, it will be used in the upper cap layer, where water depths are less than three feet.

- Type B AquaBlok™ is a mixture consisting of 70 percent stone and 30 percent bentonite, applied at a rate of 45 lb/sf. This formulation will also be used as an upper capping layer where water depths are greater than 3 feet, since it offers greater resistance to river-induced erosion than do more impervious AquaBlok™ formulations.

- Type C AquaBlok™ is a mixture consisting of 60 percent stone and 40 percent bentonite, applied at a rate of 25 lb/sf. Type C material will be the first lift placed at all locations, as it is less permeable than the other types due to its high bentonite content.

While the manufacturer suggests application of a six-inch layer of AquaBlok™, a more substantial concept is being presented here for several reasons. The thickness has been increased to address the possibility that the cap will be subject to damage from ice scour and boat traffic. Also, cap erosion may result from both normal river flows and less frequent, but high energy, storm events. Finally, as described further below, since substantial dredging is necessary to install an engineered cap system in shallow areas, that dredging work may expose more contaminated sediments than are currently found at the sediment surface; thus additional protection is warranted in the form of a one-foot-thick cap overlain by six inches of new benthic substrate.

A six-inch benthic substrate layer will be placed over the AquaBlok™ to protect it from burrowing animals and also to provide a clean substrate for repopulation by benthic organisms. The backfill will also serve as a sacrificial layer in the event of significant erosion or surficial damage. This will reduce the potential for catastrophic breaches of cap integrity and avoid maintenance emergencies, thus facilitating reliance on a routine maintenance program.

Placement of 18 inches of capping material over the river bottom, particularly in shallow areas, could result in moving the shoreline toward the river channel by as much as 25 to 50 feet, and possibly have some effect on river hydraulics. Therefore, to prevent changing the configuration of the river, 1.5 feet of sediment will be removed prior to the placement of the cap in targeted shallow areas; *i.e.*, areas with less than six feet of water. In the navigation channel, *i.e.*, where water depths exceed 12 feet, targeted sediments will be removed and no cap will be installed. It is expected that the mechanical dredging equipment previously described will also be applicable to these removal requirements.

5.2.4.2 Capping Material Manufacture and Transport for Placement

As stated previously, AquaBlok™ is manufactured by coating a gravel-sized substrate with polymer to which bentonite then adheres. The AquaBlok™ product may be manufactured at any suitable location and then transported to a riverfront location either by truck or rail. Once at the river, the capping material is loaded onto barges for placement over targeted areas. Alternatively, AquaBlok™ may be manufactured at a dockside location and loaded into barges there for subsequent transport and placement in the river.

For purposes of this FS, it is assumed that the AquaBlok™ material will be manufactured locally. The manufacturing facility will be located near a source of raw materials (*i.e.*, crushed stone or gravel). According to the manufacturer, the facility could easily be located within an existing sand and gravel operation, several of which can be found in the Fort Edward-Hudson Falls area. On this basis, the principal raw materials to be imported will be bentonite and polymer, which can be transported to the manufacturing site by either truck or rail or a combination of both. Once the AquaBlok™ has been manufactured, it will be loaded into hopper barges for in-river distribution and placement.

5.2.4.3 Cap Placement

AquaBlok™ material will be placed on the river bed from the end of a deck barge by means of a telescoping conveyor. The telescoping conveyor will be configured to distribute AquaBlok™ material within a 100-foot radius of the deck barge. Because of its gravel substrate, the material will rapidly settle over the areas where it is being released. Loads of AquaBlok™ of approximately 1,000 tons will be transported by hopper barge to targeted cap areas where a small front-end loader will load the conveyor that transfers the AquaBlok™ to a distribution barge, from which the telescoping conveyor is operated.

5.2.4.4 Dredging Requirements Related to Capping

As previously mentioned, capping alternatives also involve dredging of contaminated sediments within targeted shoreline areas and within the navigational channel. The complete set of criteria used to identify where dredging is needed follow:

- At locations where the water depth is less than 6 feet, 1.5 feet of sediments are removed and the cap placed as described above, except as noted below;

- At locations where the water depth is between 6 feet and 12 feet, no dredging occurs and the cap is placed as described above, except as noted below;

- At locations where the water depth is greater than 12 feet, contaminated sediments are removed to the depth of contamination, since placement of a cap is incompatible with the maintenance of the navigation channel;

- No cap is placed in areas where the depth of contamination is 2 feet or less; at these locations, sediments are removed to the depth of contamination;

- In the non-navigational section between the TI Dam and Lock 6, there are few areas with contamination below 2 feet in depth; therefore, it is not likely to be cost-effective to mobilize capping equipment for this portion of the river. As a result, the targeted sediments in this part of the river are removed rather than capped.

The type of dredging equipment and equipment productivity factors described for the mechanical removal concept are considered applicable to dredging operations under the capping category. Furthermore, as was the case for the removal concept, transfer facilities will be needed to process and load out the dredged sediments. Depending on the quantity of sediments being dredged and the overall sediment management strategy selected, it is possible that transfer operations will need to be established both adjacent to River Section 1 and in the Port of Albany area (*i.e.*, the northern and southern transfer facilities). Transportation modes and management options for dredged sediments would be similar to those under the removal category.

5.2.5 Management of Dredged Material

As a result of the screening analysis conducted in Chapter 4, a number of treatment technologies associated with ultimate management of dredged sediments have been retained for further evaluation:

- Sediment washing;
- Solvent extraction;

- Chemical dechlorination;
- Thermal desorption, and
- Solidification/stabilization.

There are two possible applications of these technologies: to render the dredged sediments suitable for off-site landfill disposal, and to enable beneficial use of the dredged material. Application of the first four technologies to landfill disposal is presented in subsection 5.2.5.1. Application of stabilization methods to off-site landfill disposal is discussed in subsection 5.2.5.2. Beneficial use of dredged material is detailed in subsection 5.2.5.3.

5.2.5.1 Chemical/Thermal Processing of Dredged Material for Disposal

Unit costs associated with the chemical and thermal processes that have been retained to this point are presented in a series of Chapter 4 tables. In general, unit costs for those chemical and thermal processing technologies with which there is some operating experience range between $100 and $250 per ton of processed sediment. This cost range does not include any consideration for transporting sediments either after on-site treatment or to off-site chemical/thermal treatment facilities.

As presented in the alternative-specific analysis in Chapter 8, it is expected that transportation of stabilized sediments to a TSCA-permitted landfill will cost approximately $100 per ton based on the selected disposal location. Transportation and disposal of stabilized sediments to a non-TSCA landfill will cost approximately $50 per ton based on the identified disposal facilities. Thus, disposal with prior chemical/thermal treatment is likely to substantially exceed the cost of disposal of stabilized dredged material. Consequently, the chemical/thermal processes retained in Chapter 4 will not be evaluated further in the FS.

5.2.5.2 Off-site Landfill Disposal

On-site and near-river landfill disposal were screened out in Chapter 4 based on administrative infeasibility due to public opposition. Options for off-site disposal of sediments removed from the Upper Hudson River will depend, in part, on their PCB concentrations. Dredged material with PCB concentrations of 50 mg/kg or more is subject to regulation under TSCA (40 CFR 761.61, *et seq.*). However, commercial solid waste management facilities may impose a more stringent limit of 30 to 35 mg/kg PCBs as an acceptance criterion. This provides them with a margin of safety in accepting wastes classified in bulk, using analysis of composite samples. Therefore, a trigger level of 33 ppm, not 50 ppm, will be used for the purposes of this FS to determine which removed sediments are to be disposed of in TSCA-permitted landfills and which may be managed in Subtitle D facilities or diverted for beneficial reuse. The method for estimating the quantities of non-TSCA-regulated and TSCA-regulated materials is described in Appendix E.

As part of this FS, a survey was performed to identify landfills permitted to handle materials with PCB concentrations greater than 50 mg/kg. Appendix E contains a technical memorandum on this subject. Based on that survey, it has been determined that the alternative-specific analysis presented here will be based on rail transport of the TSCA-regulated sediments to a permitted facility in Andrews, Texas. This facility has direct rail access, the capacity to handle the potential volume of material, and competitive disposal costs. However, a different landfill could be selected when implementation of a specific remedy is initiated.

Numerous alternatives are theoretically available for disposal of non-TSCA-regulated sediments. One site identified is situated in the Niagara Falls, New York area. Additional sites have been identified in Ohio, Maine, South Carolina, and Canada. The key considerations for selecting landfills for this fraction of the dredged material are landfill capacity and rail access. For purposes of the analysis presented here, it is assumed that the non-TSCA-regulated sediments will be hauled by rail to landfills within 750 miles of the Upper Hudson including the landfill at Niagara Falls, New York.

As previously noted in subsection 5.2.3, it will be necessary to dewater and stabilize dredged sediments before shipping them to a landfill. Stabilization will be accomplished at each of the transfer facilities where barges will be received and unloaded. Space requirements needed to support a stabilization operation (silos, hoppers, conveyors, pug mill, and temporary storage) are considered to be relatively modest based on recent experience at a Jersey City, New Jersey project. Thus, the option to landfill sediments that have been stabilized on site has been retained for further evaluation. This option is applicable to mechanical dredging.

Hydraulically dredged sediments will be conveyed to the northern transfer and processing facility in slurry form as described in subsection 5.2.3. Coarse solids will be separated from the slurry by means of hydrocyclones; fine solids will be removed by flocculation and then mechanically dewatered (*e.g.*, using filter presses). Dredged material processed in this manner is expected to be suitable for direct placement into rail cars without further stabilization. Thus, landfill disposal of hydraulically dredged sediments that have been separated into coarse and fine fractions will be retained for further evaluation in this FS.

5.2.5.3 Beneficial Use

Beneficial use of dredged material offers an opportunity to manage those materials more efficiently and, consequently, at lower cost than would apply to landfill disposal. In addition, since some forms of beneficial use generate commodities having considerable value in the market place, depending on particulars, treatment or processing of sediments to generate a useful commodity may be cost-effective. A possible beneficial use strategy for managing contaminated sediments dredged from the Upper Hudson River is presented here and will serve as the basis for the alternative-specific detailed analysis in Chapter 8.

For convenience, use of dredged sediments for beneficial purposes can be placed into two categories, a low-value category and a higher-value category. Forms of low-value beneficial uses of stabilized sediments include abandoned mine reclamation, use as landfill cover material, and use as construction fill material. All of these uses are likely to be off site and are suitable for sediments with relatively low concentrations of total PCBs (typically 4 to 10 mg/kg, depending on the application and local requirements). Abandoned mine reclamation in Pennsylvania coal mines using sediments with less than 4 mg/kg of total PCBs from the New York/New Jersey Harbor is currently being evaluated in a large-scale pilot study. Future availability of this option depends on pilot program results.

Different options are applicable to sediments with higher concentrations of total PCBs (greater than 10 mg/kg but less than 33 mg/kg PCBs). These options are quite different from the low-value category of uses because the PCBs are removed by thermal desorption, plasma arc vitrification, or surfactant washing and chemical treatment, and the treated sediments (clays, silts, and sands) are converted into higher-value, useful commercial products such as architectural tiles, fiberglass, cement, light-weight aggregate, or manufactured soils. Unrestricted use of these end products is permissible because they are considered to be free of PCBs.

For purposes of the detailed analysis presented in Chapter 8, the following assumptions were made as to application of beneficial use:

- Use of removed sediments as construction fill was chosen as the low-value post removal-option selected for analysis.

- Use as manufactured cement was chosen as the higher-value option selected for analysis.

- Non-TSCA material will be segregated into two fractions for the beneficial use purposes, the fraction with less than 10 mg/kg PCBs and the 10 to 33 mg/kg PCBs fraction.

- The sediment fraction with less than 10 mg/kg PCBs will be stabilized with eight percent Portland Cement at the northern and southern transfer facilities. This material will then be loaded onto trucks to be transported to off-site facilities where it will be stored for use as construction fill material. It is assumed that there is no disposal cost associated with this beneficial use option. Only the cost to transport the material to the appropriate off-site facilities is included. For the cost estimate, these facilities are assumed to be within a 200-mile radius of the transfer facilities and transportation is by truck.

- The sediment fraction with 10 to 33 mg/kg PCBs will be transported by barge to the appropriate processing facility, assumed to be located in the vicinity of New York/New Jersey Harbor. For this option, it is assumed that barges will be loaded at the dredging site and will proceed directly to the processing facility. No stabilization or further processing is assumed to be required for these sediments prior to off-loading at the vendor's location. For the detailed analysis in Chapter 8, the processing facility is assumed to be within 200 miles of Albany.

5.2.6 Backfilling and Site Reconstruction

Upon completion of removal or capping work, there is likely to be some residual contamination along the river bottom due to resettlement and incomplete removal of sediments. While the mass of PCB contamination from these sources is expected to be a minor fraction of the contamination removed, these residual surficial materials will represent a potential contamination source to the water column.

In addition to residual contamination, it is also expected that the process of removing and capping contaminated river sediments may result in some impacts to river bottom topography, river hydraulics, and the stability of the shoreline. Finally, there are potential ecosystem implications to the extensive dredging and capping operations that will be part of the active remedial alternatives. These implications include the following:

- Removal of substrate used as habitat by fish and benthic invertebrates;
- Displacement of benthic organisms;
- Loss of vegetation including wetland communities; and
- Disturbance of shoreline stability.

In order to mitigate various impacts of dredging and capping operations, each capping and removal alternative contains:

- Placement of a blanket of clean fill over those areas that will have experienced capping or removal work;
- Stabilization of disturbed shoreline areas; and
- An aquatic and wetland vegetation planting program.

Each of these activities is summarized below and described in greater detail in Appendix F.

5.2.6.1 Backfilling Approach and Methods

Placement of clean backfill material fulfills a number of important purposes in remediation of the river bed, including isolation of dredging residuals, mitigation of potential bathymetric changes in shallow areas, protection of impermeable capping materials, and habitat replacement. Of the principal purposes for placement of a clean backfill blanket within the river, habitat replacement will most likely have the greatest influence on characteristics of selected materials. As described in Appendix F, fish and benthic organisms require a diversity of bottom conditions to spawn and thrive, including stream bottoms composed of gravels, sands, and finer materials. Thus, the backfill used needs to be composed of materials of varying textures to simulate, to a reasonable degree, bottom conditions in a healthy river system.

A concept for placement of clean fill materials has been developed that provides a reasonable approach for estimating the amount of work to be accomplished and generally conforms to the habitat replacement goals described below and in Appendix F. While locations requiring habitat replacement have not been specifically delineated, development of this concept facilitates estimation of costs for the backfill component of each capping with dredging alternative. Placement of backfill material to protect the engineered cap has already been described. The backfill concept outlined below applies particularly to those areas of the river within which sediment removal alone will occur.

Elements of the concept are as follows:

- Clean fill will not be placed in the navigation channel or in other areas where deeper water environment is preferred based on ecological considerations;
- In areas of the river between the 6-foot contour and the navigation channel, 6 inches of gravel will be placed over 6 inches of sand;
- Between the shoreline and the 6-foot contour, 12 inches of sand will be placed; and
- In shallow wetland areas, pre-removal water depths will be re-established using a combination of sand and fine sand blended with silty material.

Placement of the clean backfill blanket will generally proceed from upstream to downstream following the progress of remediation; one exception to this is River Section 3, where removal and backfilling may occur prior to completion of work in other sections. Sand and gravel backfill materials will be obtained from nearby sand and gravel mining operations and will be loaded onto barges and hauled to the placement location. Where finer-textured materials are needed to achieve habitat replacement goals in disturbed wetland areas, these will be purchased from suppliers in the Hudson Valley and transported by barge to the relevant work areas.

5.2.6.2 Shoreline Stabilization

Since both the removal and capping categories involve considerable sediment removal in proximity to the banks of the river, there will be a need to renew or stabilize shoreline areas so as to limit or control the potential for erosion. Locations requiring stabilization have not been specifically delineated for purposes of this FS; however, a concept has been developed that provides a reasonable approach for estimating the quantity and cost of shoreline stabilization required on an alternative- specific basis. The approach taken for purposes of this analysis is to assume that the stabilization program will be a function of depth of sediment removal within the river immediately adjacent to each shoreline segment. In particular, the following strategy has been followed to define stabilization requirements, including the length of shoreline that will be affected and the stabilization system that will be employed:

- Where less than 2 feet of sediment removal is proposed, stabilization will consist of hydro-seeding the adjacent shoreline area;
- Where 2 or 2.5 feet of removal is proposed, dormant mattresses of plant materials will be employed to stabilize river banks; and
- Where the proposed dredge cut is 3 feet or greater, timber or log revetments (retaining walls) in combination with plant material mattresses will be employed.

It should be noted that, for all sections of the river where near-shore removal operations are planned, the backfill concept previously described requires that either sand or gravel materials be placed on the river bottom to isolate residual contamination and to re-establish ecological functions. It is expected that about one foot of material will be placed on the river bottom for these purposes, and that this layer will also serve as an additional mechanism to control bank erosion. The actual length of shoreline that would require stabilization is specific to each alternative (Chapter 8).

5.2.6.3 Habitat Replacement

As previously mentioned, sediment removal or capping may result in impacts to aquatic and wildlife habitat. Examples of potential impacts follow:

- Removal or capping of substrate used as spawning and foraging habitat by fish and benthic invertebrate species;
- Displacement of benthic organisms;
- Loss of plant communities;
- Loss of freshwater wetlands acreage and wetland functional values; and
- Disturbance of shoreline stability.

A description of existing habitats within the Upper Hudson River that may potentially be affected by removal or capping operations is presented in Appendix F. For purpose of describing potential habitat replacement measures, the physical habitats of the river have been defined as having the following four zones typical of the Upper Hudson River:

- Deep river - areas of the river that are deeper than the photic zone (*i.e.*, depth to light penetration), defined here as depths exceeding six feet. The substrate of the deep open river zone is largely characterized as non-cohesive and is not vegetated.

- Shallow river - open waters of the river that are within the photic zone (*i.e.*, depths less than six feet). In these locations there is a mixture of substrate types (cohesive and non-cohesive).

- Emergent wetlands - emergent wetlands that occur in areas of the river with reduced flow velocity (vegetated backwaters) that allow fine-grained sediments to settle out. Substrate in these areas is generally cohesive.

- River bank - the shoreline of the river (vegetated and non-vegetated).

As detailed below, several habitat replacement concepts are available for these four zones. However, these techniques are not considered applicable to the navigation channel in the Upper Hudson, which is expected to be subject to maintenance dredging. For this reason, as well as the absence of rooted aquatic vegetation in such areas, replacement of habitat substrate in the channel would accrue only marginal ecological benefits.

Deep River Habitat Replacement

Deep river areas are characterized by bottom depths below the photic zone, the illuminated water column and river bottom to which photosynthesis is restricted. The depth of light penetration in the Upper Hudson River varies on both temporal and spatial scales. However, for the purpose of formulating habitat replacement concepts, the typical depth of the photic zone is assumed to be approximately six feet. Therefore, deep river habitat replacement concepts pertain to river areas with post-backfilling depths ranging between six and 12 feet. Concepts developed for the deep river zone would replace fish and benthic habitat and encourage recolonization.

Methods applicable to the deep river zone are limited. Due to the absence of sufficient light levels for photosynthesis, establishment of rooted aquatic vegetation is not an option. The need to maintain the navigability of the river and to avoid creation of obstructions and hazards to boat traffic precludes the extensive deployment of hard structures. For these reasons, appropriate methods are restricted to the placement of suitable substrate and the possible limited deployment of boulder clusters.

Most of the remediated area within the deep river zone would likely be backfilled with a one-half-foot-thick layer of gravel over a one-half-foot-thick layer of sand. The intent is to reconstruct a stable substrate on the river bottom, often a critical requirement for fish spawning and secondary production by aquatic insects. Although a gravel substrate would be suitable for most fish species in this zone, the ideal spawning habitat for many species is a complex mixture of sediment sizes. Therefore, a one-foot deep layer of sand may be placed in some locations to create a mosaic of substrates. Backfill comprised of fine sediments would not be placed in the deep river zone. However, over time, silt and fine sands would be transported into the backfilled areas by currents, gradually increasing the heterogeneity of the substrates.

Shallow River Habitat Replacement

The shallow river zone comprises river areas within the photic zone, generally extending between the shoreline and river depths of six feet, but excluding emergent wetlands and river banks. This zone encompasses shallow water areas within the main and secondary river channels, and shoals, bars, and partially enclosed sheltered coves adjacent to the channels. It includes both predominantly non-vegetated areas and areas containing rooted submerged or rooted floating aquatic vegetation. Objectives for the shallow river zone are to replace fish habitat and benthic habitat and encourage recolonization, and replace disturbed plant communities.

Although river currents in the shallow river zone preclude the establishment of non-rooted vegetation, availability of sufficient light for photosynthesis enables use of rooted aquatic vegetation. This vegetation is planted in patches within the remediation area. Species selected are limited to non-invasive rooted submerged and rooted floating aquatic vegetation, currently occurring in or native to the Upper Hudson River. Candidate species that are valuable to fish and wildlife are discussed in Appendix F.

Only locations backfilled with the sand substrate are planted with rooted aquatic vegetation; gravel surface substrates are not planted. Planting on sand surface substrates will be implemented to establish a mosaic of vegetation cover, both in terms of species composition and plant cover density. Plant cover densities may range between 0 and 100 percent. Plant materials (species, planting stock, and availability), planting locations, and planting densities will be determined during remedial design.

Emergent Wetland Habitat Replacement

Emergent wetlands are characterized by erect, rooted, herbaceous hydrophytic plants, excluding mosses and lichens. This vegetation is present for most of the growing season in most years. Emergent wetlands occur in areas of the river with reduced flow velocity that allow fine-grained sediments to settle out. While there are forested riparian wetlands adjacent to the river, remediation activities will not occur there; therefore, this habitat replacement concept does not address forested wetlands.

Objectives for emergent wetlands are to replace fish and benthic habitat and to encourage recolonization. Additional objectives are to replace disturbed plant communities and replace wetlands. Wetland replacement will be focused on the following end points:

- Re-establish wetland function and values (habitat, flood control, water quality), and
- Re-establish habitat diversity through provision of emergent marsh with interspersed deep-water pools and scrub-shrub wetland habitat.

Candidate species useful for wetland replacement are described in Appendix F.

River Bank/Shoreline Stabilization

River banks immediately adjacent to sediment removal locations may require stabilization to control bank erosion, slumping, and sloughing. Ecological objectives for the shoreline, or river bank zone, are to replace vegetation communities and stabilize shorelines. Potential bank stabilization methods will be a function of the depth of sediment removal in the river adjacent to each shoreline segment. The basic stabilization strategy has already been described; however, the actual river bank stabilization method to be employed along each shoreline segment will be specified during the remedial design phase. Both vegetative methods and structural-vegetative methods will likely be employed, the choice being dependent on the extent of bottom sediment removal in the adjacent river and the magnitude of erosive forces.

5.2.7 Monitoring

An important component of any remedial alternative for the Hudson River is the monitoring of river conditions before, during, and after the remedial effort. The purpose of the monitoring is primarily to document the improvement in river conditions as a result of the remedial effort as well as to verify that the remedy succeeds in achieving RAOs. Additionally, monitoring will be utilized to assess the effectiveness of measures taken to mitigate potential short-term impacts resulting from the remedial activities.

Various aspects of the proposed monitoring address the long-term changes in the PCB concentrations in sediment, water, and fish. Additionally, PCB concentrations in sediment immediately prior to and subsequent to any remedial activity are also to be monitored. Finally, impacts of the remedial activities on water column and fish conditions are addressed. Each of these aspects is covered to a differing degree, depending on the remedial activity selected. The following text provides an overview of the proposed monitoring programs. A detailed discussion of the proposed programs is found in Appendix G.

The monitoring programs fall into four separate categories as follows:

- Monitored Natural Attenuation Monitoring Program
- Design Support Investigation
- Construction Monitoring Program
- Post-Construction Monitoring Program

Monitoring is not a part of the No Action alternative. Also, the monitoring program associated with MNA is treated separately from that of the programs for the active remedial alternatives. The last three programs are components of any active remedial alternative involving removal or capping. The discussion that follows presents the basic premise of each of the monitoring programs and an outline of the monitoring tasks. In several instances, the monitoring programs have several tasks in common. Additionally, the second, third, and fourth monitoring programs listed above have alternative-specific features.

The length and spatial coverage varies widely among the monitoring programs, covering a range of 1 to 30 years, and from as few as 30 to as many as 200 river miles. Figure 5-6 provides an outline of the entire suite of monitoring programs.

Each of these monitoring programs involves tasks in addition to the sampling effort itself, including, among others, tallying, reporting, and interpretation of the data. For the purposes of cost estimating, data reporting and interpretation have been estimated on a per-sample basis. MNA requires the additional effort of incorporating the data collection results into further modeling analysis to determine whether the actual data trajectory matches the model forecast. To the extent that there are differences, the models will require adjustment and possibly recalibration to reflect the actual data and make more accurate forecasts. A smaller but similar modeling program is planned for the post-construction monitoring period.

5.2.7.1 Monitored Natural Attenuation Monitoring Program

Under this alternative, an extensive monitoring program will be conducted to document the expected rate of decline in PCB concentrations in water, fish, and sediment. Additionally, this program is intended to develop data sets that can be used to validate and further refine various USEPA models. These models will require revision to enhance their accuracy over the long term and to correct any differences between the model forecast and the actual measured trends. It is expected that model review and recalibration will occur on a three-to-five year cycle to reflect the newest data in the model forecasts. This cycle time also corresponds to the frequency of the major sediment monitoring events. A five-year recalibration has been assumed for cost estimation purposes.

Surface water monitoring under the MNA alternative consists of five components. Two of these are weekly sampling of the Upper Hudson and monthly sampling of the Lower Hudson under a time-of-travel monitoring plan. Sampling events will occur at seven Upper Hudson stations and four Lower Hudson stations. Because of the important differences in congener patterns among the various potential PCB sources in the region, congener-specific data are required. Ancillary measurements include suspended solids and the fraction of organic carbon on the suspended solids.

The remaining three elements under this program are designed to collect data to further enhance the understanding of PCB loads in the Upper Hudson. These include monitoring of suspended solids and float surveys. Suspended solids monitoring is needed to further refine and improve the existing modeling analysis of solids transport in the Upper Hudson. Flow data will be required as well. The remaining water-related elements are two float survey programs, similar in design to the studies done by GE in 1996 and 1997 (O'Brien & Gere, 1998). These surveys cover River Sections 1 and 2 and are focused on the warmer months of the year. The surveys are intended to study the processes and the areas responsible for the PCB release from the sediments documented in the USEPA and GE data.

The fish monitoring program under MNA is based on the sampling program assembled by NYSDEC in 1997 (included in Appendix G). For this FS, the main goals of fish monitoring are as follows:

- To assess temporal trends in PCB concentrations in selected resident species;
- To evaluate spatial relationships in Hudson River PCB contamination as reflected by PCB concentrations in the fish; and
- To ascertain PCB concentrations in striped bass for purposes of providing or modifying health advisories and for regulating commercial fisheries.

Essentially, the program is intended to further the understanding of PCB uptake in fish while also monitoring to determine when fish levels reach acceptable concentrations for recreational and commercial use. To accomplish this, fish monitoring will continue as it has for the last several years, with the collection of resident and migratory species from both the Upper and Lower Hudson.

To assess sediment contamination, sediment cores will be collected for radionuclide dating and PCB analysis from throughout the Upper and Lower Hudson River. These cores document major releases to the river along the river's length. Eleven locations in the main stem of the Hudson plus one location in the Mohawk near its confluence with the Hudson will be occupied for this program. The sampling frequency for this program is at five-year intervals for most of the 30-year monitoring period, although cores are collected in years 1 and 4 (three years apart) to examine the initial conditions. PCB analysis is done on a congener-specific basis for this program to provide information on the transformations over time of the PCB mixtures contained within the sediment (*i.e.,* dechlorination). In this manner, these cores document the long-term response of PCB contamination in the Hudson.

In addition, the sediments of several *hot spots* will be examined every five years to assess the in-place inventory and compare it with prior inventory estimates. Additionally, composite samples similar to those collected by GE and used in the modeling analysis will be generated every five years to track changes in the surface sediment conditions. These results can be directly incorporated into the HUDTOX model as a part of future model refinements anticipated under the MNA alternative.

By sampling at this frequency, the results will permit the documentation of changes in sediment PCB inventory and concentration over time.

The final component of the MNA monitoring program is acoustic mapping of sediment properties and river bathymetry. The geophysical surveying by acoustic techniques is similar to the Phase 2 efforts completed in 1992. Several different acoustical packages will be used to collect surface sediment characteristics (side-scan sonar), sediment thickness (sub-bottom profiling), and bathymetric data (multi-beam sonar). Additional coverage of the river bottom for bathymetry, specifically to assess sediment burial or resuspension over time, will be conducted using a multi-beam system. The timing for this task is intended to provide a large quantity of data on the sediments and their variability at the beginning of the program followed by regular, less frequent monitoring later in the program. Specifically, the bathymetric survey will be conducted quarterly in the first year, followed by annual surveys in years 2 to 5, with surveying on five-year intervals thereafter. For purposes of cost estimating, surveys at five-year intervals are assumed to occur during years 6 through 30.

5.2.7.2 Design Support Investigation (Pre-Construction Monitoring)

Unlike the MNA monitoring program, the design support program does not represent a remedial alternative by itself. Rather, this program will be implemented as part of a remedial alternative involving sediment removal or capping. The purpose of the design support program is to provide current data on sediment conditions prior to initiation of sediment remediation. These data will form the basis for the final identification of sediments to be remediated, whether by removal or by capping. Because the information to be gathered on the sediments is needed for both active remediation categories, the number of samples and the sampling density are the same for both options, given the same remediation target criteria. For example, target areas incorporated in an alternative designated by 3/10/10 require the same number of samples for both removal (REM-3/10/10) and capping (CAP-3/10/10). This is because both alternatives require knowledge of the horizontal and vertical extent of contamination, since both involve sediment removal.

The design support program involves sediment, fish, and geophysical sampling during a one-year period. Included in this sampling are the MNA alternative monitoring programs involving water, fish, and dated sediment core sampling. In addition to the seven basic components from MNA (*i.e.,* the five water column elements, fish monitoring, and dated sediment), a caged fish study will also be implemented during the design support program. This will establish a baseline of conditions for comparison to caged fish studies planned for the post-construction period.

Remedial alternatives developed for the Upper Hudson River involve varying degrees of sediment removal or capping. Estimates of remediation areas and volumes for these alternatives are based on currently available data that describe the horizontal and vertical extent of contamination. However, these data would need to be updated before the sediment removal or capping operations begin. Additionally, given the anticipated magnitude of sediment removal, data will be collected at a sufficient spatial resolution to minimize, to the extent possible, the removal of clean sediments, as well as to minimize the potential for not remediating PCB-contaminated sediments meeting the specific target thresholds. On this basis, then, the design support program will refine the sediment PCB inventory of the Upper Hudson.

Estimation of the number of cores required is not straightforward, in part because of the need to select a minimum area unit for remediation and, more importantly, because of the inherent variability in the data. The design support sampling program will require the incorporation of several data sets in order to properly estimate the sampling density. Sampling density will vary with each alternative, as well as by river section, since the alternatives have different goals in each section. For the areas most likely to be removed under the Hot Spot (10 g/m^2) and Expanded Hot Spot (3 g/m^2) remediation thresholds, 40 cores per 5-acre unit are required to accurately assess sediment depth. For areas with a high probability of sediment contamination at or near those thresholds, sampling density is estimated at 36 cores per 5-acre unit. Finally, low probability areas will be sampled at a low density of one core per acre or less. Derivations of the various estimates are included in Appendix G. Ultimately, the remedial alternatives selected for detailed analysis yield between 4,800 and 7,600 coring locations for the design support sampling program. Because of the extensive removal component in a capping alternative, the sampling program is estimated to be the same for both capping and removal. Cores are nominally estimated at three feet in length, consisting of three separate core segments for PCB analyses plus additional radionuclide analyses.

The last data collection effort under the design support is geophysical surveying. The geophysical survey has two major goals: first, to establish river bathymetry and sediment type prior to the onset of remediation; and second, to re-examine the river bottom in conjunction with the sediment sampling program discussed above as an aid to the delineation of remediation areas. The collection of accurate bathymetric data is paramount for measurement of the actual volume of sediment removed, the depth of cap installed, and achievement of the desired removal depths. The design support bathymetric survey provides the reference surface for the interpretation of subsequent surveys for the dredged volumes, dredged depths, and cap thicknesses. To this end, the bathymetric cross-sections are to be obtained in a fairly dense coverage in the areas slated for remediation.

A side-scan sonar survey will provide current data on the nature of the river bottom sediments, updating the USEPA side-scan sonar survey of 1992, which would be approximately ten years old at the initiation of a design effort, and the more limited side-scan sonar data obtained during the 1999 debris survey. The side-scan sonar survey will also refine understanding of the occurrence of debris that may interfere with sediment remediation. Finally and most importantly, the side-scan sonar survey will be used in conjunction with the design support coring program to map removal/capping boundaries and sediment thicknesses, and to finalize the remedial design.

5.2.7.3 Construction Monitoring Program

This program is intended to document PCB levels in the Hudson River during the remediation of the river sediments. It contains several tasks that specifically address PCB and suspended solids levels in the vicinity of removal operations and the downstream impacts of the real operations. This program also represents the confirmatory sampling effort wherein sediment samples will be collected after removal, backfilling, and capping to ascertain the degree of cleanliness achieved. This program begins the year before the start of construction and continues until construction is completed. Depending on the alternative, construction is assumed to require either five or seven years. Thus, the construction monitoring program will have a duration of either six or eight years.

This program will continue the water column and fish monitoring begun under the design support program. It is important that these efforts begin prior to initiation of remedial operations to establish a baseline for subsequent comparisons during and after construction. Caged fish will not be monitored during the actual construction period.

During the construction period, monitoring of two important water column elements has been included. The first is the monitoring of suspended solids in the vicinity of the dredging operations. Twice-daily measurements of suspended solids via turbidity meter will be made upstream and downstream of each dredge. Approximately five percent of the turbidity measurements will be confirmed by a direct suspended solids measurement. These measurements will serve to monitor the escape of suspended solids from the dredging operations and to trigger the subsequent program element when turbidity exceeds a specific threshold. In this instance, a water column time-of-travel event will be initiated. These events represent water column sampling in addition to the weekly monitoring events described for MNA. In these events, the water column monitoring will be conducted to track the plume of increased turbidity as it travels downstream and assess its potential impacts. It may also be possible to correlate turbidity and PCB measurements in order to establish a turbidity threshold which, if exceeded, may trigger modifications to dredging operations.

The sediment monitoring task under construction monitoring is designed to document the degree of cleanup achieved by the remediation activities. Specifically, it consists of sediment core collection in the remediation zones after removal, backfilling, and capping. Where removal of PCB-contaminated sediments has been conducted, core collection will serve to document the removal of the PCB inventory and the attainment of acceptable PCB concentrations. The task has been estimated assuming that the dredged areas will exhibit the same level of variability as seen in the historical data. Thus the requirement of 36 cores per 5-acre unit as described previously is used in the estimate. Confirmatory sampling for the backfill program will be implemented to document an acceptable PCB level in the backfill as well as a sufficient thickness of material. Since only clean backfill (non-PCB contaminated material) will be used, a less intense sampling program (15 cores per 5-acre unit) will be implemented.

The capping alternative also requires confirmatory sampling. In those areas slated for removal without subsequent capping, the sampling density will be the same as that for the all removal programs. For areas to be capped, confirmatory coring is only required once the cap is in place. Areas to be partially dredged do not require post-dredge sampling since the sediment removal in these areas is only designed to permit emplacement of the cap. Sampling density for the capped areas is estimated to be the same as for the backfill component.

In all three programs, the ultimate rate of sampling will need to be adjusted once the success rate and degree of homogeneity of the remaining sediment have been tested during the remediation itself. Core lengths will be limited to about four inches with deeper sediments obtained in about ten percent of the coring locations. Core depths for the capped areas will be limited to four inches into the impermeable cap material, so as not to fully penetrate the cap. Hydration of the cap material is more complete on the exterior surfaces than in the interior of the layer. Additional hydration of fresh capping material, surrounding the core site, will generally result in self-healing of the impermeable layer.

The last program element under construction monitoring is geophysical surveying, designed to document the physical volume of sediment removed and the backfill or capping material installed on the river bottom. This will be done by simple bathymetry as well as acoustic imaging of the sediment type (side-scan sonar).

Acoustical surveys will be conducted to obtain bathymetric data and surface sediment characteristics for all areas of sediment removal. These surveys will be conducted after sediment removal to determine the volume and depth of sediment removed. These surveys will be completed prior to any confirmatory sediment core collection. Multi-beam surveys will also be performed to confirm the volume and thicknesses of backfill and capping material. For dredged areas, this represents a single additional survey after the backfill material has been installed. For the capped areas, two surveys will be required. The first follows the placement of the cap to assess the success of the installation and the thickness installed. A second survey will be required after the backfill has been installed to confirm that the specified thickness has been placed.

In addition to the program elements identified above, it is likely that an air monitoring program will be implemented in the vicinity of the transfer facilities to verify the performance of measures designed to prevent or minimize impacts to workers and the community during remediation.

5.2.7.4 Post-Construction Monitoring Program

The post-construction monitoring program is essentially similar to the MNA program, but is initiated after remediation. Initially, the frequency of data collection is similar to that of the MNA program. Unlike monitored natural attenuation alone, however, it is anticipated that the need for frequent monitoring will decline several years after active remediation is completed, at least for the sediment removal alternatives. Thus, monitoring is limited to ten years for these alternatives. Monitoring is planned for 25 years for the capping alternative, since the performance of the cap must be routinely verified.

The purpose of the post-construction monitoring program is to document the success of the remedial measures in reducing PCB levels in the water, sediments, and fish of the Hudson River. Thus, this program involves the sampling of all three media. For the removal alternatives, after the initial, intense monitoring period, monitoring decreases to quarterly time-of-travel monitoring, and the float surveys are discontinued. Water column monitoring of suspended solids also decreases from daily measurements to monthly. The periods specified above are best estimates needed for cost estimation.

The fish monitoring program for the post-construction period is identical to that of MNA, with the one exception discussed below. The purpose is to closely monitor fish body burdens throughout the Hudson River as they respond to the remedial efforts. These results will serve to document the expected decline in fish body burdens and provide the data needed by NYSDEC to regulate and eventually reopen the Hudson fishery when appropriate. Because fish body burdens are not predicted to meet PRGs over the model forecast period, even under the most extensive remedial programs, the fish monitoring program is projected to be required indefinitely. Costs are estimated for the entire 25-year post-construction period.

In addition to the regular fish monitoring described above, caged fish will also be deployed and collected in the post-construction period to monitor the impacts of water-column exposures to fish after construction. These data provide a basis for establishing the impact of the upstream dredging efforts on downstream fish exposure. This program will be implemented for ten years.

The sediment monitoring program consists of two tasks, the first designed to document the long-term response of the river to the remediation, and the second to monitor changes in the remediation areas themselves. The first task is the collection of dated sediment cores that has been previously discussed. The fact that cores integrate the annual deposition of sediment enables documentation of the long-term recovery of the Hudson, because within this annual deposition is clear evidence of the PCB load carried by the river. The duration of this task for the three removal alternatives extends 9 years, with coring events in years 1, 4, and 9. For the capping alternative, the sampling program duration is 25 years, with coring events in years 1, 4, 9, 14, 19, and 24.

The second sediment monitoring task involves monitoring the remediation areas to document the changes, if any, in the thicknesses of the backfill material and its level of contamination. It will also document any recontamination of surface sediments. Specific to the capping category, this sampling will also verify the integrity of the cap by showing that the capping material has not been exposed due to loss of backfill material. Thus the sediment sampling program is substantially longer for the cap alternative than for the removal alternatives. Specifically, for the removal category, 250 locations will be occupied on three separate occasions, that is, years 1, 4, and 9 of the post-construction period. For the capping category, the cap will be sampled in years 1, 4, 9, 14, 19, and 24. While the exact number of locations that would be applicable has not been determined, the cost estimate is based on sampling at approximately 500 locations.

Geophysical surveys will be conducted on a routine basis during the post-construction period. These surveys will monitor changes in the installed backfill and capping material and identify areas undergoing scour or deposition. These data will be important to the capping option since they can be used to assess the long-term integrity of the cap. The program is similar to the geophysical survey planned for the construction monitoring program and will use the geophysical survey data from that program as a baseline for comparison. The geophysical surveys will also be used as an aid in placing the 250 to 500 sediment core locations under the sediment monitoring program.

5.2.7.5 Monitoring Program Summary

The proposed monitoring programs cover an extensive range of alternative possibilities. Monitoring of water, sediment, and fish is involved in each of the programs discussed, and in each case, the importance of building on the current monitoring program while obtaining additional data has been emphasized. This aspect is important since a large historical record exists for the Hudson River that will aid in the interpretation of future results. In the same vein, the monitoring programs are quite extensive in order to sufficiently document changes in the conditions of the river. By extensively monitoring, deviations from the anticipated behavior under each remedial alternative can be identified as early as possible, allowing for further actions if required. As the river achieves the expected response and meets or exceeds the anticipated PCB concentrations or loads, it may be appropriate to reduce the frequency of monitoring in one or more media. This possibility has been conservatively addressed in some programs, depending upon the permanence of the remedial alternative and the anticipated recovery of the river. Ultimately, the decision to reduce monitoring can only be made during the monitoring period itself.

5.3 Potential Remedial Action Alternatives

Development of potential remedial alternatives was performed based on an evaluation of the data used to delineate remediation target threshold boundaries and the four-step modeling evaluation for alternative scenarios summarized in subsection 5.3.1 below and presented in detail in Appendix D. The evaluation also considered the potential uncertainties associated with model predictions and other lines of evidence, as described in Appendix D.

Subsection 5.3.2 describes the screening factors and metrics used to evaluate model scenarios. This evaluation was performed to narrow the field of potential alternatives while preserving an appropriate range of options. A list of potential alternatives assembled for screening in Chapter 6 (within the four alternative categories described above in Section 5.2) is provided in subsection 5.3.3.

5.3.1 Modeling Evaluation of Alternative Scenarios

Modeling of remedial alternative scenarios is described in detail in Appendix D and summarized briefly in this section. Modeling of remedial alternative scenarios was performed in four stages: 1) modeling of No Action and Monitored Natural Attenuation, 2) preliminary modeling, 3) engineering modeling, and 4) refined engineering modeling. Preliminary modeling scenarios involve initial model experiments that did not consider engineering constraints in detail. Engineering modeling scenarios involve a series of experiments that incorporated engineering constraints, to further explore the effects of various approaches to remediation, upstream boundary conditions, and target thresholds. Refined engineering modeling scenarios involve modeling of potential remedial alternatives. At each stage of the modeling, the results were used to refine the scope of modeling in the next stage.

5.3.1.1 No Action and Monitored Natural Attenuation Modeling

The No Action and MNA alternatives provide the baseline against which active remedial alternatives are evaluated. These scenarios are obtained by running the model over a 70-year forecast period (through 2067) without application of active remediation for the sediments. Model forecasts of the impacts of No Action provide a best estimate of long-term trends at the reach-averaged scale, based on currently available data. These forecasts are, however, subject to considerable uncertainty relative to projections of specific years in which RAOs or other targets are achieved. Similarly, the forecasts are also subject to considerable uncertainty relative to active remedial alternatives that remove sediments with high concentrations of PCBs from the river or provide an engineered barrier to contact between these sediment PCBs and the water column and biota. In addition, the reach-averaged model predictions are not necessarily representative of trends at the more localized scales at which resident fish feed. This is suggested by the comparison of model predictions and recent observed trends in fish and surface sediment concentration in and near the NYSDEC fish sampling location near Griffin Island in the southern end of River Section 1, as described in Appendix D. Based on the trend analysis results, an alternative bounding calculation for No Action and MNA was performed using a slowly-declining cohesive sediment exposure concentration representing localized conditions in the region of sediment PCB *hot spots* not experiencing burial by cleaner sediment.

Sediment and water PCB concentrations for No Action and MNA alternatives, including both the baseline model predictions and the alternative bounding calculation, were then fed forward through the FISHRAND model to produce forecasts of fish tissue concentration.

5.3.1.2 Preliminary Modeling

Preliminary modeling runs constitute simplified experiments to evaluate the general efficacy of the different remedial alternative categories. The primary objective of the preliminary level FS modeling was to evaluate the general effectiveness of the three remedial alternative categories, Alternative Categories 3, 4, and 5, described above in subsection 5.1.2, relative to No Action and MNA. Thirteen preliminary level remediation scenarios were simulated using the coupled mathematical models described previously to determine the effects of remediation (capping, dredging, and capping with dredging) on the resulting concentrations of PCBs in fish and surface water quality in River Sections 1, 2, and 3 of the Upper Hudson River (see Appendix D for details). As stated earlier, based on results from the preliminary level modeling, Alternative Category 3 (Capping of Target Areas and MNA) was eliminated from further consideration.

5.3.1.3 Engineering Modeling

The primary objective of the engineering level modeling was to evaluate the general effectiveness of the 2 active remedial alternative categories, Alternative Categories 4 and 5, described above, against No Action and MNA. Twenty-one engineering level remedial alternative scenarios were simulated to determine the effects of remediation (capping with dredging, and dredging) on the resulting concentrations of PCBs in fish and surface water quality in River Sections 1, 2, and 3 (see Appendix D for details). These include 11 removal (dredging) alternative scenarios and 10 containment (capping with dredging) alternative scenarios. These 21 alternative scenarios include three that test the effects of changes to the assumed upstream Tri+ PCB load at Rogers Island. In addition to these 21 scenarios, three additional removal alternative scenarios were simulated to test model sensitivity to residual sediment concentrations, and three additional containment (capping with dredging) alternative scenarios were simulated to test model sensitivity to partial failure of the containment or improper placement of the cap.

For most of the engineering model simulations, the upstream boundary condition at Fort Edward (Rogers Island) was set at a constant concentration of 10 ng/L Tri+ PCBs. The main differences between the model input for these engineering level modeling alternative scenarios and the preliminary level modeling alternative scenarios are the basic assumptions for delineating areas for sediment removal (dredging) or containment (capping with dredging). The preliminary level modeling alternatives were based on theoretical removal to a target MPA calculated from the PCB concentrations for the sediment sampling points in the database, whereas the engineering level alternatives take into consideration actual physical limitations due to the size and capacity of construction equipment (dredges and barges) and access issues (presence of rocky areas, dams, and available water depths), as well as the heterogeneity of the PCB distribution in the sediment. For practical reasons, small but isolated areas of high PCB concentration were excluded from being targeted, whereas small areas of low concentration within larger target areas were included. A detailed discussion of the development of target threshold boundaries is provided in Section 3.5.

The general conclusions from the engineering modeling results are as follows:

- At the scale of the model segments, long-term predictions of Tri+ PCB concentrations in River Sections 1, 2, and 3 are controlled by assumptions of boundary conditions for upstream Tri+ PCB loads.

- The model predicts large differences in Tri+ PCB concentrations in water, sediment, and fish immediately following remediation, with later results converging to the No Action trajectory, controlled by the upstream boundary. The rate of convergence of these predictions (and thus the apparent value of remediation) is controlled by model calibration assumptions of the rate of natural decline of Tri+ PCB surface sediment concentrations, which are subject to uncertainty. Rapid convergence is not predicted using the estimated upper bound of the No Action and MNA alternatives (Appendix D). This suggests that fish tissue concentrations in localized areas, including important habitat and fishing areas such as the historical fish sampling location near Griffin Island in the southern end of River Section 1, may decline at rates that are much slower than those predicted by the model at the reach-averaged scale.

- Predictions of non-cohesive sediment Tri+ PCB concentrations are strongly dependent on the target threshold boundaries (degree of remediation), and extensive remediation of diffuse contamination is required in River Section 1 to achieve a substantial decline in Tri+ PCB concentrations in water, sediment, and fish. Concentrations of Tri+ PCBs in the water column at the TI Dam are most strongly related to the non-cohesive sediment concentrations.

Downstream of the TI Dam, the concentration of Tri+ PCBs in the water column at the TI Dam is the most important factor controlling water column exposure.

5.3.1.4 Refined Engineering Modeling

In this fourth and final stage of the modeling of alternative scenarios, the upstream boundary condition was changed from a constant Tri+ PCB concentration boundary to a constant Tri+ PCB load boundary condition. The upstream PCB loads are associated with bedrock seeps and are not strongly flow-dependent. Therefore, a constant Tri+ PCB load boundary is more appropriate than a constant Tri+ PCB concentration boundary. The revised current constant Tri+ PCB load boundary condition of 0.16 kg/day rate represents the average daily load based on 1997-1999 GE monitoring data, and is equivalent to a Tri+ PCB concentration of approximately 13 ng/L under average annual flow conditions.

For all refined engineering alternative scenarios except No Action, further source control measures are assumed in the vicinity of the GE Hudson Falls plant due to a separate NTCRA that are expected to substantially reduce the PCBs in the upstream water column. Specifically, for these runs, the upstream load was assumed to step down from 0.16 kg/day (approximately 13 ng/L) to 0.0256 kg/day Tri+ PCB (approximately 2 ng/L) on January 1, 2005. The 2 ng/L level was determined to be reasonable for further source control at Hudson Falls, coupled with the small ongoing load from upstream of the GE plants.

Several capping with dredging and several removal alternative scenarios were evaluated that represent a full range of remediation in each of the three river sections. These alternative scenarios were then evaluated based on several criteria including the reductions in the predicted fish body burdens and water quality in each of the three river sections as compared to No Action and the predicted cumulative Tri+ PCB flux over the Federal Dam.

5.3.1.5 Scenario Nomenclature System

A specialized nomenclature system was used to designate the remedial scenarios (potential remedial alternatives) for the engineering modeling and refined engineering modeling; this nomenclature system differs from that used in the preliminary modeling. The first part of the scenario name uses three or more letters to describe the remedial alternative category, *e.g.*, removal (REM) or capping with dredging (CAP). The second part of the remedial scenario name uses numbers or letters to denote the remediation target area for each of the three river sections defined in Chapter 3 and the extent of remediation within each river section, sequentially from River Section 1 to River Section 3. The remediation designations are:

- 0: refers to Full-Section remediation (in other words, the remediation of all sediments within the river section) and designates the target areas with PCB MPA of 0 g/m^2 or greater;

- 3: refers to Expanded Hot Spot remediation and designates target areas based primarily on a PCB MPA of 3 g/m^2 or greater;

- 10: refers to Hot Spot remediation and designates target areas based primarily on a PCB MPA of 10 g/m^2 or greater;

- Select: refers to remediation of selected areas in River Section 3, designated based on additional criteria such as depth of burial by cleaner sediments and potential for scour not represented by the model, as explained in subsection 6.4.1.1;

- MNA: refers to monitored natural attenuation of the sediments only (*i.e.*, no target areas are designated).

Therefore, by this nomenclature system, the alternative that involves Full-Section capping with dredging in River Section 1, Expanded Hot Spot capping with dredging of sediments (at or above nominal PCB MPA of 3 g/m^2) in River Section 2, and no remediation of sediments (MNA only) in River Section 3, would be designated as CAP-0/3/MNA. Full-Section remediation was excluded in River Section 3 because it would require remediation of an unreasonably large area (more than 2,800 acres) and there are limited data in areas other than the five *hot spots* in this section.

5.3.1.6 List of Alternative Scenarios for Evaluation

The various engineering and refined engineering model runs are listed below. Included in the list are the model run number, the designation of the alternative to which the model run corresponds, and a summary of the upstream boundary conditions assumed for the run. The various sensitivity analysis runs are also included in the list below.

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Engineering Modeling

Run No.	Alternative Designation	Tri+ PCB Upstream Boundary Condition
E1	REM-0/0/3	Constant at 10 ng/L
E2	REM-0/3/3	Constant at 10 ng/L
E3	REM-3/3/3	Constant at 10 ng/L
E4	REM-10/10/10	Constant at 10 ng/L
E5	REM-3/10/10	Constant at 10 ng/L
E6	REM-0/0/MNA	Constant at 10 ng/L
E7	REM-0/3/MNA	Constant at 10 ng/L
E8	CAP-3/3/3	Constant at 10 ng/L
E9	CAP-10/10/10	Constant at 10 ng/L
E10	CAP-3/10/10	Constant at 10 ng/L
E11	CAP-0/3/MNA	Constant at 10 ng/L
E12	CAP-0/MNA/MNA	Constant at 10 ng/L
E13	CAP-3/MNA/MNA	Constant at 10 ng/L
E14	CAP-0/0/MNA	Constant at 10 ng/L
E15	CAP-3/3/MNA	Constant at 10 ng/L
E16	REM-0/10/MNA	Constant at 10 ng/L
E17	REM-0/10/10	Constant at 10 ng/L
E18	CAP-0/10/10	Constant at 10 ng/L

Sensitivity to change in upstream boundary condition		
Run No.	**Alternative Designation**	**Tri+ PCB Upstream Boundary Condition**
E3B	REM-3/3/3	Constant at 0 ng/L
E3C	REM-3/3/3	Constant at 30 ng/L
E8B	CAP-3/3/3	Constant at 0 ng/L

Sensitivity to residual surface concentration after dredging		
Run No.	**Alternative Designation**	**Tri+ PCB Upstream Boundary Condition**
E3S1	REM-3/3/3 (1 ppm)	Constant at 10 ng/L
E3S2	REM-3/3/3 (2 ppm)	Constant at 10 ng/L
E3S5	REM-3/3/3 (5 ppm)	Constant at 10 ng/L

Sensitivity to improper cap placement		
Run No.	**Alternative Designation**	**Tri+ PCB Upstream Boundary Condition**
E8S5	CAP-3/3/3 (5%)	Constant at 10 ng/L
E8S10	CAP-3/3/3 (10%)	Constant at 10 ng/L
E8S25	CAP-3/3/3 (25%)	Constant at 10 ng/L

Refined Engineering Modeling

Run No.	Alternative Designation	Tri+ PCB Upstream Boundary Condition
R01CW	REM-0/0/3	Constant at 0.16 kg/day
R02CW	REM-0/10/MNA	Constant at 0.16 kg/day
R03CW	REM-0/MNA/MNA	Constant at 0.16 kg/day
R04CW	REM-3/10/10	Constant at 0.16 kg/day
R05CW	REM-3/MNA/MNA	Constant at 0.16 kg/day
R06CW	REM-0/10/10	Constant at 0.16 kg/day
R07CW	REM-10/MNA/MNA	Constant at 0.16 kg/day
R01S2	REM-0/0/3	Step from 0.16 to 0.0256 kg/day
R02S2	REM-0/10/MNA	Step from 0.16 to 0.0256 kg/day
R03S2	REM-0/MNA/MNA	Step from 0.16 to 0.0256 kg/day
R04S2	REM-3/10/10	Step from 0.16 to 0.0256 kg/day
R05S2	REM-3/MNA/MNA	Step from 0.16 to 0.0256 kg/day
R06S2	REM-0/10/10	Step from 0.16 to 0.0256 kg/day
R07S2	REM-10/MNA/MNA	Step from 0.16 to 0.0256 kg/day

R01S0	REM-0/0/3	Step from 0.16 to 0.0 kg/day
R08S2	REM-0/0/3 with polygonal weighting (pw)	Step from 0.16 to 0.0256 kg/day
R09S2	REM-3/10/10 (with pw)	Step from 0.16 to 0.0256 kg/day
R10S2	REM-10/MNA/MNA (with pw)	Step from 0.16 to 0.0256 kg/day
R11S2	REM-3+Channel/10/36-37	Step from 0.16 to 0.0256 kg/day
R12S2	REM-0/10/36-37	Step from 0.16 to 0.0256 kg/day
R13S2	REM-3/10/36-37	Step from 0.16 to 0.0256 kg/day
R14S2	REM-3/10/Select + channel to implement	Step from 0.16 to 0.0256 kg/day
R15S2	CAP-3/10/Select + channel to implement	Step from 0.16 to 0.0256 kg/day
R16S2	REM-0/0/3 + channel to implement	Step from 0.16 to 0.0256 kg/day
R17S2	CAP-0/10/36-37	Step from 0.16 to 0.0256 kg/day
R18S2	CAP-0/10/MNA	Step from 0.16 to 0.0256 kg/day
R19S2	CAP-0/MNA/MNA	Step from 0.16 to 0.0256 kg/day

Sensitivity to residual surface concentration after dredging		
Run No.	**Alternative Designation**	**Tri+ PCB Upstream Boundary Condition**
R14S2-0	REM-3/10/Select (0 ppm)	Step from 0.16 to 0.0256 kg/day
R14S2-2	REM-3/10/Select (2 ppm)	Step from 0.16 to 0.0256 kg/day
R14S2-5	REM-3/10/Select (5 ppm)	Step from 0.16 to 0.0256 kg/day

Sensitivity to improper cap placement		
Run No.	**Alternative Designation**	**Tri+ PCB Upstream Boundary Condition**
R15S2-15	CAP-3/10/Select (15%)	Step from 0.16 to 0.0256 kg/day
R15S2-25	CAP-3/10/Select (25%)	Step from 0.16 to 0.0256 kg/day

5.3.2 Factors and Metrics for Evaluation of Model Scenarios

As can be seen from the list above, a wide range of possible scenarios was explored. The alternative scenarios were evaluated by comparing various factors including the:

- Mass of PCBs, areas and volumes of sediment targeted for remediation;
- Area capped;
- Volume of sediment removed;
- Surface water quality in each river section;
- Fish body burdens in each river section; and the
- PCB load over Federal Dam.

Relative improvements in surface water quality, fish body burdens, and the load over Federal Dam obtained by incremental changes in the mass of PCBs, areas, and volumes of sediment targeted for remediation in each river section among the alternative scenarios were also examined.

After comparing the results for the scenarios, based on these factors, the following ten active remediation alternatives were developed for alternative screening in addition to the No Action and the MNA alternatives:

Alternative REM-10/MNA/MNA;
Alternative REM-0/MNA/MNA;
Alternative REM-3/10/10;
Alternative REM-0/10/MNA;
Alternative REM-0/10/10;
Alternative REM-0/0/3;
Alternative CAP-0/MNA/MNA;
Alternative CAP-3/10/10;
Alternative CAP-0/10/MNA; and
Alternative CAP-0/10/10.

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For all of these alternatives, it is assumed that a separate source control NTCRA is performed in the vicinity of the GE Hudson Falls facility and that naturally occurring attenuation processes further reduce the toxicity, mobility, and volume of the remaining PCBs in the Upper Hudson River sediments after construction is completed.

This evaluation was performed to narrow the field of potential alternatives while preserving an adequate range of options (degree of remediation). For example, alternative REM-10/MNA/MNA is the least extensive alternative, consisting of Hot Spot remediation in River Section 1 (the TIP) and MNA alone in River Sections 2 and 3. Alternative REM-0/MNA/MNA involves Full-Section remediation in River Section 1 and MNA in River Sections 2 and 3. Alternative CAP-0/MNA/MNA is a similar alternative that uses a combination of capping and dredging to perform Full-Section remediation in River Section 1 and depends on MNA in River Sections 2 and 3. Alternative REM-3/10/10 involves Expanded Hot Spot removal from River Section 1, and Hot Spot removal from River Sections 2 and 3. Alternative CAP-3/10/10 is a similar alternative that uses a combination of capping and dredging to perform Expanded Hot Spot remediation in River Section 1, and Hot Spot remediation in River Sections 2 and 3. No capping is performed in River Section 3 for this alternative because the remediation target areas in this section are relatively small.

Alternative REM-0/10/MNA is a more extensive alternative that involves Full-Section removal in River Section 1, Hot Spot removal in River Section 2 and depends on MNA in River Section 3. Alternative CAP-0/10/MNA is a similarly extensive alternative that uses a combination of capping and dredging to perform Full-Section remediation in River Section 1 and Hot Spot remediation in River Section 2, and depends on MNA in River Section 3. In order to address potential scouring of *hot spots* by flows from the Hoosic River in River Section 3, Alternative REM-0/10/10 is a more extensive alternative that involves Full-Section removal in River Section 1 and Hot Spot removal in River Sections 2 and 3. Alternative CAP-0/10/10 is a similarly extensive alternative that uses a combination of capping and dredging to perform Full-Section remediation in River Section 1 and Hot Spot removal in River Sections 2 and 3. No capping is performed in River Section 3 for this alternative because the remediation target areas in this section are relatively small. Finally, Alternative REM-0/0/3 is the most extensive alternative evaluated and includes Full-Section removal in River Sections 1 and 2 and Expanded Hot Spot removal in River Section 3.

5.3.3 Listing of Potential Remedial Action Alternatives

Based on the evaluation process summarized above and described in detail in Appendix D, the following twelve alternatives (in four alternative categories, and listed below in order of increasing remediation target areas) were retained for screening based on effectiveness, implementability, and cost, described in Chapter 6:

No Action (without separate source control)

Monitored Natural Attenuation (with separate source control)

Capping with Dredging Alternatives (assumes separate source control)

CAP-0/MNA/MNA (R03S2)
CAP-3/10/10 (R09S2)
CAP-0/10/MNA (R02S2)
CAP-0/10/10 (R06S2)

Removal Alternatives (assumes separate source control)

REM-10/MNA/MNA (R10S2)
REM-0/MNA/MNA (R03S2)
REM-3/10/10 (R09S2)
REM-0/10/MNA (R02S2)
REM-0/10/10 (R06S2)
REM-0/0/3 (R08S2)

Chapter 6

6. SCREENING OF REMEDIAL ACTION ALTERNATIVES

In this chapter, the alternatives listed in subsection 5.3.3 are screened based on the criteria of effectiveness, implementability, and cost. This screening step was performed as required by CERCLA and the NCP to narrow the field of remedial alternatives that are subject to the detailed analysis presented in Chapter 8.

6.1 Evaluation Criteria and Approach

The screening criteria discussed herein conform to the remedy selection requirements set forth in Section 121 of CERCLA, the NCP [40 CFR 300.430(e)(7)], and the RI/FS Guidance. The three criteria used for the initial screening of alternatives are effectiveness, implementability, and cost.

6.1.1 Effectiveness

Effectiveness criteria are based on the outline presented in CERCLA, Section 121(b) and Section 300.430(e)(7)(I) of the NCP. The primary criterion in screening the effectiveness of a remedial alternative is its ability to protect human health and the environment. Other factors considered are:

- The ability of a remedial alternative to reduce the toxicity, mobility, or volume of contamination through treatment;
- The capability of an alternative to attain the potential ARARs presented in Chapter 2;
- The impact of the long-term uncertainties associated with land disposal;
- The persistence, toxicity, and mobility of the hazardous substances, and their propensity to bioaccumulate;
- Short-term and long-term potential for adverse human health effects due to exposure to contaminants;
- How quickly an alternative achieves protection;

- The potential for future remedial action costs if the remedial alternative in question were to fail; and
- The potential threat to human health and the environment associated with excavation, transportation, and redisposal or containment.

For this FS, the effectiveness criterion is evaluated by comparing, among other factors, the species-weighted average PCB concentrations in fish fillet as modeled for each alternative to the risk-based PRGs for human health; comparing the predicted surface water quality for each alternative with the chemical-specific ARARs for water quality; and comparing the predicted Tri+ PCB load over the Federal Dam for each alternative in the years 2003 (before remediation), 2011 (soon after completion of the most aggressive remediation), and 2035 (25 years after completion of the most aggressive remediation). This evaluation is performed by noting the relative magnitude of the areas and volumes of contaminated sediments targeted for remediation by a particular alternative in comparison with other similar alternatives.

6.1.2 Implementability

Implementability is considered in the screening process as a measure of the technical and administrative feasibility of constructing, operating, and maintaining a remedial action. Factors considered in this evaluation include:

- The ability to construct and operate alternative technologies within site-specific and technology-specific regulations and constraints. Technical aspects to be considered include operation, maintenance, monitoring, and post-implementation support.

- The ability to obtain necessary approvals from other offices and agencies. For off-site actions, this includes the ability to comply with permitting requirements that are legally applicable to the response action; and

- The availability of key alternative components, including equipment and technical specialists; treatment, storage, and disposal services; and capacity and the time required for installation (and startup, if necessary) of a remedial system.

6.1.3 Cost

The intent of the cost screening is to make order-of-magnitude comparisons to screen out alternatives that have much higher costs than other alternatives, without providing a comparative increase in protection. Costs are identified as advantageous (low) or disadvantageous (high) to aid in choosing among alternatives of the same type. Both capital and operation and maintenance (O&M) costs are considered. Alternatives that have excessive costs (at least an order of magnitude higher than a comparable alternative) and do not provide an increase in protection are eliminated from further consideration. Costs are used to compare on-site and off-site treatment technologies for screening. Costs are not used to screen between treatment and non-treatment alternatives. Cost details are presented in the detailed analysis of alternatives, Chapter 8.

6.2 Description and Screening of Remedial Alternative Categories

In this section of the FS, each alternative developed is described and screened based on the criteria of effectiveness, implementability, and cost. The alternatives are discussed under the broader headings of the four alternative types identified previously in subsection 5.1.3. Where appropriate, elements of alternative components common to alternatives of a similar type (*e.g.*, capping) are discussed once, to minimize redundancy within this section. As stated in subsection 5.3.3, the following twelve alternatives (in four alternative categories) were retained for screening. The alphanumeric codes in the parentheses represent the model runs associated with these alternatives, as presented in subsection 5.3.1.6.

- No Action (without source control)
- Monitored Natural Attenuation (with source control)
- Capping with Dredging Alternatives (with source control and monitored natural attenuation after construction is completed)

  CAP-0/MNA/MNA (R03S2)

  CAP-3/10/10 (R09S2)

  CAP-0/10/MNA (R02S2)

  CAP-0/10/10 (R06S2)

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- Removal Alternatives (with source control and monitored natural attenuation after construction is completed)

  REM-10/MNA/MNA (R10S2)

  REM-0/MNA/MNA (R03S2)

  REM-3/10/10 (R09S2)

  REM-0/10/MNA (R02S2)

  REM-0/10/10 (R06S2)

  REM-0/0/3 (R08S2)

This list provides a range of alternatives and has been arranged in order of increasing remediation target areas.

6.2.1 No Action

6.2.1.1 General Description of No Action

For this FS, the No Action alternative consists of refraining from the active application of any remediation technology to sediments in all three sections of the Upper Hudson River. The No Action alternative also excludes any source control removal action (*i.e.*, the NTCRA) near the GE Hudson Falls plant, any administrative actions (including institutional controls, such as fish consumption advisories, which are considered to be limited action under the NCP), and any monitoring. As required by Section 121 (c) of CERCLA, periodic reviews will be conducted at five-year intervals to reassess the long-term appropriateness of continued No Action.

6.2.1.2 General Evaluation of No Action

The initial evaluation of the No Action alternative based on the criteria of effectiveness, implementability, and cost is presented below.

Effectiveness

No Action is not effective in meeting the RAOs and PRGs over the 70-year model forecast period. The dominant carcinogenic and non-carcinogenic risks to human health and ecological receptors (piscivorous birds and mammals) posed by the PCB-contaminated sediments will continue for several decades. Analyses presented in Appendix D suggest there is a reasonable probability that the decline in exposure concentrations and associated risks may be much slower than predicted by the model. This is particularly true at the localized (rather than reach-averaged) scales at which fish feed, and the bounding analysis described in Appendix D suggests that risks may potentially continue at even higher levels for substantially longer periods. The risk-based PRG for protection of human health of 0.05 ppm PCBs (wet weight) in fish fillet is not met in any of the three river sections over the 70-year model forecast period. The target concentration of 0.2 ppm PCBs (one meal per month) in fish fillets is also not met in any of the three river sections. The alternate target concentration of 0.4 ppm PCBs (one meal every two months) in fish fillets is not met in River Sections 1 and 2, but is met in River Section 3 in the year 2014, according to model estimates.

The chemical-specific ARARs for PCBs in water are 0.5 μg/L (500 ng/L) federal MCL; 0.09 μg/L (90 ng/L) NYS standard for protection of human health and drinking water sources; 1 ng/L federal Ambient Water Quality Criterion; 0.12 ng/L NYS standard for protection of wildlife; and 0.001 ng/L NYS standard for protection of human consumers of fish. The first two chemical-specific ARARs for the surface water are met by the No Action alternative, whereas the remaining three chemical-specific ARARs for the surface water are not met for the entire 70-year forecast period. The bounding analysis described in Appendix D suggests that degradation of surface water quality may potentially continue at even higher levels for substantially longer periods.

The annual Tri+ PCB load over the Federal Dam predicted by the model for the No Action alternative is approximately 131 kg in 2003, 104 kg in 2011, and 63 kg in 2035. This alternative does not include remediation in River Section 3, and therefore does not address the scour of PCB-contaminated sediments associated with one-in-three-year to one-in-five-year flow events from the Hoosic River. These events have caused resuspension of PCB loading of 18 kg/day, equivalent to the peak loads at Rogers Island attributed to releases at the Allen Mills structure at Bakers Falls (USEPA, 1999b). Without addressing PCB-contaminated sediments downstream of the Hoosic

River (RM 166), PCB loads over Federal Dam will likely be higher than indicated by the modeling results.

Implementability

The complete deferral of remedial action is easily implemented from both technical and administrative standpoints, as it requires only continued periodic re-evaluation (every five years) of risks to human health and the environment.

Cost

There is no capital cost associated with this alternative. All costs are associated with the five-year reviews required by CERCLA, and these are considered to be O&M costs.

6.2.1.3 Conclusion

The No Action alternative does not actively reduce the toxicity, mobility, or volume of the contamination through treatment. The cancer risks and non-cancer human health hazards and risks to ecological receptors posed by fish consumption will continue to remain above acceptable levels (PRGs) and the surface water quality will continue to be degraded for at least the next 70 years, assuming a continued upstream load of approximately 0.16 kg/day Tri+ PCBs. No Action has been retained for detailed analysis, in accordance with CERCLA and the NCP, to serve as a basis for comparison with other remedial alternatives.

6.2.2 Monitored Natural Attenuation (MNA)

6.2.2.1 General Description of Monitored Natural Attenuation

The Monitored Natural Attenuation alternative includes natural attenuation of sediments, institutional controls, long-term monitoring and modeling to track progress, and periodic reviews at five-year intervals. This alternative would be implemented in conjunction with separate source control (*i.e.*, the NTCRA) in the vicinity of the GE Hudson Falls plant.

Natural attenuation refers to the reduction of volume and toxicity of contaminants in the sediments by naturally occurring biological, chemical, and physical processes. Attenuation processes in sediments include biodegradation, biotransformation, bioturbation, diffusion, dilution, adsorption, volatilization, chemical reaction or destruction, resuspension, and burial by cleaner material.

Unlike No Action, the MNA alternative assumes a separate source control removal action in the vicinity of the GE Hudson Falls facility. In order to address the upstream source of PCBs, USEPA has issued an approval memorandum for an engineering evaluation and cost analysis (EE/CA) for a non-time critical removal action (NTCRA) to address the discharge of PCBs into the river in the vicinity of the GE Hudson Falls plant. Assuming that a viable response action is available to address the Hudson Falls source, USEPA believes that a source control NTCRA can reasonably be completed by January 1, 2005, if not earlier. Therefore, it is assumed that as a result of this source control removal action, the average upstream Tri+ PCB load at Fort Edward (Rogers Island) is reduced from 0.16 kg/day to 0.0256 kg/day on January 1, 2005.

Institutional controls (*e.g.*, site use restrictions) are implemented as long-term control measures as part of this alternative. These restrictions include continuation or extension of the existing fish consumption advisories, and catch and release restrictions.

Continued presence of large quantities of PCB-contaminated sediments in the Upper Hudson River may necessitate operational restrictions on future non-remedial sediment removal activities (such as navigational dredging), including controls on the types of dredging equipment, constraints on barge filling practices, and restrictions on handling and disposal of the contaminated dredge spoils. However, such restrictions are incorporated into the existing permitting process and do not require separate institutional controls under a remedy. Since direct contact with sediments has not been determined to pose unacceptable risks to human health, no restrictions on sediment disturbance for changes to waterfront access or structures are contemplated as part of this alternative.

Long-term monitoring of PCBs in sediments, the water column, and biota is conducted as part of the MNA alternative. The purpose of the monitoring and modeling is to demonstrate that contaminant reduction is occurring, and that the reduction is achieving regulatory requirements, such as the NYS standard for PCBs in surface water (1 x 10^{-6} μg/l), for protection of the health of human consumers of fish. Monitoring of various media will allow ongoing evaluation of the concentrations and effects of PCBs in the vicinity of the river. Monitoring includes measurements of sediment accumulation rates or erosion/scour, PCB concentrations in the sediment by depth, bioaccumulation by benthic organisms, and the migration or harvesting of contaminated organisms. Loss of contaminants can be documented by historical trends or contaminant concentration distributions showing a reduction in the total mass of contaminants in sediments, water, and biota, or by the presence of degradation products in sediments. The series of mathematical models for the fate, transport, and bioaccumulation of PCBs described in the RBMR (USEPA, 2000a) will be refined and recalibrated on a regular basis as new data become available. Monitoring data are used as input parameters and recalibration points in the mathematical models to evaluate progress of the natural attenuation processes against the original predictions. Reviews are conducted at five-year intervals to reassess the long-term appropriateness of continued MNA.

6.2.2.2 General Evaluation of Monitored Natural Attenuation

The initial evaluation of the MNA alternative, based on the three criteria of effectiveness, implementability, and cost, is presented below.

Effectiveness

A substantial limitation of monitored natural attenuation, particularly where burial by cleaner sediments is the primary attenuation process, is that burial occurs only in depositional areas. As discussed in Appendix D, rates of attenuation of sediment exposure concentrations and associated fish body burdens are likely to be much slower in localized areas than are predicted by the model at the reach-average scale. In addition, because natural attenuation depends upon maintenance of the uncontaminated sediment layer, anthropogenic processes or severe storms may erode and scour the sediments locally and redistribute the contaminants over wide areas, even when burial is achieved. Natural attenuation is most appropriate for those portions of the Upper Hudson River where, based on existing data, natural sedimentation and other processes have been observed or are strongly expected to reduce exposure concentrations, and where there are no predicted adverse impacts on potential human or ecological receptors. Natural attenuation that depends primarily on sediment burial is not appropriate in the navigation channel of the Champlain Canal where dredging is required for maintenance.

MNA is not very effective in meeting the RAOs and PRGs over the 70-year model forecast period. Risks to human health and ecological receptors (piscivorous birds and mammals) posed by the PCB-contaminated sediments will continue for several decades. The bounding analysis described in Appendix D suggests that risks may potentially continue at even higher levels for substantially longer periods. The risk-based PRG for protection of human health of 0.05 ppm PCBs (wet weight) in fish fillet is not met in River Sections 1 and 2 over the 70-year model forecast period, but is met in River Section 3 in the year 2059. The target concentration of 0.2 ppm PCBs (one meal per month) in fish fillets is also not met in River Section 1, but is met in River Section 2 in the year 2061, and is met in River Section 3 in the year 2019. The target concentration of 0.4 ppm PCBs (one meal every two months) in fish fillets is met in River Sections 1, 2, and 3, in the years 2039, 2038, and 2011, respectively.

The failure to achieve PCB levels below 0.2 ppm in fish tissue in River Section 1 and the near- asymptotic approach to this value in River Section 2 reflect the importance of the assumption of the upstream loading late in the forecast period. Even in River Section 3, an asymptotic value around 0.05 ppm is clearly evident. Essentially, each river section approaches a condition under which the assumed load at Fort Edward produces a steady-state condition between the contamination within the active sediments and that in the water column. No further reduction in fish body burden is possible without a change in the assumed upstream load.

Under this condition, differences between asymptotic values in different river sections simply reflect the effects of dilution. River Sections 1 and 2 have similarly valued asymptotes since there are no major tributaries to these sections and little dilution occurs. In River Section 3, three major tributaries, including the Batten Kill, Fish Creek and the Hoosic River serve to dilute the PCB load and concentration and thus yield a much lower asymptote for the fish body burden. Only by assuming a lower upstream load can lower fish body burdens be achieved in any of these sections. The uncertainty associated with the estimation of the asymptotic value is relatively large since it is far out on the forecast. Additionally, the actual trend of the upstream load, while it is expected to decline due to source controls, is yet to be established, adding further uncertainty to the forecast.

The chemical-specific ARARs for PCBs in water are 0.5 μg/L (500 ng/L) federal MCL; 0.09 μg/L (90 ng/L) NYS standard for protection of human health and drinking water sources; 1 ng/L federal Ambient Water Quality Criterion; 0.12 ng/L NYS standard for protection of wildlife; and 0.001 ng/L NYS standard for protection of human consumers of fish. The first two chemical-specific ARARs for the surface water are met by the MNA alternative, whereas the remaining three chemical-specific ARARs for the surface water are not met for the entire 70-year forecast period. The bounding analysis described in Appendix D suggests that degradation of surface water quality may potentially continue at even higher levels for substantially longer periods.

The annual Tri+ PCB load over the Federal Dam predicted by the model for the MNA alternative is about 131 kg in 2003, 72 kg in 2011, and 24 kg in 2035. This alternative does not include remediation in River Section 3, and therefore does not address the scour of PCB-contaminated sediments associated with one-in-three-year to one-in-five-year flow events from the Hoosic River, as discussed in subsection 6.2.1.2. Without addressing PCB-contaminated sediments downstream of the Hoosic River (RM 166), PCB loads over Federal Dam will likely be higher than indicated by the modeling results.

Based on the modeling, it was found to be important to the long-term recovery of the river to alleviate the upstream source of PCBs to the extent possible. Absent source control, the upstream source is expected to become the dominant source of PCBs in fish over the long term. Source control alone will not, however, reduce PCB concentrations in fish to acceptable levels within a reasonable time frame, nor reduce the downstream transport of PCBs to acceptable levels (see Refined Engineering Modeling results in Appendix D).

Implementability

The MNA alternative can be easily implemented because activities like monitoring, modeling, and site use restrictions can easily be performed, and have in fact been performed to varying extent for the past twenty years; thus the resources necessary are readily available.

Continuation of the currently existing fish consumption advisories and the catch and release restrictions can be readily performed. While there are documented gaps in compliance (Hudson

River angler surveys conducted in 1991/92 and 1996 indicated that about 14 percent of Upper Hudson River anglers reported having eaten fish from the Hudson River [NYSDOH, 1999]), implementation of such restrictions is not problematic from a technical standpoint. The administrative challenge lies in motivating the general public into a greater degree of voluntary compliance.

Cost

There is no construction cost associated with the MNA alternative. The estimated major costs associated with this alternative are monitoring, modeling, and reporting costs. Costs of implementing institutional controls are expected to be relatively minor and are therefore not included. Also, there are costs associated with the five-year reviews required by Section 121(c) of CERCLA, and all of these costs are considered to be O&M costs. Due to the additional data costs associated with the data management requirements associated with the modeling process, including the cost of running and recalibrating the model, the MNA alternative will be more expensive than No Action, but less expensive than alternatives involving active sediment remediation (capping with dredging and removal categories, discussed later in this section). Only the costs pertaining to the river (sediments, water column, and biota) are included; land-based remediation costs for the NTCRA in the vicinity of the GE Hudson Falls plant are excluded for the purposes of comparison among alternatives.

6.2.2.3 Conclusion

The MNA alternative does not reduce the toxicity, mobility, or volume of the contamination through treatment. Some reduction in mobility of PCB-contaminated sediments may occur in places through burial, and some reduction in volume (in the Upper Hudson) may occur through transport of PCBs over the Federal Dam at Troy. However, these processes are not projected to be sufficiently effective to meet RAOs. Risks to human health and the environment posed by fish consumption will continue to remain above target concentrations for at least the next 40 to 45 years, and longer for the PRG (0.05 ppm PCB in fish fillet). Based on the modeling, it was found to be important to the long-term recovery of the river to alleviate the upstream source of PCBs to the extent possible.

Fish consumption advisories and catch and release restrictions are the only means to protect human health until protective levels in fish are achieved. The continuous long-term monitoring program allows for providing additional warnings to local residents and the general public if an unexpected situation develops in the future. However, as described in subsection 6.2.2.2, there is evidence that the fish consumption advisories are not fully protective of human health due to gaps in compliance. Moreover, these advisories and the monitoring program have no effect in reducing the ecological risks to piscivorous birds and mammals. Like No Action, the MNA alternative has been retained for detailed analysis to serve as a basis for comparison with other remedial alternatives.

6.2.3 Capping with Dredging of Sediments in Target Areas and Monitored Natural Attenuation (CAP) Alternatives

The four alternatives within this category are listed below:

- **Alternative CAP-0/MNA/MNA** - The CAP-0/MNA/MNA alternative uses capping with dredging to perform Full-Section remediation in the TI Pool (River Section 1) and MNA in River Sections 2 and 3. This alternative also includes MNA after completion of active remediation, and is performed in conjunction with a separate source control NTCRA in the vicinity of the GE Hudson Falls plant.

- **Alternative CAP-3/10/10** - The CAP-3/10/10 alternative uses capping with dredging to perform Expanded Hot Spot remediation in River Section 1 and Hot Spot remediation in River Section 2. No capping is performed in River Section 3 for this alternative because the remediation target areas in this section are relatively small and isolated from one another. This alternative addresses potential scouring of *hot spots* by flows from the Hoosic River in River Section 3 by Hot Spot removal. This alternative also includes MNA after completion of active remediation, and is performed in conjunction with a separate source control NTCRA in the vicinity of the GE Hudson Falls plant.

- **Alternative CAP-0/10/MNA** - The CAP-0/10/MNA alternative uses a combination of capping and dredging to perform Full-Section remediation in River Section 1 and Hot Spot remediation in River Section 2, and MNA in River Section 3. This alternative also includes

MNA after completion of active remediation, and is performed in conjunction with a separate source control NTCRA in the vicinity of the GE Hudson Falls plant.

- **Alternative CAP-0/10/10** - The CAP-0/10/10 alternative uses capping with dredging to perform Full-Section remediation in River Section 1, and Hot Spot remediation in River Section 2. No capping is performed in River Section 3 for this alternative because the remediation target areas in this section are relatively small and isolated from one another. The alternative addresses potential scouring of *hot spot*s by flows from the Hoosic River in River Section 3 by Hot Spot removal. This alternative also includes MNA after completion of active remediation, and is performed in conjunction with a separate source control NTCRA in the vicinity of the GE Hudson Falls plant.

For all above capping with dredging alternatives, after construction is completed, post-remediation monitoring of natural attenuation is conducted in river sections in which there is Expanded Hot Spot remediation (*i.e.*, in which the nominal MPA target concentrations are 3 g/m^2 PCBs or greater) and Hot Spot remediation (*i.e.*, in which the nominal MPA target concentrations are 10 g/m^2 PCBs or greater). Post-remediation monitoring of natural attenuation will also be conducted where Full-Section remediation is performed (*i.e.*, where the MPA target concentrations are 0 g/m^2 PCBs or greater) but the duration of the monitoring program will be shorter.

6.2.3.1 General Description of Capping with Dredging (CAP) Alternatives

CAP alternatives involve in-river (sub-aqueous) capping of contaminated sediments within target areas. As discussed in subsection 4.2.4.1, water depths in River Sections 1 and 2 are defined by bathymetric data gathered in 1992. In general, relative to this category of alternatives, sediments are capped after sediment removal to a depth of 1.5 feet (the thickness necessary to accommodate cap installation without a change in water depth in target areas with less than 6 feet of water). An exception is made in areas where PCB contamination is at depths of less than 1.5 to 2 feet, where only sediment removal is conducted. Sediments in target areas with water depths greater than 6 feet are capped without prior sediment removal, except in the navigation channel, typically defined as areas with water depth greater than 12 feet, based on existing bathymetric data. Sediments in target

400596

areas in the navigation channel are removed, but not capped. The cap is only installed in areas where contaminants remain after dredging.

The CAP alternatives are all performed in conjunction with a source control NTCRA in the vicinity of the GE Hudson Falls facility. It is assumed that as a result of this source control removal action, the upstream Tri+ PCB load at Fort Edward (Rogers Island) will be reduced from 0.16 kg/day to 0.0256 kg/day on January 1, 2005. Reviews are conducted at five-year intervals to evaluate the attainment of RAOs and PRGs.

The capping concept relies primarily on a product called AquaBlok™, which is applied to the area to be capped using a telescoping conveyor operating from a deck barge. AquaBlok™ is a proprietary formulation consisting of gravel particles encapsulated in a layer of bentonite to form pellets that hydrate when applied under water and expand to form a continuous layer, typically expanding to twice the initial product thickness. A layer of backfill material is placed on top of the AquaBlok™ layer to protect the impermeable layer from damage and to provide suitable habitat for benthic biota and fish. Different types of backfill material are used in different areas, based on water depth in the area and ecological conditions prior to capping and dredging.

Sediment removal is conducted using mechanical or hydraulic dredging equipment. In the case where mechanical dredging is utilized, the dredged/excavated sediments are transported by hopper barge or deck barge to the transfer facility, where water separated from the sediment during transport is removed and the dredged/excavated sediment is stabilized by mixing with cement or other appropriate pozzolanic material to absorb the remaining standing water. In the case where hydraulic dredging is utilized, the dredged material is transported via the slurry pipeline and the booster pumping stations to the transfer facility, where the water is separated from the sediments in a treatment train that includes hydrocyclones, coagulation, sedimentation, and belt filters. No stabilization is anticipated for hydraulically dredged sediments. For both dredging methods, the water will be treated to meet the discharge criteria (*e.g.*, NYSPDES limits) and returned to the river. Areas from which sediments are removed are backfilled with appropriate material to isolate residual sediments that may remain after dredging is completed and to re-establish benthic habitats. No backfill is placed in the navigation channel.

There are five options for dealing with the sediments after removal from the river:

- Landfill disposal (for hydraulic dredging);
- Stabilization and landfill disposal (for mechanical dredging);
- Beneficial use as landfill cover or construction fill material (for hydraulic dredging);
- Stabilization and beneficial use as landfill cover or construction fill material (for mechanical dredging); and
- Thermal treatment and beneficial use as manufactured commercial products such as cement, light weight aggregate, fiberglass, or architectural tiles (for both mechanical and hydraulic dredging).

For the first two options, the dredged material (with or without stabilization) will be transported off site and disposed of at a landfill. Dredged sediments with PCB concentration greater than 50 mg/kg require disposal at a TSCA-permitted landfill. However, commercial solid waste facilities may impose a more stringent limit of 30 to 35 mg/kg PCBs as an acceptance criterion. This provides them with a factor of safety in accepting wastes. For management and final disposition of dredged sediments for purposes of this FS, a trigger level of 33 mg/kg, not 50 mg/kg, will be used as the PCB concentration in sediment that will differentiate between TSCA-permitted and non-TSCA-permitted disposal. Thus, for landfill disposal associated with this category of alternatives, material with PCB concentrations of less than 33 mg/kg will be disposed of at a solid waste landfill. Estimation of the quantities of TSCA and non-TSCA sediments is addressed in Chapter 8 (detailed analysis).

For the third and fourth options, the dredged material (with less than 10 mg/kg PCBs) will be transported off site (with or without stabilization) for subsequent beneficial use as landfill cover or construction fill material (depending on the application and local site-specific requirements). The fifth option involves thermal treatment of the sediments, followed by processing the treated material to cement or another commercial product.

For the capping with dredging alternatives, the post-remediation monitoring program consists of two components: a cap integrity verification program, and a program to monitor the PCB concentrations in sediments, surface water, and biota. These were described in detail in Section 5.2.

Post-remediation monitoring of natural attenuation is an implicit component of all CAP alternatives in all river sections.

6.2.3.2 General Evaluation of Capping with Dredging (CAP) Alternatives

The initial evaluation of the Capping with Dredging (CAP) alternatives, based on the three criteria of effectiveness, implementability, and cost, is presented below.

Effectiveness

Capping is a proven technology for isolating contaminated sediments from the water column and biota if proper design, placement, and maintenance of the cap are performed to provide cap effectiveness, continued performance, and reliability. Capping will reduce the mobility of contaminants in the river but will not affect toxicity or volume of contaminants. Because PCB contamination remains in the sediment, capping alternatives may be inherently less protective of human health and the environment in the long term than removal alternatives. Even though the capping concept is designed to avoid failure, cap damage caused, for example, by dragging of large trees that fall into the river during catastrophic natural events like major floods cannot be avoided. AquaBlok™ is a manufactured product consisting of a composite of gravel particles encapsulated with bentonite. Although AquaBlok™ is a relatively new product and has not been used at many sites over relatively long periods of time, the effectiveness of the cap depends on bentonite, which has been proven as an impermeable liner material in preventing the migration of contaminants. Once deployed through the water column, the heavy nucleus of the composite material carries the bentonite-bearing particles to the bottom where the bentonite hydrates and expands to form a continuous impermeable mat. This was discussed in greater detail in Chapter 4.

Sediment capping may cause short-term adverse impacts to the river. These impacts include burial of the benthic community and temporary loss of benthos and habitat for the ecological community during capping. Replacement of the benthic habitat will be implemented through addition of appropriate backfill material on top of the cap after cap placement. Natural benthic recolonization following a disturbance is rapid, and in many instances the process begins within days after perturbation. In many cases, full recovery to pre-disturbance species composition and abundance occurs within one year (Oliver and Hulberg, 1977).

Select sediment removal may also result in short-term adverse impacts to the river. These impacts include exposure of contaminated sediments to the water column, fish, and biota due to resuspension of sediments during removal, and temporary loss of benthos and habitat for the ecological community in dredged areas. Risks due to resuspension can be minimized through control of the sediment removal mechanics and rate, and use of an appropriate sediment barrier (see Appendix E). Replacement of the benthic habitat will be implemented through addition of a layer of backfill material in dredged areas after sediment removal, which provides a protective layer for the cap, reducing damage from boat anchors, bioturbation, and the like, and also serves as substrate for fish habitat.

Sediment processing at the transfer facility may pose some short-term risks (*e.g.*, spills, accidents). Risks due to stabilization using cement or other pozzolanic material are expected to be negligible with proper handling. Transportation of contaminated sediments to off-site disposal or treatment facilities may also pose some short-term risks to the environment (*e.g.*, spills, accidents). If *ex situ* treatment of contaminated sediments is selected (higher value beneficial use option), treatment at a manufacturing facility may pose some short-term risks to the surrounding community and environment, depending on the type of treatment conducted. Short-term risks posed by emissions from thermal treatment processes are likely to be higher than those associated with other treatment processes such as soil washing. However, emissions can be reduced by the use of proper pollution controls.

Removal and off-site disposal/treatment of contaminated sediments are permanent remedies for the river. Sediment dredging and excavation are reliable technologies (see Section 5.2). Removal of sediments will reduce toxicity, volume, and mobility of contaminants in the river. Stabilization and disposal of sediments at properly managed land disposal facilities will reduce mobility of contaminants. Thermal destruction (as included in a beneficial use option) will reduce or eliminate the toxicity and volume of contaminants.

Properly managed landfills provide reliable controls for long-term management of PCB-contaminated sediments. Stabilization and thermal destruction have been demonstrated to be effective in treatment of PCB-contaminated sediments at other sites. Treatability studies may be required to demonstrate the effectiveness of specific technologies in treating sediments from the Upper Hudson River.

Implementability

As described in Section 5.2, equipment and services for sediment capping are available commercially, as are equipment and services for sediment removal, material handling, and off-site transportation. In shallow areas, special equipment packages may have to be utilized. Depending upon the locations that are eventually selected, transfer facilities with good rail access and suitable wharf facilities are expected to be available or can be developed. The potentially large volume of material required for cap construction and the large volume of sediments to be removed will require significant coordination of the sediment removal activities, cap placement, and material handling and transportation activities. A plant to manufacture the AquaBlok™ product may be set up near the site to reduce transportation costs. However, the feasibility of establishing a plant near the site will depend on the local availability of raw materials (*i.e.*, gravel and clay).

Existing permitted landfills were contacted regarding capacity and it was determined that there is sufficient, currently available, off-site land disposal capacity for both the TSCA-regulated and non-TSCA-regulated fractions of removed sediment (see Chapter 4).

No administrative difficulties are anticipated in getting the necessary approvals from USEPA, USACE, and NYSDEC for capping. However, the potentially extensive sediment removal and capping activities will result in temporary disruption of recreational uses and boating access during remediation. Shoreline disruption has been estimated (in miles) for the specific alternatives discussed below in Section 6.3. The difficulty associated with this disruption is a function both of the total length of shoreline disruption and the value of the disturbed area. However, for this screening level assessment, the implementability issues associated with shoreline disruption are assumed to be a function of the length of the disturbed shoreline. Although measures to mitigate or prevent impacts and disruptions will be employed, local communities may experience some measure of inconvenience during remedial activities. Measures that will be implemented in conjunction with this alternative category to minimize both short- and long-term disruption include:

- Accommodation of existing boat traffic during construction;
- Sediment removal prior to capping in shallow areas to maintain small craft navigation depth;
- Limited duration of the remediation period (a matter of months at any given location);
- Shoreline stabilization and waterfront restoration;
- Control of sediment removal mechanics and rates; and
- Use of sediment barriers during sediment removal.

Cost

Costs for CAP alternatives vary primarily with the total volume of sediments removed and the total area capped. In general, capital costs for a capping with dredging alternative will be lower than those for an alternative that involves sediment removal alone of the same target areas. This is because capping costs are lower than costs for dredging, off-site transport of the sediment, and final landfill disposal or treatment followed by beneficial use. However, O&M costs for a capping alternative will be higher than for a sediment removal alternative involving the same areas because of cap maintenance costs and, to a lesser extent, more extensive monitoring costs required in the long term. Based on the total area capped for each alternative and the volume of sediments to be dredged, the most expensive CAP alternative, CAP-0/10/10 would be expected to cost about half again as much as CAP-3/10/10, the least extensive CAP alternative. Total O&M costs are expected to be on the order of 15 to 20 percent of total capital costs for an alternative.

6.2.4 Removal of Sediments in Target Areas and Monitored Natural Attenuation Alternatives

There are six alternatives within this category, as follows:

- **Alternative REM-10/MNA/MNA** - The REM-10/MNA/MNA alternative represents the least extensive remedial option. It involves Hot Spot remediation in River Section 1 and MNA in River Sections 2 and 3. This alternative also includes MNA after completion of active remediation and will be performed in conjunction with a separate source control NTCRA in the vicinity of the GE Hudson Falls plant.

- **Alternative REM-0/MNA/MNA** - The REM-0/MNA/MNA alternative involves Full-Section remediation in River Section 1 and MNA in River Sections 2 and 3. This alternative also includes MNA after completion of active remediation and will be performed in conjunction with a separate source control NTCRA in the vicinity of the GE Hudson Falls plant.

- **Alternative REM-3/10/10** - The REM-3/10/10 alternative involves Expanded Hot Spot removal from River Section 1 and Hot Spot removal from River Sections 2 and 3. It addresses potential scouring of *hot spots* by flows from the Hoosic River in River Section 3. This alternative also includes monitored natural attenuation after completion of active remediation and will be performed in conjunction with a separate source control NTCRA in the vicinity of the GE Hudson Falls plant.

- **Alternative REM-0/10/MNA** - The REM-0/10/MNA alternative is a more extensive alternative that involves Full-Section removal in River Section 1 and Hot Spot removal in River Section 2, and MNA in River Section 3. This alternative also includes MNA after completion of active remediation and will be performed in conjunction with a separate source control NTCRA in the vicinity of the GE Hudson Falls plant.

- **Alternative REM-0/10/10** - The REM-0/10/10 alternative is a more extensive alternative that involves Full-Section removal in River Section 1, and Hot Spot removal in River Sections 2 and 3. It addresses potential scouring of *hot spots* by flows from the Hoosic River in River Section 3. This alternative also includes MNA after completion of active remediation and will be performed in conjunction with a separate source control NTCRA in the vicinity of the GE Hudson Falls plant.

- **Alternative REM-0/0/3** - The REM-0/0/3 alternative is the most extensive scenario developed. It includes Full-Section removal in River Sections 1 and 2 and Expanded Hot Spot removal in River Section 3. This alternative also includes MNA after completion of active remediation and will be performed in conjunction with a separate source control NTCRA in the vicinity of the GE Hudson Falls plant.

After construction is completed, post-remediation monitoring of natural attenuation is conducted in river sections in which there is Expanded Hot Spot remediation (*i.e.*, in which the nominal MPA target concentrations are 3 g/m^2 PCBs or greater) and Hot Spot remediation (*i.e.*, in which the nominal MPA target concentrations are 10 g/m^2 PCBs or greater). Post-remediation monitoring of natural attenuation will also be conducted where Full-Section remediation is performed (*i.e.*, where the MPA target concentrations are 0 g/m^2 PCBs or greater) but the duration of the monitoring program will be shorter.

As with the CAP alternatives, the major common components of this category of alternatives are described and evaluated below. The main components of sediment removal are described briefly, and the processing, transport, treatment, and disposal of the sediments after removal from the river are also discussed, as they are support technologies of the sediment removal option.

6.2.4.1 General Description of Removal (REM) Alternatives

Sediment removal will be conducted using mechanical or hydraulic dredging equipment. In the case where mechanical dredging is utilized, the dredged/excavated sediments are transported by hopper barge or deck barge to the transfer facility, where water separated from the sediments during transport is removed and the dredged/excavated sediments are stabilized by mixing with cement or other appropriate pozzolanic material to absorb the remaining standing water. In the case where hydraulic dredging is utilized, the dredged material is transported via the slurry pipeline and the booster pumping stations to the transfer facility, where the water is separated from the sediments in a treatment train that includes hydrocyclones, coagulation, sedimentation, and belt filters. For both dredging methods, the water is treated to meet the discharge criteria (*e.g.*, NYSPDES limits) and returned to the river. Areas from which sediments are removed are backfilled with appropriate material to isolate residual sediments that may remain after dredging is completed and to restore benthic habitats. No backfill is placed in the navigation channel.

400604

The REM alternatives are all performed in conjunction with a separate source control NTCRA in the vicinity of the GE Hudson Falls plant. It is assumed that as a result of this source control NTCRA, the upstream Tri+ PCB load at Fort Edward (Rogers Island) will be reduced from 0.16 kg/day to 0.0256 kg/day on January 1, 2005. A review will be conducted at five-year intervals to evaluate the attainment of RAOs and PRGs.

There are five options for dealing with the sediments after removal from the river:

- Landfill disposal (for hydraulic dredging);
- Stabilization and landfill disposal (for mechanical dredging);
- Beneficial use as landfill cover or construction fill material (for hydraulic dredging);
- Stabilization and beneficial use as landfill cover or construction fill material (for mechanical dredging); and
- Thermal treatment and beneficial use as manufactured commercial products like cement, light weight aggregate, fiberglass, or architectural tiles (for both mechanical and hydraulic dredging).

For the first two options, the dredged material (with or without stabilization) will be transported off site and disposed of at a landfill. Dredged sediments with PCB concentration greater than 50 mg/kg require disposal at a TSCA-permitted landfill. However, commercial solid waste facilities may impose a more stringent limit of 30 to 35 mg/kg PCBs as an acceptance criterion, providing the facility with a margin of safety in accepting wastes classified as non-PCB material. Therefore, for management and final disposition of dredged sediments for purposes of this FS a trigger level of 33 mg/kg, not 50 mg/kg, will be used as the PCB concentration in sediment to differentiate between TSCA-permitted and non-TSCA-permitted disposal. Thus, for landfill disposal associated with this category of alternatives, material with PCB concentrations of less than 33 mg/kg will be disposed of at a solid waste landfill. Estimation of the quantities of TSCA and non-TSCA sediments is addressed in Chapter 8.

For the third and fourth options, the dredged material (with less than 10 mg/kg PCBs) will be transported off site (with or without stabilization) for subsequent beneficial use as landfill cover or construction fill material (depending on the application and local site-specific requirements). The fifth option involves thermal treatment of the sediments, followed by processing the treated material to cement or another commercial product.

For the removal alternatives, the post-remediation monitoring program consists of a program to monitor the PCB concentrations in sediments, surface water, and biota. This is described in detail in Section 5.2. Post-remediation monitoring of natural attenuation is an implicit component of all REM alternatives in all river sections.

6.2.4.2 General Evaluation of Removal (REM) Alternatives

The initial evaluation of the Removal (REM) alternatives, based on the three criteria of effectiveness, implementability, and cost, is presented below.

Effectiveness

Removal and off-site disposal/treatment of contaminated sediments are permanent remedies for the river. Sediment dredging and excavation are reliable technologies (see Section 5.2). Removal of sediments will reduce toxicity, volume, and mobility of contaminants in the river. Stabilization and disposal of sediments at properly managed land disposal facilities will reduce mobility of contaminants. Thermal destruction (as included in a beneficial use option) will reduce or eliminate the toxicity and volume of contaminants.

Properly managed landfills provide reliable controls for long-term management of PCB-contaminated sediments. Stabilization and thermal destruction have been demonstrated to be effective in treatment of PCB-contaminated sediments at other sites. Treatability studies may be required to demonstrate the effectiveness of specific technologies in treating sediments from the Upper Hudson River.

Sediment removal may result in short-term adverse impacts to the river. These impacts include exposure of contaminated sediments to the water column, fish, and biota due to resuspension of sediments during removal, and temporary loss of benthos and habitat for the ecological community in dredged areas. Risks due to resuspension can be minimized through control of sediment removal rate and use of an appropriate sediment barrier (see Appendix E). Replacement of the benthic habitat will be implemented through addition of a layer of backfill material in dredged areas after sediment removal, which provides isolation of residual sediments that may remain after dredging is completed (see Appendix F). Natural benthic recolonization following a disturbance is rapid, and in many instances, the process begins within days after perturbation. In many cases, full recovery to pre-disturbance species composition and abundance occurs within one year (Oliver and Hulberg, 1977).

Sediment processing at the transfer facility may pose some short-term risks (*e.g.*, spills, accidents). Risks due to stabilization using cement or other pozzolanic material are expected to be negligible with proper handling. Transportation of contaminated sediments to off-site disposal or treatment facilities may also pose some short-term risks to the environment (*e.g.*, spills, accidents). If *ex situ* treatment of contaminated sediments is selected (higher value beneficial use option), treatment at a manufacturing facility may pose some short-term risks to the surrounding community and environment, depending on the type of treatment conducted. Short-term risks posed by emissions from thermal treatment processes are likely to be higher than those for other treatment processes like soil washing. However, these can be minimized by the use of proper pollution controls.

Implementability

As described in Section 5.2, equipment and services for sediment removal are available commercially, as are equipment and services for material handling and off-site transportation. In shallow draft areas, special equipment packages may have to be utilized. Depending upon the locations that are eventually selected, transfer facilities with good rail access and suitable wharf facilities are expected to be available or can be developed. The potentially large volume of sediments to be removed will require significant coordination of the dredging/excavation efforts, material handling activities, and off-site transportation logistics. Based on a survey of landfills conducted for this FS, there is sufficient, currently available, off-site land disposal capacity for both the TSCA-regulated and non-TSCA-regulated fractions of removed sediment (see Chapter 4).

No administrative difficulties are anticipated in getting the necessary approvals from USEPA, USACE, and NYSDEC for sediment removal. However, the sediment removal activities will result in temporary disruption of recreational uses and boating access during remediation. Shoreline disruption has been estimated (in miles) for the specific alternatives discussed below in Section 6.3. The difficulty associated with this disruption is a function both of the total length of shoreline disruption and the value of the disturbed area. However, for this screening level assessment the implementability issues associated with shoreline disruption are assumed to be a function of its length. Although measures to mitigate or prevent impacts and disruptions will be employed, local communities will experience some measure of inconvenience during remedial activities. Measures that will be implemented in conjunction with this alternative category to minimize both short- and long-term disruption include:

- Accommodation of existing boat traffic during construction;
- Limited duration of the remediation period (a matter of months at any given location);
- Shoreline stabilization and waterfront restoration;
- Control of sediment removal mechanics and rates; and
- Use of sediment barriers during sediment removal.

Cost

Capital costs for sediment removal, off-site transportation, and disposal or treatment are higher compared to costs involving capping of equivalent target areas, although some of the more extensive CAP alternatives involve more sediment removal than a few of the less extensive REM alternatives. O&M costs for a sediment removal alternative will be lower than for implementation of a CAP alternative for an equivalent area, as removal-only alternatives do not require long-term maintenance.

6.3 Description and Screening of Active Remediation Alternatives (CAP and REM)

In this section, the ten active remediation alternatives in two alternative categories (capping with dredging and removal) are described and screened based on effectiveness, implementability, and cost. The major differences between these two categories (CAP and REM) have been addressed in Section 6.2. As can be seen from list of alternatives in subsections 6.2.3 and 6.2.4, the most obvious difference among the specific alternatives within a particular alternative category (CAP or REM) is the target area addressed by the alternative, *i.e.*, the degree of remediation. Further, the range of target areas covered by the four CAP alternatives listed in subsection 6.2.3 is a subset of the range of target areas included in the six REM alternatives. Therefore, this section presents a description and screening of the six REM alternatives. Screening of alternatives primarily focuses on differences between varying thresholds of remediation (*i.e.*, Full-Section, Expanded Hot Spot, or Hot Spot) within the remedial alternative categories (*i.e.*, REM or CAP). At this level of analysis, comparisons are not made between alternatives in different categories for purposes of elimination. Although this evaluation is based on the REM alternatives, it is also representative of the CAP alternatives because the conclusions reached from a similar evaluation of corresponding CAP alternatives would be the same.

6.3.1 Description of REM Alternatives

The six alternatives in the REM (Removal) category are described below.

6.3.1.1 Alternative REM-10/MNA/MNA - Hot Spot Removal in River Section 1 and MNA in River Sections 2 and 3

This alternative includes removal of all sediments with nominal MPA greater than 10 g/m^2 PCBs (Hot Spot remediation) in River Section 1 and MNA in River Sections 2 and 3, as shown on Figure 6-1. There is no active sediment remediation in River Sections 2 and 3. The areas to be remediated are shown on Plate 13. The total area of sediments targeted for remediation by this alternative is approximately 150 acres. The estimated volume of sediments to be removed is about 965,000 cubic yards. This alternative involves complete or partial removal of sediments from most *hot spots* from Rogers Island to the TI Dam (*i.e.,* general locations of *Hot Spots* 5 through 20, except for *Hot Spots* 11, 12, 13, 18, and 19). (Channel maintenance dredging subsequent to NYSDEC's delineation based on 1977/78 sampling has likely eliminated *Hot Spots* 1 through 4, located in the channels around Rogers Island.) Assuming approximately 100 to 130 acres of sediment area can be dredged per year, remediation will commence in 2004 and will be completed in 2005. Sediment removal, handling, transport, treatment, and disposal will be conducted as described in subsection

6.2.4.1. This alternative is performed in conjunction with a separate source control NTCRA in the vicinity of the GE Hudson Falls facility and also relies on naturally occurring attenuation processes to reduce the toxicity, mobility, and volume of the remaining PCBs in the Upper Hudson River sediments after the construction is completed. A review of site conditions will be conducted at five-year intervals to evaluate the attainment of RAOs and PRGs.

6.3.1.2 Alternative REM-0/MNA/MNA - Full-Section Removal in River Section 1 and MNA in River Sections 2 and 3

This alternative includes removal of all sediments with MPA greater than 0 g/m^2 PCBs (Full-Section remediation) in River Section 1 and MNA in River Sections 2 and 3, as shown on Figure 6-2. There is no active sediment remediation in River Sections 2 and 3. The areas to be remediated are shown on Plate 15. The total area of sediments targeted for remediation by this alternative is approximately 470 acres. The estimated volume of sediments to be removed is 2,030,000 cubic yards. This alternative involves complete removal of contaminated sediments from Rogers Island to the TI Dam, except for inaccessible areas such as rock-bound *Hot Spot* 12.Assuming approximately 100 to 130 acres of sediment area can be dredged per year, remediation will commence in 2004 and will be completed in 2007. Sediment removal, handling, transport, treatment, and disposal will be conducted as described in subsection 6.2.4.1. This alternative is performed in conjunction with a separate source control NTCRA in the vicinity of the GE Hudson Falls plant and also relies on naturally occurring attenuation processes to reduce the toxicity, mobility, and volume of the remaining PCBs in the Upper Hudson River sediments after the construction is completed. A review of site conditions will be conducted at five-year intervals to evaluate the attainment of RAOs and PRGs. Alternative CAP-0/MNA/MNA is a comparable alternative that targets the same sediment areas as Alternative REM-0/MNA/MNA, but utilizes capping with dredging to perform the active remediation. Details on areas capped and volumes removed are shown on Table 6-1.

6.3.1.3 Alternative REM-3/10/10 - Expanded Hot Spot Removal in River Section 1 and Hot Spot Removal in River Sections 2 and 3

This alternative includes removal of all sediments with nominal MPA greater than 3 g/m^2 PCBs (Expanded Hot Spot remediation) in River Section 1, and removal of all sediments with

400610

nominal MPA greater than 10 g/m^2 PCBs (Hot Spot remediation) in River Sections 2 and 3, as shown on Figure 6-3. The areas to be remediated are shown on Plates 13 and 14. The total area of sediments targeted for remediation by this alternative is approximately 441 acres. The estimated volume of sediments to be removed is about 2.5 million cubic yards. This alternative involves complete or partial removal of sediments from *hot spots* from Rogers Island to Federal Dam (*i.e.*, general locations of *Hot Spots* 5 through 40, except for *Hot Spots* 12, 21, 23, 24, 27, 29, 30, 32, 38, and 40). Rock-bound, inaccessible areas are excluded. Assuming approximately 100 to 130 acres of sediment area can be dredged per year, remediation will commence in 2004 and will be completed in 2007. Sediment removal, handling, transport, treatment, and disposal will be conducted as described in subsection 6.2.4.1. This alternative is performed in conjunction with a separate source control NTCRA in the vicinity of the GE Hudson Falls plant and also relies on naturally occurring attenuation processes to reduce the toxicity, mobility, and volume of the remaining PCBs in the Upper Hudson River sediments after the construction is completed. A review of site conditions will be conducted at five-year intervals to evaluate the attainment of RAOs and PRGs. The CAP-3/10/10 alternative is comparable to the REM-3/10/10 alternative in that both alternatives target the same sediment areas, but CAP-3/10/10 utilizes capping with dredging to perform the active remediation.

6.3.1.4 Alternative REM-0/10/MNA - Full-Section Removal in River Section 1, Hot Spot Removal in River Section 2 and MNA in River Section 3

This alternative includes removal of all sediments with MPA greater than 0 g/m^2 PCBs (Full-Section remediation) in River Section 1, removal of all sediments with nominal MPA greater than 10 g/m^2 PCBs (Hot Spot remediation) in River Section 2, and MNA in River Section 3, as shown on Figure 6-4. There is no active sediment remediation in River Section 3. The areas to be remediated are shown on Plates 13 and 15. The total area of sediments targeted for remediation by this alternative is approximately 544 acres. The estimated volume of sediments to be removed is about 2.6 million cubic yards. This alternative involves complete removal of contaminated sediments from Rogers Island to the TI Dam, except for rock-bound, inaccessible areas such as *Hot Spot* 12, and removal of *hot spots* from the TI Dam to the Northumberland Dam (*i.e.*, general locations of *Hot Spots* 20 through 35, except for *Hot Spots* 21, 23, 24, 27, 29, 30 and 32). Assuming approximately 100 to 130 acres of sediment area can be dredged per year, remediation will commence in 2004 and will be completed in 2008. Sediment removal, handling, transport, treatment, and disposal will be conducted as described in subsection 6.2.4.1. This alternative is performed in conjunction with a separate source control NTCRA in the vicinity of the GE Hudson Falls plant and also relies on naturally occurring attenuation processes to reduce the toxicity, mobility and volume of the remaining PCBs in the Upper Hudson River sediments after the construction is completed. A review of site conditions will be conducted at five-year intervals to evaluate the attainment of RAOs and PRGs. The CAP-0/10/MNA and REM-0/10/MNA alternatives are comparable in that both target the same sediment areas, but the CAP-0/10/MNA alternative utilizes capping with dredging to perform the active remediation.

6.3.1.5 Alternative REM-0/10/10 - Full-Section Removal in River Section 1, and Hot Spot Removal in River Sections 2 and 3

This alternative includes removal of all sediments with MPA greater than 0 g/m^2 PCBs (Full-Section remediation) in River Section 1 and removal of all sediments with nominal MPA greater than 10 g/m^2 PCBs (Hot Spot remediation) in River Sections 2 and 3, as shown on Figure 6-5. The areas to be remediated are shown on Plates 13 and 15. The total area of sediments targeted for remediation by this alternative is approximately 641 acres. The estimated volume of sediments to be removed is about 3.0 million cubic yards. This alternative involves complete removal of sediments from Rogers Island to TI Dam, except for rock-bound, inaccessible areas such as *Hot Spot* 12, and removal of *hot spots* from the TI Dam to Federal Dam (*i.e.*, general locations of *Hot Spots* 5 through 40, except for *Hot Spots* 21, 23, 24, 27, 29, 30, 32, 38, and 40).Assuming approximately 100 to 130 acres of sediment area can be dredged per year, remediation will commence in 2004 and will be completed in 2008. Sediment removal, handling, transport, treatment, and disposal will be conducted as described in subsection 6.2.4.1. This alternative is performed in conjunction with a source control NTCRA in the vicinity of the GE Hudson Falls plant and also relies on naturally occurring attenuation processes to reduce the toxicity, mobility and volume of the remaining PCBs in the Upper Hudson River sediments after the construction is completed. A review of site conditions will be conducted at five-year intervals to evaluate the attainment of RAOs and PRGs. Alternative CAP-0/10/10 is a comparable alternative that targets the same sediment areas as Alternative REM-0/10/10, but utilizes capping with dredging to perform the active remediation.

400612

6.3.1.6 Alternative REM-0/0/3 - Full-Section Removal in River Sections 1 and 2, and Expanded Hot Spot Removal in River Section 3

This alternative includes removal of all sediments with MPA greater than 0 g/m^2 PCBs (full section remediation) in River Sections 1 and 2 and removal of all sediments with MPA greater than 10 g/m^2 PCBs (Expanded Hot Spot remediation) in River Section 3, as shown on Figure 6-6. The areas to be remediated are shown on Plates 14 and 15. The total area of sediments targeted for remediation by this alternative is approximately 920 acres. The estimated volume of sediments to be removed is about 3.7 million cubic yards. This alternative involves complete removal of contaminated sediments from Rogers Island to the Northumberland Dam, except for rock-bound, inaccessible areas such as *Hot Spot* 12, and complete or partial removal of *hot spots* from the Northumberland Dam to the Federal Dam (*i.e.*, general locations of *Hot Spots* 36 through 40, except for *Hot Spot* 38). Assuming approximately 100 to 130 acres of sediment area can be dredged per year, remediation will commence in 2004 and will be completed in 2010. Sediment removal, handling, transport, treatment, and disposal will be conducted as described in subsection 6.2.4.1. This alternative is performed in conjunction with a source control NTCRA in the vicinity of the GE Hudson Falls plant and also relies on naturally occurring attenuation processes to reduce the toxicity, mobility and volume of the remaining PCBs in the Upper Hudson River sediments after the construction is completed. A review of site conditions will be conducted at five-year intervals to evaluate the attainment of RAOs and PRGs.

6.3.2 Evaluation of REM Alternatives

The initial evaluation of the six REM (removal) alternatives for the criteria of effectiveness, implementability, and cost is presented below.

Effectiveness

The general effectiveness of the category of REM alternatives was described in subsection 6.2.4.2. In this subsection, the percent of sediment area and sediment volume remediated, the percent of PCB mass removed, and the percent reductions in species-weighted fish fillet PCB concentration, water column PCB concentration, and PCB load over Federal Dam are used to evaluate the effectiveness of the six REM alternatives detailed in subsection 6.3.1. Figures 6-7 through 6-23 present the predicted PCB concentrations in sediment, surface water and species-weighted average fish fillet for the six REM alternatives as compared to the No Action and MNA alternatives. These figures also present the bounding calculations for the No Action and MNA alternatives (described in Appendix D).

The REM-10/MNA/MNA alternative is not very effective in meeting the RAOs and PRGs over the 70-year model forecast period, especially in River Sections 2 and 3. Risks to human health and ecological receptors (piscivorous birds and mammals) posed by the PCB-contaminated sediments will continue for several decades. Alternative REM-0/MNA/MNA is very effective in meeting the RAOs and PRGs over the 70-year model forecast period in River Section 1, but not very effective in River Sections 2 and 3. In River Section 1, the REM-3/10/10 alternative is more effective in meeting the RAOs and PRGs over the 70-year model forecast period than the REM-10/MNA/MNA alternative, but less effective than the REM-0/MNA/MNA alternative. In River Sections 2 and 3, the REM-3/10/10 alternative is more effective in meeting the RAOs and PRGs over the 70-year model forecast period than either the REM-10/MNA/MNA or REM-0/MNA/MNA alternatives.

As expected, the REM-0/0/3 alternative is the most effective remedial alternative in meeting the RAOs and PRGs over the 70-year model forecast period for the Upper Hudson River. In River Section 1, the REM-0/0/3 alternative is as effective as the REM-0/MNA/MNA, REM-0/10/MNA, and REM-0/10/10 alternatives, but more effective than the REM-10/MNA/MNA and REM-3/10/10 alternatives. In River Section 2, the REM-0/0/3 alternative is approximately ten percent more effective than the REM-3/10/10, REM-0/10/MNA, and REM-0/10/10 alternatives, and nearly four times as effective as the REM-0/MNA/MNA and REM-10/MNA/MNA alternatives. In River Section 3, model results suggest that the REM-0/0/3 alternative is equally as effective as the REM-0/10/10, REM-0/10/MNA, REM-3/10/10, and REM-0/MNA/MNA alternatives in meeting the RAOs and PRGs over the 70-year model forecast period, and nearly 25 percent more effective than the REM-10/MNA/MNA alternative. As discussed in subsection 6.4.1.1. below, the model appears to be relatively insensitive to changes in the selected target threshold for River Section 3.

The risk-based PRG for protection of human health of 0.05 ppm PCBs (wet weight) in fish fillet is not met in River Sections 1 and 2 over the 70-year model forecast period by any of the six alternatives. However, in River Section 3, this PRG is met by the REM-10/MNA/MNA and REM-3/10/10 alternatives in the year 2051. For the REM-0/MNA/MNA, REM-0/10/MNA, REM-0/10/10, and REM-0/0/3, alternatives, the risk-based PRG for protection of human health of 0.05 ppm PCBs (wet weight) in fish fillet is met in River Section 3 in the year 2050.

In River Section 1, the target concentration of 0.2 ppm PCBs (one meal per month) in fish fillets is not met by any of the six alternatives over the 70-year model forecast period. In River Section 2, this target concentration is met by the REM-10/MNA/MNA alternative in the year 2060, by the REM-0/MNA/MNA alternative in 2051, by the REM-3/10/10 alternative in 2043, by the REM-0/10/MNA and REM-0/10/10 alternatives in 2037, and by the REM-0/0/3 alternative in 2034. In River Section 3, this target concentration is met by the REM-10/MNA/MNA alternative in the year 2017, by the REM-0/MNA/MNA and REM-3/10/10 alternatives in 2014, and by the REM-0/10/MNA, REM-0/10/10, and REM-0/0/3 alternatives in 2013.

In River Section 1, the target concentration of 0.4 ppm PCBs (one meal every 2 months) in fish fillets is met by the REM-10/MNA/MNA alternative in the year 2030, by the REM-3/10/10 alternative in 2026, and by the REM-0/MNA/MNA, REM-0/10/MNA, REM-0/10/10, and REM-0/0/3 alternatives in 2011. In River Section 2, this target concentration is met by the REM-10/MNA/MNA alternative in the year 2037, by the REM-0/MNA/MNA alternative in 2035, by the REM-3/10/10 alternative in 2025, by the REM-0/10/MNA and REM-0/10/10 alternatives in 2021, and by the REM-0/0/3 alternative in 2014. In River Section 3, this target concentration is met by the REM-10/MNA/MNA alternative in the year 2011, and by the REM-0/MNA/MNA, REM-3/10/10, REM-0/10/MNA, REM-0/10/10, and REM-0/0/3 alternatives in 2010.

The chemical-specific ARARs for PCBs in water are 0.5 μg/L (500 ng/L) federal MCL; 0.09 μg/L (90 ng/L) NYS standard for protection of human health and drinking water sources; 1 ng/L federal Ambient Water Quality Criterion; 0.12 ng/L NYS standard for protection of wildlife; and 0.001 ng/L NYS standard for protection of human consumers of fish. The first two chemical-specific ARARs for the surface water are met by all of the six REM alternatives, whereas the remaining three chemical-specific ARARs for the surface water are not met for the entire 70-year forecast period by any of these alternatives.

Just prior to remediation, in the year 2003, the Tri+ PCB load over the Federal Dam predicted by the model is approximately 131 kg annually for all six alternatives. Soon after remediation, in the year 2011, this annual Tri+ PCB load is about 63 kg for the REM-10/MNA/MNA alternative, 48 kg for the REM-0/MNA/MNA alternative, 42 kg for the REM-3/10/10 alternative, 36 kg for the REM-0/10/MNA and REM-0/10/10 alternatives, and 34 kg for Alternative REM-0/0/3. Several decades after active remediation is completed, in the year 2035, this Tri+ PCB load is approximately 22 kg for the REM-10/MNA/MNA, 20 kg for the REM-0/MNA/MNA and REM-3/10/10 alternatives, and 18 kg for the REM-0/10/MNA, REM-0/10/10, and Alternative REM-0/0/3 alternatives.

The REM-10/MNA/MNA, REM-0/MNA/MNA, and REM-0/10/MNA alternatives do not include remediation in River Section 3, and therefore do not address the scour of PCB-contaminated sediments associated with one-in-three to one-in-five-year flow events from the Hoosic River, discussed as a limitation in subsection 6.2.1.2. Without addressing PCB-contaminated sediments downstream of the Hoosic River (RM 166), the Tri+ PCB loads over Federal Dam for these three alternatives will likely be higher than indicated by the modeling results.

The table below provides a comparison of volumes of contaminated sediment and PCB inventory removed by each of the six REM alternatives, arranged from least to most extensive.

Alternative	Volume Removed (cubic yards)	PCB Mass Removed (kg)
REM-10/MNA/MNA	965,000	8,600
REM-0/MNA/MNA	2,030,000	15,000
REM-3/10/10	2,485,000	41,900
REM-0/10/MNA	2,568,000	38,600
REM-0/10/10	2,999,000	45,300
REM-0/0/3	3,706,000	60,700

400616

Implementability

The general implementability of the category of REM alternatives was described in subsection 6.2.4.2. Implementability of specific alternatives within this category is primarily a function of scale; *i.e.*, the total area remediated, volume of sediment removed, and the length of shoreline disturbed. Although all six REM alternatives are readily implementable, the REM-10/MNA/MNA and REM-0/MNA/MNA alternatives are easier to implement because all of the sediment removal work is done in River Section 1. Next, the REM-0/10/MNA alternative is also easier to implement because it does not involve sediment removal in River Section 3. However, as explained, this would not address the scouring of sediments by flows from the Hoosic River. As shown in Tables 6-1, the length of shoreline disturbed by the sediment removal activities for the REM-10/MNA/MNA alternative is estimated to be 6.6 miles and the area targeted for remediation by this alternative is approximately 4 percent of the total Upper Hudson River area. The length of shoreline disturbed by the sediment removal activities for the REM-0/0/3 alternative is estimated to be 33 miles and the area targeted for remediation by this alternative is approximately 24 percent of the total Upper Hudson River area.

Cost

The costs for the six REM alternatives primarily depend on the volume of sediments to be removed from the Upper Hudson River. Of the six alternatives, the REM-10/MNA/MNA alternative has the lowest costs, whereas the REM-0/0/3 alternative has the highest costs by a factor of about four over REM-10/MNA/MNA. Based on the volume of sediment to be removed, costs for the other four REM alternatives are expected to range between two and three times the cost for REM-10/MNA/MNA. Total O&M costs for an alternative are expected to be a small fraction (say, 2 to 5 percent) of the total capital costs.

6.3.3 Conclusion for REM Alternatives

The model analyses presented above show that remediation less than Expanded Hot Spot remediation in River Section 1 and Hot Spot remediation in River Sections 2 and 3 will not substantially reduce PCB concentrations in fish. The evaluation shows that while Full-Section remediation provides greater benefits, much larger sediment areas and volumes must be removed at considerably greater costs.

The REM-3/10/10 and REM-0/0/3 alternatives were retained for detailed analysis, based on the effectiveness, implementability, and cost screening presented above and summarized below.

The REM-3/10/10 alternative appears to provide a good balance in achieving the RAOs and PRGs at costs that are moderate as compared to the other REM alternatives that were evaluated. As described in Table 6-1, the REM-3/10/10 alternative significantly reduces the risks to human health and the environment from PCBs at the site. This conclusion is based on a combination of factors that includes the area remediated, the volume of sediments removed, the length of shoreline affected, the transport of Tri+ PCBs over the Federal Dam, the species-weighted average PCB fish fillet concentration, and the water quality in all three river sections. The REM-3/10/10 alternative also addresses PCB-contaminated sediments in all three river sections.

The REM-0/0/3 alternative is the most extensive remedial alternative, and as such provides the greatest benefits at the highest costs. It serves as the upper bound of the benefits of active remediation of the Upper Hudson River sediments. Therefore, the REM-3/10/10 and REM-0/0/3 alternatives are retained for detailed analysis.

6.3.4 Conclusion for CAP Alternatives

As stated in Section 6.3 above, the range of target areas covered by the four CAP alternatives listed in subsection 6.2.3 is a subset of the range of target areas included in the six REM alternatives. Although the evaluation provided in subsection 6.3.2 above is based on the REM alternatives, it is also representative of the CAP alternatives because the conclusions reached from a similar evaluation of corresponding CAP alternatives would be the same. Therefore, the CAP-3/10/10 alternative is also retained for detailed analysis.

6.4 Refinement of Active Remediation Alternatives Retained for Detailed Analysis

To perform the detailed analysis of the three active remediation alternatives identified above, it is necessary to further examine the *hot spots* and remediation target areas shown in Plates 13, 14, and 15 from an implementation and engineering perspective. In addition, it is important to carefully consider the information about the scour of sediments from *hot spots* by the Hoosic River flows in River Section 3, as described in Chapter 3. Other factors that need to be considered include the information about the existing water depths in the navigation channel in all three river sections provided by the Canal Corporation. In Section 5.2, the drafts required by various types of dredging equipment were discussed and evaluated.

6.4.1 Basis for Remedial Alternatives Refinement

The sections below explain the basis for refinement of the REM-3/10/10, CAP-3/10/10, and REM-0/0/3 alternatives.

6.4.1.1 Select Areas

As described in Appendix D, calibration data for the HUDTOX model are very limited in some key areas, especially in River Section 3. Based on these limited data, the spatial scale of the model segments for the sediments is relatively much larger (approximately 1,283,000 m^2) than the spatial scale of the model segments in River Section 1 (approximately 138,000 m^2). These relatively broad spatial scales do not necessarily reflect what happens at local spatial scales smaller than model segments. As shown in the predicted results presented in Figures 6-7 through 6-23, the model appears to be relatively insensitive to changes in the selected target threshold (*i.e.*, PCB MPA of 3 g/m^2 versus 10 g/m^2) in River Section 3.

The importance of the increased exposure to PCB contamination due to scouring of sediments by the Hoosic River flows has been discussed previously. *Hot Spot* 37 is immediately downstream of the confluence of the Hoosic River with the Upper Hudson River and has historically been subject to scour. *Hot Spots* 36 and 39 both include a sizeable inventory of PCBs and may be subject to scour under certain conditions. Therefore, other factors were examined in addition to the

PCB inventory and model predictions when identifying areas to be remediated for River Section 3. These factors include the flow rates, sedimentation rates, bioturbation, historical erosion patterns, and depth of PCB contamination within the *hot spot* areas, among others.

Hot Spot 39 represents a unique condition in the Upper Hudson River. Specifically, several of the core profiles obtained from this *hot spot* as part of the 1994 USEPA investigation indicated very high rates of sediment deposition. The areas within *Hot Spot* 39 undergoing significant burial were identified by sediment cores whose PCB maximum occurred below 24 inches. This criterion identified the central portion of the *hot spot* as undergoing significant burial, and this portion of *Hot Spot* 39 was excluded from the areas to be dredged. In this portion of the *hot spot,* it is believed that the bulk of sediment contamination lies sufficiently below the surface to not pose a future problem. Additionally, the high rate of deposition in this area should further isolate the contaminated sediments. The northern and southern areas of *Hot Spot 39* had core profiles more typical of Upper Hudson sediment contamination, with PCB maximum concentrations occurring in the uppermost layers of complete cores. As a result, these areas were included in the areas to be dredged.

In order to reflect the refinements discussed in this section, the nomenclature used to describe the three active alternatives was modified as described below:

- Alternative CAP-3/10/Select;
- Alternative REM-3/10/Select; and,
- Alternative REM-0/0/3.

6.4.1.2 Dredging to Implement Remedial Alternatives

Based on evaluation of the engineering productivity calculations described in Appendix E, the drafts required by various types of dredges, towboats and barges were compared with information on channel depths provided by the Canal Corporation. This evaluation showed that portions of the navigation channel would have to be dredged in all three river sections to allow the unrestricted movement of barges loaded with dredged sediments as well as to accommodate normal boat traffic on the river. Therefore, in order to properly implement the three active remediation alternatives selected for detailed analysis in subsections 6.3.3 and 6.3.4, additional areas and volumes need to be added in all three river sections to the CAP-3/10/Select, REM-3/10/Select, and REM-0/0/3 alternatives.

The areas and volumes for these three refined alternatives are presented in Table 6-3. Figures 6-24 through 6-40 present the predicted PCB concentrations in sediment, surface water and species-weighted average fish fillet for these three refined alternatives as compared to the No Action and MNA alternatives.

6.4.2 Description of Refined Remedial Alternatives

The three refined remedial alternatives (CAP-3/10/Select; REM-3/10/Select; and REM-0/0/3) are described below.

6.4.2.1 Alternative CAP-3/10/Select

This alternative includes capping with dredging to perform Expanded Hot Spot remediation (*i.e.*, in which the nominal MPA targets are 3 g/m^2 or greater) in River Section 1, Hot Spot remediation (*i.e.*, in which the nominal MPA targets are 10 g/m^2 or greater) in River Section 2, and remediation of select areas (*i.e.*, sediments with high-concentration PCB target areas and which are potentially subject to scour) in River Section 3. This alternative also includes dredging in the navigation channel as necessary to implement the remediation and to accommodate normal boat traffic on the river. Protection of the cap from damage by boat propellers and anchors, bioturbation and other disturbances is implemented through addition of a layer of backfill material suitable for replacement of fish and benthic habitat. Areas from which sediments are removed are backfilled with appropriate material to isolate residual PCBs in sediments that may remain after dredging is completed. No backfill is placed in the navigation channel. After construction is completed, MNA is implemented in each section of the river until the RAOs are achieved.

The areas to be remediated for this alternative are shown in Plate 16. The total area of sediments to be capped is approximately 207 acres. The estimated volume of sediments to be removed is 1.73 million cubic yards. Remediation will commence in 2004 and will be completed in 2008. This alternative is performed in conjunction with a separate source control removal action (*i.e.*, NTCRA) in the vicinity of the GE Hudson Falls plant and also relies on institutional controls, such as the fish consumption advisories, and naturally occurring attenuation processes to reduce the toxicity, mobility and volume of the remaining PCBs in the Upper Hudson River sediments after the construction is completed. A review of site conditions will be conducted at five-year intervals, as required by Section 121(c) of CERCLA.

6.4.2.2 Alternative REM-3/10/Select

This alternative includes Expanded Hot Spot removal (*i.e.*, in which the nominal MPA targets are 3 g/m^2 PCBs or greater) in River Section 1, Hot Spot removal (*i.e.*, in which the nominal MPA targets are 10 g/m^2 or greater) in River Section 2, and removal of select areas (*i.e.*, sediments with high-concentration PCB target areas and which are potentially subject to scour) in River Section 3. This alternative also includes sediment removal in the navigation channel as necessary to implement the remediation and to accommodate normal boat traffic on the river. Isolation of residual PCBs in sediments that may remain after dredging is completed through addition of a layer of backfill material suitable for replacement of the fish and benthic habitat. No backfill is placed in the navigation channel. After construction is completed, MNA is implemented in each section of the river until the RAOs are achieved.

The areas to be remediated for this alternative are shown in Plate 17. The total area of sediments targeted for removal is approximately 493 acres. The estimated volume of sediments to be removed is 2.65 million cubic yards. Remediation will commence in 2004 and will be completed in 2008. This alternative is performed in conjunction with a separate source control removal action (*i.e.*, NTCRA) in the vicinity of the GE Hudson Falls plant and also relies on institutional controls, such as the fish consumption advisories, and naturally occurring attenuation processes to reduce the toxicity, mobility and volume of the remaining PCBs in the Upper Hudson River sediments after the construction is completed. A review of site conditions will be conducted at five-year intervals, as required by Section 121(c) of CERCLA.

6.4.2.3 Alternative REM-0/0/3

This alternative includes Full-Section removal (*i.e.*, removal of sediments in which the MPA targets are 0 g/m^2 or greater) in River Section 1 and 2, and Expanded Hot Spot removal (*i.e.*, in which the nominal MPA targets are 3 g/m^2 or greater) in River Section 3. This alternative also includes sediment removal in the navigation channel as necessary to implement the remediation and accommodate normal boat traffic on the river. Isolation of residual PCBs in sediments that may remain after dredging is completed through addition of a layer of backfill material suitable for replacement of the fish and benthic habitat. No backfill is placed in the navigation channel.

The areas to be remediated for this alternative are shown in Plate 18. The total area of sediments targeted for removal is approximately 964 acres. The volume of sediments to be removed is estimated to be 3.82 million cubic yards. This alternative performs the most extensive remediation that can be supported by current data, and has the longest duration. Remediation will commence in 2004 and will be completed in 2010. This alternative is performed in conjunction with a separate source control removal action (*i.e.*, NTCRA) in the vicinity of the GE Hudson Falls plant and also relies on institutional controls, such as the fish consumption advisories, and naturally occurring attenuation processes to reduce the toxicity, mobility and volume of the remaining PCBs in the Upper Hudson River sediments after the construction is completed. A review of site conditions will be conducted at five-year intervals, as required by Section 121(c) of CERCLA.

Chapter 7

7. ALTERNATIVE-SPECIFIC RISK ASSESSMENTS

The alternative-specific risk assessments presented in this FS calculate risks for the Upper Hudson River (*i.e.*, the approximately 40 river miles from the northern end of Rogers Island to the Federal Dam at Troy). Although the Hudson River PCBs Superfund Site extends nearly 200 river miles (320 km) from the Fenimore Bridge at Hudson Falls (RM 197.3) to the Battery in New York City (River RM 0), alternative-specific risks are presented only for the Upper Hudson River (Federal Dam at RM 153.9 to the former Fort Edward Dam at RM 194.8), which is the focus of this FS report. This portion of the river was divided into three sections for convenience in evaluating conditions and remedial alternatives in the FS (Plate1). These three sections were individually evaluated for human health (including both cancer risks and non-cancer health hazards) and ecological risks, and the upper river as a whole was also evaluated for human health risks.

River Section 1 consists of the TI Pool, for practical purposes considered to start at the northern end of Rogers Island at RM 194.6 and extending to the TI Dam at RM 188.5. River Section 2 extends from the TI Dam (RM 188.5) to the Northumberland Dam (Lock 5) near Schuylerville (RM 183.4), a distance of about five river miles. River Section 3 extends from below the Northumberland Dam (Lock 5) to the Federal Dam at Troy (RM 153.9), a distance of nearly 29 river miles. Angler use and ecological parameters were assumed to be the same throughout the three sections of the Upper Hudson River. Cancer risks and non-cancer hazard indices (HIs) were averaged from the three sections to provide an overall (average) estimate of human health cancer risks and non-cancer health hazards associated with the Upper Hudson River.

The alternative-specific risk assessments use the same methodology and assumptions that were used in the Hudson River PCBs Site Revised HHRA (USEPA, 2000p) and Revised ERA (USEPA, 2000q). Exposure parameters, toxicity values, and time frames used herein (*i.e.*, for the baseline No Action alternative) are consistent with those used to model future PCB concentrations in both revised HHRA and ERA reports. However, the starting time for alternative-specific assessments presented in this FS differs from the starting time used for the assessments presented in the revised HHRA and ERA. The Revised HHRA used an assessment period beginning in 1999 and extending up to 40 years (*i.e.*, 1999 through 2038, inclusive) for the reasonable maximum exposure (RME) cancer assessment and seven years (*i.e.*, 1999 through 2005) for the non-cancer health assessment. The ERA used a 25-year time frame beginning in 1993 (*i.e.*, 1993-2017). Modeling for the ERA was begun in 1993 because the ecological sampling program was conducted then, which provided much of the data used in the ERA.

Calculated cancer risks and non-cancer hazards for exposure after the completion of remediation (*i.e.*, from 2008 on) are presented in this chapter of the FS. Because modeled sediment PCB concentrations decrease over time (USEPA, 2000a), the baseline risks calculated for the HHRA and ERA using the 1999 and 1993 start dates are higher than those calculated in this report using the later (2008 on) start date.

This FS focuses on risks from fish ingestion for both human and ecological receptors. The alternative-specific risk assessments presented herein are not intended to be full or complete risk assessments. Rather, they focus on the major source of risk to human and ecological receptors (*i.e.*, fish ingestion) both as a means to assess the absolute degree of risk reduction and to enable evaluation and comparison among alternatives with respect to risk-based criteria.

7.1 Use of Risk Assessments in Criteria Evaluation

Risk assessments integrate exposure to contaminants and toxicological effects to provide a risk characterization. Quantitative risk assessment is a tool for evaluating reductions in risk using mathematical models, and as such is subject to uncertainties and limitations that are described later in this chapter. In this FS, two of the RAOs (reduce the cancer risks and non-cancer health hazards for people eating fish from the Hudson River by reducing the concentration of PCBs in fish, and reduce risks to ecological receptors by reducing the concentration of PCBs in fish) and the associated preliminary remediation goals (PRGs) are directly linked to risk calculations. This section describes the methodology used to calculate risks to human health and the environment, and their integration into the alternative evaluation criteria.

Of the seven alternative-specific detailed evaluation criteria addressed in this FS, three have a risk-based component:

- Overall protection of human health and the environment

- Long-term effectiveness and permanence
- Short-term effectiveness

The use of alternative-specific risk assessments for each of these criteria is discussed below.

7.1.1 Overall Protection of Human Health and the Environment

Overall protection of human health and the environment is one of the two threshold criteria that must be met by each alternative. This evaluation criterion provides a final assessment of the extent to which a given alternative is protective of human health and the environment. The overall protectiveness criterion includes an assessment of other risk-based evaluation criteria, such as long-term effectiveness and permanence and short-term effectiveness. As part of determination of protectiveness, the evaluation describes how risks through each pathway would be eliminated, reduced, or controlled through treatment, engineering, or institutional controls. Overall protection also addresses, for example, potential volatilization of PCBs during sediment processing.

7.1.2 Long-Term Effectiveness

Long-term effectiveness is evaluated by using modeling results to project the human health and ecological impacts through the years over the exposure period of a human or ecological receptor. As described in the Revised HHRA (USEPA, 2000p),the maximum time frame used to calculate non-cancer hazards and cancer risks for human health modeling is 40 years, and ecological toxicity quotient modeling results are based on a 25-year exposure period, with starting dates ranging between 2008 and 2012 depending on the alternative and river section. The HUDTOX and FISHRAND models were run for a 70-year period (1998-2067) for this FS and the full modeling time frame is examined when determining the number of years required to reach human health and ecological target levels. The start date for the long-term effectiveness period was considered to start immediately after the equilibration period following remediation. For example, if the construction schedule for a remedy requires three years to complete, given a start date in 2004, the construction would be complete at the end of 2006, equilibration would occur over the year 2007, and the long-term period for risk calculation starts on January 1, 2008.

Risks for each section of the river for each remedy are compared separately to the No Action and MNA alternatives. Therefore, two sets of baseline alternatives for both No Action and MNA are calculated, one to coincide with the schedule for CAP-3/10/S and REM-3/10/S, and one to match the schedule of REM-0/0/3. For the entire 40 miles of the Upper Hudson River, the years 2009 (the midpoint of start years for CAP-3/10/S and REM-3/10/S) and 2011 (approximately the midpoint of start years for REM-0/0/3) are used.

7.1.2.1 Long-Term Effectiveness: Protection of Human Health

Long-term human health effects are modeled for the same exposure duration used for the baseline Revised HHRA (USEPA, 2000p), as summarized below. However, the specific years modeled vary, depending on the assumed progress of remediation within a given river segment for each alternative. Table 7-1 summarizes the time frames utilized in the calculation of the alternative-specific human health cancer risks and non-cancer hazards and ecological risks. No Action and MNA alternatives are modeled with different time periods corresponding to the three (active) remedial alternatives so that meaningful comparisons among alternatives can be made.

For carcinogenic effects:

- Reasonable maximum exposure (RME): 40 years for the adult (2011 through 2050)
- Central tendency (CT) exposure ("average" or "typical"): 12 years for the adult (2011 through 2022)

For non-cancer health effects:

- RME: seven years for the adult (2011 through 2017)
- CT exposure: 12 years for the adult (2011 through 2022)

As was done in the Revised HHRA, the modeled fish concentrations for each of the three river sections are averaged, with each year and each river section weighted equally. In addition, cancer risk and non-cancer health hazard calculations are also presented for each individual river section. The fish concentrations used are the species-weighted averages, based on Connelly *et al.* (1992), and are those considered to represent a reasonable ingestion scenario among the three fish species consumed to any significant extent by human receptors (anglers): largemouth bass (47 percent); brown bullhead (44 percent); and yellow perch (9 percent).

7.1.2.2 Long-Term Effectiveness: Ecological Assessment

The ecological assessment is based on modeled effects for two receptors, the river otter and mink. TQs are calculated for both the NOAEL and the LOAEL to provide a range of exposure risks. The bald eagle, a piscivorous bird, was also considered as a potential receptor to model for the FS. However, adult eagle risks are much lower than otter risks, and eagle egg risks are similar but slightly lower than otter risks. Therefore, only river otter (the most sensitive receptor) and mink results are presented here.

As in the evaluation of human health risks, the start date for the long-term effectiveness period was considered to be immediately after the equilibration period following remediation. Risks for each section of the river for each remedy are compared separately to the No Action alternative. The 25-year forecast period used in the Revised ERA was also selected as the mink and river otter exposure period in this FS. This exposure period is considered appropriate because it extends throughout the average lifespan of both the mammalian receptors. Mink live up to10 years (Walker, 1997; Kurta, 1995) and river otter live on the average 15 to 20 years in the wild and up to 25 years in captivity (Ohio Division of Wildlife, 2000).

7.1.3 Short-Term Effectiveness

As defined in the RI/FS Guidance and the NCP, assessment of short-term effectiveness addresses a number of factors:

- Protection of the community during remedial actions
- Protection of workers during remedial actions
- Potential adverse environmental impacts resulting from construction and implementation
- Time until remedial response objectives are achieved

The role of alternative-specific risk assessments in addressing each of these components of short-term effectiveness is described below.

For the purposes of this FS, the short-term period is considered to include the time from initiation of remedial activities, assumed to be in the year 2004, through the alternative-specific and river section-specific period for implementation, and a subsequent one- to two-year period for attenuation of residual impacts. Therefore, the short-term period is of variable duration, and extends from 2004 through the year immediately prior to the beginning of the long-term period, as shown in Table 7-1. Modeling results for active remedial alternatives are compared to No Action and MNA alternatives for the same time period, so that comparisons among alternatives are on a consistent basis.

7.1.3.1 Protection of the Community During Remedial Actions

The protection of the community during remedial actions is assessed on a qualititative basis. Community risks that are considered include both physical hazards (*e.g.*, noise, navigational hazards) and potential exposure to hazardous materials (*e.g.*, PCBs).

7.1.3.2 Protection of Workers During Remedial Actions

Potential risks to workers implementing the various remedial alternatives as well as measures to prevent, minimize, or mitigate such risks are addressed as part of this criterion. The risks to workers that are considered include both physical hazards (*e.g.*, falling off the deck of a barge or being injured in other job-related accidents) and potential exposure to hazardous materials (*e.g.*, PCBs).

The protection of workers during remedial actions is addressed qualititatively (in Section 8 of the FS); no specific quantitative risks are calculated.

7.1.3.3 Potential Adverse Environmental Impacts Resulting from Construction and Implementation

Potential adverse environmental impacts are addressed qualitatively, as there is no reliable means of quantifying potential short-term impacts from actions such as sediment resuspension, temporary habitat loss, or other transient effects. These impacts are discussed qualitatively in Chapter 8 of the FS.

7.1.3.4 Time until Remedial Response Objectives Are Achieved

As discussed earlier, modeling results do not consider the potential short-term adverse impacts of remedial actions. The time to achieve short-term remedial response objectives is evaluated using the year after the completion of the remedial action. For example, considering the Upper Hudson River as a whole, the short-term period would extend from 2004 through 2008 (for 2010 Alternative REM-0/0/3), lasting for five to seven years. The short-term period extends for the longest amount of time at River Section 3, where it ends at the beginning of 2010 or 2012. If objectives (PRGs) are achieved prior to the end of the short-term period, the modeling data are examined further to determine if the model predicts attainment of the objectives prior to or during the short-term period. The numerical human health and ecological PRGs as presented in Chapter 3 are used to evaluate this criterion.

7.2 Alternative-Specific Risk Assessment Methodology

The methodology used for the alternative-specific assessment of human health and ecological risks is presented below.

7.2.1 Protection of Human Health

Two principle criteria were used to assess overall protection of human health: the relative reduction in cancer risks and non-cancer health hazards for each of the five remedial alternatives; and the time that it would take under each of the alternatives to reach the fish PRG and the other target concentrations.

The protection of human health is assessed quantitatively through calculation of both non-cancer health hazards and cancer risks to anglers living in the towns, cities, and rural areas surrounding the Upper Hudson River. The angler population is defined as those individuals (male and female) who consume self-caught fish from the Hudson, in the absence of remediation of sediments and Hudson-specific fish consumption advisories. The assessment of fish consumption by the angler population includes childhood through adulthood. All sport fish consumed were assumed to come from the Hudson River. The RME scenario assumed a one-half pound meal (227 grams) 51 times per year (*i.e.*, 31.9 g/day) and the CT scenario assumed the same serving size 6.4 times per year (*i.e.*, 4.0 g/day) for the adult (see Table 7-2).

Cancer risks and non-cancer hazard indices were calculated for River Sections 1, 2, 3, and the Upper Hudson River as a whole using the following equation:

$$AverageDailyIntake\ (mg/kg - day) = \frac{C_{fish}\ x\ IR_{fish}\ x\ (1 - Loss)\ x\ FS\ x\ EF\ x\ ED\ x\ CF}{BW\ x\ AT}$$

where:

C_{fish} = concentration of PCBs in fish (mg/kg wet weight)
IR_{fish} = ingestion rate of fish (g/day)
Loss = cooking loss (g/g)
FS = fraction from source (unitless)
EF = exposure frequency (days/year)
ED = exposure duration (years)
CF = conversion factor (kg/g)
BW = body weight (kg)
AT = averaging time (days)

Values used for daily intake calculations (*i.e.*, for the variables in the Average Daily Intake equation above) are provided in Table 7-2. Annual mean concentrations in fish used to calculate average PCB concentrations in fish over the various multi-year time frames (7, 12, or 40 years) are listed in Table

7-3. Mean fish PCB concentrations for the 70-year period from 1998 to 2067 were predicted using the FISHRAND model (USEPA, 2000a). Largemouth bass, brown bullhead, and yellow perch are expressed on a standard fillet wet weight basis for Tri+ PCBs at the three modeling locations and averaged over the three river sections to provide an average Upper Hudson River value.

To obtain an expected value (mean) and standard deviation from the FISHRAND probabilistic model, the following procedure was used:

1. Log-transform the model output for the 25^{th}, 50^{th} and 95^{th} percentiles
2. Plot the results against the inverse of the normal cumulative distribution, yielding a straight line;
3. Obtain the parameters of the regression to estimate a geometric standard deviation (GSD, or σ, calculated as 1/slope) and μ (calculated as the intercept times σ); and
4. Obtain the mean (expected value, or E[x], of the distribution) as $E[x]=e^{\ln(x)+\sigma^2/2}$.

The mean was then used as the annual exposure point concentration (EPC), from which cancer risks and non-cancer hazards are calculated. For human health risks, annual EPCs were averaged over the appropriate exposure period (Table 7-1) and used to calculate average daily intake. Individual annual toxicity quotients were calculated for ecological receptors, which were then averaged over a 25-year exposure period (Table 7-1) to estimate risk.

7.2.1.1 Carcinogenic Risks - Quantitative Incremental Risk

Cancer risks are characterized as the incremental increase in the probability (*i.e.*, one in a million, or 10^{-6}) that an individual will develop cancer during his or her lifetime, above background risk, as a result of site-specific exposure. The phrase "incremental increase" is defined as the risk due to environmental chemical exposure above the background cancer risk experienced by all individuals in the course of daily life.

The quantitative assessment of cancer risks involves evaluation of lifetime average daily dose and application of toxicity factors reflecting the carcinogenic potency of the chemical. Specifically, excess (incremental) cancer risks are calculated by multiplying intake estimates (lifetime average daily doses) and cancer slope factors (CSFs) (USEPA, 1999i) as follows (USEPA, 1989b):

$$Cancer\ Risk = Intake\left(\frac{mg}{kg-day}\right) x\ CSF\left(\frac{mg}{kg-day}\right)^{-1}$$

Exposure levels are expressed as the chronic daily intake averaged over a lifetime of exposure, in units of mg/kg-day (mg of PCB intake per kilogram of human body weight per day). A CSF is an estimate of the upper-bound probability of an individual developing cancer as a result of a lifetime of exposure to a particular level or dose of a possible, probable, or known carcinogen. Cancer slope factors are expressed in units that are the reciprocal of those for exposure, that is, $(mg/kg\text{-}day)^{-1}$. Multiplication of the exposure level by the CSF yields a unitless estimate of cancer risk. The acceptable risk range identified in the NCP (USEPA, 1990b) is 10^{-4} to 10^{-6} (or an increased probability of developing cancer of 1 in 10,000 to 1 in 1,000,000) and refers to plausible upper bound risks (in other words, the RME risk). Alternative-specific RME and CT cancer risk estimates calculated for the fish ingestion exposure pathway are presented in Section 7.3.

As noted in subsection 1.5.1, calculations for adolescents and young children eating fish were added to the Revised HHRA (USEPA, 2000p) based on comments by the peer review panel, but were not evaluated separately in the FS because the differences between the cancer risks and non-cancer hazards for the young child vs. the adult are no greater than three-fold. For example, young child, adolescent, and adult cancer risks were summed in the Revised HHRA, but adult risks accounted for approximately half of the total cancer risk, in part based on the exposure duration. For carcinogenic effects, the RME is 40 years and the CT is 12 years.

7.2.1.2 Non-Cancer Health Effects - Hazard Indices (HIs)

The evaluation of non-cancer health effects involves a comparison of average daily exposure levels with established reference doses (RfDs) to determine whether estimated exposures exceed recommended limits to protect against chronic adverse health hazards. An RfD is defined as an estimate (with uncertainty spanning perhaps an order of magnitude or greater) of a daily exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime. Chronic RfDs are specifically developed to be protective for long-term exposure to a compound, based on a chronic duration range of seven years to a lifetime (USEPA, 1989b).

Potential health hazards from non-cancer health effects are expressed as a hazard quotient (HQ), which compares the calculated exposure (average daily doses) to the RfD. In this non-cancer health assessment, PCBs are the contaminants of concern and the HQ for PCBs is equivalent to the HI. Both exposure levels and RfDs are typically expressed in units of mass of PCB intake per kilogram of body weight per day (mg/kg-day). Unlike the evaluation of carcinogenic effects, exposures of less than lifetime duration are not averaged over an entire lifetime but rather for the duration of exposure (USEPA, 1989b).

The HQ is calculated by dividing the estimated average daily oral dose estimates by the oral RfD as follows (USEPA, 1989b):

$$Hazard\ Quotient\ (HQ) = \frac{Average\ Daily\ Dose\ (mg\,/\,kg-day)}{RfD\ (mg\,/\,kg-day)}$$

If an HI is greater than one (HI > 1), unacceptable exposures may be occurring and there is concern for potential non-cancer health effects, although the relative value of an HI above one cannot be translated into an estimate of the severity of the non-cancer hazard. Various alternatives may be compared to one another to estimate the relative hazard reduction and the hazard duration (in years).

The alternative-specific RME and CT hazard quotients calculated for the fish ingestion exposure pathway are presented in Section 7.3. For non-cancer health effects, the RME is seven years and the CT is 12 years.

7.2.1.3 Relative Reductions in Cancer Risks and Non-Cancer Health Hazards

Relative reductions in cancer risks and non-cancer health hazards are calculated to provide an estimate of risk reduction under the various remedial alternatives. The formula used to calculate risk reduction is:

$$\left(1 - \frac{Remedial\ Alternative - Specific\ Risk}{No\ Action\ Risk\ or\ MNA\ Risk}\right) x\ 100\%$$

The results of this calculation are presented as a percent reduction in risk. Measures of risk used include the incremental cancer risk, non-cancer hazard indices, and ecological toxicity quotients. For example, if a hazard index of 10 is calculated for a remedial alternative and a hazard index of 100 is calculated for the No Action alternative, the relative risk reduction would be 90 percent (*i.e.*, {1-[10/100]} x 100 percent) for that alternative.

Cancer risks and non-cancer health hazards for the entire Upper Hudson River and for each section of the river under the active remedial alternatives are compared separately (using the appropriate time frame) to the No Action and MNA alternatives to estimate the reduction in cancer risks and non-cancer health hazards achieved by each alternative. The bounded alternative is defined as the range between the modeled trajectory and the estimated upper bound trajectory. Active remedial alternatives were compared to this range for both No Action and MNA. To compare No Action and MNA, the base MNA calculations were compared to the base No Action alternative. The upper bound MNA calculations were compared to the upper bound No Action calculations. In other words, the No Action and MNA alternatives were compared using the same assumptions; *i.e.*, base to base and upper bound to upper bound. Comparison of the remedial alternatives to both the base model results and upper bound results allows cancer risks and non-cancer health hazards to be bounded by the two estimates.

For comparison of similar timeframes, the CAP-3/10/Select and REM-3/10/Select alternatives are compared to the No Action and MNA alternatives modeled from 2008 on and the REM-0/0/3 alternative is compared to the No Action and MNA alternatives modeled from 2009 on.

7.2.1.4 Time to Achieve Human Health-Based PRGs

The risk-based PRG for protection of human health is 0.05 mg/kg total PCBs in fish fillet, based on the RME adult fish consumption rate of one half-pound meal per week. Other target concentrations are 0.2 mg/kg total PCBs in fish fillet, which is protective at a fish consumption rate of about one half-pound meal per month, and 0.4 mg/kg total PCBs in fish fillet, which is protective of the average (CT) angler who consumes about one half-pound meal every two months.

These targets of higher concentrations in fish represent points at which fish consumption advisories might become less stringent (*e.g.*, the "eat none" advisory for the Upper Hudson could be relaxed) as conditions improve. The time required to reach the fish PRG is used as a measure of human health protection.

7.2.2 Protection of the Environment: Ecological Risks - NOAEL/LOAEL-Based Toxicity Quotients

The characterization of ecological risks uses the methodology developed in the Revised ERA (USEPA, 2000q) to integrate stressor-response profiles (toxicity effects) with exposure profiles to provide an estimate of risk. The quantitative assessment relies on a toxicity quotient approach in which measured or modeled concentrations are compared to appropriate benchmarks derived for ecological receptors to assess potential risks to those receptors. It is calculated as:

$$Toxicity\ Quotient = \frac{(Modeled\ or\ Measured\ Dose) / Concentration}{Benchmark\ Dose / Concentration}$$

The average modeled daily dosage of PCBs to the receptors from the fish-derived portion of the diet is expressed as:

$$ADD_{Fish} = \frac{PCB_{Fish}\ x\ IR_{Total}\ x\ PD_{Fish}}{BW_{Receptor}}\ x\ FE$$

where:

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ADD_{fish} = Average dietary dose of PCBs from ingestion of fish (mg/kg/day wet wt)

PCB_{fish} = Average concentration of PCBs in fish tissue (mg/kg wet wt)

IR_{Total} = Total ingestion rate for receptor (kg/day, wet wt)

Pd_{fish} = Fraction of total diet of receptor represented by forage and/or large fish (unitless)

FE = Areal forage effort as fraction of home range of the endpoint (unitless), and

$Bw_{receptor}$ = Body weight (kg) of receptor.

Toxicity quotients exceeding a value of one (1.0) are typically considered to indicate potential risk to ecological receptors. The toxicity quotient method provides insight into the potential for general effects of exposure to PCBs on individual animals in the local population. If effects are judged not to occur at the average individual level, they are probably insignificant at the population level. However, if risks are present at the individual level, they may or may not be important at the population level.

Ecological toxicity quotients are calculated for each of the three river sections for the mink and river otter. The river otter was evaluated in the ERA and selected for further evaluation in the FS because it was calculated to have the highest risk from consumption of PCB-contaminated prey from the Hudson River. The mink is selected because it is commonly used for assessment of ecological risk at other sites and is known to be sensitive to the effects of PCBs. The long-term exposure period for ecological receptors is considered to start immediately after a one-year equilibration period beyond the completion of work in a given section (as assumed for human health).

Annual mean concentrations in fish were used to calculate exposure point concentrations (Table 7-3), using the FISHRAND model (USEPA, 2000a). River otter are assumed to consume largemouth bass, which is expressed on a standard fillet wet weight basis for Tri+ total PCBs. Fish (*i.e.*, largemouth bass) fillet concentrations were converted to whole fish concentrations by evaluating whole body versus standard fillet lipid content to obtain a multiplier, as PCBs are known to partition into lipid. For largemouth bass, this ratio is 2.5, which was discussed with NYSDEC and thought to be comparable to values for Hudson River fish. PRGs for the river otter are provided on both a fillet and whole body basis. Mink are assumed to consume spottail shiner. As forage fish were modeled on a whole body basis, no multiplier was applied. Individual annual TQs were calculated for ecological receptors, which were then averaged over a 25-year period (Table 7-1) to estimate risk.

7.2.2.1 River Otter

River otter are assumed to consume a diet consisting entirely (100 percent) of PCB-contaminated largemouth bass (representing large [greater than 25 cm] fish). All fish consumed are assumed to come from the Hudson River. Because river otters are closely related to mink, the LOAEL and NOAEL selected from field studies of dietary exposure of mink to PCBs are used to develop toxicity reference values (TRVs) for the river otter. On the basis of a two-generation field study conducted by Restum *et al.* (1998) showing reduced reproduction and/or growth and survival of offspring in mink fed PCB-contaminated carp, the LOAEL and NOAEL TRVs (*i.e.*, benchmark concentrations) for the river otter are 0.04 mg PCBs/kg/day and 0.004 mg PCBs/kg/day, respectively.

7.2.2.2 Mink

Approximately one-third (34 percent) of the mink diet was assumed to consist of PCB-contaminated spottail shiners (representing small [less than 10 cm] fish). All fish consumed are assumed to come from the Hudson River. Although mink may consume other PCB-contaminated prey, (*e.g.*, crayfish and other aquatic invertebrates), these prey were not considered in the FS calculations. On the basis of Restum *et al.* (1998), the LOAEL and NOAEL TRVs for the mink are 0.04 mg PCBs/kg/day and 0.004 mg PCBs/kg/day, respectively.

7.2.2.3 Relative Reductions in Ecological Toxicity Quotients

Toxicity quotients for the entire Upper Hudson River and for each section of the river under the active remedial alternatives are compared separately (using the appropriate time frame) to the bounded No Action and MNA alternatives to estimate the reduction in TQs achieved by each alternative. Comparison of the alternatives to both the HUDTOX and trend analysis results allows TQs to be bounded by the two estimates.

7.2.2.4 Time to Achieve Ecological-Based PRGs

The risk-based PRG for protection of the environment is a range from 0.13 to 0.013 mg/kg total PCBs in fish fillets (0.3 to 0.03 mg/kg in whole fish), and is based on the LOAEL and NOAEL fish concentrations for river otter consumption. Mink LOAEL and NOAEL whole fish target concentrations are 0.7 and 0.07 mg/kg PCBs. Since the mink consumes small forage fish (less than 10 cm), fillet concentrations are not practical for calculations for this species. Toxicity equivalency quotient (TEQ)-based fish target concentrations are provided in subsection 3.2.2. The time required to reach the ecological target levels is used as a measure of the protection of the environment.

7.2.2.5 Ecological Probabilistic Dose-Response Analysis

The potential for population-level effects on the river otter is evaluated by comparing dose-response curves from the literature (Moore *et al.*, 1999) and cumulative distributions of exposure developed in the Revised ERA (USEPA, 2000q). The potential for population-level effects is expressed as the probability that a certain percentage of the otter population will experience a decrease in fecundity (*i.e.*, fertility). This analysis was run for River Sections 1 and 2 for 2011, 2021, and 2036, representing a range of exposures (2011 represents the exposure after completion of remedial action, 2021 represents ten years after the completion of remediation, and 2036 represents exposures representative towards the end of the modeling period). The risks in River Section 3 are lower based on calculated toxicity quotients, and therefore a probabilistic dose-response analysis was not performed for this section.

To compare the cumulative distributions with the dose-response curves from the literature, the following procedure was used. First, the Monte Carlo exposure models were used to generate the cumulative frequency of predicted dietary doses for each receptor. Output concentrations were log-transformed, and the associated cumulative frequencies, expressed as fractions, were transformed by the inverse of the normal cumulative distribution. The log-transformed Monte Carlo concentrations and the transformed cumulative frequencies yield straight lines when plotted against each other. The parameters of those regressions (one for each river mile-year combination) were used to obtain the cumulative frequency for the specified doses in the dose-response curves from the literature. The resulting curves can then be compared directly by plotting the probability of exceedance on the y-axis and the percent reduction in fecundity on the x-axis.

7.3 Alternative-Specific Human Health Cancer Risks and Non-Cancer Health Hazards and Ecological Risks

The quantitative assessment of the human health cancer risks and non-cancer health hazards for each alternative for the entire 40 miles of the Upper Hudson River and for each of the three river sections is discussed below. Ecological risks were calculated for each of the three river sections for the river otter and mink. The alternatives for which alternative-specific risks were calculated and presented are:

- No Action
- Monitored Natural Attenuation
- CAP 3/10/Select
- REM 3/10/Select
- REM 0/0/3

For each of these alternatives, alternative-specific risk assessments were performed that addressed the following criteria:

- Time to reach human health-based fish target levels;
- Cancer risks and non-cancer hazards;
- Short-term risks and hazards to human health;
- Time to reach ecological-based fish target levels; and
- Ecological risks (toxicity quotients) by receptor (river otter and mink).

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7.3.1 No Action Alternative

The No Action Alternative consists of refraining from the application of any active remediation technology to sediments in all three sections of the Upper Hudson River. The No Action alternative also excludes any separate source control removal action (*i.e.*, the NTCRA) in the vicinity of the GE Hudson Falls plant, administrative actions (including institutional controls such as fish consumption advisories), and any monitoring. Therefore, the No Action Alternative assumes continuation of existing upstream boundary conditions; *i.e.*, a constant PCB load equivalent to an average water column PCB concentration of about 13 ng/L. The HUDTOX and FISHRAND models, together with the bounding calculation described in Appendix D, were run to provide cancer risk and non-cancer health hazard estimates.

7.3.1.1 Time to Reach Human Health-Based Fish Target Levels

As stated previously, the fish concentration PRG is 0.05 ppm PCBs (wet weight) in fillet with additional target concentrations of 0.2 ppm and 0.4 ppm PCBs (wet weight). In River Sections 1, 2, and 3, the No Action alternative does not meet the human health PRG of 0.05 ppm or the target concentration of 0.2 ppm PCBs within the modeling time frame, which extends to 2067 (Table 7-5). Neither is the additional target concentration of 0.4 ppm reached in River Sections 1 and 2, but it is reached in River Section 3 in 2014 (Table 7-5). These comparisons show that target levels would not be achieved in the long term under the No Action alternative.

7.3.1.2 Cancer Risks and Non-Cancer Health Hazards

Cancer risks and non-cancer health hazards were calculated for two time frames for the No Action alternative to cover the implementation time frames of all alternatives.

Non-Cancer Health Hazards

Non-cancer RME health hazards (*i.e.*, HIs) for the No Action alternative in the Upper Hudson River range from 53 to 80 using a start date of 2009 and from 48 to 75 using a start date of 2011 (Table 7-6a). RME hazard indices (calculated for the 2009 and 2011 start dates) range from about

70 to 100 in River Section 1 (Table 7-6b), from about 80 to 130 in River Section 2 (Table 7-6c), and are about 10 in River Section 3 (Table 7-6d). There is no bounding range in River Section 3 because there are no cohesive sediments in this river section, which accounts for the difference in predicted exposure concentrations in the bounding calculation. The differences seen in this section are entirely due to the start year. CT hazard indices are about an order of magnitude lower than RME hazard indices, but are still above one at all locations except River Section 3 (Tables 7-6a to 7-6d). Non-cancer hazard indices by river section are shown on Figures 7-1 and 7-2 for the RME and CT exposure, respectively. All hazard indices except the CT estimate in River Section 3 are well above the target level of one, indicating that the No Action alternative will not meet the non-cancer hazard index target level in the long-term.

Cancer Risks

Incremental RME cancer risks for the No Action alternative in the Upper Hudson River range from 7.8 x 10^{-4} to 1.4 x 10^{-3} using a start date of 2009, and from 7.3 x 10^{-4} to 1.3 x 10^{-3} using a start date of 2011(Table 7-7a). RME cancer risks, calculated for the 2009 and 2011 start dates, range from about 1.2 x 10^{-3} to 1.8 x 10^{-3} in River Section 1 (Table 7-7b), from 9.1 x 10^{-4} to 2.2 x 10^{-3} in River Section 2 (Table 7-7c), and are about 1.6 x 10^{-4} in River Section 3 (Table 7-7d). Cancer risks by river section are shown on Figures 7-3 and 7-4 for the RME and CT exposure, respectively. The Upper Hudson River as a whole, and River Sections 1 and 2 specifically, have RME cancer risks that exceed the target risk range of 10^{-4} to 10^{-6}, indicating that the No Action alternative will not meet the cancer risk target level in the long term.

7.3.1.3 Short-Term Human Health Cancer Risks and Non-Cancer Health Hazards

Based on the modeling done to estimate long-term effects, a qualitative evaluation of short-term cancer risks and non-cancer health hazards can be made. Fish concentrations for the seven/nine year short-term period beginning in 2004 are above all target levels (Table 7-4). As PCB concentrations are highest in the initial modeling years, it is apparent that target non-cancer health hazard and cancer risk levels will not be achieved in the short-term under the No Action alternative. Short-term PCB concentrations do not differ between the base and upper bound No Action scenarios.

7.3.1.4 Time to Reach Ecological Fish Target Levels

USEPA considered NOAEL/LOAEL target concentrations of 0.03/0.3 ppm and 0.07/0.7 ppm PCBs (wet weight) in whole fish for the river otter and mink, respectively. The river otter concentrations correspond to 0.13/0.013 ppm in fish fillets. The mink target concentrations are only available on a whole fish basis and are not directly comparable to fillet-based PRGs.

The No Action alternative does not meet any of the river otter PRGs in River Sections 1, 2, and 3 for the duration of the model under the base and upper bound calculations (Table 7-8). For the base No Action alternative, the mink LOAEL target concentration is reached in River Section 2 in 2031, but it is not reached within the modeling period under the upper bound No Action alternative. In River Section 3, the mink LOAEL TQ is reached prior to 2010.

7.3.1.5 Ecological Toxicity Quotients

Toxicity quotients for the river otter are above one for all comparisons in all three sections of the river (Table 7-9). The river otter TQ is up to two orders of magnitude above the target level (Figure 7-5) as compared to the NOAEL, and is an order of magnitude greater than the LOAEL (Figure 7-6). The average mink TQ exceeds one for all comparisons except the LOAEL comparison in River Section 3 (Figures 7-7 and 7-8).

7.3.1.6 Probabilistic Dose-Response Analysis

The probabilistic dose-response analysis for the No Action (including estimated upper bound) alternative in River Section 1 (RM 189) shows about 100 percent probability of a 75 percent reduction in female river otter fecundity in the year 2011, remaining within one percent of that level through 2021 and 2036 (Table 7-10 and Figure 7-9). At the upper end of the dose response function, the No Action alternative shows between 72 to 83 percent probability of a 98 percent reduction in fecundity, falling to 56 to 70 percent in 2021, and to 54 to 68 percent in 2036. The range of probabilities represents the curves from the base and estimated bound runs. At the 50 percent effect level, there is a 100 percent probability of a 50 percent reduction in fecundity throughout the entire modeling period (through 2036).

In River Section 2 (RM 184), the No Action (including estimated upper bound) alternative shows a 100 percent probability of a 75 percent reduction in fecundity in the year 2011 (Table 7-11 and Figure 7-9). In 2021 there is a 89 to 100 percent probability of a 75 percent reduction in fecundity, with the lower end falling to 61 to 99 percent in 2036. At the upper end of the dose-response function, the No Action alternative shows between a 57 to 85 percent probability of a 98 percent reduction in fecundity in 2011, falling to 18 to 71 percent in 2021, and to 3 to 55 percent in 2036. At the 50 percent effect level, there is a 100 percent probability of a 50 percent reduction in fecundity in 2011, a 99 to 100 percent probability in 2021, and 96 to 100 percent probability in 2036.

7.3.2 Monitored Natural Attenuation

Unlike No Action, the MNA alternative assumes a separate source control removal action (NTCRA) in the vicinity of the GE Hudson Falls facility. It is assumed that as a result of the NTCRA, the upstream Tri+ PCB load at Fort Edward (Rogers Island) will be reduced from 0.16 kg/day to 0.0256 kg/day (about 2 ng/L) on January 1, 2005. The HUDTOX and FISHRAND models, together with the bounding calculation described in Appendix D, were run to provide cancer risk and non-cancer health hazard estimates. These models provide output in Tri+ PCBs, which are known to bioaccumulate in fish.

7.3.2.1 Time to Reach Human Health-Based Fish Target Levels

The MNA alternative does not meet the human health PRG fish concentration of 0.05 ppm PCBs in River Sections 1 and 2 within the modeling time frame, extending to 2067 (Tables 7-4 and 7-5). In River Section 3 it is reached in 50 years. The target concentration of 0.2 ppm is not reached in River Section 1. In River Section 2 it is reached in a time period of 54 to more than 59 years and in River Section 3 it is reached in 11 years. The 0.4 ppm target is achieved in a period from 32 to more than 60 years in River Section 1, from 31 to more than 59 years in River Section 2, and in 2 years in River Section 3. The longer time to achieve PRGs is based on the upper bound MNA alternative.

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7.3.2.2 Cancer Risks and Non-Cancer Health Hazards and Relative Reductions

Cancer risks and non-cancer health hazards were calculated for the MNA alternative and were then compared to the No Action alternative to determine the relative risk reduction. Comparisons are made between cancer risks and non-cancer health hazards calculated for the same time frames.

Non-Cancer Health Hazards

Non-cancer RME health hazards for the MNA alternative in the Upper Hudson River range from 40 to 71 using a start date of 2009 and from 34 to 66 using a start date of 2011 (Table 7-6a). Non-cancer RME hazard indices range from about 44 to 80 in River Section 1 (Table 7-6b), from about 57 to 130 in River Section 2 (Table 7-6c), and from 6 to 7 in River Section 3 (Table 7-6d). There is no bounding range in River Section 3 because there are no cohesive sediments in this river section, which accounts for the difference in predicted exposure concentrations in the bounding calculation. The differences seen in this section are entirely due to the start year. CT non-cancer health hazards are roughly an order of magnitude lower than RME non-cancer health hazards, but are still above one at all locations except River Section 3 (Tables 7-6a to 7-6d). Non-cancer hazard indices by river section are shown on Figures 7-1 and 7-2 for the RME and CT exposure, respectively. All hazard indices except the CT estimate in River Section 3 are well above the target level of one, indicating that the MNA alternative will not meet the non-cancer hazard index target level in the long term.

Based on RME and CT comparisons, the base MNA alternative achieves a 25 to 35 percent reduction in non-cancer health hazard compared to the baseline No Action alternative in the upper river, but only an 11 to 14 percent reduction when upper bound MNA concentrations are compared to upper bound No Action concentrations (Table 7-6a). Similar results are seen in individual river sections (Tables 7-6b to 7-6d), with the smallest reductions (as low as 2 percent) seen in River Section 2.

Cancer Risks

Incremental RME cancer risks for the MNA alternative in the Upper Hudson River range from 4.0 x 10^{-4} to 1.2 x 10^{-3} using a start date of 2009 and from 3.5 x 10^{-4} to 1.1 x 10^{-3} using a start date of 2011(Table 7-7a). RME cancer risks range from about 5.0 x 10^{-4} to 1.2 x 10^{-3} in River Section 1 (Table 7-7b), from 5.2 x 10^{-4} to 2.2 x 10^{-3} in River Section 2 (Table 7-7c), and from about 6.8 x 10^{-5} to 7.7 x 10^{-5} in River Section 3 (Table 7-7d). Cancer risks by river section are shown on Figures 7-3 and 7-4 for the RME and CT exposure, respectively. RME cancer risks exceed the target risk range of 10^{-4} to 10^{-6} in River Sections 1 and 2, indicating that the MNA alternative will not meet the cancer risk target level in the long term.

Based on RME and CT cancer risk comparisons, the base MNA alternative achieves a 31 to 52 percent reduction in cancer risk compared to the baseline No Action alternative in the upper river, but only a 13 to 18 percent reduction in cancer risk when the upper bound MNA concentrations are compared to the upper bound No Action concentrations (Table 7-7a). Results are similar when examined on a section-specific basis (Tables 7-7b to 7-7d), with the smallest reductions (as low as 2 percent) seen in River Section 2.

7.3.2.3 Short-Term Human Health Cancer Risks and Non-Cancer Health Hazards

Based on the modeling done to estimate long-term effects, a qualitative evaluation of short-term cancer risks and non-cancer health hazards can be made. Fish concentrations for the seven-to-nine-year short-term period beginning in 2004 exceed all target levels (Table 7-4), with the exception that the 0.4 ppm target is achieved in River Section 3 in 2011. Since PCB concentrations are highest in the initial modeling years, target non-cancer health hazard and cancer risk levels will not be achieved in the short term under the MNA alternative. Short-term PCB concentrations do not differ between the base and upper bound No Action scenarios.

7.3.2.4 Time to Reach Ecological Fish Target Levels

The MNA alternative does not meet any of the river otter PRGs in River Sections 1 and 2 for the duration of the model (Table 7-8). In River Section 3, the river otter LOAEL is reached in 14 years. There is no difference between the estimated upper bound and base MNA alternatives in River Section 3 because there are no cohesive sediments in this section of the river. Using the upper bound MNA concentrations, the mink NOAEL and LOAEL target concentrations are not reached in River Sections 1 and 2. Under the base MNA concentrations, the LOAEL target concentration for the mink is reached in River Section 1 in 22 years and in River Section 2 in 10 years, and the NOAEL target concentration is not reached in these sections at all.

7.3.2.5 Ecological Toxicity Quotients and Relative Reductions

Average toxicity quotients for the river otter are above one for all comparisons (Table 7-9). The average mink TQ exceeded one for all comparisons except the base MNA LOAEL comparison in River Section 2 and the LOAEL comparison in River Section 3.

The MNA alternative achieves between a 51 to 63 percent reduction in risk as compared to the No Action alternative in River Section 1, a 7 to 36 percent reduction in River Section 2, and a 49 to 51 percent reduction in River Section 3 (Table 7-12). Greater reductions in risk are seen when the base MNA scenario is compared to the base No Action scenario than are seen in the comparison of the upper bound scenarios for MNA and No Action.

7.3.2.6 Probabilistic Dose-Response Analysis

The probabilistic dose-response analysis for the MNA alternative (including estimated upper bound) in River Section 1 (RM 189), shows about a 92 to 99 percent probability of a 75 percent reduction in female river otter fecundity in the year 2011, falling to 59 to 90 percent in 2021, and 20 to 73 percent in 2036 (Table 7-10 and Figure 7-10). At the upper end of the dose response function, the MNA alternative shows between 23 to 50 percent probability of a 98 percent reduction in fecundity, falling to 3 to 21 percent in 2021, and to 0.2 to 7 percent in 2036. At the 50 percent effect level, there is a 100 percent probability of a 50 percent reduction in fecundity in 2011, a 95 to 100 percent probability in 2021, and a 71 to 98 percent probability in 2036.

In River Section 2 (RM 184), the MNA (including estimated upper bound) alternative shows a 97 to 100 percent probability of a 75 percent reduction in fecundity in the year 2011 (Table 7-11 and Figure 7-9). In 2021, there is a 58 to 100 percent probability of a 75 percent reduction in fecundity, falling to 3 - 98 percent in 2036. At the upper end of the dose response function, the MNA alternative shows between a 43 to 83 percent probability of a 98 percent reduction in fecundity in 2011, falling to 3 - 67 percent in 2021, and to 0 - 47 percent in 2036. At the 50 percent effect level, there is a 100 percent probability of a 50 percent reduction in fecundity in 2011, a 95 to 100 percent probability in 2021, and 31 to 100 percent probability in 2036.

7.3.3 CAP-3/10/Select

This alternative includes capping with dredging to perform Expanded Hot Spot remediation (*i.e.*, in which the nominal MPA target concentrations are 3 g/m^2 or greater) in River Section 1, Hot Spot remediation (*i.e.*, in which the nominal MPA target concentrations are 10 g/m^2 or greater) in River Section 2, and remediation of select areas (*i.e.*, sediments with high concentration PCB target areas) in River Section 3. This alternative also includes dredging in the navigation channel as necessary to implement the remediation and to accommodate normal boat traffic in the river. Remediation will commence in 2004 and will be completed in 2008. This alternative is performed in conjunction with a separate source control (*i.e.*, NTCRA) in the vicinity of the GE Hudson Falls plant and also relies on naturally occurring attenuation processes to reduce the toxicity, mobility, and volume of the remaining PCBs in the Upper Hudson River sediments after the construction is completed. A review of site conditions will be conducted at five-year intervals.

This alternative assumes that 10 percent of the area targeted for capping is not capped due to improper cap placement. Two simulations for sensitivity analyses were conducted for CAP-3/10/Select, modified by the assumption that a greater percentage of the area in the area targeted for containment (capping) is assumed not to have a cap due to improper placement during construction of the cap or to subsequent damage to the cap after placement. The two simulations that were modeled were that 15 percent and 25 percent of the areas targeted for capping were not capped. These risk and hazard results from these simulations are similar to those from the base run (Table 7-6a to 7-7d) and are therefore not discussed in detail.

7.3.3.1 Time to Reach Human Health-Based Fish Target Levels

In each of River Sections 1, 2, and 3, the CAP-3/10/Select alternative meets at least one of the target fish concentrations. In River Section 1, the 0.4 ppm target is achieved in 19 years (2026), in River Section 2 in 20 years, and in River Section 3 in one year (Table 7-5). The 0.2 ppm target concentration is achieved in 36 years (2044) in River Section 2 and in five years in River Section 3. The lowest target concentration of 0.05 ppm is reached in 42 years (2051) in River Section 3. The remaining target levels are not achieved within the modeling time frame (which ends in 2067). Results of the sensitivity runs were within two years of the base run (Table 7-5). These comparisons show that at least one of the target levels would be reached in each section of the river under the CAP-3/10/Select alternative.

7.3.3.2 Cancer Risks and Non-Cancer Health Hazards and Relative Reductions

Cancer risks and non-cancer hazards were calculated for the CAP-3/10/Select alternative. These numbers are then compared to the No Action and MNA alternatives to determine the relative risk reductions achieved by this alternative.

Non-Cancer Health Hazards

Non-cancer health hazards for the CAP-3/10/Select alternative in the Upper Hudson River are 1.3 and 15 for the CT and RME scenarios, respectively (Table 7-6a). Hazard indices for the CT and RME scenarios were 1.6 and 17 in River Section 1 (Table 7-6b), 1.9 and 22 in River Section 2 (Table 7-6c), and 0.44 and 5.4 in River Section 3 (Table 7-6d). The results for the sensitivity runs show only small differences from the base scenario; however, as would be expected, the 25 percent loss sensitivity shows the highest hazard indices of the group.

The CAP-3/10/Select alternative achieves a 72 to 81 percent RME non-cancer health hazard reduction compared to No Action and a 63 to 79 percent RME non-cancer health hazard reduction compared to MNA in the upper river (Table 7-6a). Comparisons to the CT scenario and comparisons by river section show similar reductions in risk in River Sections 1 and 2. Reductions are lower in River Section 3, where the RME and CT scenarios show a 46 and 53 percent reduction, respectively,

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compared to No Action, and a 23 and 26 percent risk reduction compared to MNA. Non-cancer hazard indices by river section are shown on Figures 7-1 and 7-2 for the RME and CT exposure, respectively.

Cancer Risks

Incremental cancer risks for the CAP-3/10/Select alternative in the Upper Hudson River are 4.5 x 10^{-6} and 1.8 x 10^{-4} for the CT and RME scenarios, respectively (Table 7-7a). Cancer risks for CT and RME exposure are 5.4 x 10^{-6} and 2.4 x 10^{-4} in River Section 1 (Table 7-7b), 6.6 x 10^{-6} and 2.4 x 10^{-4} in River Section 2 (Table 7-7c), and 1.5 x 10^{-6} and 5.8 x 10^{-5} in River Section 3 (Table 7-7d). The results for the sensitivity runs show only small differences from the base scenario; however, the highest incremental cancer risk is associated with the 25 percent loss sensitivity run, as would be expected.

The CAP-3/10/Select alternative achieves a 77 to 87 percent RME cancer risk reduction compared to No Action and a 55 to 84 percent reduction compared to MNA in the upper river (Table 7-7a). Comparisons to the CT scenario and comparisons by river section show similar reductions in cancer risk in River Sections 1 and 2. In River Section 3 reductions are 65 and 53 percent compared to the No Action alternative and 25 and 26 percent compared to the MNA for RME and CT exposure, respectively. Incremental cancer risks by river section are shown on Figures 7-3 and 7-4 for the RME and CT exposure, respectively.

All of the calculated cancer risks are within the range of 10^{-4} to 10^{-6}, indicating that the CAP-3/10/Select alternative will meet the cancer risk target level in the long-term.

7.3.3.3 Short-Term Human Health Cancer Risks and Non-Cancer Health Hazards

Based on the modeling done to estimate long-term effects, a qualitative evaluation of short-term cancer risks and non-cancer health hazards can be made. Fish concentrations for the seven-year short-term period beginning in 2004 indicate that only the 0.4 ppm fish concentration target level in River Section 3 would be met in the short term, in 2010 (Table 7-4); none of the other non-cancer health hazard and cancer risk target levels will be achieved in the short term under this alternative.

7.3.3.4 Time to Reach Ecological Fish Target Levels

The CAP-3/10/Select alternative achieves the LOAEL target concentration for mink in River Sections 2 and 3 by the completion of the remedial action in 2010, and the mink LOAEL in River Section 1 is reached in five years (2014). The CAP-3/10/Select alternative does not meet any of the NOAEL target levels for the river otter in any of the river sections within the modeling time frame, but reaches the otter LOAEL target concentration in River Sections 2 and 3 in 52 years and 8 years, respectively (Table 7-8).

The 15 and 25 percent loss sensitivity analyses showed similar times to reach target concentrations, requiring at most two years longer than the base capping scenario to achieve some of the target levels (Table 7-8).

7.3.3.5 Ecological Toxicity Quotients and Relative Reductions

Toxicity quotients for the river otter are above one for comparisons at River Sections 1 and 2 (Table 7-9). In River Section 3, only the otter NOAEL comparison has a TQ above one, while all other comparisons are below one. The mink LOAEL TQ is below one at River Section 2.

Reductions in TQs in comparisons between the CAP-3/10/Select and the No Action alternative range from 78 to 82 percent in the River Section 1, from 75 to 87 percent reduction in River Section 2, and from 64 to 65 percent in River Section 3 (Table 7-12). Reductions compared to the MNA alternative are between 45 and 64 percent in the River Section 1 and 62 and 86 percent in River Section 2, and are 29 percent in River Section 3 (Table 7-12).

The TQs for the sensitivity analyses are similar to those of the base CAP-3/10/Select alternative (Table 7-9). TQs for the 25 percent cap failure are slightly greater than the other scenarios (Table 7-9). Reductions in risk range for 25 percent cap failure as compared to the No Action alternative range between 76 to 81 percent in the River Section 1 and 70 to 84 percent in River Section 2, and are 62 percent in River Section 3 (Table 7-12). These are slightly lower than the reductions seen in the base scenario. Reductions as compared to the MNA alternative for the 25 percent cap failure scenario are between 38 and 61 percent in the River Section 1, 54 and 83 percent in River Section 2, and 23 and 25 percent in River Section 3 (Table 7-12).

7.3.3.6 Probabilistic Dose-Response Analysis

The probabilistic dose-response analysis for the CAP-3/10/Select alternative in River Section 1 (RM 189), shows about a 47 percent probability of a 75 percent reduction in female river otter fecundity in the year 2011, falling to 19 percent in 2021, and 10 percent in 2036 (Table 7-10 and Figure 7-11). At the upper end of the dose-response function, the CAP-3/10/Select alternative shows about a 1 percent probability of a 98 percent reduction in fecundity, falling to 0.1 percent in 2021, and to 0 percent in 2036. At the 50 percent effect level, there is a 91 percent probability of a 50 percent reduction in fecundity in 2011, a 71 percent probability in 2021, and a 55 percent probability in 2036.

In River Section 2 (RM 184), the CAP-3/10/Select alternative shows a 40 percent probability of a 75 percent reduction in fecundity in the year 2011 (Table 7-11 and Figure 7-11). In 2021 there is a 5 percent probability of a 75 percent reduction in fecundity in 2011, falling to 0.1 percent in 2036. At the upper end of the dose-response function, the CAP-3/10/Select alternative shows a 0.9 percent probability of a 98 percent reduction in fecundity, falling to 0 percent in 2021 and in 2036. At the 50 percent effect level, there is a 88 percent probability of a 50 percent reduction in fecundity in 2011, a 42 percent probability in 2021, and a 6 percent probability in 2036.

7.3.4 REM-3/10/Select

This alternative includes Expanded Hot Spot remediation (*i.e.*, in which the nominal MPA target concentrations are 3 g/m^2 PCBs or greater) in River Section 1, Hot Spot remediation (*i.e.*, in which the nominal MPA target concentrations are 10 g/m^2 or greater) in River Section 2, and dredging of select areas (*i.e.*, sediments with high concentration PCB target areas) in River Section 3. This alternative also includes dredging in the navigation channel as necessary to implement the remediation and to accommodate normal boat traffic on the river. Remediation will commence in 2004 and will be completed in 2008. This alternative is performed in conjunction with a separate source control (*i.e.*, NTCRA) in the vicinity of the GE Hudson Falls plant. After construction is completed, this alternative relies on institutional controls such as the fish consumption advisories and on MNA in areas not remediated until the RAOs are achieved. A review of site conditions will be conducted at five-year intervals.

In addition to the base case, three simulations for sensitivity analyses were conducted based on the input for REM-3/10/Select, with assumptions of three different residual Tri+ PCB concentrations in sediment:

- 0 mg/kg in the entire depth of sediment modeled in dredged areas;
- 2 mg/kg in the top 10 cm of sediment in dredged areas; and
- 5 mg/kg in the top 10 cm of sediment in dredged areas.

The sensitivity runs utilized these assumptions of residual PCB concentrations in place of the original (base case) assumption of a residual concentration of 0.25 mg/kg PCBs for cohesive sediments and 0.5 mg/kg for non-cohesive sediments in the entire depth of sediments in dredged areas. The quantitative risks associated with the three sensitivity analysis runs are similar to the base run and are therefore not discussed in detail below.

7.3.4.1 Time to Reach Human Health Fish Target Levels

In each of River Sections 1, 2, and 3, the REM-3/10/Select alternative meets at least one of the target fish concentrations. In River Section 1, the 0.4 ppm target is achieved in 18 years (2025), in River Section 2 in 16 years, and River Section 3 in one year (Table 7-5). The 0.2 ppm target concentration is achieved in 32 years (2040) in River Section 2 and in five years in River Section 3. The most stringent target concentration of 0.05 ppm is reached in 42 years (2051) in River Section 3. The remaining target levels are not achieved during the modeling time frame. The sensitivity run results were within ten years of the base run (Table 7-5), with the 5 ppm residual run exhibiting the greatest difference. These comparisons show that at least one of the target levels would be reached in each section of the river under the REM-3/10/Select alternative.

7.3.4.2 Cancer Risks and Non-Cancer Health Hazards and Relative Reductions

Cancer risks and non-cancer health hazards are calculated for the REM-3/10/Select alternative. These numbers are then compared to the No Action and MCA alternatives to determine the relative risk reduction achieved by this alternative.

Non-Cancer Health Hazards

Non-cancer health hazards for the REM-3/10/Select alternative in the Upper Hudson River are 1.2 and 13 for the CT and RME scenarios, respectively (Table 7-6a). Hazard indices for the CT and RME scenarios were 1.5 and 16 in River Section 1 (Table 7-6b), 1.5 and 18 in River Section 2 (Table 7-6c), and 0.44 and 5.3 in River Section 3 (Table 7-6d). The results of the sensitivity runs do not differ much from the base scenario, with the exception of the 5 ppm residual run, which shows the highest non-cancer hazard indices of the group (as expected).

The REM-3/10/Select alternative achieves a 75 to 84 percent RME hazard index reduction compared to No Action and a 67 to 82 percent RME hazard index reduction compared to MNA in the upper river (Table 7-6a). Comparisons to the CT scenario and comparisons by river section show similar reductions in hazard indices in River Sections 1 and 2. Reductions are lower in River Section 3; reductions for the RME and CT scenarios show a 47 and 54 percent reduction compared to No Action and a 24 and 27 percent reduction in hazard index compared to MNA. Non-cancer hazard indices by river section are shown on Figures 7-1 and 7-2 for the RME and CT exposure, respectively.

Cancer Risks

Incremental cancer risks for the REM-3/10/Select alternative in the Upper Hudson River are 4.0×10^{-6} and 1.7×10^{-4} for the CT and RME scenarios, respectively (Table 7-7a). Cancer risks for CT and RME exposure are 5.2×10^{-6} and 2.3×10^{-4} in River Section 1 (Table 7-7b), 5.3×10^{-6} and 2.0×10^{-4} in River Section 2 (Table 7-7c), and 1.5×10^{-6} and 5.7×10^{-5} in River Section 3 (Table 7-7d). The sensitivity runs show that a 5 ppm residual can substantially increase cancer risks in the

400655

upper river and River Sections 1 and 2. The 2 ppm residual scenario shows a smaller, but noticeable, increase in cancer risks.

The REM-3/10/Select alternative achieves a 79 to 88 percent RME cancer risk reduction compared to No Action and a 58 to 86 percent RME cancer risk reduction compared to MNA in the upper river (Table 7-7a). Comparisons to the CT scenario and comparisons by river section show similar reductions in cancer risk in River Sections 1 and 2. In River Section 3, reductions are 66 and 54 percent compared to the No Action alternative and 26 and 27 percent compared to the MNA for the RME and CT exposures, respectively. Cancer risk reduction decreases with increasing residual concentrations. Incremental cancer risks by river section are shown on Figures 7-3 and 7-4 for the RME and CT exposure, respectively.

All of the calculated cancer risks are within the target risk range of 10^{-4} to 10^{-6}, indicating that the REM-3/10/Select alternative will meet the cancer risk target level in the long-term.

7.3.4.3 Short-Term Human Health Cancer Risks and Non-Cancer Health Hazards

Based on the modeling done to estimate long-term effects, a qualitative evaluation of short-term cancer risks and non-cancer health hazards can be made. For the seven-year short-term period beginning in 2004, only the 0.4 ppm fish concentration target level in River Section 3 would be met (Table 7-4); none of the other non-cancer health hazard and cancer risk target levels will be achieved in the short term under this alternative.

7.3.4.4 Time to Reach Ecological Fish Target Levels

The REM-3/10/Select alternative achieves the LOAEL target concentration for mink in River Sections 2 and 3 by the completion of the remedial action by 2009 and 2010, respectively (Table 7-8). The REM-3/10/Select alternative does not meet any of the NOAEL target levels for the river otter in any of the river sections within the modeling time frame (see Table 7-8), but the otter LOAEL in River Section 3 is reached in 2018.

The sensitivity runs showed similar times to reach target concentrations, with the exception of the 5 ppm residual, which takes more than 16 years longer than the base removal scenario to achieve some of the target levels (Table 7-8).

7.3.4.5 Ecological Toxicity Quotients and Relative Reductions

Toxicity quotients for the river otter are above one for comparisons at River Sections 1 and 2 (Table 7-9). The mink LOAEL TQs are below one at all river sections. In River Section 3, only the river otter NOAEL TQ is greater than one.

Reductions in toxicity quotients between REM-3/10/Select and the No Action alternative range from 78 to 83 percent in the River Section 1 and 79 to 89 percent in River Section 2, and are 65 percent in River Section 3 (Table 7-12). Reductions as compared to the MNA alternative range from 44 to 65 percent in the River Section 1, 67 to 88 percent in River Section 2, and 28 to 30 percent in River Section 3 (Table 7-12).

The TQs for the sensitivity runs are similar to those of the base CAP-3/10/Select alternative (Table 7-9), although TQs for mink LOAEL TQ at River Section 1 are greater than one for the 2 ppm and 5 ppm residual scenarios. The river otter LOAEL TQ at River Section 3 is above one for the 5 ppm residual scenario.

Reductions in risk for the sensitivity analysis runs as compared to the No Action alternative range from 65 to 84 percent in the River Section 1, 56 to 90 percent in River Section 2, and 54 to 66 percent in River Section 3 (Table 7-12). Reductions in risk for the sensitivity analysis runs as compared to the MNA alternative range from14 to 67 percent in the River Section 1, 34 to 89 percent in River Section 2, and 9 to 33 percent in River Section 3 (Table 7-12). The greatest reductions in TQs as compared to the No Action alternative are seen in the runs with the lowest residual sediment PCB concentrations.

400657

7.3.4.6 Probabilistic Dose-Response Analysis

The probabilistic dose-response analysis for the REM-3/10/Select alternative in River Section 1 (RM 189), shows about a 41 percent probability of a 75 percent reduction in female river otter fecundity in the year 2011, falling to 17 percent in 2021, and 10 percent in 2036 (Table 7-10 and Figure 7-11). At the upper end of the dose-response function, the REM-3/10/Select alternative shows about a 1 percent probability of a 98 percent reduction in fecundity, falling to 0.1 percent in 2021, and to 0 percent in 2036. At the 50 percent effect level, there is a 89 percent probability of a 50 percent reduction in fecundity in 2011, a 68 percent probability in 2021, and a 54 percent probability in 2036.

In River Section 2 (RM 184), the REM-3/10/Select alternative shows a 23 percent probability of a 75 percent reduction in fecundity in the year 2011 (Table 7-11 and Figure 7-11). In 2021 there is a 3 percent probability of a 75 percent reduction in fecundity, falling to 0.1 percent in 2036. At the upper end of the dose-response function, the REM-3/10/Select alternative shows a 0.2 percent probability of a 98 percent reduction in fecundity in 2011, falling to 0 percent in 2021 and in 2036. At the 50 percent effect level, there is a 75 percent probability of a 50 percent reduction in fecundity in 2011, a 30 percent probability in 2021, and a 4 percent probability in 2036.

7.3.5 REM-0/0/3

This alternative includes Full-Section remediation (*i.e.*, in which the MPA target concentrations are 0 g/m^2 or greater) in River Sections 1 and 2, and Expanded Hot Spot remediation (*i.e.*, in which the nominal MPA target concentrations are 3 g/m^2 or greater) in River Section 3. This alternative also includes dredging in the navigation channel as necessary to implement the remediation and to accommodate normal boat traffic on the river. Remediation will commence in 2004 and will be completed in 2010. This alternative is performed in conjunction with a separate source control (*i.e.*, NTCRA) in the vicinity of the GE Hudson Falls plant. After construction is completed, this alternative relies on institutional controls such as fish consumption advisories and MNA in areas not remediated until the RAOs are achieved. A review of site conditions will be conducted at five-year intervals.

7.3.5.1 Time to Reach Human Health Fish Target Levels

REM-0/0/3 meets at least one of the target concentrations in all three sections of the river within the modeling time frame (Tables 7-4 and 7-5). The 0.4 ppm target concentration is achieved in 2013, in 2015, and in 2010 in River Section 1, River Section 2, and in River Section 3, respectively (Table 7-4). The 0.2 ppm target concentration is achieved in 2034 in River Section 2 and in 2013 in River Section 3. The most stringent target concentration of 0.05 mg/kg PCBs in fish fillets is reached in 2050 in River Section 3. Table 7-5 shows the number of years to achieve these target levels for each river section under the REM-0/0/3 alternative. Note that all alternatives share the same start years in this table (although REM-0/0/3 is completed later than the other alternatives) to allow a direct comparison between alternatives.

7.3.5.2 Cancer Risks and Non-Cancer Health Hazards and Relative Reductions

Cancer risks and non-cancer health hazards calculated for the REM-0/0/3 alternative are compared to target levels to determine cancer risks and non-cancer health hazards. These results are then compared to the No Action and MNA alternatives to determine the relative cancer risk and non-cancer health hazard reduction achieved by this alternative.

Non-Cancer Health Hazards

Non-cancer health hazards for the REM-0/0/3 alternative in the Upper Hudson River are 0.7 and 7.6 for the CT and RME scenarios, respectively (Table 7-6a). CT and RME hazard indices are 1.0 and 10 in River Section 1 (Table 7-6b), 0.87 and 9.7 in River Section 2 (Table 7-6c), and 0.3 and 3.6 in River Section 3 (Table 7-6d). All CT hazard indices are below one, with the exception of the CT at River Section 1, which equals one.

The REM-0/0/3 alternative achieves an 84 to 90 percent RME non-cancer health hazard reduction compared to No Action and a 77 to 88 percent RME non-cancer health hazard reduction compared to MNA in the Upper Hudson River as a whole (Table 7-6a). Comparisons to the CT scenario and comparisons by river section show similar reductions in non-cancer health hazards in River Sections 1 and 2. In River Section 3, reductions range from 60 to 65 percent compared to the

No Action alternative and from 37 to 40 percent compared to MNA. Non-cancer hazard indices by river section are shown on Figures 7-1 and 7-2 for the RME and CT exposure, respectively.

Cancer Risks

Incremental cancer risks for the REM-0/0/3 alternative in the Upper Hudson River are 2.4 x 10^{-6} and 1.2 x 10^{-4} for the CT and RME scenarios, respectively (Table 7-7a). CT and RME cancer risks are 3.3 x 10^{-6} and 1.7 x 10^{-4} in River Section 1 (Table 7-7b), 3.0 x 10^{-6} and 1.3 x 10^{-4} in River Section 2 (Table 7-7c), and 1.0 x 10^{-6} and 4.3 x 10^{-5} in River Section 3 (Table 7-7d).

The REM-0/0/3 alternative achieves an 84 to 91 percent RME risk reduction compared to No Action and a 66 to 89 percent RME risk reduction compared to MNA (Table 7-7a). Comparisons to the CT scenario and comparisons by river section show similar reductions in risk in River Sections 1 and 2. In River Section 3, reductions are 65 to 73 percent compared to the No Action alternative and 36 to 40 percent compared to the MNA. Cancer risks by river section are shown on Figures 7-3 and 7-4 for the RME and CT exposure, respectively.

All of the calculated cancer risks are within the target risk range, indicating that the REM-3/10/Select alternative will meet the cancer risk target level in the long term.

7.3.5.3 Short-Term Human Health Cancer Risks and Non-Cancer Health Hazards

Based on the modeling done to estimate long-term effects, a qualitative evaluation of short-term cancer risks and non-cancer health hazards can be made. Fish concentrations for the nine-year short-term period beginning in 2004 indicate that only the 0.4 ppm fish concentration target level in River Section 3 would be met in the short-term, in 2010 (Table 7-4); none of the other non-cancer health hazard and cancer risk target levels will be achieved in the short term under this alternative.

7.3.5.4 Time to Reach Ecological Fish Target Levels

The REM-0/0/3 alternative achieves the LOAEL target concentration for mink in River Sections 2 and 3 by the completion of the remedial action in 2010 (Table 7-8). The REM-0/0/3 alternative does not meet any of the NOAEL target levels for the river otter in any of the river sections within the modeling time frame (see Table 7-8), but the otter LOAEL in River Sections 2 and 3 is reached in 2044 and 2015, respectively.

7.3.5.5 Ecological Toxicity Quotients and Relative Reductions

Average toxicity quotients for the river otter are above one at River Sections 1 and 2 (Table 7-9). In River Section 3, only the otter NOAEL has a TQ above one, with all other comparisons below one. The mink LOAEL TQs are also below one at River Sections 1 and 2. This alternative has the lowest calculated ecological toxicity quotients.

Reductions in TQs compared to the No Action alternative are between 84 and 87 percent in the River Section 1, 86 and 93 percent in River Section 2, and 47 and 49 percent in River Section 3 (Table 7-12). Reductions compared to the MNA alternative are between 59 and 75 percent in the River Section 1, 79 and 93 percent in River Section 2, and 47 and 49 percent in River Section 3 (Table 7-12).

7.3.5.6 Probabilistic Dose-Response Analysis

The probabilistic dose-response analysis for the REM-0/0/3 alternative in River Section 1 (RM 189) shows about a 12 percent probability of a 75 percent reduction in female river otter fecundity in the year 2011, falling to 7 percent in 2021, and 6 percent in 2036 (Table 7-10 and Figure 7-11). At the upper end of the dose-response function, the REM-0/0/3 alternative shows about a 0.1 percent probability of a 98 percent reduction in fecundity, falling to 0 percent in 2021 and 2036. At the 50 percent effect level, there is a 60 percent probability of a 50 percent reduction in fecundity in 2011, a 47 percent probability in 2021, and a 46 percent probability in 2036.

In River Section 2 (RM 184), the REM-0/0/3 alternative shows a 5 percent probability of a 75 percent reduction in fecundity in the year 2011 (Table 7-11 and Figure 7-11). In 2021 there is a 0.3 percent probability of a 75 percent reduction in fecundity, falling to 0 percent in 2036. At the upper end of the dose-response function, the REM-0/0/3 alternative shows a 0 percent probability of a 98 percent reduction in fecundity in 2011, 2021, and 2036. At the 50 percent effect level, there is a 40 percent probability of a 50 percent reduction in fecundity in 2011, a 9 percent probability in 2021, and a 2 percent probability in 2036.

7.4 Uncertainties in Human Health and Ecological Risk Characterization

The uncertainties associated with the human health and ecological risk assessment procedures are discussed in detail in the Revised HHRA (USEPA, 2000p) and Revised ERA (USEPA, 2000q), respectively. Uncertainties associated with the HUDTOX fate and transport modeling and the FISHRAND bioaccumulation modeling are discussed in the RBMR (USEPA, 2000a) and in Appendix D of this FS. This section provides a brief summary of these findings.

The uncertainties associated with characterization of risks under a given set of exposure concentrations are consistent among alternatives and should not influence estimates of relative reductions in risk. In contrast, uncertainty in forecasts of exposure concentrations can alter estimates of relative reductions in risk. This is because the level of uncertainty in predicting exposure concentrations is believed to be greater for No Action and MNA than for active remediation, as discussed in Appendix D. Future trends in surface sediment concentrations in particular are subject to high levels of uncertainty for No Action and MNA, for which the model predicts reductions over time by a combination of burial and exchange with the water column. Active remediation, in which PCBs are permanently removed from the river, has a much higher level of certainty. Uncertainties associated with the exposure and bioaccumulation modeling are common to both the human health and ecological risk assessments and are discussed in the following text.

7.4.1 Uncertainties in Exposure Pathway Assumptions

The assumptions used for the selection of human health exposure pathways, defining the angler population, PCB concentrations in fish, fish ingestion rate, fraction from source, angler exposure duration, and PCB cooking losses are considered to be reasonable, and the associated uncertainty is not expected to influence the overall conclusions of the Revised HHRA (USEPA, 2000p). Likewise, the assumptions used for the ecological exposure pathways are considered to be reasonable and the associated uncertainty is not expected to influence the overall conclusions of the Revised ERA (USEPA, 2000q).

7.4.2 Uncertainties in Toxicological Data

The toxicity values used in the human health risk assessment have been peer reviewed and are the most current values recommended by USEPA in its Integrated Risk Information System (IRIS) (USEPA, 1999i). A number of epidemiological studies in human populations and animal toxicity studies have been conducted since the IRIS files for Aroclors 1016 and 1254 were last updated. USEPA is currently evaluating these toxicity data as part of the non-cancer re-assessment and will determine if modifications to the RfD are warranted. The fact that any previous exposures (either background or past consumption of PCB-contaminated fish) may still be reflected in an individual's current body burden is an additional source of uncertainty, and may result in an underestimate of non-cancer health hazards. The uncertainties in the cancer slope factor (CSF) suggest that estimated cancer risks may be either over- or under-estimated (USEPA, 1996c; USEPA, 1999d).

To minimize uncertainty associated with the difference among species in sensitivity to PCBs in ecological receptors, the TRVs utilized for the Hudson River ecological risk assessments and utilized for this FS are based on studies conducted on species the same as or closely related to (*i.e.*, within the same taxonomic family) the ecological receptors evaluated in this FS (river otter and mink). Both laboratory and field studies were used to develop TRVs.

7.4.3 Uncertainties in Exposure and Bioaccumulation Modeling

Two models - HUDTOX and FISHRAND - were used to predict fish concentrations used in this FS. Uncertainties associated with these models are summarized below and discussed in greater detail in Appendix D.

7.4.3.1 Uncertainties in the HUDTOX Fate and Transport Modeling

The HUDTOX mass balance fate and transport model is the quantitative foundation for the alternative-specific risk assessments presented in this FS. HUDTOX provides a best-estimate interpretation of the 1977–99 history of observed PCB fate and transport in the Upper Hudson River, at a model segment-averaged spatial scale. While this model is calibrated to provide a best-estimate 400663 interpretation of data, the interpretations are not necessarily exact. First, the calibrated model is limited by the quality of available calibration data. In some key areas, the calibration data are limited (*e.g.*, there are only very limited data available on surface-layer sediment PCB concentrations over time). Further, deficiencies in the calibration data could result in a model that is biased in the sense that causal relationships are not perfectly captured, which may result in inaccuracies when the model is used in a forecast mode. Bias might also be introduced if there has been a qualitative change in the nature of PCB fate and transport in the river relative to the model calibration period. Finally, the model cannot capture all the details of PCB fate and transport at the local scale at which transport from the environment into biota, and thus potentially to humans, actually occurs.

Uncertainties associated with HUDTOX model calibration and spatial segmentation, as well as an empirical analysis of recent data-based trends in fish and sediment (Appendix D), raise the distinct possibility of a slower rate of natural attenuation of sediment exposure concentrations than that predicted by the HUDTOX model, particularly at the localized spatial scales associated with the foraging range of resident fish. This would result in overestimation of the benefits of natural attenuation.

The trend analyses suggest the possibility that the model-predicted rate of decline of surface sediment Tri+ PCB concentrations in locations associated with NYSDEC fish sample collection, and, as a result, the rate of decline of fish concentrations driven by sediment exposures, may be too fast. The discrepancy is most likely due to cohesive sediments, as these sediments provide the main route of exposure to fish. This, in turn, suggests that the use of a bounding forecast for No Action/MNA constructed using a slower rate of decline in cohesive sediment concentrations is an appropriate method to address uncertainty. A full discussion of the development of the bounding forecast is contained in Appendix D.

7.4.3.2 Uncertainties in FISHRAND Bioaccumulation Modeling

Like HUDTOX, the FISHRAND bioaccumulation model similarly provides a best-estimate interpretation of the history of observed PCB concentrations in fish, conditional on the HUDTOX interpretation of PCB fate and transport. FISHRAND bioaccumulation modeling is also subject to uncertainties and potential errors.

The literature review and experimental data collected for the Hudson River has shown that: (1) river ecosystem characteristics vary significantly from one location to another depending on flow rate, depth, sediment structure, etc.; and (2) certain parameters in the model (such as feeding preferences) are only imprecisely known. Moreover, most of the observed data are not easily related to FISHRAND input parameters because observations are taken at specific points in space and time, while the FISHRAND model parameters are values corresponding to averages over time, space, and species. It is also important to remember that calibration of the FISHRAND model was conducted using environmental concentration estimates from HUDTOX as the forcing function. Thus, any uncertainties in the HUDTOX model calibration will also propagate into the FISHRAND calibration.

The RBMR shows that the relative percent difference between FISHRAND predictions and observed data is typically within 25 to 40 percent, and significantly less than that for many individual years, species, and locations. This suggests roughly a factor of two, or less, uncertainty in the mean estimate of fish concentration. Fortunately, most of the identified sources of uncertainty in the bioaccumulation modeling are likely to apply equally to the evaluation of No Action, MNA, and active remediation scenarios. This means that estimates of the relative risk reduction among remedial alternatives, and between remedial alternatives and No Action or MNA, are subject to less uncertainty.

7.4.4 Impacts of Uncertainty

As evident from the foregoing discussion, there are a number of potential sources of uncertainty in the fate and transport, bioaccumulation, and risk estimation tools used to develop and compare the alternative-specific human health and ecological risk assessments. Accordingly, the characterizations of risk associated with each alternative are also uncertain. Although these estimates are uncertain, the uncertainty that applies to the evaluation of all alternatives (including No Action) has no impact on the relative risk reduction ranking of remedial alternatives.

Analysis of relative risk reduction is potentially impacted more seriously by sources of uncertainty that apply unequally to active remediation versus No Action and MNA, or by any potential biases in the component models. As discussed, the major issue for the evaluation of relative risk reduction is the potential for biases in the HUDTOX modeling, especially in the forecast of exposure concentrations at localized spatial scales under the No Action or MNA alternatives. These issues are set out in full detail in Appendix D. In Appendix D, an evaluation of potential sources of error in the HUDTOX calibration coupled with analysis of other lines of evidence, including evaluation of recently observed trends in fish tissue and surface sediment concentrations, is used to develop a bounding calculation on cohesive sediment exposure concentrations and resulting fish tissue concentrations. Use of this bounding calculation, supported by the data, is appropriate to provide reasonable assurances on the degree of risk and hazard reduction attainable under the No Action and MNA alternatives.

Chapter 8

8. DETAILED ANALYSES OF REMEDIAL ALTERNATIVES

Chapter 8 presents a detailed description and analysis of each remedial alternative that passed the effectiveness, implementability, and cost screening evaluation in Chapter 6. Five remedial alternatives in four different categories were retained for detailed analysis. Section 8.1 provides a summary of the detailed analysis process, the nine criteria used to analyze each remedial alternative, and the manner in which these criteria are applied in this FS. Sections 8.2 through 8.6 present the detailed description and analyses of these five alternatives. To minimize redundancy, the description of the alternatives makes use of the general description of common elements (such as capping, removal, and monitoring) presented previously in Section 5.2. However, any differences or alternative-specific issues related to the implementation of these technologies are addressed in the alternative-specific descriptions and evaluations presented below. As described further in subsections 8.1.8 and 8.1.9 below, the two modifying criteria (State Acceptance and Community Acceptance) are not addressed in this FS report. The extent to which alternatives are analyzed during the detailed evaluation is determined, to a large degree, by the available data and the use of best engineering judgment.

8.1 Evaluation Process and Evaluation Criteria

The detailed description of the remedial alternatives includes the following:

- A description of the alternative, including the technologies comprising the alternative;

- A description of engineering, safety, environmental, public health, or other considerations that affect the feasibility of the alternative;

- The aspects of the sediment and surface water contamination problem that the alternative will or will not control; and

- A preliminary conceptual engineering design including necessary facilities, equipment, and construction items. A breakdown of the quantities, dimensions, and sizing of major components of the conceptual design is provided as a basis for cost estimation. Consistent with the RI/FS Guidance, the level of detail in the preliminary design is focused on providing cost estimates with an accuracy in the range of -30 percent to +50 percent.

The NCP provides nine key criteria to address the CERCLA requirements for analysis of remedial alternatives. The first two criteria are threshold criteria that must be met by each alternative. The next five criteria are the primary balancing criteria upon which the analysis is based. The final two criteria are referred to as modifying criteria and are applied, following the public comment period, to evaluate state and community acceptance.

The two **threshold criteria** are:

- Overall Protection of Human Health and the Environment; and
- Compliance with ARARs.

The five **primary balancing criteria** upon which the analysis is based are:

- Long-Term Effectiveness and Permanence;
- Reduction of Toxicity, Mobility or Volume through Treatment;
- Short-Term Effectiveness;
- Implementability; and
- Cost.

The two **modifying criteria** will be evaluated following comments on the Proposed Plan and will be described in the ROD for the site. The modifying criteria are not addressed in this FS. These criteria are:

- State Acceptance; and
- Community Acceptance.

Each of these nine criteria is described below and seven of them are employed in the detailed analysis of alternatives for remediation of Upper Hudson River sediments. The two modifying criteria (State Acceptance and Community Acceptance) will be addressed in USEPA's ROD.

It must be stressed that the alternatives described in the following analyses are conceptual. Any characteristics of these alternatives (such as remediation locations, depths, and removal/capping rates), while based on the available data and information, should be considered to be preliminary. In addition, some of the alternatives may impact wetlands adjacent to the banks of the river. If necessary, estimates of the wetland impacts will be refined, and replacement and mitigation methods will be developed during remedial design.

Brief discussions on each of the nine criteria are presented in the sections below.

8.1.1 Threshold Criterion 1: Overall Protection of Human Health and the Environment

This evaluation criterion provides a final assessment as to whether each alternative adequately protects human health and the environment, and draws on the assessments conducted under other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs. As part of determination of protectiveness, the evaluation describes how risks through each pathway would be eliminated, reduced, or controlled through treatment, engineering, or institutional controls. This criterion considers unacceptable short-term or synergistic (*e.g.*, cross-media) effects posed by an alternative. For example, overall protection considers potential volatilization of PCBs during sediment processing at the transfer facilities.

Long-term effectiveness is evaluated by using modeling results to project the human health and ecological impacts through the years over the exposure period of a human or ecological receptor. As described in Section 7.1, the maximum time frame used to calculate non-cancer health hazards and cancer risks for human health modeling is 40 years, and ecological toxicity quotient (TQ) modeling results are based on a 25-year exposure period, with starting dates ranging between 2008 and 2012 depending on the alternative and river section. The FISHRAND model was run for a 70-year period (1998 to 2067) for this FS, and the full modeling time frame is examined when determining the number of years required to reach human health and ecological target levels. As explained in Section 7.1, these time frames are consistent with the time periods for the Revised HHRA (USEPA 2000p) and Revised ERA (USEPA, 2000q). Short-term effectiveness is evaluated primarily by a qualitative evaluation of effects associated with each alternative and secondarily by examining whether preliminary remedial goals (PRGs) would be met in the short term using modeling results (not considering the effects of remedial action). Compliance with ARARs is evaluated using a straightforward comparison of modeled results with criteria.

8.1.1.1 Protection of Human Health

The protection of human health is assessed quantitatively through calculation of both non-cancer health hazards and carcinogenic health risks as described previously in subsection 7.2.1.

8.1.1.2 Protection of the Environment - Ecological Risks and Downstream Transport

The protection of the environment is assessed through the evaluation of risks to ecological receptors, and the downstream transport of PCBs. The risks to ecological receptors (specifically, the river otter and mink) are addressed quantitatively through calculation of NOAEL/LOAEL-based TQs as described previously in subsection 7.2.2. Downstream transport is evaluated through modeled projections of Tri+ PCB loads transported from one river section to the next, and from the Upper Hudson River to the Lower Hudson River.

8.1.2 Threshold Criterion 2: Compliance with ARARs

Alternatives are assessed as to whether they attain federal and state legally applicable or relevant and appropriate requirements (ARARs), including:

- Chemical-specific ARARs (*e.g.*, maximum contaminant levels [MCLs], Ambient Water Quality Criteria [AWQC]);
- Location-specific ARARs (*e.g.*, requirements for constructing a hazardous waste facility in a floodplain);
- Action-specific ARARs (*e.g.*, Toxic Substances Control Act requirements for PCB remediation waste); and
- Other criteria, advisories, and guidelines, as appropriate.

USEPA may select a remedial action that does not attain a particular ARAR under certain conditions outlined in CERCLA Section 121(d) and the NCP. These waivers are discussed in subsection 2.1.4.

8.1.3 Primary Balancing Criterion 1: Long-Term Effectiveness and Permanence

Alternatives are also assessed for the long-term effectiveness and permanence they afford, and the degree of certainty that the alternative will prove successful. Factors that can be considered, according to the NCP and RI/FS Guidance, are as follows:

- Long-term reliability and adequacy of the engineering and institutional controls, including uncertainties associated with land disposal of untreated wastes and residuals.

- Magnitude of residual risks in terms of amounts and concentrations of wastes remaining following implementation of a remedial action, considering the persistence, toxicity, mobility, and propensity to bioaccumulate of such hazardous substances and their constituents.

The time period for the evaluation of the long-term effectiveness and permanence is considered to extend from the end of the short-term period, *i.e.*, beginning in 2010 for all alternatives (except in 2012 for The REM-0/0/3 alternative, as discussed in subsection 8.1.5). Depending on the particular aspect of the criterion being analyzed, the end dates vary, as discussed below.

8.1.3.1 Magnitude of Residual Risks

The magnitude of residual risks for each alternative is based on both human health and ecological effects. These were evaluated as follows.

Long-Term Effectiveness - Human Health Evaluation

Long-term human health effects are modeled for the same time period as was used for the Revised HHRA (USEPA, 2000p) as summarized previously in subsection 7.1.2.1 and reiterated below:

For cancer risks:

- Reasonable maximum exposure (RME): 40 years (2011 through 2050)
- Central tendency (CT) exposure ("average"): 12 years (2011 through 2022)

For non-cancer health hazards:

- RME: seven years (2011 through 2017)
- CT exposure: 12 years (2011 through 2022)

However, as noted on Table 7-1, the specific years modeled vary, depending on the assumed progress of remediation within a given river segment for each alternative; No Action and MNA alternatives are modeled with time periods that correspond to the three active remedial alternatives so that meaningful comparisons among alternatives can be made. Table 7-1 summarizes the time frames utilized in the calculation of the alternative-specific human health and ecological risks and hazards.

As was done in the Revised HHRA, the modeled fish concentrations for each of the three river sections are averaged, with each year and each river section weighted equally. In addition, risk calculations are also presented for each individual section of the Upper Hudson River. The fish concentrations used are the species-weighted averages, based on Connelly *et al.* (1992), and are those considered to represent a reasonable ingestion scenario among the three fish species modeled that are consumed to any significant extent by human receptors (anglers): largemouth bass (47 percent); brown bullhead (44 percent); and yellow perch (9 percent).

The alternative-specific long-term human health risk calculations for fish ingestion for each alternative are presented in Chapter 7. More detail on the process for this calculation is provided above in subsection 7.2.1.

Long-Term Effectiveness - Ecological Assessment

The ecological assessment in Chapter 7 is based on modeled effects for two receptors, the river otter and mink. TQs are calculated for both the NOAEL and the LOAEL to provide a range of exposure risks. The bald eagle, a piscivorous bird, was also considered as a potential receptor to model for the FS. However, adult eagle risks are much lower than otter risks, and eagle egg risks are similar (but slightly lower) than otter risks. Therefore, only river otter (the most sensitive receptor) and mink results are presented here.

As in the evaluation of human health risks, the start date for the long-term effectiveness period was considered to be immediately after the equilibration period following remediation. Ecological risks for each section of the river for each active alternative are compared separately to the No Action and MNA alternatives. The 25-year forecast period used in the Revised ERA was also selected as the mink and river otter exposure period in this FS. This exposure period is considered appropriate because it extends throughout the average lifespan of both mammalian receptors. Mink live up to 10 years (Walker, 1997; Kurta, 1995) and river otter live on the average 15 to 20 years in the wild and up to 25 years in captivity (Ohio Division of Wildlife, 2000).

The alternative-specific long-term ecological risk calculations for each receptor and each alternative are tabulated and summarized in Chapter 7. More detail on the process for this calculation is provided above in subsection 7.2.2.

8.1.3.2 Adequacy and Reliability of Controls, if Any, Used to Manage Untreated Wastes or Treatment Residuals

In general, this criterion is qualitative and is based on review of documentation regarding the various technologies, and professional judgment as to how the specific conditions in the Upper Hudson River (and in individual river sections, as applicable) affect the use of information available in the literature.

400674

For capping, a semi-quantitative assessment was made of the effectiveness of the controls, assuming that partial cap failure or other defects occurred. This assessment is discussed in greater detail in the alternative-specific analysis of this criterion.

8.1.3.3 Remedy Replacement and the Continuing Need for Repairs/Maintenance

For this FS, only two elements may possibly require ongoing maintenance or activity. These are the engineered cap (a component of one of the alternatives subject to detailed analysis) and monitoring of sediments, water quality, and PCB concentrations in fish (a long-term component of all alternatives). Both elements are addressed in the conceptual design of the alternatives and in the cost estimates. A more detailed assessment for each alternative is discussed in the alternative-specific analysis for this criterion. As noted above, assumptions are made regarding the magnitude of potential cap defects, as well as their frequency. Possible consequences of the failure to detect or repair defects in the cap are discussed.

8.1.4 Primary Balancing Criterion 2: Reduction of Toxicity, Mobility, or Volume Through Treatment

CERCLA expresses a preference for remedial alternatives that employ treatment that reduces the toxicity, mobility, or volume of hazardous substances. Relevant factors include:

- The treatment processes that the remedies employ and the materials they will treat;
- The amount of hazardous materials that will be destroyed or treated;
- The degree of expected reduction in toxicity, mobility, or volume;
- The degree to which the treatment is irreversible;
- The type and quantity of residuals that will remain following treatment, considering the persistence, toxicity, mobility, and propensity to bioaccumulate of such hazardous substances and their constituents; and
- Whether the alternative would satisfy the statutory preference for treatment as a principal element.

For this FS, this criterion is evaluated both by assessment of the extent to which the mass of PCBs is reduced and the degree to which the toxicity, mobility, or volume of PCB-contaminated sediments is reduced in each of the five alternatives. Removal alternatives are considered to achieve a reduction in the volume of contaminated sediments at the site; however, the extent to which destruction of toxic contaminants (*i.e.*, PCBs) would occur varies depending on the final treatment or disposition of the removed sediments.

One alternative is analyzed that involves capping as a component (along with dredging). The extent to which the capping achieves irreversible reduction in contaminant mobility is also discussed under this criterion.

8.1.5 Primary Balancing Criterion 3: Short-Term Effectiveness

The short-term effectiveness of alternatives is assessed considering such appropriate factors as:

- Protection of the community during remedial actions;
- Protection of the workers during remedial actions;
- Potential adverse environmental impacts resulting from construction and implementation; and
- Time until remedial response objectives (*i.e.*, RAOs and PRGs) are achieved.

For the purposes of this FS, the short-term period is considered to include the time from initiation of remedial activities, assumed to be in the year 2004, through the alternative-specific and river section-specific period for implementation, and a subsequent one- to two-year period for attenuation of residual impacts. Therefore, the short-term period is of variable duration, and extends from 2004 through the year immediately prior to the beginning of the long-term period, as shown on Table 7-1. Modeling results for active remedial alternatives are compared to No Action and MNA alternatives for the same time period, so that comparisons among alternatives are on a consistent basis.

400676

8.1.5.1 Protection of the Community During Remedial Actions

Community risks that are considered include both physical hazards (*e.g.*, noise, navigation hazards) and potential exposure to hazardous materials (*e.g.*, PCBs).

The protection of the community during remedial actions is assessed on a qualitative basis because the HUDTOX model does not account for potential resuspension of sediments during remediation, and therefore the full benefits of the remedial action shown by the model may not be achieved by the year indicated by the model. However, an estimate of the additional PCB load to the water column resulting from dredging activities is made; and this is presented in the discussion of potential adverse impacts environmental impacts resulting from construction and implementation (as described in general in subsection 8.1.5.3, below).

8.1.5.2 Protection of Workers During Remedial Actions

Potential risks to workers implementing the various remedial alternatives as well as measures to prevent, minimize, or mitigate such risks are addressed as part of this criterion. The risks to workers that are considered include both physical hazards (*e.g.*, falling off the deck of a barge or being injured in other job-related accidents) and potential exposure to hazardous materials (*e.g.*, PCBs).

8.1.5.3 Potential Adverse Environmental Impacts Resulting from Construction and Implementation

Potential adverse environmental impacts are addressed both qualitatively and semi-quantitatively. As a result of a removal action, environmental conditions may be adversely affected both at the site of remedial operations as well as at locations downstream. Both concerns were considered in the development of the remedial alternatives as well as in the selection of engineering techniques to implement the alternatives. Appendix E.6 contains a detailed discussion of a semi-quantitative model used to assess short-term resuspension impacts as a result of sediment removal. These calculations are focused on the potential increase in downstream PCB loads and water column concentrations, which represent the primary route for environmental impacts in areas not directly affected by the remedial construction. Estimates of short-term loads and concentrations are compared with HUDTOX forecasts in the absence of sediment remediation to place the short-term impacts in perspective. Potential short-term impacts from actions such as temporary habitat loss are discussed qualitatively since there is no reliable means of quantifying them.

8.1.5.4 Time until Remedial Response Objectives are Achieved

As discussed earlier, modeling results do not consider the potential short-term adverse impacts of remedial actions. The time to achieve short-term remedial response objectives is evaluated using the year after the completion of the remedial action. For example, considering the Upper Hudson River as a whole, the short-term period would extend from 2004 through 2008 (or through 2010 for The REM-0/0/3 alternative), lasting for five to seven years. The short-term period is the longest for River Section 3, ending in 2010 (or 2012 for The REM-0/0/3 alternative).

As discussed earlier, HUDTOX/FISHRAND modeling results do not consider the potential short-term adverse impacts of remedial actions. The time to achieve short-term remedial response objectives is evaluated by examining conditions in the year after the completion of the remedial action. These conditions are based on the forecasts produced by HUDTOX/FISHRAND. For example, considering the Upper Hudson River as a whole, the short-term period for capping or removal alternatives extends from 2004 through 2008 (or through 2010 for The REM-0/0/3 alternative), lasting for five to seven years. The short-term period is greatest in duration for River Section 3, ending in 2010 (or 2012 for The REM-0/0/3 alternative). This arises from the fact that this section is downstream of the remedial efforts that begin upstream and that this section will be remediated last (to the extent practicable) under any remedial alternative.

The numerical human health and ecological PRGs presented in Chapter 3 are used to evaluate this criterion. The model forecast is compared to the PRGs to estimate the year in which each PRG is attained. It is important to remember that forecasts are subject to considerable uncertainty. Therefore, the estimated year of target attainment should be considered a general guide. The estimates serve best as a basis for comparison among alternatives where large differences (5 to 10 years or more) among alternatives in attaining a PRG can be identified.

8.1.6 Primary Balancing Criterion 4: Implementability

The ease or difficulty of implementing the alternatives are assessed by considering the following factors:

- Technical Feasibility

  - Degree of difficulty associated with constructing and operating the technology;
  - Expected operational reliability of the technologies;
  - Ease of undertaking additional remedial actions, if necessary; and
  - Ability to monitor the effectiveness of the alternative.

- Administrative Feasibility

  - Need to coordinate with and obtain necessary approvals and permits (*e.g.*, obtaining permits for off-site activities, rights-of-way for construction, etc.) from other agencies and offices.

- Availability of Services and Materials

  - Availability of necessary equipment and specialists;
  - Availability of adequate capacity and location of needed treatment, storage, and disposal services;
  - Availability of prospective technologies; and
  - Availability of services and materials, plus the potential for obtaining competitive bids.

8.1.7 Primary Balancing Criterion 5: Cost

Costs for CERCLA evaluation are divided into two principal categories, *i.e.*, capital costs and annual operation and maintenance (O&M) costs. A number of principal elements of a remedial alternative may fall into the category of direct and indirect capital costs:

- Construction costs;
- Equipment costs;
- Site development costs;
- Building and services costs;
- Transport and disposal costs;
- Engineering expenses;
- Startup and shakedown costs; and
- Contingency allowances.

Those items not placed into the capital cost category are considered to be O&M costs, among which are the following:

- Operating labor costs;
- Materials and energy costs;
- Purchased services;
- Administrative and insurance costs; and
- Costs of periodic site reviews.

Where expenditures will occur over differing time frames, the RI/FS Guidance (USEPA, 1988) specifies that a present worth analysis be conducted to enable comparison of different remedial alternatives on the basis of a single cost figure. A discount rate of seven percent before taxes and after inflation is used for the present worth analysis.

Consistent with the RI/FS Guidance, cost estimates performed during the feasibility study stage are expected to provide an accuracy of -30 percent to +50 percent; further, after the present worth of each alternative is calculated, individual costs may be evaluated through a sensitivity analysis if there is sufficient uncertainty concerning specific assumptions (see Section 9.2). Sensitivity analysis is to be considered for those factors that can substantially change overall costs of an alternative with only small changes in their values, especially if such factors have a high degree of uncertainty associated with them. Several factors are identified as potential candidates for consideration in a sensitivity analysis, including delineation of target area boundaries and volume of contaminated material. These are discussed further in Section 9.2.

The capital and O&M cost estimates incorporated in this FS were generated using the USACE MCACES cost estimating system. MCACES is a computer-based estimating system that uses a series of databases to build an estimate. The basic databases incorporated into the MCACES system are the Labor Rates Database and the Equipment Rates Database. Inputs from these two databases are employed to generate work crew requirements (laborers and associated equipment) and then unit prices (unit costs for accomplishing a specific task by a specific crew). An example of the procedure followed by the MCACES system that has relevance to this FS is as follows:

- Establish crew size/configuration and then the hourly cost for a dredge crew ($/hour);
- Establish dredge equipment operating costs ($/hour);
- Determine productivity applicable to work in the Hudson River (cubic yards/hour);
- Estimate the unit cost of dredging from labor and crew databases ($/cubic yard); and
- Estimate total dredging costs ($/alternative).

The estimates provided were based on the Washington County, New York prevailing wage rates. Major items such as transportation and disposal costs ($/ton) were obtained through communication with transportation companies and waste management entities. Costs of major equipment items were based on quotes or derived from historical data. Costs for certain specific items (*e.g.*, roads, rail spurs, buildings, clearing) were built up from the MCACES unit price database (BSD Costlink, 1998).

Work considered to be performed by subcontractors is loaded with either 10 or 15 percent overhead (depending on size of contract) and 10 percent profit. The prime contractor's home office overhead is included at 15 percent, profit at 8 percent, and bond at 0.60 percent. Railroad costs and landfill fees have prime contractor loadings of 2 percent for overhead, and 3 percent profit.

A 10 percent contingency on labor, a 5 percent contingency on materials, and a 10 percent design contingency have been added to the estimate to account for the level of detail available at the feasibility stage. Historic costs have been escalated at the highest price level adjustment, and an 8.25 percent state sales tax has been added to material purchases.

Further information on and detailed results from the MCACES cost estimating effort can be found in Appendix I. Output from the estimating effort is summarized in this chapter for each remedial alternative that is subject to detailed evaluation.

8.1.7.1 Present Worth Analysis

In order to compare costs for alternatives that have different implementation time frames, a present worth analysis was conducted for each remedial alternative. The present worth costs were calculated assuming an inflation rate of three percent and an annual interest rate of ten percent, for an effective discount rate of seven percent. For all alternatives that involve active remediation, the timeline used to calculate the present worth is as follows: design support testing was assumed to be conducted in 2002, remedial design was assumed to be conducted in 2003, and remediation was assumed to be conducted from 2004 through 2008 (except for The REM-0/0/3 alternative, which is assumed to have a construction period of seven years, *i.e.*, 2004 through 2010). The No Action and MNA alternatives were costed for a period of 30 years, with the 30-year period starting in 2004. Post remediation monitoring and O&M are assumed to extend 25 years after remediation is complete for the capping with select removal alternative, and for ten years after remediation is complete for the removal alternatives.

None of the cost estimates presented in the detailed analysis includes the costs of the Engineering Evaluation/Cost Analysis (EE/CA) or expected NTCRA for source control in the vicinity of the GE Hudson Falls plant, which will be conducted as a separate removal action.

8.1.8 Modifying Criterion 1: State Acceptance

This criterion provides the state - in this case, the State of New York - with the opportunity to assess any technical or administrative issues and concerns regarding each of the alternatives. State acceptance is not addressed in this FS, but will be addressed in the ROD.

8.1.9 Modifying Criterion 2: Community Acceptance

Issues and concerns the public may have regarding each of the alternatives falls into this category of evaluation. Community acceptance is not addressed in this FS document, but will be addressed in the ROD.

8.2 Alternative: No Action

8.2.1 Description

The No Action alternative consists of refraining from the active application of any remediation technology to sediments in all three sections of the Upper Hudson River. The No Action alternative also excludes any source control removal action (*i.e.*, the NTCRA) in the vicinity of the GE Hudson Falls plant, any administrative actions (including institutional controls, such as fish consumption advisories, which are considered to be limited action under the NCP), and any monitoring. As required by Section 121© of CERCLA, reviews will be conducted at five-year intervals to reassess the long-term appropriateness of continued No Action.

For this alternative, the upstream Tri+ PCB load at Fort Edward (Rogers Island) is assumed to remain constant at 0.16 kg/day indefinitely. The Tri+ PCB loads over the TI Dam, the Northumberland Dam, and the Federal Dam predicted by the model for the No Action alternative are presented in Tables 8-1, 8-2, and 8-3, respectively.

A summary of the details of the cost estimate for the No Action alternative is given in Table 8-4. The estimated net present worth cost of this alternative, calculated at a 7 percent discount rate, is approximately $140,000. There is no capital cost associated with this alternative. The estimated annual average O&M cost is about $15,400 and represents the periodic cost of the five-year reviews over a 30-year period. The estimated present worth of the O&M cost for No Action is about $140,000.

8.2.2 Analysis

8.2.2.1 Overall Protection of Human Health and the Environment

Under No Action, the release of PCBs from contaminated sediments into the surface water and subsequently to the air, as well as the transport of PCBs from the Upper Hudson River over the Federal Dam to the Lower Hudson River, will continue indefinitely and thereby degrade the environment.

No Action is not effective in meeting the RAOs and PRGs over the 70-year model forecast period. The dominant carcinogenic and non-carcinogenic risks to human health and ecological receptors (piscivorous birds and mammals) posed by the PCB-contaminated sediments will continue for several decades. Analyses presented in Appendix D suggest that there is a reasonable probability that the decline in exposure concentrations and associated risks may be much slower than predicted by the model. This is particularly true at the localized (rather than reach-averaged) scales at which fish feed, and the bounding analysis described in Appendix D suggests that risks may potentially continue at even higher levels for substantially longer periods. The No Action alternative does not include institutional controls such as fish consumption advisories to protect humans from exposure to PCBs through consumption of contaminated fish.

Overall Protection of Human Health

The risk-based PRG for protection of human health of 0.05 ppm PCBs (wet weight) in fish fillet is not met in any of the three river sections over the 70-year model forecast period. The target concentration of 0.2 ppm PCBs (one meal per month) in fish fillets is also not met in any of the three river sections. The target concentration of 0.4 ppm PCBs (one meal every two months) in fish fillets is not met in River Sections 1 and 2, but is met in River Section 3 in the year 2014, according to model estimates.

400684

For the No Action alternative, cancer risks and non-cancer health hazards are calculated for two time frames using start dates of 2009 and 2011 to cover the implementation time frames for all alternatives. The RME and CT non-cancer hazard indices are discussed in detail in subsection

7.3.1.2 and are presented in Tables 7-6a through 7-6d for the Upper Hudson River and separately for River Sections 1, 2, and 3, respectively. RME and CT non-cancer hazard indices by river section are shown on Figures 7-1 and 7-2, respectively. The CT hazard indices are approximately an order of magnitude lower than the RME hazard indices, and are all well above the target level of one except for the CT hazard index in River Section 3. Similarly, the RME and CT incremental cancer risks are discussed in detail in subsection 7.3.1.2 and are presented in Tables 7-7a through 7-7d for the Upper Hudson River and separately for River Sections 1, 2, and 3, respectively. RME and CT incremental cancer risks by river section are also shown on Figures 7-3 and 7-4, respectively. The RME incremental cancer risks all exceed the target risk range of 10^{-4} to 10^{-6} and the CT incremental cancer risks lie within this range.

Overall Protection of the Environment - Ecological Receptors

The risk-based PRG for protection of the environment is a range from 0.3 to 0.03 mg/kg in whole fish (this corresponds to a range from 0.13 to 0.013 mg/kg total PCBs in fish fillets), based on the LOAEL and NOAEL fish concentrations consumed by the river otter. The corresponding LOAEL and NOAEL target concentrations for the mink are 0.7 and 0.07 mg/kg PCBs in whole fish, respectively. For the river otter, none of the PRGs is met in any of the three river sections over the 70-year model forecast period. For the mink, the LOAEL target concentration is not met in River Section 1 over the 70-year model forecast period, but is met in River Section 2 in 21 years and is met in River Section 3 prior to 2010.

For the No Action alternative, the ecological toxicity quotients for the river otter and the mink are discussed in subsection 7.3.1.5 and presented in Table 7-9. For the river otter, the NOAEL and LOAEL TQs by river section are shown in Figures 7-5 and 7-6, respectively. The river otter TQs are two orders of magnitude above the NOAEL target level and one order of magnitude above the LOAEL target level. For the mink, the NOAEL and LOAEL TQs by river section are shown in Figures 7-7 and 7-8, respectively. All of the mink TQ comparisons exceed one, except for the comparison with the LOAEL target level in River Section 3.

Overall Protection of the Environment - Downstream Transport of PCBs

The Tri+ PCB load over the TI Dam predicted by the model for the No Action alternative is approximately 104 kg in 2003, 88 kg in 2011, and 60 kg in 2035. The Tri+ PCB load over the Northumberland Dam is about 122 kg in 2003, 105 kg in 2011, and 60 kg in 2035. The Tri+ PCB load over the Federal Dam is 131 kg in 2003, 104 kg in 2011, and 62 kg in 2035. This alternative does not address the scour of PCB-contaminated sediments associated with one-in-three-year to one-in-five-year flow events from the Hoosic River in River Section 3. These events have caused resuspension of PCB loading of 18 kg/day, equivalent to the peak loads at Rogers Island attributed to releases at the Allen Mills structure (USEPA, 1999b). Without addressing PCB-contaminated sediments downstream of the Hoosic River (RM 166), PCB loads over Federal Dam will likely be higher than indicated by the modeling results.

8.2.2.2 Compliance with ARARs

The chemical-specific ARARs for PCBs in the water-column are 0.5 μg/L (500 ng/L) federal MCL; 0.09 μg/L (90 ng/L) NYS standard for protection of human health and drinking water sources; 1 ng/L federal Ambient Water Quality Criterion; 0.12 ng/L NYS standard for protection of wildlife; and 0.001 ng/L NYS standard for protection of human consumers of fish. The first two chemical-specific ARARs for the surface water are met by the No Action alternative, whereas the remaining three chemical-specific ARARs for the surface water are not met for the entire 70-year forecast period. The bounding analysis described in Appendix D suggests that degradation of surface water quality may potentially continue at even higher levels for substantially longer periods. Since there is no active remedial action associated with this alternative, action-specific ARARs do not apply. No location-specific ARARs are applicable to this alternative.

The evaluation of the two threshold criteria shows that the No Action alternative is not protective of human health and the environment. Therefore, the five primary balancing criteria are not evaluated for this alternative.

400686

8.3 Alternative: Monitored Natural Attenuation (MNA)

8.3.1 Description

The principal components of the Monitored Natural Attenuation alternative include, as described below:

- Source control by a separate removal action in the vicinity of the GE Hudson Falls plant;
- Natural attenuation of sediments;
- Institutional controls;
- A long-term sediment, surface water, and fish monitoring program;
- A series of mathematical models for the fate, transport, and bioaccumulation of PCBs; and
- Reviews at five-year intervals under Section 121© of CERCLA.

Unlike No Action, the MNA alternative assumes a separate non-time critical removal action (NTCRA) for source control in the vicinity of the GE Hudson Falls plant. It is assumed that, as a result of this source control NTCRA, the upstream Tri+ PCB load at Fort Edward (Rogers Island) is reduced from 0.16 kg/day to 0.0256 kg/day on January 1, 2005. USEPA has authorized the performance of an Engineering Evaluation/Cost Analysis (EE/CA) to evaluate potential NTCRAs to address the discharge of PCBs into the river in the vicinity of GE's Hudson Falls plant. GE has discussed with USEPA and NYSDEC a conceptual approach to contain the release of PCB oil from the vicinity of the Hudson Falls facility. Assuming that the conceptual approach proposed by GE, or a similarly effective system, is available to address the Hudson Falls source, USEPA believes that a source control NTCRA can reasonably be completed by January 1, 2005, if not earlier.

Natural attenuation refers to the reduction of volume and toxicity of contaminants in the sediments by naturally occurring biological, chemical, and physical processes. Attenuation processes in sediments include biodegradation, biotransformation, bioturbation, diffusion, dilution, adsorption, volatilization, chemical reaction or destruction, resuspension, and burial by cleaner material.

Institutional controls (*e.g.*, site use restrictions) are implemented as long-term control measures as part of this alternative. These restrictions include continuation or modification of the existing fish consumption advisories, and catch and release restrictions.

Continued presence of large quantities of PCB-contaminated sediments in the Upper Hudson River may necessitate operational restrictions on future non-remedial sediment removal activities such as navigational dredging, including controls on the types of dredging equipment, constraints on barge filling practices, and restrictions on handling and disposal of the contaminated dredge spoils. However, such restrictions are incorporated into the existing permitting process and do not require separate institutional controls under a remedy. Since direct contact with sediments has been determined not to pose unacceptable risks to human health, no restrictions on sediment disturbance for changes to waterfront access or structures are contemplated as part of this alternative.

Long-term monitoring (assumed to extend over a 30-year period for cost estimating purposes) is conducted in sediments, in the water column, and in fish as part of the MNA alternative. The purpose of the monitoring and modeling is to demonstrate that contaminant reduction is occurring, and that the reduction is achieving regulatory requirements, such as the NYS standard for PCBs in surface water (1×10^{-6} μg/L) for protection of the health of human consumers of fish.

The number and distribution of sediment, water, and fish samples that are collected as part of this alternative are described in subsection 5.2.7.1 and in Appendix G, and are outlined on Figure 5-6. Monitoring includes measurements of water column contamination, dated sediment cores, sediment PCB inventory, sediment physical properties (geophysics), and bioaccumulation by resident fish. Reductions in PCB concentrations and the PCB inventory are documented by historical trends or concentration distributions showing a reduction in the total mass of PCBs in sediments, water, or biota, or by the presence of degradation products in sediments. The series of mathematical models for the fate, transport, and bioaccumulation of PCBs (described in the RBMR, USEPA, 2000a) will be refined and recalibrated on a regular basis as new data become available. This refinement includes resegmentation of the existing model grid, especially for River Sections 2 and 3. The monitoring data are also used as input parameters and recalibration points in the mathematical models to evaluate progress of the natural attenuation processes against the original predictions.

400688

The sediment samples (dated cores) are analyzed for radionuclides, congener-specific PCBs, and total organic carbon (TOC). Acoustic mapping of sediment properties, flow measurements, and bathymetric surveys are also performed. Water column samples are analyzed for congener-specific PCBs, total suspended solids (TSS), and fraction of organic carbon on the suspended solids. Samples of the resident fish species including largemouth bass, brown bullhead, and yellow perch are analyzed for total PCBs (Aroclors), congener-specific PCBs, and lipid content. As required by Section 121© of CERCLA, five-year reviews are conducted (assumed to extend for a 30-year period for cost estimating purposes).

To complete the analysis of the monitoring data, the USEPA's Hudson River models (HUDTOX and FISHRAND) will be updated and recalibrated as necessary to reflect the information gathered in the monitoring program. The results of this analysis will be used in the evaluation of the effectiveness of MNA.

8.3.2 Analysis

8.3.2.1 Overall Protection of Human Health and the Environment

The overall protection of human health and the environment achieved by the MNA alternative is considerably more than that achieved by the No Action alternative because this alternative assumes the separate source control NTCRA in the vicinity of the GE Hudson Falls plant and also relies on the fish consumption advisories and catch and release restrictions to protect people from exposure to PCBs through consumption of contaminated fish. There are some health risks to site workers for the short and long term because direct exposure pathways do exist; these risks, though assumed to be small, may increase over existing levels due to the expansion of the sampling and monitoring program involved in this alternative.

This alternative relies on the naturally-occurring processes such as sediment deposition, bioturbation, dispersion, advection, and biotransformation to sequester, destroy, or dilute the sediment PCB inventories of the Upper Hudson, resulting in a decline in surface sediment and water column PCB concentrations. As discussed in several of the Reassessment RI reports (USEPA, 1997a, 1998a, 1998b, and 1999b), these processes do not perform reliably. Biodegradation processes, specifically anaerobic dechlorination, may decrease the level of chlorination of some of the PCBs. Much of the PCB inventory of the sediments appears largely unaffected by this process, with minimal mass loss (less than 10 percent on average) (USEPA, 1997a). The degree to which chlorination affects PCB toxicity remains uncertain and debated within the scientific community. Yet, animal studies supported by GE and reviewed in the 1996 PCB cancer reassessment (USEPA, 1996) found tumors in lab animals for all Aroclor mixtures tested (Aroclor 1016, 1242, 1254 and 1260), spanning a wide range of chlorination (USEPA, 1996c). Thus, it is not clear the degree to which the transformation from more highly chlorinated PCBs to lesser chlorinated congeners would alter the PCB toxicity, if at all.

Sediment deposition has failed to sequester the PCBs of the Upper Hudson, given the clear evidence of ongoing PCB release from the sediments (see Section 3.5). Additionally, PCB inventory comparisons over time have shown extensive PCB losses from the sediments, suggesting bioturbation or sediment resuspension as major factors in replenishing and maintaining surface PCB concentrations. The release of PCBs from contaminated sediments into the water column has continued largely unchanged over the past 10 years, based on annual loads of total PCBs originating from the River Section 1. Model forecasts suggest only a gradual decline in surface sediment and water column concentrations and have large uncertainties associated with these estimates. Thus the transport of PCBs from the sediments of the Upper Hudson River over the Federal Dam to the Lower Hudson River will persist for many decades and thereby continue to degrade environments throughout the Hudson.

A substantial limitation of the MNA alternative, particularly where burial by less contaminated sediments is the primary attenuation process, is that burial occurs only in truly depositional areas. Long-term deposition of sediment is not a general characteristic of the river bed although portions of the river may be depositional. As discussed in Appendix D, rates of attenuation of surface sediment PCB concentrations and associated fish body burdens may be much slower in local regions than those predicted by the model at the reach-average scale. In addition, because natural attenuation in this instance depends upon maintenance of the overlying less-contaminated sediment layer, anthropogenic processes or severe storms may erode and scour the sediments and redistribute the PCBs over wide areas, even when burial is (temporarily) achieved. Natural attenuation is most appropriate for those portions of the Upper Hudson River where, based on existing data, natural sedimentation and other processes have been observed, or are strongly expected, to reduce surface sediment concentrations. These areas appear to be quite limited, based on the sediment evidence, which shows the majority of the PCB inventory to lie within the top 9 inches of sediment (see Section 3.5, and USEPA, 1998b). Additionally, natural attenuation that depends primarily on sediment burial is not appropriate in the navigation channel of the Champlain Canal where dredging is required for maintenance.

MNA is not very effective in meeting the RAOs and PRGs over the 70-year model forecast period. Risks to human health and ecological receptors (piscivorous birds and mammals) posed by the PCB-contaminated sediments will continue for several decades. The bounding analysis described in Appendix D suggests that risks may potentially continue at even higher levels for substantially longer periods.

Protection of Human Health

The risk-based PRG for protection of human health of 0.05 ppm PCBs (wet weight) in fish fillet is not met in River Sections 1 and 2 over the 70-year model forecast period, but is met in River Section 3 in the year 2059. The target concentration of 0.2 ppm PCBs (one meal per month) in fish fillets is also not met in River Section 1, but is met in River Section 2 in the year 2061 and is met in River Section 3 in the year 2019. The target concentration of 0.4 ppm PCBs (one meal every two months) in fish fillets is met in River Sections 1, 2, and 3 in the years 2039, 2038, and 2011, respectively.

Cancer risks and non-cancer health hazards for the MNA alternative are calculated for two time frames using start dates of 2009 and 2011 to cover the implementation time frames for all alternatives. The RME and CT non-cancer health hazard indices are discussed in detail in subsection 7.3.2.2 and are presented in Tables 7-6a through 7-6d for the Upper Hudson River and separately for River Sections 1, 2, and 3, respectively. RME and CT non-cancer hazard indices by river section are shown on Figures 7-1 and 7-2, respectively. The CT hazard indices are approximately an order of magnitude lower than the RME hazard indices, and are all well above the target level of one except for the CT hazard index in River Section 3. Similarly, the RME and CT incremental cancer risks are discussed in detail in subsection 7.3.2.2 and are presented in Tables 7-7a through 7-7d for the Upper Hudson River and separately for River Sections 1, 2, and 3, respectively. RME and CT incremental cancer risks by river section are also shown on Figures 7-3 and 7-4, respectively. The RME incremental cancer risks for the Upper Hudson River and River Sections 1 and 2 all exceed the target risk range of 10^{-4} to 10^{-6}, whereas the RME incremental cancer risk for River Section 3 lies within this range. All of the CT incremental cancer risks lie within this range.

Protection of the Environment - Ecological Receptors

The risk-based PRG for protection of the environment is a range from 0.3 to 0.03 mg/kg in whole fish (this corresponds to a range from 0.13 to 0.013 mg/kg total PCBs in fish fillets), based on the LOAEL and NOAEL fish concentrations consumed by the river otter. The corresponding LOAEL and NOAEL target concentrations for the mink are 0.7 and 0.07 mg/kg PCBs in whole fish. For the river otter, the PRGs are not met in River Sections 1 and 2 over the 70-year model forecast period, but the LOAEL target concentration is met in River Section 3 in 14 years. For the mink, the LOAEL target concentration is met in River Section 1 in 22 years, in River Section 2 in 10 years, and in River Section 3 prior to 2010. For the mink, the NOAEL target concentration is not met in River Sections 1 and 2, but is met in River Section 3 in 12 years.

The ecological TQs for the river otter and the mink are discussed in subsection 7.3.2.5 and presented in Table 7-9. For the river otter, the NOAEL and LOAEL TQs by river section are shown in Figures 7-5 and 7-6, respectively. The river otter TQs are two orders of magnitude above the NOAEL target level and one order of magnitude above the LOAEL target level. For the mink, the NOAEL and LOAEL TQs by river section are shown in Figures 7-7 and 7-8, respectively. All of the mink TQ comparisons exceed one, except for the comparison with the LOAEL target level in River Sections 2 and 3.

Since MNA is not an active remediation, there are no impacts specific to the short-term. Monitoring under MNA is not expected to have an impact on ecological receptors.

Protection of the Environment - Downstream Transport of PCBs

The Tri+ PCB load over the TI Dam predicted by the model for the MNA alternative is about 104 kg in 2003, 44 kg in 2011, and 14 kg in 2035. The Tri+ PCB load over the Northumberland Dam is 123 kg in 2003, 63 kg in 2011, and 15 kg in 2035. The Tri+ PCB load over the Federal Dam is approximately 131 kg in 2003, 72 kg in 2011, and 24 kg in 2035. This alternative does not address the scour of PCB-contaminated sediments associated with one-in-three-year to one-in-five-year flow events from the Hoosic River in River Section 3. One such event was observed in 1993 (USEPA, 1997b), which caused a PCB loading of 18 kg/day by resuspension of Hudson River sediment. This loading was equivalent to the peak loads at Rogers Island that same year, attributed to releases at the Allen Mills structure (USEPA, 1999b). Without addressing PCB-contaminated sediments downstream of the Hoosic River (RM 166), PCB loads over Federal Dam will likely be higher than indicated by the modeling results.

8.3.2.2 Compliance with ARARs

The chemical-specific ARARs for PCBs in the water-column are 0.5 μg/L (500 ng/L) federal MCL; 0.09 μg/L (90 ng/L) NYS standard for protection of human health and drinking water sources; 1 ng/L federal Ambient Water Quality Criterion; 0.12 ng/L NYS standard for protection of wildlife; and 0.001 ng/L NYS standard for protection of human consumers of fish. The first two chemical-specific ARARs for the surface water are met by the MNA alternative, whereas the remaining three chemical-specific ARARs for the surface water are not met for the entire 70-year forecast period. The bounding analysis described in Appendix D suggests that degraded surface water quality conditions may potentially continue at even higher levels for substantially longer periods. Since there is no active remedial action for the sediments associated with this alternative, action-specific ARARs do not apply. No location-specific ARARs are applicable to this alternative.

8.3.2.3 Long-Term Effectiveness and Permanence

Magnitude of Residual Risks

This alternative will result in continuation of the degraded condition of surficial sediments and surface water quality (albeit gradually reduced) of the Upper Hudson River, especially in River Section 1, for several decades, regardless of any reduction in the upstream water column loadings. The long-term transport of PCBs over the Federal Dam and to the Lower Hudson River will continue indefinitely. The Tri+ PCB load over the Federal Dam predicted by the model for the MNA alternative is approximately 131 kg in 2003, 72 kg in 2011, and 24 kg in 2035. As a result of the separate source control NTCRA in the vicinity of the GE Hudson Falls plant, the Tri+ PCB load over Federal Dam is reduced by approximately 62 percent in 2035 compared to the No Action alternative. Risks to human health and ecological receptors (piscivorous birds and mammals) posed by the PCB-contaminated sediments would continue unabated for several decades. This alternative does not address the scour of PCB-contaminated sediments associated with one-in-three-year to one-in-five-year flow events from the Hoosic River in River Section 3.

Adequacy of Controls

This alternative does not provide for engineering controls on the river sediments. The MNA alternative assumes source control in the vicinity of the GE Hudson Falls plant. As discussed in Revised HHRA (USEPA, 2000p), the existing fish consumption advisories and fishing bans are not completely effective. Therefore, the existing institutional controls, which rely on voluntary compliance, are not fully adequate in reducing exposure to PCBs due to consumption of contaminated fish. In addition, institutional controls are ineffective for protection of the environment (*e.g.*, ecological receptors).

Reliability of Controls

Only institutional controls such as the existing fish consumption advisory and catch and release restrictions would continue to provide some measure of protection for human health from the consumption of PCB contaminated fish. Although the MNA alternative is more protective of

400694

human health than the No Action alternative, it is not very reliable, as the institutional controls associated with this alternative do not address ecological receptors, and human risk reduction relies on knowledge of and voluntary compliance with the fish consumption advisories. The planned annual monitoring program provides a basis to adjust the advisories in response to changing PCB levels in fish and to add new advisories for the protection of the public if the expected declines do not occur. However, the monitoring program has no effect on reducing the ecological risks to fish, piscivorous birds, and mammals.

8.3.2.4 Reduction of Toxicity, Mobility, or Volume through Treatment

This alternative does not involve any containment or removal of contaminants from the Upper Hudson River sediments and does not include any treatment. The separate source control NTCRA in the vicinity of the GE Hudson Falls plant which is assumed for the MNA alternative is expected to reduce the upstream water column Tri+ PCB load to the site (*i.e.*, at Rogers Island) from 0.16 kg/day to 0.0256 kg/day by January 1, 2005. Sediment contributions of Tri+ PCBs in 2005 are expected to be about 0.1 kg/day, or about four times greater than the reduced input from Hudson Falls. The MNA alternative relies on naturally-occurring processes such as sediment deposition, dispersion, advection, and biotransformation processes to sequester, destroy, or dilute the PCB inventories of the Upper Hudson River, resulting in a decline in surface sediment and water column PCB concentrations. Biodegradation processes may convert some of the more highly chlorinated PCB congeners (*e.g.*, tetrachlorobiphenyls) to less chlorinated congeners (monochloro- and dichloro-biphenyls) and biphenyl, although dechlorination is not expected to continue to extensively modify the PCB inventory over time since it appears to occur only within the first few years of deposition (USEPA, 1997a). The degree to which chlorination affects PCB toxicity remains uncertain and debated within the scientific community. Yet, animal studies supported by GE and reviewed in the 1996 PCB cancer reassessment (USEPA, 1996c) found tumors in lab animals for all Aroclor mixtures tested (Aroclor 1016, 1242, 1254 and 1260), spanning a wide range of chlorination (USEPA, 1996c). Thus, it is not clear the degree to which the transformation from more highly chlorinated PCBs to lesser chlorinated congeners would alter the PCB toxicity, if at all.

Natural dilution of the contaminated sediments will also reduce the toxicity, but the overall volume of contaminated sediments will increase as PCBs are contributed to the Upper Hudson from upstream. Concentrations of PCBs in fish, and thus the toxicity and volume, will respond slowly over time to decreases in the concentrations in sediments and surface water. Reductions sufficient to meet PRGs will require several decades.

8.3.2.5 Short-Term Effectiveness

Short-term effectiveness is assessed through review of the four components previously described (subsection 8.1.5), which are protection of the community during remedial actions, protection of workers during remedial actions, potential adverse environmental impacts resulting from construction and implementation, and time until remedial response objectives are achieved.

Protection of the Community During Remedial Actions

No construction activities are associated with the remediation of sediments for the MNA alternative, so it does not increase the potential for direct contact and ingestion and inhalation of PCBs from the surface water and the sediments. The risks to human health and to ecological receptors due to the PCB-contaminated sediments will persist throughout the short term. Due to the separate source control NTCRA in the vicinity of the GE Hudson Falls plant, the upstream water column Tri+ PCB load to the site (*i.e.*, at Rogers Island) expected to be reduced from 0.16 kg/day to 0.0256 kg/day by January 1, 2005. As a result, risks to human health and to ecological receptors for the MNA alternative are slightly lower than those under the No Action alternative in the short term. For the MNA alternative, the institutional controls (fish consumption advisories and catch-and-release restrictions) will continue to be the only means for protecting human health. There are no such controls in the No Action alternative. The monitoring program associated with this alternative is unlikely to pose any risk to the community.

Protection of Workers During Remedial Actions

The persons performing the sampling activities will follow OSHA health and safety procedures and wear the necessary personal protective equipment. A slight increase in occupational risk may be associated with the MNA alternative due to the greater degree of sampling involved in the river. There are potential short-term risks to site workers from contact with or accidental ingestion of PCB-contaminated surface water and sediments; however, these risks are small. Limited risks also may arise from physical hazards associated with the work (*e.g.*, boating accidents).

Potential Adverse Environmental Impacts Resulting from Construction and Implementation

No construction activities associated with the river sediments are conducted for the MNA alternative. The monitoring program for the MNA alternative is not anticipated to have any adverse effect on the environment, beyond that already caused by the PCB contamination of the sediments in the Upper Hudson River.

Time until Remedial Response Objectives Are Achieved

Before discussing the time to achieve various PRGs, it is important to note that forecasts are subject to considerable uncertainty. Therefore, the estimated year of target attainment should be considered a general guide. In particular, the time estimates given below are based on the model forecast and do not represent the upper-bound estimate for MNA, which yields substantially longer periods to achieve PRGs. The risk-based PRG for protection of human health of 0.05 ppm PCBs (wet weight) in fish fillets is not met in River Sections 1, 2, and 3 in the short term. The target concentration of 0.2 ppm PCBs (one meal per month) in fish fillets is also not met in River Sections 1, 2, and 3 in the short term. The alternate target concentration of 0.4 ppm PCBs (one meal every two months) in fish fillets is not met in River Sections 1 and 2 in the short term, but is met in River Section 3 in the year 2011 for the MNA alternative.

The risk-based PRG for protection of the environment is a range from 0.13 to 0.013 mg/kg total PCBs in fish fillets (this corresponds to a range from 0.3 to 0.03 mg/kg in whole fish), and is based on the LOAEL and NOAEL fish concentrations consumed by the river otter. The corresponding LOAEL and NOAEL whole fish target concentrations for the mink are 0.7 and 0.07 mg/kg PCBs. For the river otter, the PRGs are not met in River Sections 1, 2, and 3 in the short term. For the mink, the LOAEL target concentration is not met in River Sections 1 and 2 in the short term, but is met in River Section 3 prior to 2010. For the mink, the NOAEL target concentration is not met in River Sections 1, 2, and 3 in the short term.

The release of PCBs from the contaminated sediments into the surface water, and subsequently to the air, as well as the transport of PCBs from the Upper Hudson River over the Federal Dam, will continue indefinitely.

8.3.2.6 Implementability

Technical Feasibility

This alternative only requires using computer modeling and standard sampling and analytical methods to implement; therefore, it is technically feasible and readily implementable.

Administrative Feasibility

In general, the principal administrative task under the MNA alternative is the continuation of institutional controls, such as the fish consumption advisories and the performance of the five-year reviews. Those tasks are currently being performed and are relatively straightforward to implement.

Availability of Services and Materials

All the services and materials needed to implement this alternative are readily available.

8.3.2.7 Cost

A summary of the details of the cost estimate for Alternative MNA is given in Table 8-5. The estimated net present worth cost of this alternative, calculated at a 7 percent discount rate, is approximately $39 million.

Capital Cost

The capital cost associated with this alternative is about $508,000; this cost is entirely for model refinement and calibration. The present worth of the capital cost for the MNA alternative is $417,000.

O&M Costs

Due to the varying frequency of different elements of the monitoring program, and the five-year period for reviews, O&M costs will vary on an annual basis. The annual average O&M costs for this alternative are estimated to be about 3.6 million dollars and represents the monitoring costs, the periodic cost of the modeling, and the five-year reviews. This cost has been estimated for a 30-year period. The estimated present worth of the O&M cost for this alternative is about $38.2 million.

8.4 Alternative CAP-3/10/Select: Capping with Dredging of Expanded Hot Spots in River Section 1; Capping with Dredging of Hot Spots in River Section 2; and Dredging of Select Areas in River Section 3

8.4.1 Description

The principal components of this alternative include, as described below:

- Source control via separate removal action in the vicinity of the GE Hudson Falls plant;
- An implementation schedule and sequence of operations for the remediation;
- Engineered capping of sediments in selected target areas following dredging as necessary;
- Dredging of sediments in remaining target areas;
- In-river transport of capping materials, backfill materials, and dredged sediments;
- Processing of sediments at the northern and southern material management and transfer facilities;
- Treatment of the water entrained in removed (dredged) sediments to NYSPDES discharge criteria;
- Backfilling and habitat replacement,
- Transportation of dewatered and stabilized materials to off-site dredged material management locations; and
- A performance monitoring program.

This alternative includes capping with dredging to perform Expanded Hot Spot remediation (*i.e.*, in which the nominal MPA targets are 3 g/m^2 or greater) in River Section 1, Hot Spot remediation (*i.e.*, in which the nominal MPA targets concentrations are 10 g/m^2 or greater) in River

Section 2, and remediation of select areas (*i.e.*, sediments with high-concentration PCB target areas) in River Section 3. This alternative also includes sediment removal in the navigation channel as necessary to implement the alternative (*i.e.*, to accommodate dredges and barges). The areas to be remediated for this alternative are shown on Plate 16. The total area of sediments to be capped is approximately 207 acres. The estimated volume of sediments to be removed is 1.73 million cubic yards. This alternative also relies on naturally occurring attenuation processes to reduce the toxicity, mobility, and volume of the remaining PCBs in the Upper Hudson River sediments after the construction is completed. Institutional controls (*e.g.*, site use restrictions) are implemented as long-term control measures as part of this alternative. These restrictions include continuation or modification of the existing fish consumption advisories and catch and release restrictions. A review of site conditions will be conducted at five-year intervals, as required by Section 121© of CERCLA.

In this alternative, in River Section about 1,160 acres of PCB-contaminated sediments are capped and 849,000 cubic yards of sediments containing 7,100 kg of PCBs are removed. An additional 66,100 cubic yards of sediments containing 200 kg of PCBs are removed from the navigation channel in River Section 1. In River Section 2, 52 acres of PCB-contaminated sediments are capped and 292,000 cubic yards of sediments containing 15,600 kg of PCBs are removed. An additional 15,400 cubic yards of sediments containing 700 kg of PCBs are removed from the navigation channel in River Section 2. In River Section 3, there is no capping and 392,900 cubic yards of sediments containing 6,700 kg of PCBs are removed. No capping is performed in River Section 3 for this alternative because the portions of the remediation target areas meeting the criteria for capping in this section are relatively small and isolated from one another. An additional 117,000 cubic yards of sediments containing 2,800 kg of PCBs are removed from the navigation channel in River Section 3. Estimates of the areas, volumes, and mass of PCBs remediated, and the areas capped, volumes removed, and the mass of PCBs removed from the sediment target areas and the navigation channel for each river section, are presented in Table 8-6.

8.4.1.1 Source Control in the Vicinity of the GE Hudson Falls Plant

The CAP-3/10/Select alternative assumes a separate non-time critical removal action (NTCRA) for source control in the vicinity of the GE Hudson Falls plant. It is assumed that, as a result of this source control NTCRA, the upstream Tri+ PCB load at Fort Edward (Rogers Island) entering the Hudson River PCBs site is reduced from 0.16 kg/day to 0.0256 kg/day on January 1, 2005. USEPA has authorized the performance of an Engineering Evaluation/Cost Analysis (EE/CA) to evaluate potential NTCRAs to address the discharge of PCBs into the river in the vicinity of the GE Hudson Falls plant. GE has discussed with USEPA and NYSDEC a conceptual approach to contain the release of PCB oil from the vicinity of the Hudson Falls facility. Assuming that the conceptual approach proposed by GE, or a similarly effective system, is available to address the Hudson Falls source, USEPA believes that a source control NTCRA can reasonably be completed by January 1, 2005, if not earlier.

8.4.1.2 Implementation Schedule and Sequence of Operations

Remediation will commence in 2004 and will be completed in 2008. To the extent practicable, sediments near Rogers Island will be remediated first, and the work will progress downstream towards the Federal Dam at Troy in River Section 3. Dredging of River Section 3 may occur simultaneously with removal operations elsewhere as a result of the need to gain access to the site or because doing so will improve overall efficiency. For this alternative, dredging of contaminated sediments will be initiated before capping begins, and removal operations will continue for approximately five years. It is expected that dredging work will precede capping in each work area. Capping material (12 inches of hydrated AquaBlok™) and backfill (6 inches of fill consisting of sand, silt, and gravel) will be placed in the targeted areas as described in subsection 5.2.6, and other site reconstruction activities will be conducted as described below.

8.4.1.3 Engineered Capping, Select Removal, and In-river Transport Operations

As described in subsection 5.2.4, the AquaBlok™ material will be manufactured locally and transported by truck to a bulkhead located along the Champlain Canal. The material will be placed in a large hopper barge (capacity of 2,000 tons) and towed to the area of cap placement. Using a conveyor, the material will be transferred to a shallow draft barge equipped with a mounted telescoping conveyor. The barge-mounted telescoping conveyor will be used to spread the AquaBlok™ material over the area to be capped. The cap material will be placed in the target areas at an estimated rate of approximately one acre per day per lift per crew. Two lifts will be required to place the cap, as described earlier in subsection 5.2.4. Capping operations will not be conducted continuously because the area to be capped must be completely dredged first, and the cap can be installed at a rate faster than the rate at which the dredge can remove contaminated sediments. For this alternative, the quantities of AquaBlok™ material that will be placed are presented in Table 8-7.

In order to accomplish the sediment removal planned for this alternative within the five-year construction period, a number of dredges and other marine equipment will be needed for the in-river operations. The number and type of dredges needed to accomplish the work depend on the volume of material to be removed, the time frame for the work, the productivity of the equipment, and the limitations on the in-river and out-of-river transportation systems. Based on the target areas for this alternative, Table 8-7 provides a list of the number and types of dredges that will be operated, the number of barge loads of sediment that will be received at the northern and southern transfer facilities, and quantity estimates for other engineering productivity parameters.

8.4.1.4 On-Site Material Management and Transfer Facilities

At the northern and southern dredged material management and transfer facilities, the sediments will be dewatered and stabilized by blending with eight percent Portland cement as described in subsection 5.2.2 and Appendix E. This blending serves to improve both the material handling and disposal properties of the dredged material. The rates at which this material is processed in the northern and southern facilities are presented in Table 8-7. This stabilized material will then be loaded into rail cars or barges as described in subsections 5.2.2 and 5.2.5 for transfer to disposal or beneficial use facilities. The estimated number of rail cars loaded at each material management and transfer facility for this alternative is also presented in Table 8-7.

8.4.1.5 Water Treatment Subsequent to Removal

The water associated with the dredged material will be treated at the northern and southern water treatment plants to NYSPDES discharge criteria as described previously in subsection 5.2.2.

8.4.1.6 Backfilling and Site Reconstruction

As described in subsection 5.2.6, site reconstruction measures will be undertaken to mitigate disturbances to the hydraulics of the river channel, the shoreline, and the aquatic habitat caused by removal and capping operations. Areas that are dredged but not capped will be backfilled with one foot of imported clean fill. This backfill will consist of gravel, silt and sand in order to re-establish a range of habitat types for a variety of aquatic biota, especially the resident fish. The navigation channel will not be backfilled. Areas capped with AquaBlok™ will be backfilled with six inches of a sand, silt and gravel mixture.

Disturbed portions of the shoreline will have to be either stabilized or reconstructed. The stabilization measures envisioned in this FS report consist of hydro-seeding the shoreline where disturbance is expected to be minimal, and then expanding the scale of the effort where the disturbances increase. Thus, in near-shore areas where between two and three feet of sediment will be removed, the stabilization concept consists of placement of an approximately 20-foot-wide vegetative mattress. Where shoreline disturbance will equal or exceed three feet of sediment removal, the stabilization concept includes either a log or wood crib revetment in addition to the vegetative mattress. Table 8-7 shows the extent of shoreline disturbance and stabilization anticipated for this alternative. Where shoreline wetlands (critical areas) will be removed by the dredging work, it is expected that the original bottom elevation will be re-established and that the new upper layer of substrate would be a silty material. The quantities of gravel, sand, and silt required for backfill and reconstruction of areas of the river bottom are also presented on Table 8-7.

Beyond physical replacement of the river bottom substrate, it is also anticipated that a spectrum of in-river plantings will be undertaken to further reduce the time for the river to return to a productive ecological condition. The plantings will consist of various types of wetland and aquatic species. The species being considered for this component of the program are detailed in Appendix F. The general type and quantity of planting envisioned for the CAP-3/10/Select alternative are shown on Table 8-7.

8.4.1.7 Off-Site Transport and Dredged Material Management

Of the total estimated volume of about 1.73 million cubic yards of sediments removed from the Upper Hudson River under the CAP-3/10/Select alternative, about 722,000 cubic yards (with PCB concentrations greater than 33 mg/kg) will be managed as TSCA-regulated material, and just over 1.0 million cubic yards (containing less than 33 mg/kg PCBs) will be handled as non-TSCA material. The TSCA material will be sent to a TSCA-permitted landfill and the non-TSCA material will be sent to a non-TSCA landfill as described in subsection 5.2.5. If facilities and adequate capacity for beneficial use are available based on market conditions at the time when this alternative is implemented, some or all of the non-TSCA material will be utilized for such purposes as described in subsection 5.2.5.3. This includes both low-value beneficial uses as material for construction fill, landfill cover, or abandoned mine reclamation, and higher-value beneficial uses as manufactured commercial products.

8.4.1.8 Performance Monitoring Program

The performance monitoring program consists of two components: monitoring during construction of the alternative and post-construction monitoring.

Construction Monitoring

During construction of this alternative, the monitoring program described in subsection 5.2.7.3 will be implemented. The purpose of this monitoring is to confirm that removal, capping, and backfilling of areas targeted for remediation has been performed as designed. The construction monitoring program will begin the year after design support testing is completed and will last for six years. This program includes collection of samples from the sediment, water column, and biota.

Post-Construction Monitoring

The post-construction performance of this alternative will be monitored through the implementation of the sampling program described in subsection 5.2.7.4 and in Appendix G, and as outlined in Figure 5-6. Long-term monitoring for a 25-year period after remediation is completed in 2008 and will be conducted in sediments, in the water column, and in biota as part of this alternative. Monitoring will include measurements of water column contamination, dated sediment cores, sediment PCB inventory, sediment physical properties (geophysics), and bioaccumulation by resident fish. Loss of contaminants can be documented by historical trends or contaminant concentration distributions showing a reduction in the total mass of contaminants in sediments, water, or biota, or by the presence of degradation products in sediments. The monitoring data will also be used as input parameters in the mathematical models to evaluate progress of the natural attenuation processes against the original predictions.

The number and distribution of sediment, water, and fish samples that will be collected are presented in the alternative-specific tables in Appendix G. The sediment samples (cores and surface grab samples) will be analyzed for total PCBs (Aroclors) and total organic carbon. Bathymetric surveys will also be performed. Water column samples will be analyzed for congener-specific PCBs, TSS, and fraction of organic carbon on TSS. Samples of the resident fish species including largemouth bass, brown bullhead, and yellow perch will be analyzed for total PCBs, congener-specific PCBs, and lipid content. A review of site conditions will be conducted at five-year intervals assumed to extend for a 25-year period beyond completion of construction for cost estimating purposes (*i.e.*, 30 years after initiation of the alternative).

8.4.2 Analysis

8.4.2.1 Overall Protection of Human Health and the Environment

The overall protection of human health and the environment achieved by the CAP-3/10/Select alternative is considerably more than that achieved by the No Action and MNA alternatives because this alternative is a permanent alternative that involves both containment and removal of contaminated sediments in River Sections 1 and 2, and removal of contaminated sediments in River Section 3. It also provides for some limited on-site treatment of the PCBs in the sediments by the stabilization process (addition of eight percent Portland cement) discussed above. In addition, the CAP-3/10/Select alternative assumes the separate source control NTCRA in the vicinity of the GE Hudson Falls plant, and also relies on the fish consumption advisories and catch and release restrictions to protect human health.

The existing fish consumption advisories and restricted access to portions of the river undergoing remediation reduce risks to the local community. The CAP-3/10/Select alternative also relies on such natural attenuation processes as burial by cleaner sediments, bioturbation, biodegradation, dispersion, dilution through advection and recharge, adsorption, and volatilization to further reduce the concentration of PCB-contaminant sediments remaining in the river after construction to address is completed.

There are five options for dealing with the sediments after removal from the river: landfill disposal (for hydraulic dredging); stabilization and landfill disposal (for mechanical dredging); beneficial use as landfill cover or construction fill material (for hydraulic dredging); stabilization and beneficial use as landfill cover or construction fill material (for mechanical dredging); and thermal treatment and beneficial use as manufactured commercial products like cement, light weight aggregate, fiberglass, or architectural tiles (for both mechanical and hydraulic dredging). For the landfill disposal option, the PCB-contaminated sediments would be permanently removed and contained at a permitted and regulated facility. For the beneficial use option, the removed and stabilized sediments will be further treated at the off-site facility, and the PCBs will be permanently sequestered (for the construction fill/landfill cover option) or destroyed (for the manufacture of commercial products option).

For the CAP-3/10/Select alternative, risks to human health and ecological receptors (piscivorous birds and mammals) will be reduced through capping of an estimated 207 acres of PCB-contaminated sediments and dredging of approximately 33,100 kg of PCBs contained in an estimated 1.73 million cubic yards of sediments. Capping reduces the mobility of contaminants in the river but does not affect their toxicity or volume. Dredging the sediments reduces the toxicity, mobility, and volume of the contaminants in the river. After construction is completed, natural attenuation processes may further reduce the toxicity and volume of contaminants in sediments (*e.g.*, through biodegradation) or reduce their mobility (*e.g.*, though burial by cleaner sediments).

Capping is a proven technology for isolating contaminated sediments from the water column and biota. AquaBlok™ is a manufactured product consisting of a composite of gravel particles encapsulated with bentonite. Although AquaBlok™ is a relatively new product and has not been used at many sites over relatively long periods of time, the effectiveness of the cap depends on bentonite, which has been proven as an impermeable liner material in preventing the migration of contaminants. However, proper design, placement, and maintenance of the cap are required for cap effectiveness, continued performance, and reliability. Because PCBs remain in the sediment, the CAP-3/10/Select alternative may be inherently less protective of human health and the environment in the long term than a comparable dredging alternative. Even though the capping concept is designed to avoid failure, cap damage caused by, for example, large trees that fall into the river during natural events like major floods cannot be avoided.

Overall Protection of Human Health

For the CAP-3/10/Select alternative, the risk-based PRG for protection of human health of 0.05 ppm PCBs (wet weight) in fish fillet is not met in River Sections 1 and 2 over the 70-year model forecast period, but is met in River Section 3 in the year 2051. The target concentration of 0.2 ppm PCBs (one meal per month) in fish fillets is also not met in River Section 1, but is met in River Section 2 in the year 2044 and is met in River Section 3 in the year 2014. The target concentration of 0.4 ppm PCBs (one meal every two months) in fish fillets is met in River Sections 1, 2, and 3 in the years 2026, 2028, and 2010, respectively.

The failure to achieve PCB levels below 0.2 ppm in fish tissue in River Section 1 and the near- asymptotic approach to this value in River Section 2 reflect the importance of the assumption of the upstream loading late in the forecast period. Even in River Section 3, an asymptotic value of approximately 0.05 ppm is clearly evident. Significant reductions in fish tissue concentrations are accomplished as a result of the sediment remediation and the source control NTCRA .However, each river section approaches a condition under which the assumed load at Fort Edward produces a steady-state condition between the contamination within the active sediments and that in the water column. No further reduction in fish body burden is possible without a change in the assumed upstream load.

For the CAP-3/10/Select alternative, cancer risks and non-cancer health hazards are calculated using a start date of 2009. The RME and CT non-cancer hazard indices are discussed in detail in subsection 7.3.3.2, and are presented in Tables 7-6a through 7-6d for the Upper Hudson River and separately for River Sections 1, 2, and 3, respectively. RME and CT non-cancer hazard indices by river section are shown on Figures 7-1 and 7-2, respectively. The CT hazard indices are approximately an order of magnitude lower than the RME hazard indices, and are all above the target level of one except for the CT hazard index in River Section 3. Similarly, the RME and CT incremental cancer risks are discussed in detail in subsection 7.3.3.2, and are presented in Tables 7-7a through 7-7d for the Upper Hudson River and separately for River Sections 1, 2, and 3, respectively. RME and CT incremental cancer risks by river section are also shown on Figures 7-3 and 7-4, respectively. The RME incremental cancer risks for the Upper Hudson River and River Sections 1 and 2 all slightly exceed the acceptable risk range of 10^{-4} to 10^{-6}, whereas the RME incremental cancer risk for River Section 3 lies within this range, as do all of the CT incremental cancer risks.

Overall Protection of the Environment - Ecological Receptors

The risk-based PRG for protection of the environment is a range from 0.13 to 0.013 mg/kg total PCBs in fish fillets (this corresponds to a range from 0.3 to 0.03 mg/kg in whole fish), and is based on the LOAEL and NOAEL fish concentrations consumed by the river otter. The corresponding LOAEL and NOAEL whole fish target concentrations for the mink are 0.7 and 0.07 mg/kg PCBs. For the river otter, the NOAEL target concentration is not met in any of the three river sections over the 70-year model forecast period. For the river otter, the LOAEL target concentration is not met in River Section 1, but is met in River Section 2 in 52 years and is met in River Section 3 in 8 years. For the mink, the LOAEL target concentration is met in River Section 1 in 45 years and is met in River Sections 2 and 3 prior to 2010. For the mink, the NOAEL target concentration is not met in River Sections 1 and 2, but is met in River Section 3 in 5 years.

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For the CAP-3/10/Select alternative, the ecological TQs for the river otter and the mink are discussed in subsection 7.3.3.5 and presented in Table 7-9. For the river otter, the NOAEL and LOAEL TQs by river section are shown in Figures 7-5 and 7-6, respectively. The river otter TQs are two orders of magnitude above the NOAEL target level in River Sections 1 and 2 and one order of magnitude above the NOAEL target level in River Section 3. The river otter TQs are one order of magnitude above the LOAEL target level in River Sections 1 and 2. In River Section 3, the river otter toxicity quotient is below one for the LOAEL comparison. For the mink, the NOAEL and LOAEL TQs by river section are shown in Figures 7-7 and 7-8, respectively. All of the mink TQ comparisons are below one, except for the comparison with the NOAEL target level in River Sections 1 and 2.

Overall Protection of the Environment - Downstream Transport of PCBs

The Tri+ PCB load over the TI Dam predicted by the model for the CAP-3/10/Select alternative is about 104 kg in 2003, 23 kg in 2011, and 11 kg in 2035. The Tri+ PCB load over the Northumberland Dam is approximately 123 kg in 2003, 29 kg in 2011, and 11 kg in 2035. The Tri+ PCB load over the Federal Dam is about 131 kg in 2003, 43 kg in 2011, and 20 kg in 2035. This alternative does address the scour of PCB-contaminated sediments associated with one-in-three-year to one-in-five-year flow events from the Hoosic River in River Section 3, and is therefore effective in reducing the PCB load over Federal Dam to the Lower Hudson River. PCB loads due to resuspension from dredging operations are estimated to be 32 kg (about 6 kg/yr) over the entire Upper Hudson River for the five-year period.

8.4.2.2 Compliance with ARARs

The chemical-specific ARARs for PCBs in the water-column are 0.5 μg/L (500 ng/L) federal MCL; 0.09 μg/L (90 ng/L) NYS standard for protection of human health and drinking water sources; 1 ng/L federal Ambient Water Quality Criterion; 0.12 ng/L NYS standard for protection of wildlife; and 0.001 ng/L NYS standard for protection of human consumers of fish. As shown in Figures 6-33 through 6-37, the first two chemical-specific ARARs for the surface water are met by the CAP-3/10/Select alternative and the remaining three chemical-specific ARARs for the surface water are not met by this alternative for the 70-year forecast period. These figures also show that the water quality is substantially improved for the CAP-3/10/Select alternative, compared to the No Action and MNA alternatives. These differences are most apparent for the first 20 years (between 2005 and 2024) of the forecast period. However, even towards the end of the forecast period (in 2067), there is a very substantial difference between the water quality for the No Action alternative (approximately 30 ng/L at TID and Schuylerville and 10 ng/L at Federal Dam) and Alternative CAP-3/10/Select (approximately 5 ng/L at TID and Schuylerville and 1.7 ng/L at Federal Dam).

The CAP-3/10/Select alternative will comply with action-specific ARARs (*e.g.*, CWA Sections 401 and 404; TSCA; Section 3004 of RCRA; Section 10 of the Rivers and Harbors Act; New York State ECL Article 3, Title 3, and Article 27, Titles 7 and 9) and location-specific ARARs (*e.g.*, Endangered Species Act; Fish and Wildlife Coordination Act; Farmland Protection Policy Act; National Historic Preservation Act; and the New York State Freshwater Wetlands Law).

8.4.2.3 Long-Term Effectiveness and Permanence

Magnitude of Residual Risks

For the CAP-3/10/Select alternative, residual risk is reduced through capping 207 acres of PCB-contaminated sediments and removal of 1.73 million cubic yards of sediments containing 33,100 kg PCBs. For this alternative, the Tri+ PCB load over the Federal Dam are predicted to decrease from about 131 kg in 2003 to less than 20 kg in 2035. Soon after construction in 2011, the CAP-3/10/Select alternative achieves a 58 percent reduction in the Tri+ PCB load over Federal Dam compared to the No Action alternative and a 40 percent reduction in the Tri+ PCB load over Federal Dam compared to the MNA alternative. After a longer period of time, in 2035, the CAP-3/10/Select alternative results in a 68 percent reduction in the Tri+ PCB load over Federal Dam compared to the No Action alternative and a 16 percent reduction in the Tri+ PCB load over Federal Dam compared to the MNA alternative. The similarity in modeled PCB loads over Federal Dam between the MNA and the CAP-3/10/Select alternatives by this time (*e.g.*, 2035 and beyond) reflects the fact that both are largely controlled by the value assumed for the unknown upstream PCB load.

The CAP-3/10/Select alternative does not completely eliminate long-term risks for target areas that are capped. Sediments are removed in areas only to the degree necessary for cap installation and, in some areas, highly contaminated sediments may be left in place below the cap and backfill. Anthropogenic or natural processes (*e.g.*, navigation accidents, severe storms, or longer-term changes in the depositional/erosional regime in a given location) may damage or erode and scour the cap materials and redistribute PCB-contaminated capped sediments over wider areas of the Upper Hudson River. Non-routine repair or replacement of large sections of the cap may have to be undertaken if a breach occurs in a highly contaminated area (*e.g.*, *Hot Spot* 14 in River Section 1 or *Hot Spot* 28 in River Section 2) due to catastrophic events such as a major flood. Depositional buildup of sediments adjacent to the cap could shift currents over the cap creating the potential for erosion in an unexpected area.

The influence of regional aquifer systems on the hydrologic regime of Upper Hudson River has not been evaluated. Groundwater level fluctuations can result from a wide variety of hydrologic phenomena (*e.g.*, groundwater recharge due to seasonal heavy rainfall, or bank-storage effect near the river) and the subsequent inflow of groundwater may breach the cap in multiple areas and transport PCBs into the river. During periods of extremely low flow, sections of the cap could be exposed to the air and a different range of temperatures and other conditions unlike the submerged environment, resulting in freeze-thaw damage or desiccation cracking.

The CAP-3/10/Select alternative also relies on natural attenuation processes such as burial by cleaner sediments, bioturbation, biodegradation, dispersion, dilution through advection and recharge, adsorption, and volatilization to further reduce the concentration of any contaminants that remain after construction is completed. However, as discussed in subsection 8.4.2.1, modeling results predict that this alternative will not completely achieve the PRGs for the site within the modeled period, although RAOs are met in part or in full. The limitation in meeting PRGs largely stems from the assumption of the upstream Tri+ PCB load at Fort Edward (Rogers Island) of 0.0256 kg/day beginning in 2005. Greater achievement of the PRGs is estimated based on a 0 kg/day assumption. Thus, remediating PCB-contaminated sediment in combination with control of the upstream load can be expected to achieve PRGs to a greater extent than either approach alone.

Adequacy of Controls

The CAP-3/10/Select alternative provides for dredging of some contaminated sediments in target areas and placement of an engineered cap over the remaining target areas. This alternative also assumes a separate source control NTCRA in the vicinity of the GE Hudson Falls plant. Like the MNA alternative, this alternative also provides for institutional controls such as the fish consumption advisories and catch and release restrictions. As discussed for the MNA alternative, the existing institutional controls are not fully adequate in reducing exposure to PCBs from consumption of contaminated fish. In addition, institutional controls are inadequate for protection of the environment.

The planned post-construction fish, water column, and sediment monitoring program allows for tracking the natural recovery of the river after remediation is completed and determining the need to continue the existing fish consumption advisory. It also provides data to strengthen or extend the fishing advisories in the event that fish levels do not decline as expected. However, these advisories and the monitoring program have no effect on reducing the ecological risks to fish, piscivorous birds, and mammals.

Reliability of Controls

Sediment capping, sediment removal (dredging and excavation), backfilling and habitat replacement, and off-site disposal/treatment of removed sediments are all reliable and proven technologies. However, for the CAP-3/10/Select alternative, proper design, placement, and maintenance of the cap in perpetuity are required for its effectiveness, continued performance, and reliability. This presents a challenge for the Upper Hudson River. The cap concept for the Upper Hudson River requires maintenance of nearly 12 miles of long, narrow strips of cap with high length-to-width and of perimeter-to-surface area ratios. A cap placed in a relatively sheltered embayment or cove would be easier to maintain, since it would not be subject to the significant variations in river conditions typical of a river channel. The cap integrity monitoring and maintenance program planned for the CAP-3/10/Select alternative provides for as reasonably reliable maintenance as could be expected, if consistently and thoroughly followed. The challenge lies in overcoming the natural human tendency to relax vigilance as time goes on, especially as the rationale for the cap's placement in the first place fades from public consciousness. The fish consumption advisories will continue to provide some measure of protection of human health until PCB concentrations in fish are reduced and the PRG for protection of human health is attained. However, even the attainment of acceptable levels in the fish may serve to undermine vigilance in maintaining the cap in the future.

8.4.2.4 Reduction of Toxicity, Mobility, or Volume through Treatment

For the CAP-3/10/Select alternative, the mobility of the PCBs in capped areas (approximately 207 acres) is reduced because these PCBs are sequestered under the bentonite cap. However, capping does not satisfy the CERCLA statutory preference for treatment. In addition, there is no reduction in the toxicity or volume of the PCBs under the cap. Under this alternative, the mass of PCBs and the volume of contaminated sediments within the Upper Hudson River are permanently reduced because approximately 1.73 million cubic yards of sediment, containing an estimated 33,100 kg of PCBs, are removed. The CAP-3/10/Select alternative also assumes a separate source control NTCRA in the vicinity of the GE Hudson Falls plant which is expected to reduce the upstream water column Tri+ PCB load to the Hudson River PCBs site (*i.e.*, at Rogers Island) from 0.16 kg/day to 0.0256 kg/day by January 1, 2005. The sediment remediation will serve to greatly reduce sediment-to-water transfer of PCBs by removal or isolation of the contaminated sediments. In addition, after construction of the alternative is completed, natural attenuation processes will provide further (but slower) reductions in the toxicity of PCBs in the remaining sediments and surface water.

For the mechanical dredging option, the sediments that are removed undergo limited treatment (stabilization with Portland cement) prior to landfill disposal. Based on the large volume of sediments that are removed from the river under the CAP-3/10/Select alternative, but not subjected to treatment other than stabilization, it does not satisfy the statutory preference for treatment as a principal element of the remedy (CERCLA Section 121(b)). A different treatment process may be employed for the high-value beneficial use option, thus satisfying the statutory preference for treatment in such a case.

8.4.2.5 Short-Term Effectiveness

Short-term effectiveness is assessed through review of the four components described previously in subsection 8.1.5: protection of the community during remedial actions; protection of the workers during remedial actions; potential adverse environmental impacts resulting from construction and implementation; and time until remedial response objectives are achieved.

Protection of the Community During Remedial Actions

Risks to humans posed by consumption of PCB-contaminated fish will be reduced more rapidly under the CAP-3/10/Select alternative than under the No Action and MNA alternatives. As discussed in below, exposure levels for fish are not expected to increase substantively during this remedial action so that risks from consuming fish will remain largely the same during the construction period. The fish consumption advisories and restricted access to portions of the river undergoing remediation provide protection from risks to human health for the local community and the general public in the short term.

Transfer facilities and treatment areas present potential short-term risks to the community. Therefore, access to these areas will be restricted to authorized personnel. In addition, monitoring and engineering controls will be employed to minimize short-term effects due to material processing activities. Increased traffic will also present an incremental risk to the community. The potential for traffic accidents may increase marginally as additional vehicles are on the road. These effects are likely to be minimal because most transportation of sediments for disposal will be accomplished by rail. In addition to vehicular traffic, there will be increased river traffic. Work areas in the river will be isolated (access-restricted), with an adequate buffer zone so that pleasure craft and commercial shipping can safely avoid such areas. Finally, the increased in-river barge traffic will be monitored and controlled to minimize, to the extent possible, adverse effects on the commercial or recreational use of the Upper Hudson River.

Protection of Workers During Remedial Actions

For the CAP-3/10/Select alternative, potential occupational risks to site workers from direct contact, ingestion, and inhalation of PCBs from the surface water and sediments, and routine physical hazards associated with construction work and working on water, are significantly higher than for the No Action and MNA alternatives. For this alternative, site personnel will follow a site-specific health and safety plan, OSHA health and safety procedures, and wear the necessary personal protective equipment.

Potential Adverse Environmental Impacts Resulting from Construction and Implementation

For the CAP-3/10/Select alternative, the release of PCBs from the contaminated sediments into the water column during construction (dredging and cap placement), as well as the transport of PCBs over Federal Dam, will be controlled by operational practices (*e.g.*, control of sediment removal rates; use of enclosed dredge buckets; and use of sediment barriers). Although precautions to minimize resuspension will be taken, it is likely that there will be a transient increase of suspended PCB concentrations in the water column, and possibly in PCB concentrations in fish. Studies have shown that such effects are controllable, small, and transient, and that longer-term improvement is seen (*e.g.*, WRI, 2000; MDEQ, 1999).

Remedial activities may also result in the temporary impacts to aquatic and wildlife habitat of the Upper Hudson. Backfilling and habitat replacement measures will be implemented to mitigate these impacts. A monitoring program will be established to verify the attainment of the habitat replacement objectives. The degree of impact is directly related to the area remediated and volume dredged. From this perspective, the impacts of the CAP-3/10/Select and the REM-3/10/Select alternatives will be similar, since each alternative will modify the same total area of the river. However, the impacts of these modifications are not considered to be significant due to their transient nature and the mitigation measures which will be utilized.

As part of this evaluation, a semi-quantitative analysis of the possible increase in PCB loads and concentrations from dredging operations was performed for the regions downstream and outside of the target areas. These areas, in fact, represent the largest portion of the Upper Hudson within the site boundaries (*i.e.*, areas not subject to remediation). This calculation is intended to describe the mean increase in water column PCB concentration over each dredging season in these areas. The detailed description of the model and analysis used to estimate resuspension losses is provided in Appendix E.6. The results of the analysis are summarized here. The resuspension losses for this alternative apply only to the areas undergoing dredging. Areas undergoing capping only are assumed to yield little additional resuspension. Since this alternative involves the least sediment removal of the three active alternatives, additional PCB loads are smallest. Only mechanical dredging, as represented by an enclosed bucket dredge, is considered for sediment removal under this alternative. The resuspension rate assumed for the bucket dredge is a relatively conservative estimate since the available data describe the impacts of a less sophisticated dredge than that selected for the engineering concept for this alternative.

Resuspension modeling results indicate that dredging associated with this alternative would increase water column Tri+ PCB concentrations during remediation by an estimated average of 2.3 ng/L in River Section 1, 12 ng/L in River Section 2, and 5 ng/L in River Section 3. The estimated overall average increase in Tri+ PCBs is 5 ng/L. Note that the increases in PCB concentration would occur only during the remediation construction period. That is, water column concentrations would increase by 2.3 ng/L in River Section 1 during the three years of operation there. The increase in water column concentrations in River Sections 2 and 3 would be less during this period due to further settling and dilution of the material released from River Section 1. Similarly, water column concentrations in River Section 2 would increase by an average of 12 ng/L during the one year of operation in this river section. There would be no impact to River Section 1, which is upstream, and a lesser impact to River Section 3, since dilution and settling would serve to reduce the increase. The 5 ng/L increase in River Section 3 applies only during the last year of construction. The estimates for the increased PCB concentrations in River Sections 2 and 3 are based on the assumption that construction can be sequenced so that dredging occurs from upstream to downstream. To the extent that dredging of the various river sections occurs in parallel rather than in sequence, water column concentrations at the downstream dredging areas would be higher than those estimated by the model. The incremental concentration increases would not be strictly additive, however, since settling between the dredging areas will serve to reduce the increase produced by the upstream location.

It is important to place these estimated increases in the Tri+ PCB load in perspective. In particular, concentrations of Tri+ PCBs in the water column at the TI Dam were in the range of 14.4 to 532 (mean of 66 ng/L) in May through November 1999, the period of the year corresponding to the proposed remedial operations. At the expected time of implementation, the mean concentration at the TI Dam during this period is expected to be 29 ng/L based on the HUDTOX forecast. Concentrations in River Section 2 are generally similar to those in River Section 1 while those in River Section 3 are reduced by about 25 to 50 percent, depending on distance downstream due to dilution from tributary flow. Thus in all river sections, these expected increases represent relatively minor changes as compared to current or projected water column concentrations. Indeed, these additions are within the year-to-year and season-to-season variations regularly observed in the Upper Hudson. They are also well below the order-of-magnitude increase in mean water column concentrations seen in the early 1990s. The water column PCB concentrations increases observed in the early 1990s resulted in an approximate doubling of some fish levels. Thus, by analogy, the PCB releases associated with the CAP-3/10/Select alternative should have only a minor impact on fish body burdens in the Upper Hudson. It should be noted that Total PCB concentration increases may be greater, perhaps two to three times higher than those for Tri+ PCBs. However, current and projected water column total PCB concentrations at the TI Dam are also two to three times higher than those for Tri+ PCBs. Thus the expected increase in total PCB represents the same percentage increase relative to projected conditions as anticipated for the Tri+ increase.

While the previous paragraph has placed the dredging-related increase in water column concentrations of Tri+PCB in perspective, it should be noted that where particularly high sediment concentrations are likely to be encountered, additional measures to limit and control sediment resuspension could be employed. One location where additional measures may be warranted is the vicinity of *Hot Spot* 28 in River Section 2 where elevated PCB levels are known to exist. At this location it may be possible to perform some of the work in dry conditions by erecting a port-o-dam or other structural barrier system (see Appendix E for a discussion of turbidity barriers) and then draining the work area to reduce water levels. Once the area has been isolated and dewatered, work could proceed by means of excavation equipment with much less concern over the release of sediments into the water column. This and other approaches to further control and limit sediment resuspension, in specific circumstances, will be evaluated during the design phase.

In addition to the examination of the increase in PCB concentration, the model analysis also included an estimate of the total amount of Tri+ PCB mass released by dredging operations. Overall, the remediation would yield an additional 32 kg of Tri+ PCBs over the five-year operation, or about 6 kg/yr. This value should be compared to the estimated release of Tri+ PCBs during the remediation period in the absence of remediation (461 kg or about 92 kg/yr for No Action, and 295 kg or about 59 kg/yr for MNA). The resuspension-related increase is only about 10 percent of the expected annual release under MNA and even less relative to No Action. In fact, the modeled PCB load increase is well within the range of year-to-year variability. The current annual rate of release of Tri+ PCBs, approximately 109 kg/year (a rate which is largely unchanged over the last 10 years), would generate 545 kg over a period equivalent to the CAP-3/10/Select remedial operations.

The additional release from the CAP-3/10/Select alternative is less than the PCB release estimated from a single 100-year flood event (*i.e.*, about 60 kg), as noted in the RBMR (USEPA, 2000a). As discussed in the RBMR, the 100-year flood was not expected to have a major impact on fish or river PCB levels, with associated increases not lasting more than one to two years. With the remedial releases spread out over five years, the impact should be much smaller with a residual impact (after completion of construction) of even shorter duration than the 100-year flood.

Based on these analyses, it appears unlikely that the dredging of sediments associated with the CAP-3/10/Select alternative will yield substantively higher levels of PCB in the water or fish of the Upper Hudson during remedial construction. Based on the similarity to the release associated with the 100-year flood event, it is unlikely that the residual effects after the construction will last more than a few years.

However, for the CAP-3/10/Select alternative there is a potential transient impact from the temporary exposure of deeper, contaminated sediments during the time interval between excavation and cap placement. It may be possible to reduce impacts associated with exposure of deeper sediments by detailed planning of all phases of the dredging and capping operations. However, the level of coordination between the different elements of this alternative will render the overall remedial program under CAP-3/10/Select particularly complex. In addition, it will not be possible to fully avoid water quality and related ecological impacts resulting from the temporary exposure of contaminated sediments that are targeted for capping. Due to the transient nature of this exposure, the impact cannot be quantified. Nonetheless, it is unlikely to be greater than that originating from sediment resuspension.

Time until Remedial Response Objectives Are Achieved

As noted previously, forecasts are subject to considerable uncertainty. Therefore, the estimated years of target attainment discussed below should be considered a general guide. The risk-based PRG for protection of human health of 0.05 ppm PCBs (wet weight) in fish fillets is not met in River Sections 1, 2, and 3 in the short term. The target concentration of 0.2 ppm PCBs (one meal per month) in fish fillets is also not met in River Sections 1, 2, and 3 in the short term. The alternate target concentration of 0.4 ppm PCBs (one meal every two months) in fish fillets is not met in River Sections 1 and 2 in the short term, but is met in River Section 3 in the year 2010 for the CAP-3/10/Select alternative. Due to the potential effects of sediment resuspension discussed above, there may be a delay of a few years in achieving the reductions forecast by the model.

The risk-based PRG for protection of the environment is a range from 0.3 to 0.03 mg/kg in whole fish (this corresponds to a range from 0.13 to 0.013 mg/kg total PCBs in fish fillets), based on the LOAEL and NOAEL fish concentrations consumed by the river otter. The corresponding LOAEL and NOAEL target concentrations for the mink are 0.7 and 0.07 mg/kg PCBs in whole fish. For the river otter, the PRGs are not met in River Sections 1, 2, and 3 in the short term. For the mink, the LOAEL target concentration is not met in River Section 1 in the short term, but is met in River Sections 2 and 3 prior to 2010. For the mink, the NOAEL target concentration is not met in River Sections 1, 2, and 3 in the short term.

Therefore, in the short term, many RAOs and PRGs are not met for the CAP-3/10/Select alternative, and this alternative is not protective of human health or the environment during the construction period. However, the conditions associated with the implementation of this alternative are not expected to be much more detrimental than those associated with MNA. Subsequent to the implementation, conditions will improve substantively relative to MNA as discussed under long-term effectiveness.

8.4.2.6 Implementability

Technical Feasibility

Technical feasibility for the CAP-3/10/Select alternative is discussed below in terms of the main components of the alternative. Principal elements of the overall system that must be constructed, operated, and otherwise be available in order to cap and selectively remove targeted sediments, are as follows:

- Mechanical dredging equipment,
- Transfer facilities,
- AquaBlok^{TM} system and facilities,
- Barges and towboats, and
- Transportation and disposal systems.

Dredging Equipment

Removal work under this alternative would be accomplished by means of mechanical dredges. In general, the mechanical dredging systems (excavators outfitted with the appropriate auxiliary equipment) needed to implement this alternative are either available, or can be fabricated.

Central to establishing the technical feasibility of the dredging program that would need to be conducted under this alternative is the ability of the selected equipment to productively remove as little as one or two feet of contaminated sediment. Buckets, such as those developed by Cable Arm and certain European equipment suppliers, have been designed specifically for removal of sediments in large area, shallow, flat cuts. These buckets also incorporate features to minimize sediment resuspension and to monitor the precision of removal operations. The Cable Arm concept has been used on several remedial projects in the US and Canada, and the European Horizontal Profiler has now undergone its initial US demonstration at New Bedford Harbor (see Chapter 5 and Appendix A). Based on these experiences it is concluded that the shallow removal work called for under this alternative can be efficiently accomplished as a result of recent innovations in the auxiliary systems that are fitted to conventional hydraulic excavators.

Buckets such as the Cable Arm and the Horizontal Profiler have been specifically designed to minimize sediment resuspension. In addition, operational controls (*e.g.*, cycle time) can be implemented during removal operations to further reduce sediment resuspension. An analysis of the short-term water quality implications of using a modern environmental bucket are presented in Appendix E. The analysis indicates that rates of resuspension expected from use of the newest generation of mechanical equipment (and the resulting water quality impacts) are well below those reported in the technical literature regarding mechanical dredging operations as recently as a few years ago. Based on the design of the new generation of mechanical dredging equipment and the potential to further limit resuspension by operational controls, minimal downstream impact is expected during removal work. Semi-quantitative estimates of the impacts on water column loads and PCB loads are discussed in subsection 8.4.2.5 (see also Appendix E).

Transfer Facilities

Under the CAP-3/10/Select alternative, transfer facilities will be established at two locations to process sediments generated by removal operations. These transfer facilities will require wharf facilities as well as access to an operating rail line. In addition, adequate land area must be available to process incoming sediments and to load the processed sediments into rail cars. Development of the two transfer operations, one at a location adjacent to River Section 1 and one at a southern location near Albany, is considered technically feasible. While the availability of suitable locations adjacent to River Section 1 is limited, locations do exist where such operations can be established. In the Port of Albany area, there are a number of materials handling operations that can be configured to serve as sediment handling and processing facilities.

AquaBlok™ System and Facilities

Evaluation of the AquaBlok™ system is currently in progress at several remedial sites (*e.g.*, Ottawa River, Ohio and Fort Richardson, Alaska). Therefore, while some experience already exists with this technology, its long-term performance has not yet been established. However, the principal component of the system is bentonite, which is a stable, low-permeability barrier material. Bentonite has been used in capping systems for years and has demonstrated effectiveness for long-term encapsulation of contaminants.

As can be noted from the conceptual plan that has been developed for this alternative (see Plate 16), the pattern of work under CAP-3/10/Select is particularly complex. Capping would occur in extended linear patterns with a high perimeter-to-surface area ratio. The capping concept is constrained by areas where capping is impractical or infeasible (*e.g.*, the navigation channel and areas where depth of contamination is two feet or less). Because the dredging and capping operations will occur in an irregular, patchwork pattern dictated by these linear features, there will be a need to coordinate the in-river work with some precision so that contaminated sediment exposure will be minimized as much as possible. Furthermore, since manufacturing of capping materials may occur at a different location than that at which dredged material is being processed, the complexity of this alternative extends beyond dredging and capping to encompass activities at two transfer facilities and possibly a cap manufacturing site. The degree of coordination required at in-river work areas, and at material handling locations makes technical feasibility somewhat more of a challenge than for dredging alone.

Barge and Towboat Operations

Considerable use of barges and towboats will be necessary to implement this alternative. Barges will be needed to haul dredged sediments to the northern and southern transfer facilities and to haul capping materials to the various in-river capping locations. Based on preliminary information received from the New York State Canal Corporation (Dergosits, 2000) it appears that movement of loaded barges through the Champlain Canal will be feasible, provided that some navigational dredging is accomplished in the early stages of remedial work. An estimate of the quantity of material that must be removed to enable barges loaded with approximately 1,000 tons to move through the canal system has been made. Costs for this additional removal work have been included in overall cost of the alternative. Thus, from the standpoint of available draft, movement of barges and towboats from the work site to the transfer facilities is considered technically feasible. Other clearance and operating restrictions imposed by the canal system are not expected to preclude implementation of the CAP-3/10/Select alternative.

400722

Transportation and Disposal

Rail is the principal transportation mode considered for shipping dredged sediments out of the Hudson Valley. Although barges could be a link in the transportation scheme, barge transport beyond transfer facilities has been considered in this FS only in association with beneficial use of dredged sediments. Under this alternative, approximately 16 carloads of sediment would be processed at the northern transfer facility each day, and approximately 14 carloads at the Albany transfer facility. It is expected that this level of rail activity can be readily accommodated in the Upper Hudson River area, given the resources of the two Class I railroads that serve the region.

As explained in Appendix E, adequate landfill capacity with rail access exists to manage Hudson River sediments. This includes capacity at TSCA and non-TSCA landfills. Though transportation distance to these facilities is considerable, landfilling stabilized Hudson River sediments is considered feasible.

Administrative Feasibility

For the CAP-3/10/Select alternative, it is expected that the two transfer facilities, both constructed on land adjacent to the river, will be considered "on-site" for the purposes of the permit exemption under CERCLA Section 121(e), although any such facilities will comply with the substantive requirements of any otherwise necessary permits. Operations under this alternative will have to be performed in conformance with substantive requirements of regulatory programs implemented by USACE under Section 10 of the Rivers and Harbors Act and Sections 401 and 404 of the CWA. In addition, discharges during remediation will conform to NYS regulations related to maintenance of Hudson River water quality. Backfilling and habitat replacement will be implemented in accordance with federal and state ARARs.

It is expected that contract documents for this alternative will contain substantial restrictions on construction activity, including controls on the types of dredging and capping equipment to be used, restrictions on the speed of operations, constraints on barge filling practices, and controls on temporary storage of contaminated dredge spoils. Construction activities will also have to be coordinated with the Canal Corporation, which operates the locks on the Upper Hudson River from

May through November. Finally, requirements of other regulatory programs will be incorporated as necessary on the basis of information developed during remedial design.

Availability of Services and Materials

This section details the availability of services and materials that will be needed to implement the CAP-3/10/Select alternative.

Dredges

It is expected that mechanical dredging equipment can be obtained as needed for the CAP-3/10/Select alternative.

Barges and Towboats

Commercial activity on the Champlain Canal has all but ceased. Therefore, it is unlikely that the full complement of towboats and barges is available in the immediate project vicinity to conduct capping and dredging operations. Procurement of towboats and barges will require advance planning and may entail fabricating some equipment

Processing and Stabilization Equipment

This equipment includes silos, hoppers, conveyors, and pug mills and is considered to be commercially available on relatively short notice.

Cement or Substitute

The demand for and, therefore the availability of, cement varies with market conditions. During mid-2000 demand was high and obtaining adequate supplies in the Hudson Valley could have been a problem. Substitutes for cement (cement kiln dust or fly ash) are generally available, usually at substantially reduced costs in comparison to Portland cement. The utility and cost-effectiveness of these substitutes will need to be demonstrated via bench scale tests. Since there is likely to be a number of options available for processing dredged sediments (see Appendix E), it is concluded here that the availability of Portland cement (or lack thereof) will not prevent processing and off-site disposal of dredged sediments.

AquaBlok™

AquaBlok™ cap material will be manufactured either near the work site or at a location in the Hudson Valley at a quarry where there is a supply of sand and gravel. The other constituents of this composite aggregate material, clay and polymer, are also considered readily available.

Rail Cars

The availability of rail cars fluctuates with the state of the economy. Since the CAP-3/10/Select alternative will be implemented over five years, and substantial planning will take place prior to construction, it is expected that rail cars can be obtained within the cost parameters used in this FS.

Landfill Capacity

Based on a survey of existing permitted TSCA and non-TSCA landfills (Appendix E), it is concluded that adequate landfill capacity with rail access exists for disposal of Hudson River sediments.

8.4.2.7 Cost

A summary of the details of the cost estimate for the CAP-3/10/Select alternative is given in Tables 8-8a and 8-8b. Table 8-8a presents the summary for the disposal of stabilized dredged materials at both TSCA and non-TSCA landfills. Table 8-8b presents the summary for the option where the non-TSCA material is utilized for beneficial purposes. The estimated net present worth costs of this alternative, calculated at a 7 percent discount rate, are approximately $370 million assuming landfill disposal and $338 million assuming beneficial use.

Capital Cost

Since the construction will be performed over a five-year period, capital costs will vary on an annual basis. The total capital costs for this alternative are estimated to be about $504 million assuming landfill disposal and about $459 million assuming beneficial use. The estimated present worth of the capital costs for this alternative is $344 million assuming landfill disposal and $314 million for beneficial use.

O&M Costs

Due to the varying frequency of different elements of the monitoring program and the five-year reviews, O&M costs will vary on an annual basis. The estimated annual average O&M costs for this alternative are about $3.45 million for both landfill disposal and beneficial use options, and represents the monitoring costs and the periodic cost of the modeling and the five-year reviews. These costs have been estimated for a 25-year period. The estimated present worth of the O&M costs for this alternative is $24 million for both landfill disposal and beneficial use options.

8.5 Alternative REM-3/10/Select: Expanded Hot Spot Removal in River Section 1; Hot Spot Removal in River Section 2; and Removal of Select Areas in River Section 3

8.5.1 Description

The principal components of the REM-3/10/Select alternative include, as described below:

- Source control via separate removal action in the vicinity of the GE Hudson Falls plant;
- An implementation schedule and sequence of operations for the remediation;
- Removal (dredging) of sediments in selected target areas;
- In-river transport of backfill materials and dredged sediments;
- Processing at the northern and southern material management and transfer facilities;
- Treatment of the water entrained in removed (dredged) sediments to NYSPDES discharge criteria;
- Backfilling and habitat replacement;

400726

- Transportation of dewatered and stabilized materials to off-site dredged material management locations; and
- A performance monitoring program.

This alternative includes remediation by Expanded Hot Spot removal (*i.e.*, in which the nominal MPA targets are 3 g/m^2 PCBs or greater) in River Section 1, Hot Spot removal (*i.e.*, in which the nominal MPA targets 10 g/m^2 or greater) in River Section 2, and removal of select areas (*i.e.*, sediments with high-concentration PCB target areas) in River Section 3. This alternative also includes dredging in the navigation channel as necessary to implement the remediation (*e.g.*, barges and towboats). The areas to be remediated for this alternative are shown in Plate 17. The total area of sediments targeted for removal is approximately 493 acres. The estimated volume of sediments to be removed is 2.65 million cubic yards. This alternative also relies on naturally occurring attenuation processes to reduce the toxicity, mobility, and volume of the remaining PCBs in the Upper Hudson River sediments after the construction is completed. Institutional controls (*e.g.*, site use restrictions) are implemented as long-term control measures as part of this alternative. These restrictions include continuation or modification of the existing fish consumption advisories and catch and release restrictions. A review of site conditions will be conducted at five-year intervals, as required by Section 121(c) of CERCLA.

Under the REM-3/10/Select alternative, in River Section 1, 266 acres of PCB-contaminated sediments are remediated and nearly 1.5 million cubic yards of sediments containing 11,600 kg of PCBs are removed. An additional 66,100 cubic yards of sediments containing 200 kg of PCBs are removed from the navigation channel in River Section 1. In River Section 2, 74 acres of PCB-contaminated sediments are remediated and 565,000 cubic yards of sediments containing 23,600 kg of PCBs are removed. An additional 15,400 cubic yards of sediments containing 700 kg of PCBs are removed from the navigation channel in River Section 2. In River Section 3, 92 acres of PCB-contaminated sediments are remediated and 393,000 cubic yards of sediments containing 6,700 kg of PCBs are removed. An additional 117,000 cubic yards of sediments containing 2,800 kg of PCBs are removed from the navigation channel in River Section 3. Estimates of the areas remediated, as well as the volumes and the mass of PCBs removed from the sediment target areas and the navigation channel for each river section, are presented in Table 8-9.

8.5.1.1 Source Control in the Vicinity of the GE Hudson Falls Facility

The REM-3/10/Select alternative assumes a separate non-time critical removal action (NTCRA) for source control in the vicinity of the GE Hudson Falls plant. The assumed separate source control NTCRA, is expected to reduce the upstream water column Tri+ PCB load to the Hudson River PCBs site at Fort Edward (Rogers Island) from 0.16 kg/day to 0.0256 kg/day on January 1, 2005. USEPA has authorized the performance of an Engineering Evaluation/Cost Analysis (EE/CA) to evaluate potential NTCRAs to address the discharge of PCBs into the river in the vicinity of the GE Hudson Falls plant. GE has discussed with USEPA and NYSDEC a conceptual approach to contain the release of PCB oil from the vicinity of the Hudson Falls facility. Assuming that the conceptual approach proposed by GE, or a similarly effective system, is available to address the Hudson Falls source, USEPA believes that a source control NTCRA can reasonably be completed by January 1, 2005, if not earlier.

8.5.1.2 Implementation Schedule and Sequence of Operations

Remediation will commence in 2004 and will be completed in 2008. To the extent practicable, sediments near Rogers Island in River Section 1 will be remediated first, and the work will progress downstream towards the Federal Dam at Troy in River Section 3. Dredging of River Section 3 may occur simultaneously with removal operations elsewhere as a result of the need to gain access to the site or because doing so will improve overall efficiency. For this alternative, removal operations are estimated to continue for approximately five years. Areas that correspond to the navigation channel will be dredged first, followed by the areas in the intermediate depth zone and shallow zone, in that order. Subsequently, backfill (12 inches of sand, silt, and gravel) will be placed in the targeted areas as described in subsection 5.2.6, and other site restoration activities will be performed as described below.

8.5.1.3 Removal and In-River Transport Operations

In order to accomplish the sediment removal planned for this alternative within the five-year construction period, a number of dredges and other marine equipment will be needed for the in-river operations. The number and type of dredges needed to accomplish the work depend on the volume

400728

of material to be removed, the time frame for the work, the productivity of the equipment, and the limitations on the in-river and out-of-river transportation systems. Sediment removal can be performed using either mechanical or hydraulic dredging equipment. Where mechanical dredging is utilized, the dredged/excavated sediments are transported by hopper barge or deck barge to the transfer facility. Where hydraulic dredging is utilized, the dredged material is transported via the slurry pipeline and the booster pumping stations to the transfer facility. Based on the remediation targets for this alternative, Table 8-10a provides a list of the number and types of mechanical dredges that will be operated, the number of barge loads of sediment that will be received at the northern and southern transfer facilities, and quantity estimates for other engineering productivity parameters. Table 8-10b provides a similar list of the number and types of hydraulic dredges, the number of barge loads of sediment, and quantity estimates for other engineering productivity parameters.

8.5.1.4 On-Site Material Management and Transfer Facilities

Where mechanical dredging is utilized, the water separated from the sediments during transport is removed at the transfer facility and the dredged sediments are stabilized by mixing with cement or other appropriate pozzolanic material to absorb the remaining standing water. At the northern and southern dredged material management and transfer facilities, the sediments will be dewatered and blended with eight percent Portland cement as described in subsection 5.2.2 and Appendix E. This blending serves to improve both the handling and disposal properties of the dredged material. The rates at which this material is processed in the northern and southern facilities are presented in Table 8-10a. This stabilized material will then be loaded into rail cars or barges as described in subsections 5.2.2 and 5.2.5 for transfer to beneficial use and/or disposal facilities. The estimated number of rail cars loaded at each material management and transfer facility for this alternative is also presented in Table 8-10a.

Where hydraulic dredging is utilized, the dredged material is transported via the slurry pipeline and the booster pumping stations to the transfer facility, where the water is separated from the sediments in a treatment train that includes hydrocyclones, coagulation, sedimentation, and belt filters. The rates at which the separated solids are processed in the northern and southern facilities are presented in Table 8-10b. These separated solids will then be loaded into rail cars or barges as described in subsections 5.2.3 and 5.2.5 for transfer to beneficial use and/or disposal facilities. The estimated number of rail cars loaded at each material management and transfer facility for this alternative is also presented in this Table 8-10b.

8.5.1.5 Water Treatment Subsequent to Removal

The water associated with the dredged material will be treated at the northern and southern water treatment plants to NYSPDES discharge criteria as described previously in subsections 5.2.2 and 5.2.3.

8.5.1.6 Backfilling and Site Reconstruction

As described in subsection 5.2.6, measures will be undertaken to mitigate disturbances to the hydraulics of the river channel, the shoreline, and the aquatic habitat caused by removal operations. The areas that are dredged will be backfilled with one foot of imported clean fill. This backfill will consist of gravel, silt, and sand in order to re-establish a range of habitat types for a variety of aquatic biota, especially the resident fish. The navigation channel will not be backfilled.

The disturbed portions of the river shoreline will have to be either stabilized or reconstructed. The stabilization measures envisioned in this FS consist of hydro-seeding the shoreline where disturbance is expected to be minimal and then expanding the scale of the effort where the disturbances increase. Thus, in near-shore areas where between two and three feet of sediment would be removed, the stabilization concept consists of placement of an approximately 20-foot-wide vegetative mattress; where shoreline disturbance would equal or exceed 3 feet of sediment removal, the stabilization concept includes either a log or wood crib revetment in addition to the vegetative mattress. Tables 8-10a and 8-10b show the extent of shoreline disturbance and stabilization anticipated for the REM-3/10/Select alternative. Where shoreline wetlands (critical areas) will be removed by the dredging work, it is expected that the original bottom elevation will be re-established and that the new upper layer of substrate would be a silty material. The quantities of gravel, sand, and silt required for backfill and reconstruction of areas of the river bottom are also presented on Tables 8-10a and 8-10b.

Beyond physical replacement of the river bottom substrate, it is also anticipated that a spectrum of in-river plantings will be undertaken to further reduce the time for the river to return to a productive ecological condition. The plantings will consist of various types of wetland and aquatic species. The species being considered for this component of the program are detailed in Appendix F. The general type and quantity of planting envisioned for the REM-3/10/Select alternative are shown on Tables 8-10a and 8-10b.

8.5.1.7 Off-Site Transport and Dredged Material Management

Of the total volume of about 2.65 million cubic yards of sediments removed from the Upper Hudson River under the REM-3/10/Select alternative, it is estimated that more than 1.1million cubic yards (containing greater than 33 mg/kg PCBs) will need to be managed as TSCA-regulated material, and 1.54 million cubic yards (containing less than 33 mg/kg PCBs) will be handled as non-TSCA material. The TSCA material will be sent to a TSCA-permitted landfill and the non-TSCA material will be sent to a non-TSCA landfill, as described in subsection 5.2.5. If facilities and adequate capacity for beneficial use are available based on market conditions at the time when this alternative is implemented, some or all of the non-TSCA material will be utilized for such purposes as described in subsection 5.2.5.3. This includes both low-value beneficial uses as material for construction fill, landfill cover, or abandoned mine reclamation and higher-value beneficial uses as manufactured commercial products.

8.5.1.8 Performance Monitoring Program

The performance monitoring program consists of two components, monitoring during construction of the alternative and post-construction monitoring.

Construction Monitoring

During construction of the REM-3/10/Select alternative, the construction monitoring program described in subsection 5.2.7.3 will be implemented. The purpose of this monitoring is to confirm that removal and backfilling of areas targeted for remediation has been performed as designed for this alternative. The construction monitoring program will begin the year after design support testing is completed and will last for six years. This program includes collection of samples from the sediment, water column, and biota.

Post-Construction Monitoring

The post-construction performance of this alternative will be monitored through the implementation of the sampling program described in subsection 5.2.7.4 and in Appendix G. Figure 5-6 presents the outline of this monitoring program. Long-term monitoring for a ten-year period after remediation is completed in 2008 will be conducted in sediments, in the water column, and in biota as part of this alternative. Monitoring will include measurements of water column contamination, dated sediment cores, sediment PCB inventory, sediment physical properties (geophysics), and bioaccumulation by resident fish. Loss of contaminants can be documented by historical trends or contaminant concentration distributions showing a reduction in the total mass of contaminants in sediments, water, or biota, or by the presence of degradation products in sediments. The monitoring data will also be used as input parameters in the mathematical models to evaluate progress of the natural attenuation processes against original predictions.

The number and distribution of sediment, water column, and fish samples that will be collected are presented in the alternative-specific tables in Appendix G. The sediment samples (cores and surface grab samples) will be analyzed for total PCBs and total organic carbon. Bathymetric surveys will also be performed. Water column samples will be analyzed for congener-specific PCBs, TSS, and fraction of organic carbon on TSS. Samples of the resident fish species including largemouth bass, brown bullhead, and yellow perch will be analyzed for total PCBs (Aroclors), congener-specific PCBs, and lipid content. A review of site conditions will occur at the end of every five years for a 10-year period.

8.5.2 Analysis

8.5.2.1 Overall Protection of Human Health and the Environment

The overall protection of human health and the environment achieved by the REM-3/10/Select alternative is considerably more than that achieved by the No Action and MNA alternatives because this alternative is a permanent alternative that involves removal of contaminated sediments in River Sections 1, 2, and 3. It also provides for some limited on-site treatment of the PCBs in the sediments by the stabilization process (addition of eight percent Portland cement) discussed above. In addition, the REM-3/10/Select alternative assumes a separate source control NTCRA in the vicinity of the GE Hudson Falls plant, and also relies on the fish consumption advisories and catch and release restrictions to protect human health.

The existing fish consumption advisories and restricted access to portions of the river undergoing remediation reduce risks to the local community. This alternative also relies on such natural attenuation processes as burial by cleaner sediments, bioturbation, biodegradation, dispersion, dilution through advection and recharge, adsorption, and volatilization to further reduce the concentration of PCB-contaminant sediments remaining in the river after construction is completed.

There are five options for dealing with the sediments after removal from the river: landfill disposal (for hydraulic dredging); stabilization and landfill disposal (for mechanical dredging); beneficial use as landfill cover or construction fill material (for hydraulic dredging); stabilization and beneficial use as landfill cover or construction fill material (for mechanical dredging); and thermal treatment and beneficial use as manufactured commercial products like cement, light weight aggregate, fiberglass, or architectural tiles (for both mechanical and hydraulic dredging). For the landfill disposal option, the PCB-contaminated sediments would be permanently removed and contained at a permitted and regulated facility. For the beneficial use option, the removed and stabilized sediments will be further treated at the off-site facility and the PCBs will be permanently sequestered (for the construction fill/landfill cover option) or destroyed (for the manufacture of commercial products option).

For the REM-3/10/Select alternative, risks to human health and ecological receptors (piscivorous birds and mammals) will be reduced through remediation of an estimated 493 acres of PCB-contaminated sediments and removal of approximately 45,600 kg of PCBs contained in an estimated 2.65 million cubic yards of sediments. Removal of the sediments reduces the toxicity, mobility, and volume of the contaminants in the river. After construction is completed, natural attenuation processes may further reduce the toxicity and volume of PCBs in sediments (*e.g.*, through biodegradation) or reduce their mobility (*e.g.*, though burial by cleaner sediments).

Overall Protection of Human Health

For Alternative REM-3/10/Select, the risk-based PRG for protection of human health of 0.05 ppm PCBs (wet weight) in fish fillet is not met in River Sections 1 and 2 over the 70-year model forecast period, but is met in River Section 3 in the year 2051. The target concentration of 0.2 ppm PCBs (one meal per month) in fish fillets is also not met in River Section 1, but is met in River Section 2 in the year 2040 and is met in River Section 3 in the year 2014. The target concentration of 0.4 ppm PCBs (one meal every two months) in fish fillets is met in River Sections 1, 2, and 3, in the years 2025, 2024, and 2010, respectively. As discussed previously, further recovery as forecast by the model (*i.e.*, reduction in fish PCB concentrations) is limited due to the assumption made for the upstream PCB load.

As for the CAP-3/10/Select alternative, the failure to achieve further reduction in PCB levels in each river section reflects the importance of the assumption of the upstream loading late in the forecast period. Significant reductions are accomplished as a result of the sediment remediation and the source control NTCRA but no further reduction in fish body burden is possible without a change in the assumed upstream load.

For the REM-3/10/Select alternative, cancer risks and non-cancer health hazards are calculated using a start date of 2009. The RME and CT non-cancer hazard indices are discussed in detail in subsection 7.3.4.2 and are presented in Tables 7-6a through 7-6d for the Upper Hudson River and separately for River Sections 1, 2, and 3, respectively. RME and CT non-cancer hazard indices by river section are shown on Figures 7-1 and 7-2, respectively. The CT hazard indices are approximately an order of magnitude lower than the RME hazard indices, and are all above the target level of one except for the CT hazard index in River Section 3. Similarly, the RME and CT incremental cancer risks are discussed in detail in subsection 7.3.4.2 and are presented in Tables 7-7a through 7-7d for the Upper Hudson River and separately for River Sections 1, 2, and 3, respectively. RME and CT incremental cancer risks by river section are also shown on Figures 7-3 and 7-4, respectively. The RME incremental cancer risks for the Upper Hudson River and for River Sections 1 and 2 all slightly exceed the acceptable risk range of 10^{-4} to 10^{-6}, whereas the RME incremental cancer risk for River Section 3 lies within this range. All of the CT incremental cancer risks lie within this range.

400734

Overall Protection of the Environment - Ecological Receptors

The risk-based PRG for protection of the environment is a range from 0.13 to 0.013 mg/kg total PCBs in fish fillets (this corresponds to a range from 0.3 to 0.03 mg/kg in whole fish), based on the LOAEL and NOAEL fish concentrations consumed by the river otter. The corresponding LOAEL and NOAEL whole fish target concentrations for the mink are 0.7 and 0.07 mg/kg PCBs. For the river otter, the NOAEL target concentration is not met in any of the three river sections over the 70-year model forecast period. For the river otter, the LOAEL target concentration is not met in River Section 1, but is met in River Section 2 in 52 years and in River Section 3 in 8 years. For the mink, the LOAEL target concentration is met in River Section 1 in 4 years, and is met in River Sections 2 and 3 prior to 2010. For the mink, the NOAEL target concentration is not met in River Sections 1 and 2, but is met in River Section 3 in 5 years.

For the REM-3/10/Select alternative, the ecological TQs for the river otter and the mink are discussed in subsection 7.3.4.5 and presented in Table 7-9. For the river otter, the NOAEL and LOAEL TQs by river section are shown in Figures 7-5 and 7-6, respectively. The river otter TQs are two orders of magnitude above the NOAEL target level in River Sections 1 and 2 and one order of magnitude above the NOAEL target level in River Section 3. The river otter TQs are one order of magnitude above the LOAEL target level in River Sections 1 and 2. In River Section 3, the river otter TQ is below one for the LOAEL comparison. For the mink, the NOAEL and LOAEL TQs by river section are shown in Figures 7-7 and 7-8, respectively. All of the mink TQ comparisons are below one, except for the comparison with the NOAEL target level in River Sections 1 and 2.

Overall Protection of the Environment - Downstream Transport of PCBs

The Tri+ PCB load over the TI Dam predicted by the model for the REM-3/10/Select alternative is approximately 104 kg in 2003, 22 kg in 2011, and 11 kg in 2035. The Tri+ PCB load over the Northumberland Dam is about 123 kg in 2003, 27 kg in 2011, and 11 kg in 2035. The Tri+ PCB load over the Federal Dam is 131 kg in 2003, 42 kg in 2011, and 20 kg in 2035. This alternative addresses the scour of PCB-contaminated sediments associated with one-in-three-year to one-in-five-year flow events from the Hoosic River in River Section 3, and is therefore effective in reducing the PCB load over Federal Dam to the Lower Hudson River.

8.5.2.2 Compliance with ARARs

The chemical-specific ARARs for PCBs in the water-column are 0.5 μg/L (500 ng/L) federal MCL; 0.09 μg/L (90 ng/L) NYS standard for protection of human health and drinking water sources; 1 ng/L federal Ambient Water Quality Criterion; 0.12 ng/L NYS standard for protection of wildlife; and 0.001 ng/L NYS standard for protection of human consumers of fish. As shown in Figures 6-33 through 6-37, the first two chemical-specific ARARs for the surface water are met by the REM-3/10/Select alternative and the remaining three chemical-specific ARARs for the surface water are not met by this alternative for the 70-year forecast period. These figures also show that the water quality is substantially improved for the REM-3/10/Select alternative, compared to the No Action and MNA alternatives. These differences are most apparent for the first 20 years (between 2005 and 2024) of the forecast period. However, even towards the end of the forecast period (in 2067), there is a very substantial difference between the water quality for the No Action alternative (approximately 30 ng/L at TID and Schuylerville and 10 ng/L at Federal Dam) and the REM-3/10/Select alternative (approximately 5 ng/L at TID and Schuylerville and 1.7 ng/L at Federal Dam).

The REM-3/10/Select alternative will comply with action-specific ARARs (*e.g.*, CWA Sections 401 and 404; TSCA; Section 3004 of RCRA; Section 10 of the Rivers and Harbors Act; New York State ECL Article 3, Title 3, and Article 27, Titles 7 and 9) and location-specific ARARs (*e.g.*, Endangered Species Act; Fish and Wildlife Coordination Act; Farmland Protection Policy Act; National Historic Preservation Act; and New York State Freshwater Wetlands Law).

8.5.2.3 Long-Term Effectiveness and Permanence

Magnitude of Residual Risks

For the REM-3/10/Select alternative, residual risk is reduced through remediation of 493 acres of PCB-contaminated sediments and removal of 2.65 million cubic yards of sediments containing 45,600 kg PCBs. For this alternative, the Tri+ PCB load over the Federal Dam is approximately 131 kg in 2003, 42 kg in 2011, and slightly less than 20 kg in 2035. Soon after construction in 2011, the REM-3/10/Select alternative results in a 60 percent reduction in the Tri+ PCB load over Federal Dam compared to the No Action alternative and a 42 percent reduction in the

Tri+ PCB load over Federal Dam compared to the MNA alternative. After a longer period of time, in 2035, the REM-3/10/Select alternative results in a 69 percent reduction in the Tri+ PCB load over Federal Dam compared to the No Action alternative and a 17 percent reduction in the Tri+ PCB load over Federal Dam compared to the MNA alternative. The similarity in PCB loads over Federal Dam between the MNA and the REM-3/10/Select alternatives by this time (*e.g.*, 2035 and beyond) is reflects the fact that both are largely controlled by the assumed, but unknown, upstream PCB load.

The REM-3/10/Select alternative also relies on natural attenuation processes such as burial by cleaner sediments, bioturbation, biodegradation, dispersion, dilution through advection and recharge, adsorption, and volatilization to further reduce the concentration of any contaminants that remain after construction is completed. However, modeling results predict that this alternative will not completely achieve 0.05 ppm PRG in fish fillet for River Sections 2 and 3 within the modeled period. However, it is predicted to be nearly achieved for the Upper Hudson River as a whole within the modeled time frame. The limitation in meeting this PRG largely stems from the assumption of the upstream Tri+ PCB load to the Hudson River PCBs site at Fort Edward (Rogers Island). It was assumed that this load will be reduced 0.0256 kg/day beginning in 2005, but will remain at this (non-zero) load for the duration of the modeled period. Greater achievement of the PRGs is achieved if the upstream PCB input to the site were assumed to be 0 kg/day. Thus, remediating PCB-contaminated sediment in combination with further control of the upstream load can be expected to achieve far more PRGs and target concentrations than either approach alone.

Adequacy of Controls

The REM-3/10/Select alternative provides for removal of contaminated sediments in target areas. This alternative also assumes a separate source control NTCRA in the vicinity of the GE Hudson Falls plant. Like the MNA alternative, this alternative also provides for institutional controls such as the fish consumption advisories and catch and release restrictions. As discussed for the MNA alternative, the existing institutional controls, which rely on voluntary compliance, are not fully adequate in reducing exposure to PCBs due to consumption of fish. In addition, institutional controls are inadequate for protection of the environment (*e.g.*, ecological receptors).

The planned post-construction fish, water column, and sediment monitoring program allows for tracking the natural recovery of the river after remediation is completed and collection of data necessary for possible relaxing of the fish consumption advisories.

Reliability of Controls

Sediment removal (dredging and excavation), backfilling and habitat replacement, and off-site disposal/treatment of removed sediments are all reliable and proven technologies. The REM-3/10/Select alternative is more reliable than the CAP-3/10/Select alternative because there is little or no long-term maintenance or residual risk associated with the remedial work. Also, the fish consumption advisories will continue to provide some measure of protection of human health until PCB concentrations in fish are reduced to 0.05 ppm and the PRG for protection of human health is attained.

8.5.2.4 Reduction of Toxicity, Mobility, or Volume through Treatment

For the REM-3/10/Select alternative, the toxicity, mobility, and volume of the PCBs in approximately 493 acres of river sediments are permanently reduced (although not through treatment) because approximately 2.65 million cubic yards of sediment, containing an estimated 45,600 kg of PCBs are removed from the ecosystem of the Upper Hudson River. Because the REM-3/10/Select alternative also assumes a separate source control NTCRA in the vicinity of the GE Hudson Falls plant, the Tri+ PCB load to the water column is expected to be reduced from 0.16 kg/day to 0.0256 kg/day by January 1, 2005. In addition, after construction of the alternative is completed, natural attenuation processes will provide further (but slower) reductions in the toxicity of PCBs in the remaining sediments and surface water.

For the mechanical dredging option, the sediments that are removed undergo limited treatment (stabilization with Portland cement) prior to landfill disposal. For the hydraulic dredging option, the sediments that are removed are processed through hydrocyclones, coagulation, sedimentation, and belt filters to separate them from the water. However, these sediments do not undergo stabilization with Portland cement prior to landfill disposal. Based on the large volume of sediments that are removed from the river but not subjected to treatment other than stabilization, the

REM-3/10/Select alternative does not satisfy the statutory preference for treatment as a principal element of the remedy (CERCLA Section 121(b)). A different treatment process may be employed for the high-value beneficial use option, thus satisfying the statutory preference for treatment in such a case.

8.5.2.5 Short-Term Effectiveness

Short-term effectiveness is assessed through review of the four components described above (subsection 8.1.5): protection of the community during remedial actions, protection of workers during remedial actions, potential adverse environmental impacts resulting from construction and implementation, and time until remedial response objectives are achieved.

Protection of the Community During Remedial Actions

Risks to humans posed by consumption of PCB-contaminated fish will be reduced more rapidly under the REM-3/10/Select alternative than under the No Action and MNA alternatives. As discussed later in this subsection, exposure levels for fish are not expected to increase substantively during this remedial action so that risks from consuming fish will remain largely the same during the construction period. The fish consumption advisories and restricted access to portions of the river undergoing remediation provides protection from risks to human health for the local community in the short term.

Transfer facilities and treatment areas present potential short-term risks to the community. Therefore, access to these areas will be restricted to authorized personnel. In addition, monitoring and engineering controls will be employed to minimize short-term effects due to material processing activities. Increased traffic will also present an incremental risk to the community. The potential for traffic accidents may increase marginally as additional vehicles are on the road. These effects are likely to be minimal because most transportation of sediments for disposal will be accomplished by rail. In addition to vehicular traffic, there will be increased river traffic. Work areas in the river will be isolated (access-restricted), with an adequate buffer zone so that pleasure craft and commercial shipping can safely avoid such areas. Finally, the increased in-river barge traffic will be monitored and controlled to minimize, to the extent possible, adverse effects on the commercial or recreational use of the Upper Hudson River.

Protection of Workers During Remedial Actions

For the REM-3/10/Select alternative, potential occupational risks to site workers from direct contact, ingestion, and inhalation of PCBs from the surface water and sediments and routine physical hazards associated with construction work and working on water are substantially higher than for the No Action and MNA alternatives. For this alternative, site personnel will follow a site-specific health and safety plan, OSHA health and safety procedures, and wear the necessary personal protective equipment.

Potential Adverse Environmental Impacts Resulting from Construction and Implementation

For the REM-3/10/Select alternative, the release of PCBs from the contaminated sediments into the surface water during construction (dredging), as well as the transport of PCBs over the Federal Dam, will be controlled by operational practices (*e.g.*, control of sediment removal rates; use of enclosed dredge buckets; and use of sediment barriers). Although precautions to minimize resuspension will be taken, it is likely that there will be a temporary increase of suspended PCB concentrations, and possibly an increase in fish PCB body burdens. Studies have shown that such effects are controllable, small, and transient, and that longer-term improvement is seen (*e.g.*, WRI, 2000; MDEQ, 1999).

Remedial activities may also result in temporary impacts to aquatic and wildlife habitat of the Upper Hudson. Backfilling and habitat replacement measures will be implemented to mitigate these impacts. A monitoring program will be established to verify the attainment of the habitat replacement objectives. The degree of impact is directly related to the area remediated and volume dredged. From this perspective, the impacts of the REM-3/10/Select and the CAP-3/10/Select alternatives will be similar, since each alternative will modify the same total area of the river. However, these impacts are not considered to be significant due to their transient nature and the mitigation measures which will be utilized.

As part of this evaluation, a semi-quantitative analysis of the possible increase in PCB loads and concentrations was performed for the regions downstream and outside of the target areas. These areas, in fact, represent the largest portion of the Upper Hudson within the site boundaries. This calculation is intended to describe the mean increase in water column PCB concentration over each dredging season in these areas. The detailed description of the model and analysis to estimate resuspension losses is provided in Appendix E.6. The results of the analysis are summarized here. This alternative involves a greater volume of sediment removal than CAP-3/10/Select and less than REM-0/0/3. Correspondingly, the mass of sediment resuspended for REM-3/10/Select lies between the other two alternatives. As part of this analysis, the short-term impacts of a 12-inch cutterhead dredge and an enclosed bucket dredge are considered for sediment removal. For all comparisons between the two dredging methods, the production rate of dredge spoil material is the same for both methodologies. Specifically, the production rate of a 12-inch cutterhead dredge is comparable to that of three 4-cubic-yard enclosed bucket dredges. The 12-inch cutterhead dredge and three 4-cubic-yard enclosed bucket dredges form the basis for comparisons below.

The resuspension rate for the bucket dredge represents a relatively conservative estimate. Specifically, the available data for the bucket dredge describe the impacts of a less sophisticated dredge than that selected for the engineering concept for this alternative. Although the results of the resuspension modeling indicate somewhat greater PCB concentrations and loads due to mechanical dredges versus hydraulic equipment, resuspension considerations will not be the main consideration in selecting one concept over another, since the mechanical dredge estimate is considered conservative. Rather, other engineering issues, such as sediment transfer, processing and handling as well as operational logistics, will be more important considerations.

The model results indicate that dredging operations associated with this alternative would serve to raise water column Tri+ PCB concentrations during the remediation an average of 2.4 ng/L in River Section 1 utilizing the cutter-head dredge and an average of 4 ng/L using the enclosed bucket dredges. For the expected one year of operation in River Section 2, the cutterhead dredge would raise water column Tri+ PCB concentrations by 9 ng/L, whereas the bucket dredges would raise concentrations by 15 ng/L. The last year of operation, set for River Section 3, is projected to raise water column Tri+ PCB concentrations by 5 ng/L via the cutterhead dredge and 8 ng/L via the bucket dredges. The overall average increase in Tri+ PCBs is estimated to be 4 ng/L for the cutterhead dredge and 7 ng/L for the bucket dredges. Estimated water column PCB concentration increases from the cutterhead dredge are consistently about 40 percent lower than the three bucket dredges. This is based on a somewhat lower rate of resuspension for the cutterhead and a more conservative estimate of resuspension for the bucket dredges. See Appendix E.6 for further discussion of the comparison.

The increases in PCB concentration would occur only during the remedial construction period. For example, using the three enclosed bucket dredges, water column concentrations would increase by an average of 4 ng/L in River Section 1 during the three years of operation there. The increase in water column concentrations in River Sections 2 and 3 would be less during this period due to further settling and dilution of the material released from River Section 1. Similarly, water column concentrations in River Section 2 would increase by an average of 15 ng/L during the one year of operation in this river section. There would be no impact to River Section 1, which is upstream, and a lesser impact to River Section 3, since dilution and settling would serve to reduce the increase. The 8 ng/L increase in River Section 3 applies only during the last year of construction.

The estimates for the increased PCB concentrations in River Sections 2 and 3 are based on the assumption that construction can be sequenced so that dredging occurs from upstream to downstream. To the extent that dredging of the various river sections occurs in parallel rather than in sequence, water column concentrations at the downstream dredging areas would be higher than those estimated by the model. The incremental concentration increases would not be strictly additive, however, since settling between the dredging areas will serve to reduce the increase produced by the upstream location.

It is important to place these estimated increases in the Tri+ PCB load in perspective. In particular, concentrations of Tri+ PCBs in the water column at the TI Dam were in the range of 14 to 532 ng/L (mean of 66 ng/L) in May through November (1999), the period (time of year) corresponding to the remedial operations. During the anticipated period of implementation, the mean concentration at the TI Dam is expected to be 29 ng/L, based on the HUDTOX forecast. Thus implementation of the REM-3/10/Select alternative is only expected to increase mean water column concentrations in River Section 1 by 14 percent. Forecast concentrations in River Section 2 are generally similar to those in River Section 1. Under REM-3/10/Select, water column concentrations would increase by about 30 percent with the cutterhead dredge in River Section 2 (29 ng/L, plus an increase of 9 ng/L) or by about 50 percent with the bucket dredges (29 ng/L, plus an increase of 15 ng/L), but only for the one year of operation in this river section. Average concentrations would be expected to increase by about 50 percent in River Section 3 during the one year of operation in this river section.

While the previous paragraph has placed the dredging related increase in water column concentrations of Tri+PCB in perspective, it should be noted that where particularly high sediment concentration are likely to be encountered additional measures to limit and control sediment resuspension could be employed. One location where additional measures may be warranted is the vicinity of *Hot Spot* 28 in River Section 2 where elevated PCB levels are known to exist. At this location it may be possible to perform some of the work in dry conditions by erecting a port-o-dam or other structural barrier system (see Appendix E for a discussion of turbidity barriers) and then pumping the work area to reduce water levels. Once the area has been isolated and dewatered, work could proceed by means of excavation equipment with much less concern over the release of sediments into the water column. This and other approaches to further control and limit sediment resuspension, in specific circumstances, will be evaluated during the design phase.

Thus, in River Section 1, the projected increases in Tri+ PCB load from sediment resuspension represent relatively minor changes as compared to current or projected water column PCB concentrations, regardless of dredge type. Indeed, these increases in load are well below the year-to-year and season-to-season variations regularly observed in the Upper Hudson. Changes in River Sections 2 and 3 are more substantial but relatively short in duration (the 30 weeks of a single dredging season). In all cases however, the projected increases for all three river sections are well below the order-of-magnitude increase in mean water column concentrations seen in the early 1990s. These water column increases resulted in an approximate doubling of some fish PCB concentrations in some river sections. Thus, by analogy, PCB releases associated with the REM-3/10/Select alternative should have only a minor impact on fish body burdens in the Upper Hudson. It should be noted that total PCB concentration increases may be greater, perhaps two to three times higher, than those estimated for Tri+ PCBs. However, current and projected water column total PCB concentrations at the TI Dam are also two to three times higher than those for Tri+ PCBs. Thus the expected increase in total PCB represents the same percentage increase relative to projected conditions as anticipated for the Tri+ PCB concentration increase.

In addition to the examination of the increase in PCB concentration, the model analysis also included an estimate of the total amount of Tri+ PCB mass released by dredging operations. Overall, the remediation would yield an additional 28 kg of Tri+ PCBs over the five-year operation utilizing the cutterhead dredge, or about 6 kg/yr. The bucket dredges would yield about 47 kg, or 9 kg/yr. These values should be compared to the estimated release of Tri+ PCBs from the sediments during the remediation period in the absence of remediation (461 kg or about 92 kg/yr for No Action and 295 kg or about 59 kg/yr for MNA from River Section 1 alone). The increase due to the use of the cutterhead dredge is only about 10 percent of the expected annual release under MNA and even less under No Action. In fact the load difference is well within the range of year-to-year variability. The bucket dredge release is a little higher but still less than 16 percent of the expected annual release under MNA and even less under No Action. Notably, the current annual release of Tri+ PCBs is 109 kg/year. This rate of release, which is largely unchanged over the last 10 years, would yield 545 kg over a period equivalent to the remedial operations for the REM-3/10/Select alternative.

The additional release from the REM-3/10/Select alternative (28 to 47 kg) is less than the PCB release estimated from a single 100-year flood event (*i.e.*, 60 kg) as noted in the RBMR (USEPA, 2000a). As discussed in the RBMR, the 100-year flood was not expected to have a major impact on fish or river PCB levels, with associated increases not lasting more than one to two years. With the remedial releases spread out over five years, the impact should be much smaller with a residual impact (after completion of construction) of even shorter duration than the 100-year flood.

Based on these analyses, it appears unlikely that the removal of sediments associated with the REM-3/10/Select alternative will yield substantively higher PCB concentrations in Upper Hudson fish during remedial construction. Water column increases may be as high as 30 to 50 percent in River Sections 2 and 3 but the higher levels are short-lived. Based on the similarity to the release associated with the 100-year flood event, it is unlikely that the residual effects will last more than a few years after the construction is completed.

Due to the greater extent of sediment removal, river conditions may be slightly worse than those anticipated during the implementation of the CAP-3/10/Select alternative. However, the impact of additional resuspension losses under the REM-3/10/Select alternative may be partially or entirely offset by the increased exposure of contaminated sediments under CAP-3/10/Select. However, the impact of the latter could not be estimated.

Time until Remedial Response Objectives Are Achieved

As noted previously, forecasts are subject to considerable uncertainty. Therefore, the estimated years of target attainment discussed below should be considered a general guide. The risk-based PRG for protection of human health of 0.05 ppm PCBs (wet weight) in fish fillets is not met in River Sections 1, 2, and 3 in the short term. The target concentration of 0.2 ppm PCBs (one meal per month) in fish fillets is also not met in River Sections 1, 2, and 3 in the short term. The target concentration of 0.4 ppm PCBs (one meal every two months) in fish fillets is not met in River Sections 1 and 2 in the short term, but is met in River Section 3 in the year 2010 for the REM-3/10/Select alternative. Due to potential effects of sediment resuspension discussed above, there may be a delay of a few years in achieving the reductions forecast by the model.

The risk-based PRG for protection of the environment is a range from 0.13 to 0.013 mg/kg total PCBs in fish fillets (this corresponds to a range from 0.3 to 0.03 mg/kg in whole fish), based on the LOAEL and NOAEL fish concentrations consumed by the river otter. The corresponding LOAEL and NOAEL whole fish target concentrations for the mink are 0.7 and 0.07 mg/kg PCBs. For the river otter, the PRGs are not met in River Sections 1, 2, and 3 in the short term. For the mink, the LOAEL target concentration is not met in River Section 1 in the short term, but is met in River Sections 2 and 3 prior to 2010. For the mink, the NOAEL target concentration is not met in River Sections 1, 2, and 3 in the short term.

Therefore, in the short term, many RAOs and PRGs are not met for the REM-3/10/Select alternative, and this alternative is not protective of human health or the environment during the construction period. However, the conditions associated with the implementation of this alternative are not expected to be much more detrimental than those associated with MNA. Subsequent to the implementation, conditions will improve substantively relative to MNA as discussed under long-term effectiveness.

8.5.2.6 Implementability

Technical Feasibility

Technical feasibility is evaluated for the principal equipment and systems that are expected to be required for the REM-3/10/Select alternative:

- Mechanical or hydraulic dredging equipment;
- Transfer facilities;
- Barges and towboats; and
- Transportation and disposal systems.

Dredging Equipment

Mechanical Dredging Equipment

Removal work under this alternative (REM-3/10/Select) would be accomplished by means of several mechanical dredges operating simultaneously for five construction seasons. The dredging equipment needed to implement this alternative (estimated to be four excavators outfitted with the appropriate auxiliary equipment) is either available or can be fabricated.

Central to establishing the technical feasibility of the dredging program under this alternative is the ability of the selected equipment to productively (*i.e.*, cost-effectively) remove as little as one or two feet of contaminated sediment. Buckets, such as those developed by Cable Arm and European equipment suppliers, have been designed specifically for removal of sediments in large area, shallow, flat cuts. These buckets also incorporate features to minimize sediment resuspension and to monitor the precision of removal operations. The Cable Arm concept has been used on several remedial projects in the US and Canada, and the European Horizontal Profiler has now undergone its initial US demonstration at New Bedford Harbor (see Chapter 5 and Appendix A).

Based on these experiences it is concluded that the shallow removal work called for under this alternative can be efficiently accomplished as a result of ongoing innovations in the design of excavators and the associated auxiliary equipment.

Buckets such as the Cable Arm and the Horizontal Profiler have been specifically designed to minimize sediment resuspension. Furthermore, beyond the design features that have been incorporated into the equipment, it is also possible to impose controls on actual removal operations (*e.g.*, cycle time) so that further reductions in sediment resuspension can be attained. An analysis of the short term water quality implications of using a modern environmental bucket are presented in Appendix E. The analysis indicates that rates of resuspension expected from the newest generation of mechanical equipment are well below those reported in the technical literature regarding mechanical dredging operations, as recently as a few years ago. Based on the design of the new generation of mechanical dredging equipment and the potential to further limit resuspension by operational controls, minimal downstream impact is expected during removal work (see Appendix E). The estimated Tri+ PCB loads due to resuspension from mechanical dredging operations is 47 kg (about 9 kg/yr) over the entire Upper Hudson River for the five-year period. This value should be compared to the estimated release of Tri+ PCBs from the sediments during the remediation period in the absence of remediation (461 kg or about 92 kg/yr for No Action and 295 kg or about 59 kg/yr for MNA from River Section 1 alone). Therefore, an alternative based on mechanical removal of targeted sediments is environmentally feasible.

Hydraulic Dredging Equipment

Details on the hydraulic dredging concept are presented in Appendix G. This concept indicates that one suction dredge outfitted with a cutterhead can remove the targeted sediments in River Sections 1 and 2 in about four years. Given the limitations on slurry line length described in Appendix H, it will also be necessary to employ several mechanical dredges for removal operations in River Section 3. It is expected that the required hydraulic dredge and mechanical dredges are either commercially available or can be fabricated for this project.

Hydraulic dredge designs have undergone substantial modifications in reaction to the need to reduce sediment resuspension and to conduct removal operations as precisely as possible. It is expected that continuing improvements will be made to cutterhead and inlet pipe geometry, control of the cutterhead swing, and the geometry of shrouds added for resuspension control. An analysis of sediment resuspension rates expected during operation of a modern suction dredge is presented in Appendix E. The estimated Tri+ PCB loads due to resuspension from hydraulic dredging operations is 28 kg (about 6 kg/yr) over the entire Upper Hudson River for the five-year period. This value should be compared to the estimated release of Tri+ PCBs from the sediments during the remediation period in the absence of remediation (461 kg or about 92 kg/yr for No Action and 295 kg or about 59 kg/yr for MNA from River Section 1 alone). Therefore, an alternative based on hydraulic removal of targeted sediments is environmentally feasible.

Transfer Facilities

Mechanical Dredging

Transfer facilities will be established at two locations to process sediments generated by mechanical removal operations under this alternative. These transfer facilities require wharf facilities as well as access to an operating rail line. In addition, adequate land area must be available to process incoming sediments and to load the processed sediments into rail cars. Development of the two transfer operations, one at a location adjacent to River Section 1 and one at a southern location near Albany, is considered technically feasible. While the availability of suitable locations adjacent to River Section 1 is limited, locations do exist where such operations can potentially be established. In the Port of Albany area there are a number of materials handling operations that can be configured to serve as sediment handling and processing facilities.

Hydraulic Dredging

Transfer facilities will be established at two locations to process sediments generated by hydraulic removal operations under this alternative. These transfer facilities require wharf facilities as well as access to an operating rail line. In addition, adequate land area must be available to process incoming sediments and to load the processed sediments into rail cars. Development of the two transfer operations, one at a location adjacent to River Section 1 and one at a southern site near Albany, is considered technically feasible.

While the availability of suitable locations adjacent to River Section 1 is limited, locations do exist where transfer operations can potentially be established. Under the hydraulic dredging scenario, land area requirements at the northern transfer facility are somewhat more extensive than necessary for removal operations conducted by only mechanical dredges. This is a consequence of the need to process (dewater) incoming sediment slurry at the rate of approximately 8,000 gpm. While the additional land area required for slurry processing (perhaps several acres) somewhat complicates establishing a transfer facility adjacent to River Section 1, it is expected that a location can be identified for this purpose. With regard to a transfer facility in the Albany vicinity, it is expected that a location with existing wharf facilities and rail access can be found along the industrial waterfront zone.

Barge and Towboat Operations

Mechanical Dredging

Considerable use of barges and towboats will be necessary to implement the mechanical dredging option for this alternative. Barges will be needed to haul dredged sediments to the northern and southern transfer facilities and to place backfill in the river at the completion of removal operations. Based on preliminary information received from the New York State Canal Corporation (Dergosits, 2000) it appears that movement of loaded barges through the Champlain Canal will be feasible, provided that some navigational dredging is accomplished in the early stages of remedial work. An estimate of the quantity of material that must be removed to enable barges loaded with approximately 1,000 tons to move through the canal system has been made. Costs for this additional removal work have been included in overall cost of the alternative. Thus, from the standpoint of available draft, movement of barges and towboats from the work site to the transfer facilities is considered technically feasible. Other clearance and operating restrictions imposed by the canal system are not expected to preclude implementation of the REM-3/10/Select alternative .

Hydraulic Dredging

Considerable use of barges and towboats will be necessary to implement the hydraulic dredging option of this alternative. Barges will be needed to haul dewatered sediments from the northern to the southern transfer facilities and to haul mechanically dredged sediments directly to the southern transfer facility. Based on preliminary information received from the New York State Canal Corporation, it appears that movement of loaded barges through the Champlain Canal will be feasible provided that some navigational dredging is accomplished in the early stages of remedial work. An estimate of the quantity of material that must be removed to enable barges loaded with approximately 1,000 tons to move through the canal system has been made. Costs for this additional removal work have been included in the overall cost of the alternative. Thus, from the standpoint of available draft, movement of barges and towboats between transfer facilities is considered technically feasible. Other clearance and operating restrictions imposed by the canal system are not expected to preclude accomplishing the program.

Transportation and Disposal

Mechanical Dredging

Rail is the principal transportation mode considered for shipping dredged sediments out of the Hudson Valley. Although barges could be a link in the transportation scheme, barge transport has been considered in this FS only in association with beneficial use of dredged sediments. Under this alternative, approximately 16 carloads of sediment would be processed at the northern transfer facility each day and approximately 29 carloads at the Albany transfer facility. It is expected that this level of rail activity can be accommodated in the Hudson Valley, given the resources of the two Class I railroads that serve the region.

As explained in Appendix E, adequate landfill capacity with rail access exists to manage Hudson River sediments. This includes TSCA-permitted landfill capacity and capacity for non-TSCA materials. The considerable transportation distance to these facilities impacts overall alternative costs but not the technical feasibility of landfill disposal.

Hydraulic Dredging

As with mechanical dredging, rail is the principal transportation mode considered for shipping hydraulically dredged sediments out of the Hudson Valley. Although barging may be a link in the transportation scheme, barge transport has been considered in this FS only in association with beneficial use of dredged sediments. Under this alternative, when hydraulic dredging operations are in progress, approximately 16 carloads of sediment would be processed at the northern transfer facility each day and approximately 26 carloads at the southern transfer facility. It is expected that this level of rail activity (which is slightly less than that estimated for the mechanical dredging option) can be accommodated in the Upper Hudson River area, given the resources of the two Class I railroads that serve the region.

As explained in Appendix E, adequate landfill capacity with rail access exists to manage Hudson River sediments. This includes TSCA-permitted landfill capacity and capacity for non-TSCA materials. The considerable transportation distance to these facilities affects overall costs but not the feasibility of landfill disposal.

Administrative Feasibility

For the REM-3/10/Select alternative, it is expected that the two transfer facilities, both constructed on land adjacent to the river, will be considered "on-site" for the purposes of the permit exemption under CERCLA Section 121(e), although any such facilities will comply with the substantive requirements of any otherwise necessary permits. Operations under this alternative will have to be performed in conformance with substantive requirements of regulatory programs implemented by USACE under Section 10 of the Rivers and Harbors Act and Sections 401 and 404 of the CWA. In addition, discharges during remediation will conform to NYS regulations related to maintenance of Hudson River water quality. Backfill and habitat replacement will be implemented in accordance with federal and state ARARs.

It is expected that contract documents for this alternative will contain substantial restrictions on construction activity including controls on the types of dredging and capping equipment to be used, restrictions on the speed of operations, constraints on barge filling practices, and controls on temporary storage of contaminated dredge spoils. Construction activities will also have to be coordinated with the Canal Corporation, which operates the locks on the Upper Hudson River from May through November. Finally, requirements of other regulatory programs will be incorporated as necessary on the basis of information developed during remedial design.

Availability of Services and Materials

Mechanical Dredging

This section details the availability of services and materials needed to implement the REM-3/10/Select alternative using mechanical dredges.

Mechanical Dredges

It is expected that mechanical dredging equipment needed for the REM-3/10/Select alternative is either commercially available or can be readily fabricated.

Barges and Towboats

Commercial activity on the Champlain Canal has all but ceased. Therefore, it is unlikely that the full complement of towboats and barges is available in the immediate project vicinity to conduct the removal operations. Procurement of towboats and barges will require advance planning and may entail fabricating some equipment.

Processing and Stabilization Equipment

The principal components of the sediment stabilization system are silos, hoppers, conveyors, and pug mills. A processing system will be erected at both the southern and northern transfer facilities to process mechanically dredged sediments. Stabilization equipment can be purchased from a number of manufacturers and suppliers and is considered to be available for purposes of this FS.

Cement or Substitute

The demand for and, therefore, the availability of, Portland cement varies with market conditions. During mid-2000 demand was high and obtaining adequate supplies in the Hudson Valley could have been a problem. Substitutes for cement (cement kiln dust or fly ash) are generally available, usually at substantially reduced costs in comparison to Portland cement. The utility and cost-effectiveness of these substitutes will need to be demonstrated via bench scale tests. Since there is likely to be a number of options available for processing dredged sediments (see Appendix E), it is concluded that the availability of Portland cement (or lack thereof) will not prevent processing and off-site disposal of dredged sediments.

Rail Cars

The availability of rail cars fluctuates with the state of the economy. Since the REM-3/10/Select alternative will be implemented over five years, and substantial planning will take place prior to construction, it is expected that rail cars can be obtained within the cost parameters used in this FS.

Landfill Capacity

Based on a survey of existing permitted TSCA and non-TSCA landfills (see Appendix E), it is concluded that adequate landfill capacity with rail access exists for disposal of dredged material generated by the REM-3/10/Select alternative.

Hydraulic Dredging

This section details the availability of services and materials needed to implement the REM-3/10/Select alternative using a hydraulic dredging system in River Sections 1 and 2 and mechanical dredges in River Section 3.

Dredges

It is expected that the hydraulic and mechanical dredging equipment required to implement the REM-3/10/Select alternative is either commercially available or can be fabricated as needed.

Barges and Towboats

Commercial activity on the Champlain Canal has all but ceased. Therefore, it is unlikely that the full complement of towboats and barges is available in the immediate project vicinity to conduct removal operations. Procurement of towboats and barges will require advance planning and may entail fabricating some equipment.

Dewatering Equipment

Incoming slurry generated by the hydraulic dredging operations (about 8,000 gpm average pumped to the northern transfer facility) will be processed via a series of hydrocyclones, flocculation and settling tanks, and belt presses for purposes of dewatering the dredged sediments prior to off-site shipment (see Appendix E). This equipment can be purchased from a number of manufacturers and suppliers and is considered to be available for purposes of this FS.

Processing and Stabilization Equipment

The principal components of the sediment stabilization system are silos, hoppers, conveyors, and pug mills. This system will be erected at the southern transfer facility to process mechanically dredged sediments coming from River Section 3. This equipment can be purchased from a number of manufacturers and suppliers and is considered to be available for purposes of this FS.

Cement or Substitute

The demand for and, therefore, the availability of, Portland cement varies with market conditions. During mid-2000 demand was high and obtaining adequate supplies in the Hudson Valley could have been a problem. Substitutes for cement (cement kiln dust or fly ash) are generally available, usually at substantially reduced costs in comparison to Portland cement. The utility and cost-effectiveness of these substitutes will need to be demonstrated through bench scale tests. Since there is likely to be a number of options available for processing dredged sediments (see Appendix E), it is concluded here that the availability of Portland cement (or lack thereof) will not prevent processing and off-site disposal of dredged sediments.

Rail Cars

The availability of rail cars fluctuates with the state of the economy. Since the REM-3/10/Select alternative will be implemented over five years, and substantial planning will take place prior to initiating construction, it is expected that rail cars can be obtained within the cost parameters used in this FS.

Landfill Capacity

Based on a survey of existing permitted TSCA and non-TSCA landfills (see Appendix E), it is concluded that adequate landfill capacity with rail access exists for disposal of Hudson River sediments.

8.5.2.7 Cost

A summary of the details of the cost estimate for the REM-3/10/Select alternative is given in Tables 8-11a, 8-11b, and 8-11c. Table 8-11a presents the summary for mechanical dredging with the disposal of all stabilized dredged materials at both TSCA and non-TSCA landfills. Table 8-11b presents the summary for the option where the non-TSCA material is utilized for beneficial purposes. Table 8-11c presents the summary for optional use of hydraulic dredging with the disposal of all dredged materials at both TSCA and non-TSCA landfills. The estimated net present worth costs of this alternative, calculated at a 7 percent discount rate, are approximately \$460 million for mechanical dredging and landfill disposal, \$413 million for mechanical dredging and beneficial use, and \$448 million for hydraulic dredging and landfill disposal.

Capital Cost

Since the construction will be performed over a five-year period, capital costs will vary on an annual basis. The total capital costs estimated for this alternative are \$658 million for mechanical dredging and landfill disposal, \$585 million for mechanical dredging and beneficial use, and \$637 million for hydraulic dredging and landfill disposal. The present worth of the capital costs for this alternative is estimated to be \$448 million for mechanical dredging and landfill disposal, \$399 million for mechanical dredging and beneficial use, and $434 million for hydraulic dredging and landfill disposal.

O&M Costs

Due to the varying frequency of different elements of the monitoring program, and the five-year reviews, O&M costs will vary on an annual basis. The estimated annual average O&M costs for this alternative are about $3.2 million for all three options and represents the monitoring costs, the periodic cost of the modeling, and the five-year reviews. O&M costs have been estimated for a ten-year period. The estimated present worth of the O&M costs for this alternative is about $13.5 million for mechanical dredging and either landfill disposal or beneficial use, and $13.75 million for hydraulic dredging and landfill disposal.

8.6 Alternative REM-0/0/3: Full-Section Removal in River Sections 1 and 2 and Expanded Hot Spot Removal in River Section 3

8.6.1 Description

The principal components of this alternative, as described below, include:

- Source control via separate removal action in the vicinity of the GE Hudson Falls plant;
- An implementation schedule and sequence of operations for the remediation;
- Removal (dredging) of sediments in selected target areas;
- In-river transport of backfill materials and dredged sediments;
- Processing of sediments at the northern and southern material management and transfer facilities;
- Treatment of the water entrained in removed (dredged) sediments to NYSPDES discharge criteria;
- Backfilling and habitat replacement;
- Transportation of dewatered and stabilized materials to off-site dredged material management locations; and
- A performance monitoring program.

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This alternative includes remediation by Full-Section removal (*i.e.*, in which the nominal MPA targets are 0 g/m^2 or greater) in River Section 1 and 2 and Expanded Hot Spot removal (*i.e.*, in which the nominal MPA targets are 3 g/m^2 or greater) in River Section 3. This alternative also includes sediment removal in the navigation channel as necessary to implement the remediation. The areas to be remediated for this alternative are shown in Plate 18. The total area of sediments targeted for removal is approximately 964 acres. The volume of sediments to be removed is estimated to be 3.83 million cubic yards. This alternative also relies on naturally occurring attenuation processes to reduce the toxicity, mobility, and volume of the remaining PCBs in the Upper Hudson River sediments after the construction is completed. Institutional controls (*e.g.*, site use restrictions) are implemented as long-term control measures as part of this alternative. These restrictions include continuation or modification of the existing fish consumption advisories and catch and release restrictions. A review of site conditions will be conducted at five-year intervals, as required by Section 121© of CERCLA.

In River Section 1, 470 acres of PCB-contaminated sediments are remediated and nearly 2.0 million cubic yards of sediments containing 15,000 kg of PCBs are removed. In River Section 2, 316 acres of PCB-contaminated sediments are remediated and approximately 1.1 million cubic yards of sediments containing more than 35,000 kg of PCBs (see explanation for estimated mass in Appendix E) are removed. In River Section 3, 134 acres of PCB-contaminated sediments are remediated and 571,000 cubic yards of sediments containing 10,700 kg of PCBs are removed. An additional 117,000 cubic yards of sediments containing 2,800 kg of PCBs are removed from the navigation channel in River Section 3. Estimates of the areas remediated, as well as the volumes and the mass of PCBs removed from the sediment target areas and the navigation channel for each river section, are presented in Table 8-12.

8.6.1.1 Source Control in the Vicinity of the GE Hudson Falls Plant

The REM-0/0/3 alternative assumes a separate non-time critical removal action (NTCRA) for source control in the vicinity of the GE Hudson Falls plant. It is assumed that as a result of this source control (NTCRA), the upstream Tri+ PCB load at Fort Edward (Rogers Island) is reduced from 0.16 kg/day to 0.0256 kg/day on January 1, 2005. USEPA has authorized the performance of an Engineering Evaluation/Cost Analysis (EE/CA) to evaluate potential NTCRAs to address the discharge of PCBs into the river in the vicinity of the GE Hudson Falls plant. GE has discussed with USEPA and NYSDEC a conceptual approach to contain the release of PCB oil from the vicinity of the Hudson Falls facility. Assuming that the conceptual approach proposed by GE, or a similarly effective system, is available to address the Hudson Falls source, USEPA believes that a source control NTCRA can reasonably be completed by January 1, 2005, if not earlier.

8.6.1.2 Implementation Schedule and Sequence of Operations

Remediation will commence in 2004 and be completed in 2010. To the extent practicable, sediments near Rogers Island in River Section 1 will be remediated first, and the work will progress downstream towards the Federal Dam at Troy in River Section 3. Dredging in River Section 3 may occur simultaneously with removal operations elsewhere as a result of the need to ensure navigational access to the site or because doing so will improve overall efficiency. For this alternative, removal operations are estimated to continue for approximately seven years. Areas that correspond to the intermediate depth zone will be dredged first, followed by the areas in the shallow zone and the navigation channel, in that order. Subsequently, backfill (12 inches of sand, silt, and gravel) will be placed in the targeted areas as described in subsection 5.2.6, and other site reconstruction activities will be performed as described below.

8.6.1.3 Removal and In-River Transport Operations

In order to accomplish the sediment removal planned for the REM-0/0/3 alternative within the seven-year construction period, a number of dredges and other marine equipment will be needed for the in-river operations. The number and type of dredges needed to accomplish the work depend on the volume of material to be removed, the time frame for the work, the productivity of the equipment, and the limitations on the in-river and out-of-river transportation systems. Sediment removal can be performed using either mechanical or hydraulic dredging equipment. Where mechanical dredging is utilized, the dredged/excavated sediments are transported by hopper barge or deck barge to the transfer facility. Where hydraulic dredging is utilized, the dredged material is transported via the slurry pipeline and the booster pumping stations to the transfer facility. Based on the remediation targets for this alternative, Table 8-13a provides a list of the number and types of mechanical dredges that will be operated, the number of barge loads of sediment that will be received at the northern and southern transfer facilities, and quantity estimates for other engineering productivity parameters. Table 8-13b provides a similar list of the number and types of hydraulic dredges, the number of barge loads of sediment, and quantity estimates for other engineering productivity parameters.

8.6.1.4 On-Site Material Management and Transfer Facilities

Where mechanical dredging is utilized, the water separated from the sediments during transport is removed at the transfer facility and the dredged/excavated sediments are stabilized by mixing with cement or other appropriate pozzolanic material to absorb the remaining standing water. At the northern and southern dredged material management and transfer facilities, the sediments will be dewatered and blended with eight percent Portland cement as described previously in subsection 5.2.2 and Appendix E. This blending serves to improve both the handling and disposal properties of the dredged material. The rates at which this material is processed in the northern and southern facilities are presented on Table 8-13a. This stabilized material will then be loaded into rail cars or barges as described in subsections 5.2.2 and 5.2.5 for transfer to beneficial use or disposal facilities. The estimated number of rail cars loaded at each material management and transfer facility for this alternative are also presented on Table 8-13a.

Where hydraulic dredging is utilized, the dredged material is transported via the slurry pipeline and the booster pumping stations to the transfer facility, where the water is separated from the sediments in a treatment train that includes hydrocyclones, coagulation, sedimentation, and belt filters. The rates at which the separated solids are processed in the northern and southern facilities are presented on Table 8-13b. These separated solids will then be loaded into rail cars or barges as described in subsections 5.2.3 and 5.2.5 for transfer to beneficial use and/or disposal facilities. The estimated number of rail cars loaded at each material management and transfer facility for this alternative are also presented on Table 8-13b.

8.6.1.5 Water Treatment Subsequent to Removal

The water associated with the dredged material will be treated at the northern and southern water treatment plants to NYSPDES discharge criteria as described previously in subsections 5.2.2 and 5.2.3.

8.6.1.6 Backfilling and Site Reconstruction

As described in subsection 5.2.6, site reconstruction measures will be undertaken to mitigate disturbances to the hydraulics of the river channel, the shoreline, and the aquatic habitat caused by removal operations. The areas that are dredged will be backfilled with one foot of imported clean fill. This backfill will consist of gravel, silt and sand in order to re-establish a range of habitat types for a variety of aquatic biota, especially the resident fish. The navigation channel will not be backfilled.

The disturbed portions of the river shoreline will have to be either stabilized or reconstructed. The stabilization measures envisioned in this FS consist of hydro-seeding the shoreline where disturbance is expected to be minimal and then expanding the scale of the effort where the disturbances increase. Thus, in near-shore areas where between two and three feet of sediment would be removed, the stabilization concept consists of placement of an approximately 20-foot-wide vegetative mattress; where shoreline disturbance would equal or exceed 3 feet of sediment removal, the stabilization concept includes either a log or wood crib revetment in addition to the vegetative mattress. Tables 8-13a and 8-13b show the extent of shoreline disturbance and stabilization anticipated for the REM-0/0/3 alternative. Where shoreline wetlands (critical areas) will be removed by the dredging work, it is expected that the original bottom elevation will be re-established and that the new upper layer of substrate would be a silty material. The quantities of gravel, sand, and silt required for backfill and reconstruction of areas of the river bottom are also presented on Tables 8-13a and 8-13b.

Beyond physical replacement of the river bottom substrate, it is also anticipated that a spectrum of in-river plantings will be undertaken to further reduce the time for the river to return to a productive ecological condition. The plantings will consist of various types of wetland and aquatic

400760

species. The species considered for this component of the program are detailed in Appendix F. The general type and quantity of planting envisioned for the REM-0/0/3 alternative are shown on Tables 8-13a and 8-13b.

8.6.1.7 Off-Site Transport and Dredged Material Management

Of the total estimated volume of about 3.82 million cubic yards of sediments removed from the Upper Hudson River under the REM-0/0/3 alternative, 1.42 million cubic yards (containing greater than 33 mg/kg PCBs) will be handled as material subject to regulation under TSCA, and 2.4 million cubic yards (containing less than 33 mg/kg PCBs) will be handled as non-TSCA material. The TSCA material will be sent to a landfill permitted and regulated under TSCA, and the non-TSCA material will be sent to a non-TSCA landfill, as described in subsection 5.2.5. If facilities and adequate capacity for beneficial use are available based on market conditions at the time when this alternative is implemented, some or all of the non-TSCA material will be utilized for such purposes as described in subsection 5.2.5.3. This includes both low-value beneficial uses as material for construction fill, landfill cover, or abandoned mine reclamation and higher-value beneficial uses as manufactured commercial products.

8.6.1.8 Performance Monitoring Program

The performance monitoring program consists of two components, monitoring during construction of the alternative and post-construction monitoring.

Construction Monitoring

During the construction of the REM-0/0/3 alternative, the construction monitoring program described in subsection 5.2.7.3 will be implemented. The purpose of this monitoring is to confirm that removal and backfilling of areas targeted for remediation has been performed as designed for this alternative. The construction monitoring program will begin the year after design support testing is completed and will last for eight years. This program includes collection of samples from the sediment, water column, and biota.

Post-Construction Monitoring

The post-construction performance of this alternative will be monitored through the implementation of the sampling program described in subsection 5.2.7.4 and in Appendix G. Figure 5-6 presents the outline of this monitoring program. Long-term monitoring for a ten-year period after remediation is completed in 2010 will be conducted in sediments, the water column, and biota as part of this alternative. Monitoring will include measurements of water column contamination, dated sediment cores, sediment PCB inventory, sediment physical properties (geophysics), and bioaccumulation by resident fish. Loss of contaminants can be documented by historical trends or contaminant concentration distributions showing a reduction in the total mass of contaminants in sediments, water, or biota, or by the presence of degradation products in sediments. The monitoring data will also be used as input parameters in the mathematical models to evaluate progress of the natural attenuation processes against the original predictions.

The number and distribution of sediment, water column, and fish samples that will be collected are presented in the alternative-specific tables in Appendix G. The sediment samples (cores and surface grab samples) will be analyzed for total PCBs (Aroclors) and total organic carbon. Bathymetric surveys will also be performed. Water column samples will be analyzed for congener-specific PCBs, TSS, and fraction of organic carbon on TSS. Samples of the resident fish species, including largemouth bass, brown bullhead, and yellow perch, will be analyzed for total PCBs , congener-specific PCBs, and lipid content. A review of site conditions would occur at the end of every five years (for a 10-year period).

8.6.2 Analysis

8.6.2.1 Overall Protection of Human Health and the Environment

The REM-0/0/3 alternative provides the greatest overall protection of human health and the environment achieved by any of the remedial alternatives for the Upper Hudson River evaluated in the detailed analysis. This alternative is a permanent remedy that involves removal of the largest amount of contaminated sediments in River Sections 1, 2, and 3. It also provides for some limited on-site treatment of the PCBs in the sediments by the stabilization process (addition of eight percent

Portland cement) discussed above. In addition, the REM-0/0/3 alternative assumes the separate source control NTCRA in the vicinity of the GE Hudson Falls plant, and also relies on the fish consumption advisories and catch and release restrictions to protect human health.

The existing fish consumption advisory and restricted access to portions of the river undergoing remediation reduce risks to the local community. The REM-0/0/3 alternative also relies on such natural attenuation processes as burial by cleaner sediments, bioturbation, biodegradation, dispersion, dilution through advection and recharge, adsorption, and volatilization to further reduce the concentration of PCB-contaminated sediments remaining in the river after construction is completed in 2010.

There are five options for dealing with the sediments after removal from the river: landfill disposal (for hydraulic dredging); stabilization and landfill disposal (for mechanical dredging); beneficial use as landfill cover or construction fill material (for hydraulic dredging); stabilization and beneficial use as landfill cover or construction fill material (for mechanical dredging); and thermal treatment and beneficial use as manufactured commercial products like cement, light weight aggregate, fiberglass, or architectural tiles (for both mechanical and hydraulic dredging). For the landfill disposal option, the PCB-contaminated sediments would be permanently removed and contained at an off-site permitted and regulated facility. For the beneficial use option, the removed and stabilized sediments will be further treated at the off-site facility and the PCBs will be permanently sequestered (for the construction fill/landfill cover option) or destroyed (for the manufacture of commercial products option).

For the REM-0/0/3 alternative, risks to human health and ecological receptors (piscivorous birds and mammals) will be reduced through remediation of an estimated 964 acres of PCB-contaminated sediments and removal of more than approximately 63,500 kg of PCBs (see explanation for estimated mass in Appendix E) contained in an estimated 3.82 million cubic yards of sediments. Removal of the sediments reduces the toxicity, mobility, and volume of the contaminants in the river. After construction is completed, natural attenuation processes may further reduce the toxicity and volume of PCBs in sediments (*e.g.*, through biodegradation) or reduce their mobility (*e.g.*, though burial by cleaner sediments).

Overall Protection of Human Health

For the REM-0/0/3 alternative, the risk-based PRG for protection of human health of 0.05 ppm PCBs (wet weight) in fish fillet is not met in River Sections 1 and 2 over the 70-year model forecast period, but is met in River Section 3 in the year 2050. The target concentration of 0.2 ppm PCBs (one meal per month) in fish fillets is also not met in River Section 1, but is met in River Section 2 in the year 2034 and is met in River Section 3 in the year 2013. The target concentration of 0.4 ppm PCBs (one meal every two months) in fish fillets is met in River Sections 1, 2, and 3 in the years 2013, 2015, and 2010, respectively. Due to potential effects of sediment resuspension as discussed below (subsection 8.6.2.5), there may delay of a few years in achieving the reductions forecast by the model.

As for the CAP-3/10/Select and the REM-3/10/Select alternative, the failure to achieve further reduction in PCB levels in each river section reflects the importance of the assumption of the upstream loading late in the forecast period. Significant reductions are accomplished as a result of the sediment remediation and the source control NTCRA but no further reduction in fish body burden is possible without a change in the assumed upstream load

For the REM-0/0/3 alternative, cancer risks and non-cancer health hazards are calculated using a start date of 2011. The RME and CT non-cancer hazard indices are discussed in detail in subsection 7.3.5.2 and are presented in Tables 7-6a through 7-6d for the Upper Hudson River and separately for River Sections 1, 2, and 3, respectively. RME and CT non-cancer hazard indices by river section are shown on Figures 7-1 and 7-2, respectively. The CT hazard indices are approximately an order of magnitude lower than the RME hazard indices. The RME hazard indices are all above the target level of one. The CT hazard indices are all below the target level of one, except for the CT hazard index in River Section 1, which is equal to one. Similarly, the RME and CT incremental cancer risks are discussed in detail in subsection 7.3.5.2 and are presented in Tables 7-7a through 7-7d for the Upper Hudson River and separately for River Sections 1, 2, and 3, respectively. RME and CT incremental cancer risks by river section are also shown on Figures 7-3 and 7-4, respectively. The RME incremental cancer risks for the Upper Hudson River and River Sections 1 and 2 all slightly exceed the acceptable risk range of 10^{-4} to 10^{-6}, whereas the RME

400764

incremental cancer risk for River Section 3 lies within this range. All of the CT incremental cancer risks lie within this range.

Overall Protection of the Environment - Ecological Receptors

The risk-based PRG for protection of the environment is a range from 0.13 to 0.013 mg/kg total PCBs in fish fillets (this corresponds to a range from 0.3 to 0.03 mg/kg in whole fish), based on the LOAEL and NOAEL fish concentrations consumed by the river otter. The corresponding LOAEL and NOAEL whole fish target concentrations for the mink are 0.7 and 0.07 mg/kg PCBs. For the river otter, the NOAEL target concentration is not met in any of the three river sections over the 70-year model forecast period. For the river otter, the LOAEL target concentration is not met in River Section 1, but is met in River Section 2 in 35 years and in River Section 3 in five years. For the mink, the LOAEL target concentration is met in River Section 1 in 2 years and is met in River Sections 2 and 3 prior to 2010. For the mink, the NOAEL target concentration is not met in River Section 1, but is met in River Section 2 in 52 years and in River Section 3 in four years.

For the REM-0/0/3 alternative, the ecological TQs for the river otter and the mink are discussed in subsection 7.3.5.5 and presented in Table 7-9. For the river otter, the NOAEL and LOAEL TQs by river section are shown in Figures 7-5 and 7-6, respectively. The river otter TQs are two orders of magnitude above the NOAEL target level in River Sections 1 and 2 and one order of magnitude above the NOAEL target level in River Section 3. The river otter TQs are one order of magnitude above the LOAEL target level in River Sections 1 and 2. In River Section 3, the river otter toxicity quotient is below one for the LOAEL comparison. For the mink, the NOAEL and LOAEL TQs by river section are shown in Figures 7-7 and 7-8, respectively. All of the mink TQ comparisons are below one, except for the comparison with the NOAEL target level in River Sections 1 and 2.

Overall Protection of the Environment - Downstream Transport of PCBs

The Tri+ PCB load over the TI Dam predicted by the model for the REM-0/0/3 alternative is about 104 kg in 2003, 14 kg in 2011, and 9.5 kg in 2035. The Tri+ PCB load over the Northumberland Dam is 123 kg in 2003, 17 kg in 2011, and 9.5 kg in 2035. The Tri+ PCB load over the Federal Dam is 131 kg in 2003, 34 kg in 2011, and less than 18 kg in 2035. This alternative addresses the scour of PCB-contaminated sediments associated with one-in-three-year to one-in-five-year flow events from the Hoosic River in River Section 3 and is the most effective in reducing the PCB load over Federal Dam to the Lower Hudson River.

8.6.2.2 Compliance with ARARs

The chemical-specific ARARs for PCBs in the water-column are 0.5 μg/L (500 ng/L) federal MCL; 0.09 μg/L (90 ng/L) NYS standard for protection of human health and drinking water sources; 1 ng/L federal Ambient Water Quality Criterion; 0.12 ng/L NYS standard for protection of wildlife; and 0.001 ng/L NYS standard for protection of human consumers of fish. As shown in Figures 6-33 through 6-37, the first two chemical-specific ARARs for the surface water are met by the REM-0/0/3 alternative and the remaining three chemical-specific ARARs for the surface water are not met by this alternative for the 70-year forecast period. These figures also show that the water quality is best for the REM-0/0/3 alternative, compared to the No Action and MNA alternatives. These differences are most apparent for the first 20 years (between 2005 and 2024) of the forecast period. However, even towards the end of the forecast period (in 2067), there is a very substantial difference between the water quality for the No Action alternative (approximately 30 ng/L at TID and Schuylerville and 10 ng/L at Federal Dam) and the REM-0/0/3 alternative (approximately 5 ng/L at TID and Schuylerville and 1.7 ng/L at Federal Dam).

The REM-0/0/3 alternative will comply with action-specific ARARs (*e.g.*, CWA Sections 401 and 404; Toxic Substances Control Act; Section 3004 of RCRA; Section 10 of the Rivers and Harbors Act; New York State ECL Article 3, Title 3, and Article 27, Titles 7 and 9) and location-specific ARARs (*e.g.*, Endangered Species Act; Fish and Wildlife Coordination Act; Farmland Protection Policy Act; National Historic Preservation Act; and New York State Freshwater Wetlands Law).

8.6.2.3 Long-Term Effectiveness and Permanence

Magnitude of Residual Risks

For the REM-0/0/3 alternative, residual risk is reduced through remediation of 964 acres of PCB-contaminated sediments and removal of 3.82 million cubic yards of sediments containing more than 63,500 kg PCBs. Appendix E contains an explanation for estimated mass. For this alternative, the Tri+ PCB load over the Federal Dam is approximately 131 kg in 2003, 34 kg in 2011, and less than 18 kg in 2035. Soon after construction in 2011, the REM-0/0/3 alternative results in a 67 percent reduction in the Tri+ PCB load over Federal Dam compared to the No Action alternative and a 53 percent reduction in the Tri+ PCB load over Federal Dam compared to the MNA alternative. After a longer period of time, in 2035, the REM-0/0/3 alternative results in a 72 percent reduction in the Tri+ PCB load over Federal Dam compared to the No Action alternative and a 25 percent reduction in the Tri+ PCB load over Federal Dam compared to the MNA alternative. The similarity in modeled PCB loads over Federal Dam between the MNA and the REM-0/0/3 alternatives by this time (*e.g.*, 2035 and beyond) reflects the fact that both are largely controlled by the value assumed for the unknown upstream PCB load.

The REM-0/0/3 alternative also relies on natural attenuation processes such as burial by cleaner sediments, bioturbation, biodegradation, dispersion, dilution through advection and recharge, adsorption, and volatilization to further reduce the concentration of any contaminants that remain after construction is completed. Due to the extensive removal performed for this alternative, there is less reliance on natural process for further remediation than in other alternatives. This alternative achieves the greatest reduction in fish tissue concentrations and ensuing impacts among all of the alternatives. However, modeling results predict that this alternative will not completely achieve the 0.05 ppm PRG in fish fillet for River Sections 1 and 2 for the site within the modeled period. The limitation in meeting this PRG largely stems from the assumption of the upstream Tri+ PCB load at Fort Edward (Rogers Island) of 0.0256 kg/day beginning in 2005. Greater achievement of the PRGs is estimated employing a 0 kg/day assumption at Fort Edward.

Adequacy of Controls

The REM-0/0/3 alternative provides for removal of contaminated sediments in target areas. The REM-0/0/3 alternative also assumes source control in the vicinity of the GE Hudson Falls plant. Like the MNA alternative, this alternative also provides for institutional controls such as the fish consumption advisories and catch and release restrictions. As discussed for the MNA alternative, the existing institutional controls, which rely on voluntary compliance, are not fully adequate in reducing exposure to PCBs due to consumption of contaminated fish. In addition, institutional controls are inadequate for protection of the environment (*e.g.*, ecological receptors).

The planned post-construction fish, water column, and sediment monitoring program allows for tracking the natural recovery of the river after remediation is completed and collection of data necessary for possible relaxing of the fish consumption advisories.

Reliability of Controls

Sediment removal (dredging), backfilling and habitat replacement, and off-site disposal/ treatment of removed sediments are all reliable and proven technologies. The REM-0/0/3 alternative is the most reliable alternative because there is little or no long-term maintenance or residual risk associated with the remedial work. Also, the fish consumption advisories will continue to provide some measure of protection of human health until PCB concentrations in fish are reduced to meet PRGs for protection of human health.

8.6.2.4 Reduction of Toxicity, Mobility, or Volume through Treatment

For the REM-0/0/3 alternative, the toxicity, mobility, and volume of the PCBs in approximately 964 acres of river sediments are permanently reduced (although not through treatment) because approximately 3.82 million cubic yards of sediment containing more than an estimated 63,500 kg of PCBs (Appendix E) are removed from the ecosystem of the Upper Hudson River. Because the REM-0/0/3 alternative also assumes a separate source control NTCRA in the vicinity of the GE Hudson Falls plant, the Tri+ PCB load to the water column is expected to be reduced from 0.16 kg/day to 0.0256 kg/day by January 1, 2005. In addition, after construction of the alternative is completed, natural attenuation processes will provide further (but slower) reductions in the toxicity of PCBs in the remaining sediments and surface water.

For the mechanical dredging option, the sediments that are removed undergo limited treatment (stabilization with Portland cement) prior to landfill disposal. For the hydraulic dredging option, the sediments that are removed are processed through hydrocyclones, coagulation, sedimentation, and belt filters to separate them from the water. However, these sediments do not undergo stabilization with Portland cement prior to landfill disposal. Based on the large volume of sediments that are removed from the river under this alternative but not subject to treatment other than stabilization, the REM-0/0/3 alternative does not satisfy the statutory preference for treatment as a principal element of the remedy (CERCLA Section 121(b)0. A different treatment process may be employed for the high-value beneficial use option, thus satisfying the statutory preference for treatment in such a case.

8.6.2.5 Short-Term Effectiveness

Short-term effectiveness is assessed through review of the four components described above (subsection 8.1.5): protection of the community during remedial actions; protection of workers during remedial actions; potential adverse environmental impacts resulting from construction and implementation; and time until remedial response objectives are achieved.

Protection of the Community During Remedial Actions

Risks to humans posed by consumption of PCB-contaminated fish will be reduced most rapidly under the REM-0/0/3 alternative, more than under any other remedial alternative for the Upper Hudson River. As discussed in later in this subsection, exposure levels for fish are not expected to increase substantively during this remedial action so that risks from consuming fish will remain largely the same during the construction period. The fish consumption advisories and restricted access to portions of the river undergoing remediation provides protection from risks to human health for the local community in the short term.

Transfer facilities and treatment areas present potential short-term risks to the community. Therefore, access to these areas will be restricted to authorized personnel. In addition, monitoring and engineering controls will be employed to minimize short-term effects due to material processing activities. Increased traffic will also present an incremental risk to the community. The potential for traffic accidents may increase marginally as additional vehicles are on the road. These effects are likely to be minimal because most transportation of sediments for disposal will be accomplished by rail. In addition to vehicular traffic, there will be increased river traffic. Work areas in the river will be isolated (access-restricted), with an adequate buffer zone so that pleasure craft and commercial shipping can safely avoid such areas. Finally, the increased in-river barge traffic will be monitored and controlled to minimize, to the extent possible, adverse effects on the commercial or recreational use of the Upper Hudson River.

Protection of Workers During Remedial Actions

For the REM-0/0/3 alternative, potential occupational risks to site workers from direct contact, ingestion, and inhalation of PCBs from the surface water and sediments, and routine physical hazards associated with construction work and working on water, are substantially higher than for any of the other remedial alternatives. For this alternative, site personnel will follow a site-specific health and safety plan, OSHA health and safety procedures, and wear the necessary personal protective equipment.

Potential Adverse Environmental Impacts Resulting from Construction and Implementation

For the REM-0/0/3 alternative, the release of PCBs from the contaminated sediments into the surface water during construction (dredging), as well as the transport of PCBs over Federal Dam, will be controlled by operational practices (*e.g.*, control of sediment removal rates; use of enclosed dredge buckets; and use of sediment barriers). Although precautions to minimize resuspension will be taken, it is likely that there will be a temporary increase of suspended PCB concentrations, and possibly an increase in PCB concentrations in fish. Studies have shown that such effects are controllable, small, and transient, and that longer-term improvement is seen (*e.g.*, WRI, 2000; MDEQ, 1999).

Remedial activities may also result in temporary impacts to aquatic and wildlife habitat of the Upper Hudson. Backfilling and habitat replacement measures will be implemented to mitigate these impacts. A monitoring program will be established to verify the attainment of the habitat replacement objectives. The degree of impact is directly related to the area remediated and volume dredged. From this perspective, the impacts of the REM-0/0/3 alternative will be the greatest of any alternative since this alternative involves the remediation of nearly all areas of River Sections 1 and 2. (The impact in River Section 3 is nearly the same in this regard as CAP-3/10/Select and REM-3/10/Select since there only minor differences between the Select and the Expanded Hot Spot boundaries in this river section.) However, these impacts are considered to be temporary due to the short duration of the remedial construction and the mitigation measures which will be utilized.

As part of this evaluation, a semi-quantitative analysis of the possible increase in PCB loads and concentrations was performed for the regions downstream and outside of the target areas. These areas, in fact, represent the largest portion of the Upper Hudson within the site boundaries. This calculation is intended to describe the mean increase in water column PCB concentration over each dredging season in these areas. The detailed description of the model and analysis to estimate resuspension losses is provided in Appendix E.6. The results of the analysis are summarized here. This alternative involves the greatest volume of sediment of any alternative. Correspondingly, the mass of sediment resuspended for REM-0/0/3 is greater than for the other alternatives. As part of this analysis, the short-term impacts of a 12-inch cutterhead dredge and an enclosed bucket dredge are considered for sediment removal. For all comparisons between the two dredging methods, the production rate of dredge spoil material is the same for both methods. Specifically, the production rate of a 12-inch cutterhead dredge is comparable to that of three 4-cubic-yard enclosed bucket dredges. The 12-inch cutterhead dredge and three 4-cubic-yard enclosed bucket dredges form the basis for comparisons below.

The resuspension rate for the bucket dredge represents a relatively conservative estimate. Specifically, the available data for the bucket dredge describe the impacts of a less sophisticated dredge than that selected for the engineering concept for this alternative. Although the results of the resuspension modeling indicate somewhat greater PCB concentrations and loads due to mechanical dredges versus hydraulic equipment, resuspension considerations will not be the main consideration in selecting one concept over another, since the mechanical dredge estimate is considered conservative. Rather, other engineering issues, such as sediment transfer, processing and handling as well as operational logistics, will be more important considerations. .

The model results indicate that dredging operations associated with the REM-0/0/3 alternative would increase water column Tri+ PCB concentrations during remediation an estimated average of 2 ng/L in River Section 1 utilizing the cutterhead dredge and an average of 3.5 ng/L using the enclosed bucket dredges. These values are lower than those for the other two active remedial alternatives because a much greater volume of less-contaminated sediments will be removed under REM-0/0/3. The period of removal is also one year longer. For the expected two years of operation in River Section 2, the cutterhead dredge would raise water column Tri+ PCB concentrations by 4 ng/L whereas the bucket dredges would raise concentrations by 7 ng/L. The last year of operation, assumed to be in River Section 3, is projected to increase water column Tri+ PCB concentrations by 5 ng/L using the cutter-head dredge and 10 ng/L using the bucket dredges. The overall average increase in Tri+ PCBs for the seven-year operation is estimated to be 3 ng/L for the cutterhead dredge and 5 ng/L for the bucket dredges. The water column Tri+ PCB concentration increases associated with use of the cutterhead dredge are consistently about 40 percent lower than those from the three bucket dredges, based on a somewhat lower rate of resuspension for the cutterhead and a more conservative estimate of resuspension for the bucket dredges. See Appendix E.6 for further discussion of the comparison.

The increases in PCB concentration would occur only during the remedial construction period. For example, using the three enclosed bucket dredges, water column PCB concentrations would increase by an average of 3.5 ng/L in River Section 1 during the four years of operation there. The increase in water column concentrations in River Sections 2 and 3 would be less during this period due to further settling and dilution of the material released from River Section 1. Similarly, water column concentrations in River Section 2 would increase by an average of 7 ng/L during the two years of operation in this river section, but there would be no impact to River Section 1 (upstream of River Section 2), and a lesser impact to River Section 3, since dilution and settling would reduce the increase. The 9 ng/L increase in River Section 3 applies only during the last year of construction; *i.e.*, during implementation of remedial activities within River Section 3, and would have no impact (*i.e.*, no water column PCB concentration increase) on River Sections 1 or 2.

It is important to place these estimated increases in the Tri+ PCB load in perspective. In particular, concentrations of Tri+ PCBs in the water column at the TI Dam were in the range of 14.4 to 532 ng/L (mean of 66 ng/L) in May through November (1999), the part of the year during which remedial operations are assumed to occur. During the anticipated period of implementation, the mean concentration at the TI Dam is expected to be 29 ng/L, based on the HUDTOX forecast. Thus, the implementation of the REM-0/0/3 alternative is only expected to increase mean water column concentrations in River Section 1 by 12 percent (29 ng/L + 3.5 ng/L). Forecast concentrations in River Section 2 are generally similar to those in River Section 1. Under the REM-0/0/3 alternative, water column concentrations would increase by about 14 percent using the cutterhead dredge in River Section 2 (29 ng/L, plus 4 ng/L increase), or about 24 percent with the bucket dredges (29 ng/L, plus 7 ng/L increase), but only for the two years of operation in this river section. Average water column PCB concentrations would be expected to increase by about 60 percent in River Section 3 during the one year of operation in this river section.

Thus, in River Section 1, these expected increases represent relatively minor changes as compared to current or projected water column concentrations, regardless of dredge type. Indeed, these increases are well below the year-to-year and season-to-season variations regularly observed in the Upper Hudson. Change in River Sections 2 and 3 are more substantial but relatively short in duration (one to two dredging seasons). In all cases however, the projected increases for all three river sections are well below the order-of-magnitude increase in mean water column concentrations seen in the early 1990s. These water column increases resulted in an approximate doubling of some PCB concentrations in fish in some river sections. Thus, by analogy, PCB releases associated with the REM-0/0/3 alternative should have only a minor impact on fish body burdens in the Upper Hudson. It should be noted that total PCB concentration increases may be greater, perhaps two to three times higher than those for Tri+ PCBs. However, current and projected water column total PCB concentrations at the TI Dam are also two to three times higher than those for Tri+ PCBs. Thus the expected increase in total PCB concentrations represents the same percentage increase relative to projected conditions as anticipated for the Tri+ PCB increase.

In addition to the examination of the increase in PCB concentration, the model analysis also included an estimate of the total amount of Tri+ PCB mass released by dredging operations. Overall the remediation would yield an additional 29 kg of Tri+ PCBs over the seven-year operation utilizing the cutterhead dredge, or about 4 kg/yr. The bucket dredges would yield about 48 kg, or 7 kg/yr. These values should be compared to the estimated release of Tri+ PCBs from the sediments during the remediation period in the absence of remediation (637 kg or about 91 kg/yr for No Action, and 383 kg or about 55 kg/yr for MNA from River Section 1 alone). The increase due to the use of the cutterhead dredge is only about 10 percent of the expected annual release under MNA and even less under No Action. In fact, the load increase is well within the range of year-to-year variability. The bucket dredge release is a slightly higher but still less than 13 percent of the expected annual release under MNA and even less under No Action. The current annual release of Tri+ is 109 kg/year; this rate of release, which is largely unchanged over the last 10 years, would generate 763 kg over a period equivalent to the remedial operations for the REM-0/0/3 alternative.

The additional release from the REM-0/0/3 alternative (29 to 48 kg) is less than the PCB release estimated from a single 100-year flood event (*i.e.*, 60 kg) as noted in the RBMR (USEPA, 2000a). As discussed in the RBMR, the 100-year flood was not expected to have a major impact on fish or river PCB levels, with associated increases not lasting more than one to two years. With the remedial releases spread out over five years, the impact should be much smaller with a residual impact (after completion of construction) of even shorter duration than the 100-year flood.

Based on these analyses, it appears unlikely that the removal of sediments associated with the REM-0/0/3 alternative will generate substantively higher PCB concentrations in fish of the Upper Hudson during remedial construction. Water column increases may reach 25 to 60 in River Sections 2 and 3 but the higher concentrations are short-lived. Based on the similarity in magnitude to the release associated with the 100-year flood event, it is unlikely that the residual effects will last more than a few years after the construction is completed .

Time until Remedial Response Objectives Are Achieved

The risk-based PRG for protection of human health of 0.05 ppm PCBs (wet weight) in fish fillets is not met in River Sections 1, 2, and 3 in the short term. The target concentration of 0.2 ppm PCBs (one meal per month) in fish fillets is also not met in River Sections 1, 2, and 3 in the short term. The target concentration of 0.4 ppm PCBs (one meal every two months) in fish fillets is not met in River Sections 1 and 2 in the short term, but is met in River Section 3 in the year 2010 for the

REM-0/0/3 alternative. Due to potential effects of sediment resuspension discussed above, there may delay of a few years in achieving the reductions forecast by the model.

The risk-based PRG for protection of the environment is a range from 0.3 to 0.03 mg/kg in whole fish (corresponding to a range from 0.13 to 0.013 mg/kg total PCBs in fish fillets), based on the LOAEL and NOAEL fish concentrations consumed by the river otter. The corresponding LOAEL and NOAEL target concentrations for the mink are 0.7 and 0.07 mg/kg PCBs in whole fish. For the river otter, the PRGs are not met in River Sections 1, 2, and 3 in the short term. For the mink, the LOAEL target concentration is not met in River Section 1 in the short term, but is met n River Sections 2 and 3 prior to 2010. For the mink, the NOAEL target concentration is not met in River Sections 1, 2, and 3 in the short term.

Therefore, in the short term, many RAOs and PRGs are not met for the REM-0/0/3 alternative, and this alternative is not protective of human health or the environment during the construction period. However, water column and fish tissue PCB concentrations associated with the implementation of this alternative are not expected to be much more detrimental than the typical conditions associated with MNA. Subsequent to the implementation, conditions will improve substantively relative to MNA in terms of these measures as discussed under long-term effectiveness. This alternative does involve the modification of nearly all habitat in River Sections 1 and 2. While the impact from the habitat modification will be mitigated to the extent possible, some longer term, although not permanent, impacts to ecological habitat are anticipated.

8.6.2.6 Implementability

Technical Feasibility

Technical feasibility is evaluated for the principal equipment and systems that are expected to be required for the REM-0/0/3 alternative:

- Mechanical or hydraulic dredging equipment;
- Transfer facilities;

- Barges and towboats; and
- Transportation and disposal systems.

Dredging Equipment

Mechanical Dredging Equipment

It is estimated that removal work under the REM-0/0/3 alternative will be accomplished by five mechanical dredges operating simultaneously for seven construction seasons. Dredging equipment needed to implement this alternative is either commercially available or can be fabricated. On an annual basis, approximately three percent more material is removed under the REM-0/0/3 alternative as compared to REM-3/10/Select (546,000 cubic yards per year versus 530,000 cubic yards per year). Thus, there is little to distinguish the two alternatives from the perspective of the scale of equipment and operations. One difference between the two alternatives is the depth of targeted sediments. The REM-0/0/3 alternative targets substantial areas where the depth of contamination is one foot or less, whereas the REM-3/10/Select alternative targets minimum cuts of two feet. As a result, the selection of equipment for REM-0/0/3 will be heavily influenced by the need to remove sediment in one foot of water.

Central to establishing the technical feasibility of the dredging program under the REM-0/0/3 alternative is the ability of the selected equipment to productively (*i.e.*, cost-effectively) remove as little as one or two feet of contaminated sediments. Buckets, such as those developed by Cable Arm and certain European equipment suppliers, have been designed specifically for removal of sediments in large-area, shallow, flat cuts. These buckets also incorporate features to minimize sediment resuspension and to monitor the precision of removal operations. The Cable Arm concept has been used on several remedial projects in the US and Canada, and the European Horizontal Profiler has now undergone its initial US demonstration at New Bedford Harbor (see Chapter 5 and Appendix A). Based on these experiences, it is concluded that the shallow removal work called for under this alternative can be efficiently accomplished as a result of ongoing innovations in the design of excavators and associated auxiliary equipment.

400776

Buckets such as the Cable Arm and the Horizontal Profiler have been specifically designed to minimize sediment resuspension. Furthermore, beyond the design features that have been incorporated into the equipment, it is also possible to impose controls on removal operations (*e.g.*, increased cycle time) so that further reductions in sediment resuspension can be attained. An analysis of the short-term water quality implications of using a modern environmental bucket are presented in Appendix E. The analysis indicates that rates of resuspension expected from the newest generation of mechanical equipment are well below those reported in the technical literature as recently as a few years ago regarding mechanical dredging operations. It is concluded, given the design features of the new generation of mechanical dredging equipment and the potential to further limit resuspension by operational controls, that minimal downstream impact will be observed during removal work (see Appendix E). The estimated Tri+ PCB loads due to resuspension from mechanical dredging operations is 48 kg (about 7 kg/yr) over the entire Upper Hudson River for the seven-year period. This value should be compared to the estimated release of Tri+ PCBs from the sediments during the remediation period in the absence of remediation (637 kg or about 91 kg/yr for No Action, and 383 kg or about 55 kg/yr for MNA from River Section 1 alone). Therefore, an alternative based on mechanical removal of targeted sediments is environmentally feasible.

Hydraulic Dredging Equipment

Details on the hydraulic dredging concept are presented in Appendix H. This concept indicates that one suction dredge outfitted with a cutterhead can remove the targeted sediments in River Sections 1 and 2 in about five years. Given the limitations on slurry line length described in Appendix H, it will also be necessary to employ several mechanical dredges for removal operations in River Section 3. The hydraulic and mechanical dredges required for this alternative are either commercially available or can be fabricated for this project.

Hydraulic dredging efficiency (and resuspension rates) may be negatively affected when shallow removal cuts are attempted. Since the REM-0/0/3 alternative targets sediments where the depth of contamination is one foot, it has been assumed in this analysis (see Appendix H) that two feet of removal will occur in these areas to avoid the impracticality of a one foot cut. Thus, an additional 90,000 cubic yards of uncontaminated sediment will be dredged under the REM-0/0/3 alternative to accommodate limitations of the hydraulic equipment. While this results in a higher estimated cost, the trade-off is warranted for engineering practicality. From the perspective of removing targeted sediments, use of the selected hydraulic technology is considered feasible.

Hydraulic dredge designs have undergone substantial modifications in response to the need to reduce sediment resuspension and the need to conduct removal operations as precisely as possible. It is expected that continuing improvements will be made to cutterhead and inlet pipe geometry, control of the cutterhead swing, and the geometry of shrouds added for resuspension control. An analysis of sediment resuspension rates expected during operation of a modern suction dredge is presented in Appendix E. The estimated Tri+ PCB loads due to resuspension from hydraulic dredging operations is 29 kg (about 4 kg/yr) over the entire Upper Hudson River for the seven-year period. This value should be compared to the estimated release of Tri+ PCBs from the sediments during the remediation period in the absence of remediation (461 kg or about 92 kg/yr for No Action and 295 kg or about 59 kg/yr for MNA from River Section 1 alone). Therefore, an alternative based on hydraulic removal of targeted sediments is environmentally feasible.

Transfer Facilities

Mechanical Dredging

Transfer facilities will be established at two locations to process sediments generated by mechanical removal operations under the REM-0/0/3 alternative. These transfer facilities require wharf facilities as well as access to an operating rail line. In addition, adequate land area must be available to process incoming sediments and to load the processed sediments into rail cars. Development of the two transfer operations, one at a location adjacent to River Section 1 and one at a southern location near Albany, is considered technically feasible. While the availability of suitable locations adjacent to River Section 1 is limited, locations do exist where such operations can potentially be established. In the Port of Albany area there are a number of materials handling operations that can be configured to serve as sediment handling and processing facilities.

Hydraulic Dredging

Transfer facilities will be established at two locations to process sediments generated by hydraulic removal operations under this alternative. These transfer facilities require wharf facilities as well as access to an operating rail line. In addition, adequate land area must be available to process incoming sediments and to load the processed sediments into rail cars. Development of the two transfer operations, one at a location adjacent to River Section 1 and one at a southern location near Albany, is considered technically feasible.

While the availability of suitable locations adjacent to River Section 1 is limited, locations do exist where transfer operations can potentially be established. Under the hydraulic dredging option, land area requirements at the northern transfer facility are somewhat more extensive than is the case when mechanical dredges are used. This is a consequence of the need to process (dewater) incoming sediment slurry at the rate of approximately 8,000 gpm. While the additional land area required for slurry processing (perhaps several acres) somewhat complicates establishing a transfer facility adjacent to River Section 1, it is expected that a location can be identified for this purpose. With regard to a transfer facility in the Port of Albany vicinity, it is expected that a location with existing wharf facilities and rail access can be found along the industrial waterfront zone.

Barge and Towboat Operations

Mechanical Dredging

Considerable use of barges and towboats will be necessary to implement this alternative. Barges will be needed to haul dredged sediments to the northern and southern transfer facilities and to place backfill in the river at the completion of removal operations. Based on preliminary information received from the New York State Canal Corporation, it appears that movement of loaded barges through the Champlain Canal will be feasible, provided that some navigational dredging is accomplished in the early stages of remedial work. An estimate of the quantity of material that must be removed to enable barges loaded with approximately 1,000 tons to move through the canal system has been made. Costs for this additional removal work have been included in the overall cost of the alternative. Thus, from the standpoint of available draft, movement of barges and towboats from the work site to the transfer facilities is considered technically feasible. Other clearance and operating restrictions imposed by the canal system are not expected to preclude accomplishing the program.

Hydraulic Dredging

Considerable use of barges and towboats will be necessary to implement this alternative. Barges will be needed to haul dewatered sediments from the northern to the southern transfer facilities and to haul mechanically dredged sediments directly to the southern transfer facility. Based on preliminary information received from the New York State Canal Corporation, it appears that movement of loaded barges through the Champlain Canal will be feasible provided that some navigational dredging is accomplished in the early stages of remedial work. An estimate of the quantity of material that must be removed to enable barges loaded with approximately 1,000 tons) to move through the canal system has been made. Costs for this additional removal work have been included in the overall cost of the alternative. Thus, from the standpoint of available draft, movement of barges and towboats between transfer facilities is considered technically feasible. Other clearance and operating restrictions imposed by the canal system are not expected to preclude accomplishing the program.

Transportation and Disposal

Mechanical Dredging

Rail is the principal transportation mode considered in the FS for shipping dredged sediments out of the Hudson Valley. Although barging may be a link in the transportation scheme, barge transport has been considered in this FS only in association with beneficial use of dredged sediments. Under the REM-0/0/3 alternative, approximately 16 carloads of sediment would be processed at the northern transfer facility each day and approximately 30 carloads at the southern transfer facility. It is expected that this level of rail activity can be accommodated in the Upper Hudson River area, given the resources of the two Class I railroads that serve the region.

As explained in Appendix E, adequate landfill capacity with rail access exists to manage Hudson River sediments. This includes TSCA-permitted landfill capacity and capacity for non-TSCA materials. The considerable transportation distance to these facilities affects overall alternative costs but not the technical feasibility of landfill disposal.

Hydraulic Dredging

Rail is the principal transportation mode considered for shipping hydraulically dredged sediments out of the Hudson Valley. Although barging may be a link in the transportation scheme, barge transport has been considered in this FS only in association with beneficial use of dredged sediments. Under the REM-0/0/3 alternative, when hydraulic dredging operations are in progress, approximately 16 carloads of sediment would be processed at the northern transfer facility each day and approximately 34 carloads at the southern transfer facility, a slightly higher total (50 carloads per day, as opposed to 46) than the estimate for the mechanical dredging option. It is expected that this level of rail activity can be accommodated in the Hudson Valley, given the resources of the two Class I railroads that serve the region.

As explained in Appendix E, adequate landfill capacity with rail access exists to manage Hudson River sediments. This includes TSCA-permitted landfill capacity and capacity for non-TSCA materials. The considerable transportation distance to these facilities affects overall alternative costs but not the technical feasibility of landfill disposal.

Administrative Feasibility

For the REM-0/0/3 alternative, it is expected that the two transfer facilities, both constructed on land adjacent to the river, will be considered "on-site" for the purposes of the permit exemption under CERCLA Section 121(e), although any such facilities will comply with the substantive requirements of any otherwise necessary permits. Operations under this alternative will have to be performed in conformance with substantive requirements of regulatory programs implemented by USACE under Section 10 of the Rivers and Harbors Act and Sections 401 and 404 of the CWA. In addition, discharges during remediation will conform to NYS regulations related to maintenance of

Hudson River water quality. Backfilling and habitat replacement will be implemented in accordance with federal and state ARARs.

It is expected that contract documents for this alternative will contain substantial restrictions on construction activity including controls on the types of dredging and capping equipment to be used, restrictions on the speed of operations, constraints on barge filling practices, and controls on temporary storage of contaminated dredge spoils. Construction activities will also have to be coordinated with the Canal Corporation, which operates the locks on the Upper Hudson River from May through November. Finally, requirements of other regulatory programs will be incorporated as necessary on the basis of information developed during remedial design.

Availability of Services and Materials

Mechanical Dredging

This section details the availability of services and materials needed to implement the REM-0/0/3 alternative using mechanical dredges.

Dredges

It is expected that mechanical dredging equipment can be obtained as needed for the REM-0/0/3 alternative.

Barges and Towboats

Commercial activity on the Champlain Canal has all but ceased. Therefore, it is unlikely that the full complement of towboats and barges is available in the immediate project vicinity to conduct the required removal operations. Procurement of towboats and barges will require advance planning and may entail fabricating some equipment.

400782

Processing and Stabilization Equipment

The principal components of the sediment stabilization system are silos, hoppers, conveyors, and pug mills. A system will be erected at both the southern and northern transfer facilities to process mechanically dredged sediments. The stabilization equipment can be purchased from a number of manufacturers and suppliers and is considered to be available for purposes of the REM-0/0/3 alternative.

Cement or Substitute

The demand for and, therefore, the availability of Portland cement varies with market conditions. During mid-2000 demand was high and obtaining adequate supplies in the Hudson Valley could have been a problem. Substitutes for cement (cement kiln dust or fly ash) are generally available, usually at substantially reduced costs in comparison to Portland cement. The utility and cost-effectiveness of these substitutes will need to be demonstrated via bench scale tests. Since there is likely to be a number of options available for processing dredged sediments (see Appendix E), it is concluded here that the availability of Portland cement (or lack thereof) will not prevent processing and off-site disposal of dredged sediments.

Rail Cars

The availability of rail cars fluctuates with the state of the economy. Since the REM-0/0/3 alternative is a relatively long-term project of about five years, and substantial planning will take place prior to construction, it is expected that rail cars can be obtained within the cost parameters used in this FS.

Landfill Capacity

The REM-0/0/3 alternative generates about 45 percent more material requiring disposal than REM-3/10/Select. However, based on a survey of existing permitted TSCA and non-TSCA landfills (see Appendix E), it is concluded that adequate landfill capacity with rail access exists for disposal of the contaminated sediments.

Hydraulic Dredging

This section details the availability of services and materials needed to implement the REM-0/0/3 alternative using a hydraulic dredging system in River Sections 1 and 2 and mechanical dredges in River Section 3.

Dredges

It is expected that the hydraulic and mechanical dredging equipment required to implement the REM-0/0/3 alternative is either commercially available or can be fabricated as necessary.

Barges and Towboats

Commercial activity on the Champlain Canal has all but ceased. Therefore, it is unlikely that the full complement of towboats and barges is available in the immediate project vicinity to conduct removal operations. Procurement of towboats and barges will require advance planning and may entail fabricating some equipment.

Dewatering Equipment

Incoming slurry generated by the hydraulic dredging operations (about 8,000 gpm on average pumped to the northern transfer facility) will be processed by a series of hydrocyclones, flocculation and settling tanks, and belt presses to dewater the dredged sediments prior to off-site shipment (see Appendix E). This equipment can be purchased from a number of manufacturers and suppliers and is considered to be available for this FS.

Processing and Stabilization Equipment

The principal components of the sediment stabilization system are silos, hoppers, conveyors, and pug mills. This system will be erected at the southern transfer facility to process mechanically dredged sediments coming from River Section 3. The equipment can be purchased from a number of manufacturers and suppliers and is considered to be available for this FS.

Cement or Substitute

The demand for and, therefore, the availability of, Portland cement varies with market conditions (mechanically dredged sediments would be stabilized under this alternative). During mid-2000 demand was high and obtaining adequate supplies in the Hudson Valley could have been a problem. Substitutes for cement (cement kiln dust or fly ash) are generally available, usually at substantially reduced costs in comparison to Portland cement. The utility and cost-effectiveness of these substitutes will need to be demonstrated through bench scale tests. Since there is likely to be a number of options available for processing dredged sediments (see Appendix E), it is concluded here that the availability of Portland cement (or lack thereof) will not prevent processing and off-site disposal of dredged sediments.

Rail Cars

The availability of rail cars fluctuates with the state of the economy. Since the REM-0/0/3 alternative is a relatively long-term project of about seven years duration, and substantial planning will take place prior to initiating construction, it is expected that rail cars can be obtained within the cost parameters used in this FS.

Landfill Capacity

This alternative generates about 45 percent more material requiring disposal than does the REM-3/10/Select alternative. However, based on a survey of existing permitted TSCA and non-TSCA landfills (see Appendix E), it is concluded that adequate landfill capacity with rail access exists for disposal of the contaminated sediments.

8.6.2.7 Cost

A summary of the details of the cost estimate for the REM-0/0/3 alternative is given in Tables 8-14a, 8-14b, and 8-14c. Table 8-14a presents the summary for mechanical dredging with the disposal of stabilized dredged materials at both TSCA and non-TSCA landfills. Table 8-14b presents the summary for the option where non-TSCA material is utilized for beneficial purposes.

Table 8-14c presents the summary for optional use of hydraulic dredging with the disposal of dredged materials at both TSCA and non-TSCA landfills. The estimated net present worth costs of this alternative, calculated at a 7 percent discount rate, are approximately $570 million for mechanical dredging and landfill disposal, $496 million for mechanical dredging and beneficial use, and $550 million for hydraulic dredging and landfill disposal.

Capital Cost

Since the construction will be performed over a seven-year period, capital costs will vary on an annual basis. The estimated total capital costs for this alternative are about $929 million for mechanical dredging and landfill disposal, $806 million for mechanical dredging and beneficial use, and $896 million for hydraulic dredging and landfill disposal. The estimated present worth of the capital costs for this alternative is approximately $556 million for mechanical dredging and landfill disposal, $483 million for mechanical dredging and beneficial use, and $536 million for hydraulic dredging and landfill disposal.

O&M Costs

Due to the varying frequency of different elements of the monitoring program and the five-year reviews, O&M costs will vary on an annual basis. The estimated annual average O&M costs for this alternative, which consist of the monitoring costs, the periodic cost of the modeling, and the five-year reviews, are about $3.35 million for all three options. These costs have been estimated for a ten-year period. The estimated present worth of the O&M costs for this alternative is about $12.5 million for mechanical dredging and landfill disposal or beneficial use, and $13.1 million for hydraulic dredging and landfill disposal. (The last figure is higher because, based on productivity estimates for the selected dredge, construction for the hydraulic dredging option may be able to be completed sooner.)

Chapter 9

9. COMPARATIVE ANALYSIS AND COST SENSITIVITY ANALYSES

This chapter provides an overall comparison of the five remedial alternatives analyzed in detail in Chapter 8, using the seven NCP criteria (Sections 9.1 through 9.7). The comparative analysis encompasses the two threshold criteria and the five balancing criteria. The two modifying criteria of state acceptance and community acceptance will be evaluated in USEPA's ROD. For the three active remedial alternatives, a comparison of the impacts of managing the non-TSCA-regulated dredged materials (beneficial use versus landfill disposal) is also presented where this distinction is relevant. In addition, this chapter also compares the impact on relevant criteria of mechanical dredging versus hydraulic dredging options for the two removal alternatives.

A discussion of the sensitivity of the cost estimates for the three active remedial alternatives to various factors (*e.g.,* the areas targeted for remediation and the assumed threshold PCB concentration for characterizing the removed sediments into TSCA-regulated and non-TSCA-regulated categories) is presented in Section 9.8. The sensitivity of the cost estimates for the capping with dredging alternative to a reduction in the cap thickness is examined and evaluated in this section. The sensitivity of the cost estimates for the two removal alternatives to the depth of sediments targeted for removal is also included in this section.

9.1 Overall Protection of Human Health and the Environment

This evaluation criterion provides a final assessment as to whether each alternative adequately protects human health and the environment. Relative reductions in risk for each remedial alternative as compared to the No Action and Monitored Natural Attenuation alternatives are discussed below. Consideration of the impacts of the upstream boundary concentration is also discussed.

9.1.1 Overall Protection of Human Health

Overall protection of human health was evaluated in two primary ways:

- The time that it would take under each of the alternatives to reach the fish PRG and the other target concentrations, and
- The relative reduction in cancer risks and non-cancer health hazards under the five remedial alternatives.

9.1.1.1 Time to Reach Fish Target Levels

The fish PRG is 0.05 ppm PCBs (wet weight) in fillet. In addition, USEPA considered a target concentration of 0.2 ppm PCBs (wet weight) in fillet based on one fish meal per month, and a target concentration of 0.4 ppm, based on the average (CT) consumption rate of one fish meal every two months. The target concentrations correspond to points at which the fish consumption advisories might be relaxed from the current "eat none" recommendation in the Upper Hudson River. The following table shows the time required under each of the alternatives to reach the fish consumption PRG and target concentrations.

Years to Reach PCB Target Concentration in Fish Averaged Over Entire Upper Hudson River			
Alternative	0.05 ppm PRG	0.2 ppm (1 meal/ month) target	0.4 ppm (1 meal/ 2 months) target
No Action *	>67	>67	>67
MNA*	>67	60 to >67	34 to >67
CAP-3/10/Select	>67	35	21
REM-3/10/Select	>67	35	20
REM-0/0/3	>67	26	11

*Both No Action and MNA results are calculated as a range, with the first value representing the base case, and the second value representing the upper bound. For No Action, none of the fish target concentrations are achieved within the modeled period for either the base case or upper bound; the same limitation applies to MNA for the 0.05 ppm PRG. Therefore, only a single value is shown for these entries on the table.

The overall protection of human health achieved by the active alternatives is considerably more than that achieved by the No Action and MNA alternatives. For the CAP-3/10/Select, REM-3/10/Select, and REM-0/0/3 alternatives, risk is reduced through removal or capping with dredging

400789

of contaminated sediments in River Sections 1 and 2, and removal of contaminated sediments in River Section 3, followed by Monitored Natural Attenuation.

In River Section 3, all of the active remediation alternatives meet the PRG target concentration of 0.05 ppm PCBs between the years 2050 and 2051 (which is 40 to 43 years after construction is complete, depending on the alternative); the MNA alternative reaches it in the year 2059; and the No Action alternative does not meet the PRG within the modeling time frame. As a result, the PRG of 0.05 ppm also is expected to be attained in the majority of the Lower Hudson River, due to the lower initial concentration of PCBs in the Lower Hudson compared to the Upper Hudson. Due to the continuing Tri+ PCB load of 2 ng/L assumed after implementation of the source control action in the vicinity of the GE Hudson Falls plant, the PCB concentration in fish averaged over the Upper Hudson is expected to be reduced to a range of 0.09 to 0.14 ppm, which is slightly above the PRG of 0.05 ppm.

The protectiveness of the active remedial alternatives is further enhanced through implementation of institutional controls, such as the fish consumption advisories. The modeled results suggest that the advisories could be relaxed somewhat at various points in the future for the different river sections. Specifically, the 0.2 ppm target concentration is met in River Section 2 in 2044 for CAP-3/10/Select (about 36 years after remediation is complete), 2040 for REM-3/10/Select, and 2034 for REM-0/0/3. In comparison, it is met in 2061 for the base MNA alternative and is not met withing the modeled time frame for the estimated upper bound. The 0.2 ppm target concentration is not met within the modeled time frame for No Action.

For the CAP-3/10/Select alternative, the modeling projects that the target concentration of 0.4 ppm is attained in River Section 1 within 16 years of active remediation, within 15 years for REM-3/10/Select, and within 3 years for REM-0/0/3. The target of 0.2 ppm, protective of an adult who consumes one fish meal per month, is attained in River Section 2 within 32 years of active remediation. These time periods are significantly shorter than the time periods projected for attaining the 0.4 ppm target under either the No Action alternative or the MNA alternative.

400790

9.1.1.2 Relative Reductions in Cancer Risks and Non-Cancer Health Hazards

The model output years included in the exposure calculations were identified on a river section basis using different long-term period starting dates, depending on the construction schedule for each remedial alternative. The long-term exposure period was considered to start immediately after a one-year equilibration period beyond the completion of work in a given river section. For example, if the construction schedule for an alternative requires three years to complete in River Section 1, given a start date in 2004, the construction would be complete at the end of 2006, equilibration would occur over the year 2007, and the long-term period for calculation of cancer risks and non-cancer health hazards would start on January 1, 2008.

Cancer risks and non-cancer health hazards for the entire Upper Hudson River (RMs 189 to 154) and for each section of the river under the active remedial alternatives were compared separately (using the appropriate time frame) to the cancer risks and non-cancer health hazards under the No Action and MNA alternatives, including their estimated upper bounds, to estimate the reduction in cancer risks and non-cancer health hazards achieved by each alternative. Non-cancer health hazard and cancer risk reductions predicted for the adult angler (both RME and CT) are presented on Tables 7-6a through 7-6d (for non-cancer health hazards averaged over the entire Upper Hudson River and calculated for each river section individually) and on Tables 7-7a through 7-7d (for cancer risk). The underlying non-cancer health hazard index and cancer risk data are presented graphically in Figures 7-1 through 7-4.

The fish concentration predictions used are the species-weighted averages, based on relative species consumption reported in the 1991 state-wide New York angler survey (Connelly *et al.*, 1992). The fish consumption rates and time periods assumed for exposure are the same as those utilized in the Revised HHRA (USEPA 2000p) and summarized in Chapter 7. Because the PCB concentration in fish declines for the projected 70-year period covered by this FS, the average concentration (over time) actually declines as the exposure period increases. Thus, the average concentration and, by extension, the average PCB intake in terms of mg/kg-day, in a 7-year exposure period is actually greater than the average concentration over, for example, 12 years. As a result of the declining trend in PCB concentration in fish over time, the average daily dose decreases as the exposure duration increases.

The RME non-cancer health hazards for adult anglers for each alternative by river section are shown in Figure 7-1, and the corresponding CT exposure non-cancer health hazards for each alternative by river section are shown in Figure 7-2. Similarly, the RME cancer risks for adult anglers for each alternative by river section are shown in Figure 7-3 and the corresponding CT exposure cancer risks for each alternative by river section are shown in Figure 7-4. The RME cancer risks and non-cancer health hazards for adult anglers for each alternative and for the entire Upper Hudson River are shown in the table below.

Non-Cancer Health Hazards and Cancer Risks from Fish Ingestion Averaged over the Entire Upper Hudson River

Non-Cancer Health Hazard Index or Cancer Risk	No Action	MNA	CAP-3/10/Select	REM-3/10/Select	REM-0/0/3
HI-RME (2009-2015)	53-80	40-71	15	13	
HI-RME (2011-2017)	48-75	34-66			8
HI-CT (2009-2020)	5.0-7.7	3.4-6.7	1.3	1.2	
HI-CT (2011-2022)	4.5-7.3	2.9-6.3			0.7
Cancer risk - RME (2009-2048)	7.8E-04 to 1.4E-03	4.0E-04 to 1.2E-03	1.8E-04	1.7E-04	
Cancer risk - RME (2011-2050)	7.3E-04 to 1.3E-03	3.5E-04 to 1.1E-03			1.2E-04
Cancer risk - CT (2009-2020)	1.7E-05 to 2.6E-05	1.2E-05 to 2.3E-05	4.5E-06	4.0E-06	
Cancer risk - CT (2011-2022)	1.5E-05 to 2.5E-05	1.0E-05 to 2.1E-05			2.4E-06

The table below shows a summary of predicted RME cancer risk and non-cancer health hazard reductions for all active alternatives compared to the No Action and MNA alternatives, and for MNA compared to No Action.

400792

Summary of Cancer Risk and Non-Cancer Health Hazard Reductions						
	Compared to No Action			**Compared to MNA**		
Alternative	**Upper Hudson & River Section 1**	**River Section 2**	**River Section 3**	**Upper Hudson & River Section 1**	**River Section 2**	**River Section 3**
MNA	<2 to 4-fold	<2 to 4-fold	<2 to <3-fold			
CAP-3/10/Select	4 to 8-fold	4 to 9-fold	<2 to 3-fold	2 to 6-fold	3 to 9-fold	<2-fold
REM-3/10/Select	4 to 8-fold	5 to 11-fold	<2 to 3-fold	2 to 7-fold	3 to 11-fold	<2-fold
PEM-0/0/3	6 to 11-fold	7 to 16-fold	3 to 4-fold	3 to 9-fold	4 to 16-fold	<2-fold

Compared to the estimated upper bound of No Action, the REM-0/0/3 alternative achieves an order of magnitude (*i.e.*, 10-fold) or more reduction in RME cancer risks and non-cancer health haza-ds in the Upper River as a whole, and in River Sections 1 and 2 individually. Predicted reductions in River Section 3 are smaller (approximately three-fold) since sediments included in target areas make up a much smaller fraction of the overall surface area of this section and there is much greater dilution due to tributary flows. When compared to the MNA base forecast, the reductions for the REM-0/0/3 alternative in River Sections 1 and 2 and for the entire Upper River are on the order of three-to-five fold. Reductions for River Section 3 are less than two-fold.

Generally speaking, the more extensive the alternative, the greater the reduction in risk or health hazard. Based on modeling assumptions and considering the average for the Upper Hudson as a whole, non-cancer health hazard reduction under the REM-3/10/Select alternative compares incrementally favorably to that for CAP-3/10/Select (*i.e.*, health hazard reductions are within a few percentage points of each other for these two alternatives). As shown on Tables 7-6a through 7-6d, health hazard reduction under the REM-0/0/3 alternative represents approximately a 10-percentage-point advantage over the REM-3/10/Select alternative. Cancer risk reductions presented on Tables 7-7a through 7-7d show a similar, though generally more tightly bounded, trend for the equivalent comparisons. For example, the difference in cancer risk reduction between the REM-0/0/3 alternative and REM-3/10/Select is only about five percentage points. On the other hand, the differences between comparisons to No Action and MNA are somewhat greater for cancer risk reduction than for non-cancer health hazard reduction.

Since the assumed (separate) upstream source control component is the same for all active alternatives and for MNA, greater extensiveness in sediment remediation yields greater benefits in health hazard reduction and in cancer risk reduction. These increases in benefits, however, are not linearly proportional to increases in the volume or area of sediment remediated. Since these parameters are directly related to cost, it follows that similar increments in risk reduction will come at greater and greater cost, requiring tradeoffs based on analysis of other criteria.

9.1.2 Overall Protection of the Environment

Ecological risks were calculated for each of the three river sections for the river otter and the mink. The river otter is a piscivorous mammal and was the receptor found to be at greatest risk in the Upper Hudson River in the Revised ERA (USEPA, 2000q), due to the high proportion of fish in its diet. The mink is a piscivorous mammal and is known to be sensitive to PCBs. The long-term exposure period for the river otter and mink is considered to start immediately after a one-year equilibration period beyond the completion of work in a given section, as was assumed for human health calculations. Risks to other ecological receptors are assumed to be equal to or less than those calculated for river otter and mink. Moreover, risks to ecological receptors in the Lower Hudson River are assumed to be equal to or less than those calculated for River Section 3 based on lower concentration of PCBs in the Lower Hudson River.

9.1.2.1 River Otter

River otters were assumed to consume a diet consisting entirely of PCB-contaminated largemouth bass. The TQs calculated for the river otter are based on the LOAEL and NOAEL TRVs of 0.04 mg PCBs/kg/day and 0.004 mg PCBs/kg/day, respectively. The NOAEL and LOAEL river otter toxicity quotients are shown for each alternative in Figures 7-5 and 7-6, respectively. The NOAEL and LOAEL ecological toxicity quotients calculated for the river otter for each of the three river sections are shown in the table below.

Ecological Toxicity Quotients - River Otter (Average of 25-Year Time Frame)							
	No Action start year 2008	**No Action** start year 2009	**MNA** start year 2008	**MNA** start year 2009	**CAP-3/10/Select**	**REM-3/10/Select**	**REM-0/0/3**
River Section 1 (RM 189)	Modeling time frame is 2008-2032 for CAP-3/10/Select and REM-3/10/Select and 2009-2033 for REM-0/0/3						
LOAEL	**24-30**	**23-29**	**9.7-15**	**9.1-14**	**5.3**	**5.2**	**3.7**
NOAEL	**240-300**	**230-290**	**97-150**	**91-140**	**53**	**52**	**37**
River Section 2 (RM 184)	Modeling time frame is 2009-2033 for CAP-3/10/Select and REM-3/10/Select and 2011-2035 for REM-0/0/3						
LOAEL	**14-27**	**12-26**	**9.2-24**	**7.8-23**	**3.5**	**2.9**	**1.8**
NOAEL	**140-270**	**120-260**	**92-240**	**78-230**	**35**	**29**	**18**
River Section 3 (RM 154)	Modeling time frame is 2010-2034 for CAP-3/10/Select and REM-3/10/Select and 2012-2036 for REM-0/0/3						
LOAEL	**2.4**	**2.3**	**1.2**	**1.1**	0.87	0.86	0.62
NOAEL	**24**	**23**	**12**	**11**	**8.7**	**8.6**	**6.2**

Notes:
TQs above the target level of 1.0 are shown in boldface type.
Range of years calculated using bounding estimates are presented for the No Action and MNA alternatives.

Toxicity quotients calculated for the river otter exceed one for LOAEL and NOAEL comparisons in River Sections 1 and 2 at RMs 189 and 184 and for all NOAEL comparisons in River Section 3 at RM 154. In River Section 3, LOAEL TQs are below one for all active remediation alternatives, but exceed one for the MNA and No Action alternatives.

A TQ of one is not reached by 2067 (the end of the modeling period) on a LOAEL or NOAEL basis in River Section 1 or on a NOAEL basis in River Sections 2 and 3. In River Section 2, as shown on Table 7-8, on a LOAEL basis a TQ of one is reached in 35 to 52 years with active remediation and not for more than 59 years under the No Action and MNA alternatives. In River Section 3, on a LOAEL basis a TQ of one is reached in 5 to 8 years with active remediation, in 14 years under the MNA alternative, and not for more than 58 years under the No Action alternative.

The table below shows a summary of predicted reductions in river otter TQs for all active alternatives compared to the No Action and MNA alternatives for the modeled time periods presented on the table above, and for MNA compared to No Action. Since the NOAEL is calculated as an order of magnitude higher than the LOAEL in all cases, the reductions for both NOAEL and LOAEL compared to the respective No Action and MNA are the same; therefore only a single result is presented in each case.

Reductions in Ecological Toxicity Quotients - River Otter				
	MNA	**CAP-3/10/Select**	**REM-3/10/Select**	**REM-0/0/3**
River Section 1 (RM 189)				
No Action	2 to 3-fold	5 to 6-fold	5 to 6-fold	6 to 8-fold
MNA		2 to 3-fold	2 to 3-fold	2 to 4-fold
River Section 2 (RM 184)				
No Action	<2 to 3-fold	4 to 8-fold	4 to 8-fold	7 to 14-fold
MNA		3 to 7-fold	3 to 8-fold	4 to 13-fold
River Section 3 (RM 154)				
No Action	2-fold	3-fold	3-fold	4-fold
MNA		<2-fold	<2-fold	2-fold

As may be determined from the table above, reductions in toxicity quotient for the river otter compared to No Action and MNA vary with extensiveness of the remediation. Reductions for the CAP-3/10/Select and REM-3/10/Select alternatives are virtually identical, while those for the REM-0/0/3 alternative are higher. All active alternatives show greater risk reductions than. Reductions in River Section 2 for the REM-0/0/3 alternative, compared to the estimated upper bounds for both No Action and MNA, exceed an order of magnitude. Compared against the base case for No Action, risk reduction decreases with distance downstream for the CAP-3/10/Select and REM-3/10/Select alternatives. This trend does not consistently hold for other comparisons for River Sections 1 and 2, however. On the other hand, reductions in River Section 3 are consistently smaller than those upstream, since sediments included in target areas make up a much smaller fraction of the overall surface area of this section and there is much greater dilution due to tributary flows.

9.1.2.2 Mink

Approximately one-third (34 percent) of the mink diet was assumed to consist of PCB-contaminated spottail shiners (*i.e.*, representing fish less than 10 cm in length).The TQs calculated for the mink are based on the LOAEL and NOAEL TRVs of 0.04 mg PCBs/kg/day and 0.004 mg PCBs/kg/day, respectively. The average NOAEL and LOAEL mink toxicity quotients are shown for each alternative in Figures 7-7 and 7-8, respectively. The NOAEL and LOAEL ecological toxicity quotients calculated for the mink for each of the three river sections are shown in the table below.

Ecological Toxicity Quotients - Mink
(Average of 25-Year Time Frame)

	No Action start year 2008	**No Action** start year 2009	**MNA** start year 2008	**MNA** start year 2009	**CAP-3/10/Select**	**REM-3/10/Select**	**REM-0/0/3**
River Section 1 (RM 189) Modeling time frame is 2008-2032 for CAP-3/10/Select and REM-3/10/Select and 2009-2033 for REM-0/0/3							
LOAEL	**4.6-5.3**	**4.5-5.2**	**1.7-2.6**	**1.6-2.5**	0.94	0.95	0.70
NOAEL	**46-53**	**45-52**	**17-26**	**16-25**	**9.4**	**9.5**	**7.0**
River Section 2 (RM 184) Modeling time frame is 2009-2033 for CAP-3/10/Select and REM-3/10/Select and 2011-2035 for REM-0/0/3							
LOAEL	**1.5-2.7**	**1.3-2.6**	0.94-**2.5**	0.79-**2.4**	0.36	0.31	0.19
NOAEL	**15-27**	**13-26**	**9.4-25**	**7.9-24**	**3.6**	**3.1**	**1.9**
River Section 3 (RM 154) Modeling time frame is 2010-2034 for CAP-3/10/Select and REM-3/10/Select and 2012-2036 for REM-0/0/3							
LOAEL	0.21	0.20	0.11	0.09	0.07	0.08	0.06
NOAEL	**2.1**	**2.0**	**1.1**	0.9	0.75	0.75	0.55

Notes:
TQs above the target level of 1.0 are shown in boldface type.
Range of years calculated using bounding estimates are presented for the No Action and MNA alternatives.

Toxicity quotients calculated for the mink are below or equal to one for LOAEL comparisons for active alternatives in all river sections. In River Section 3, NOAEL comparisons for active remediation alternatives are also below one. Under the No Action and MNA alternatives, all NOAEL and LOAEL TQs in River Sections 1 and 2 exceed one, except for the LOAEL base case for the MNA alternative. LOAEL TQs in River Section 2 exceed one for the No Action alternative and estimated upper bound of the MNA alternative. NOAEL TQs in River Section 3 exceed one for the No Action alternative, whether starting in the Year 2008 or 2009, and for the MNA alternative starting in the Year 2008.

A TQ of one on a LOAEL basis is reached in two to five years with active remediation in River Section 1. Under the MNA alternative, a TQ of one is reached in a time frame of 22 years to more than 60 years, and under the No Action alternative it is not reached for more than 60 years (the extent of the modeling period). In River Section 2, a TQ of one on a LOAEL basis is reached before the long-term modeling period for all active alternatives. Under the base MNA and No Action alternatives, a TQ of one is reached in 10 and 21 years, respectively, while under the estimated upper bounds for these alternatives, it is not reached for more than 59 years. Under active remediation in River Section 3, a TQ of one on a NOAEL basis is reached in four to five years, in 12 years under the MNA alternative, and in more than 58 years under the No Action alternative.

The table below shows a summary of predicted reductions in Mink TQs for all active alternatives compared to the No Action and MNA alternatives, and for MNA compared to No Action. Since the NOAEL is calculated as an order of magnitude higher than the LOAEL in all cases, the reductions for both NOAEL and LOAEL compared to the associated No Action and MNA are the same; therefore only a single result is presented in each case.

Reductions in Ecological Toxicity Quotients - Mink				
	MNA	**CAP-3/10/Select**	**REM-3/10/Select**	**REM-0/0/3**
River Section 1 (RM 189)				
No Action	2 to 3-fold	5 to 6-fold	5 to 6-fold	6 to 7-fold
MNA		2 to 3-fold	2 to 3-fold	2 to 4-fold
River Section 2 (RM 184)				
No Action	<2 to 3-fold	4 to 8-fold	5 to 9-fold	7 to 14-fold
MNA		3 to 7-fold	3 to 8-fold	4 to 13-fold
River Section 3 (RM 154)				
No Action	2-fold	3-fold	3-fold	3-fold
MNA		<2-fold	<2-fold	<2-fold

As may be determined from the table above, reductions in toxicity quotient for the mink compared to No Action and MNA vary with extensiveness of the remediation. Reductions for the CAP-3/10/Select and REM-3/10/Select alternatives are virtually identical (slightly favoring REM-3/10/Select in River Section 2), while those for the REM-0/0/3 alternative are higher. All active alternatives show greater risk reductions than MNA. Reductions in River Section 2 for the REM-0/0/3 alternative, compared to the upper bounds for both No Action and MNA, exceed an order of magnitude. Compared against the base case for No Action, risk reduction decreases with distance downstream for the CAP-3/10/Select and REM-3/10/Select alternatives. This trend does not consistently hold for other comparisons for River Sections 1 and 2, however. On the other hand, reductions in River Section 3 are consistently smaller than those upstream, since sediments included in target areas make up a much smaller fraction of the overall surface area of this section and there is much greater dilution due to tributary flows.

9.1.3 Downstream Transport of PCBs

Remedial action objectives for the site call for minimizing long-term downstream transport of PCBs over the Federal Dam. The table below (based on Tables 8-1 through 8-3) provides a summary of the annual Tri+ PCB loads passing the dams at the downstream ends of all three river sections for three points in time. The year 2003 represents the period immediately preceeding the start of remedial construction under any of the active remedial alternatives, while 2011 represents a period shortly after completion of construction (*i.e.*, 2008 for CAP-3-10-Select and REM-3/10/Select, and 2010 for REM-0/0/3). The year 2035 represents the approximate mid-point of the ends of the ecological modeling time frames for the various alternatives. This is also approximately the end of the period for which cost estimates are prepared (*i.e.*, about 30 years from the start of construction).

Predicted Annual Downstream Transport of Tri+ PCB Load (kg)									
	Thompson Island Dam			Northumberland Dam			Federal Dam		
	Year 2003	Year 2011	Year 2035	Year 2003	Year 2011	Year 2035	Year 2003	Year 2011	Year 2035
No Action	104	88	2011	122	105	60	131	104	62
MNA	104	44	14	123	63	15	131	72	24

Predicted Annual Downstream Transport of Tri+ PCB Load (kg)									
	Thompson Island Dam			Northumberland Dam			Federal Dam		
CAP-3/10/Select	104	23	11	123	29	11	131	43	20
REM-3/10/Select	104	22	11	123	27	11	131	42	20
REM-0/0/3	104	14	9.5	123	17	9.5	131	34	18

Neither the No Action alternative nor the MNA alternative addresses the scour of PCB-contaminated sediments associated with one-in-three-year to one-in-five-year flow events from the Hoosic River in River Section 3. These events have caused resuspension of PCB loading of 18 kg/day, equivalent to the peak loads at Rogers Island attributed to releases at the Allen Mills structure (USEPA, 1999b). Without addressing PCB-contaminated sediments downstream of the Hoosic River (RM 166), PCB loads over Federal Dam will likely be higher than indicated by the modeling results. All three active remedial alternatives address the scour of PCB-contaminated sediments associated with flow events from the Hoosic River in River Section 3, and are therefore effective in reducing the PCB load over Federal Dam to the Lower Hudson River, with the REM-0/0/3 alternative being most effective. The similarity in modeled Tri+ PCB loads over Federal Dam between the MNA and the active alternatives by the year 2035 and beyond reflects the fact that all are largely controlled by the value assumed for the unknown upstream PCB load. Additional Tri+ PCB loads due to resuspension from dredging operations are estimated to be less than the release estimated from a single 100-year flood event, as discussed in subsection 9.5.3.

9.2 Compliance with ARARs

The chemical-specific ARARs for PCBs in the water column are 0.5 μg/L (500 ng/L) federal MCL; 0.09 μg/L (90 ng/L) NYS standard for protection of human health and drinking water sources; 1 ng/L federal ambient water criterion for navigable waters; 0.12 ng/L NYS standard for protection of wildlife; and 0.001 ng/L NYS standard for protection of human consumers of fish.

As shown in Figures 6-33 through 6-37, the first two chemical-specific ARARs for the surface water are met by all five remedial alternatives, and the remaining three chemical-specific ARARs for the surface water are not met by any of the five alternatives for the 70-year model forecast period. The effect of the separate source control NTCRA in the vicinity of the GE Hudson Falls plant is observed in the difference (separation) between the trajectories for the No Action and MNA alternatives. The benefits of active remediation of the sediments are readily apparent in the differences in the trajectories for the MNA alternative and those for the active remediation alternatives. As expected, the water quality is best for the REM-0/0/3 alternative and substantially improved for the CAP-3/10/Select and REM-3/10/Select alternatives, compared to MNA. These differences are most apparent for the first 20 years of the forecast period, between 2005 and 2024. However, even in 2067, towards the end of the forecast period, there is a very substantial difference between the water quality for the No Action alternative (approximately 30 ng/L at TID and Schuylerville and 10 ng/L at Federal Dam) and the other four alternatives (approximately 5 ng/L at TID and Schuylerville and 1.7 ng/L at Federal Dam).

Because there is no active remedial action associated with the sediments for the No Action and MNA alternatives, action-specific and location-specific ARARs do not apply. The three active remedial alternatives will comply with action-specific ARARs identified in table 2-2A (*e.g.*, CWA Sections 401 and 404; TSCA; Section 3004 of RCRA; Section 10 of the Rivers and Harbors Act; New York State ECL Article 3, Title 3, and Article 27, Titles 7 and 9, and location-specific ARARs listed in table 2-2B (*e.g.*, Endangered Species Act; Fish and Wildlife Coordination Act; Farmland Protection Policy Act; National Historic Preservation Act; and New York State Freshwater Wetlands Law).

9.3 Long-Term Effectiveness and Permanence

The long-term effectiveness of an alternative is assessed through the following criteria, as evaluated individually in this section:

- Reduction in residual risk;
- Adequacy of controls; and
- Reliability of controls.

9.3.1 Reduction of Residual Risk

The No Action and MNA alternatives result in continuation of the degraded condition of surficial sediments and surface water quality of the Upper Hudson River for several decades (albeit gradually reduced), especially in River Section 1, regardless of any reduction in the upstream water column loadings. The long-term transport of PCBs over the Federal Dam and to the Lower Hudson River will continue indefinitely, although a substantial portion of this transport is due to the assumed upstream boundary condition; *i.e.*, the PCB load entering the Upper Hudson at Rogers Island. Table 8-3 presents the Tri+ PCB load over the Federal Dam in 2003 (approximately 130 kg), in 2011(104 kg), and in 2035 (63 kg) for the No Action alternative. Similarly, this table also presents the Tri+ PCB load over the Federal Dam in 2003 (approximately 130 kg), in 2011 (72 kg), and in 2035 (24 kg) for the MNA alternative. In 2035, as a result of the separate source control NTCRA in the vicinity of the GE Hudson Falls plant, the Tri+ PCB load over Federal Dam is reduced by approximately 62 percent.

For the CAP-3/10/Select alternative, residual risk is reduced through capping 207 acres of PCB-contaminated sediments and removal of 1.73 million cubic yards of sediments containing 33,100 kg PCBs. For this alternative, Table 8-3 presents the Tri+ PCB load over the Federal Dam in 2003 (approximately 130 kg), in 2011(45 kg), and in 2035 (20 kg). In 2011, soon after construction ends, the CAP-3/10/Select alternative results in a 58 percent reduction in the Tri+ PCB load over Federal Dam compared to the No Action alternative and a 40 percent reduction in the load over Federal Dam compared to the MNA alternative. After a longer period of time, in 2035, the CAP-3/10/Select alternative results in a 68 percent reduction in the Tri+ PCB load over Federal Dam compared to the No Action alternative and a 16 percent reduction in the load over Federal Dam compared to the MNA alternative.

The CAP-3/10/Select alternative does not completely eliminate long-term risks for target areas that are capped. Sediments are removed in areas only to the degree necessary for cap installation and, in some areas, highly contaminated sediments may be left in place below the cap and backfill. Anthropogenic or natural processes (*e.g.*, navigation accidents, severe storms, or longer-term changes in the depositional/erosional regime in a given location) may damage or erode and scour the cap materials and redistribute PCB-contaminated capped sediments over wider areas of the Upper Hudson River. Non-routine repair or replacement of large sections of the cap may have to be undertaken if a breach occurs in a highly contaminated area (*e.g.*, *Hot Spot* 14 in River Section 1 or *Hot Spot* 28 in River Section 2) due to catastrophic events such as a major flood. Depositional buildup of sediments adjacent to the cap could shift currents over the cap creating the potential for erosion in an unexpected area.

The influence of regional aquifer systems on the hydrologic regime of Upper Hudson River has not been evaluated. Groundwater level fluctuations can result from a wide variety of hydrologic phenomena (*e.g.*, groundwater recharge due to seasonal heavy rainfall, or bank-storage effect near the river) and the subsequent inflow of groundwater may breach the cap in multiple areas and transport PCBs into the river. During periods of extremely low flow, sections of the cap could be exposed to the air and a different range of temperatures and other conditions unlike the submerged environment, resulting in freeze-thaw damage or desiccation cracking.

For the two removal alternatives, a total volume of contaminated sediment from 2.65 million cubic yards (REM-3/10/Select) to 3.82 million cubic yards (REM-0/0/3), containing a mass of PCBs from 45,600 kg (REM-3/10/Select) to an estimated mass of more than 63,500 kg (REM-0/0/3) located in areas from 493 to 964 acres (REM-3/10/Select and REM-0/0/3, respectively) of the Upper Hudson River will be remediated. Appendix E contains the basis for estimation of mass. For the REM-3/10/Select alternative, Table 8-3 presents the Tri+ PCB load over the Federal Dam in 2003 (approximately 130 kg), in 2011(42 kg), and in 2035 (20 kg). In 2011, soon after construction ends, the REM-3/10/Select alternative results in a 60 percent reduction in the Tri+ PCB load over Federal Dam compared to the No Action alternative and a 42 percent reduction in the load over Federal Dam compared to the MNA alternative. After a longer period of time, in 2035, the REM-3/10/Select alternative results in a 69 percent reduction in the Tri+ PCB load over Federal Dam compared to the No Action alternative and a 17 percent reduction in the load over Federal Dam compared to the MNA alternative.

For the REM-0/0/3 alternative, Table 8-3 presents the Tri+ PCB load over the Federal Dam in 2003 (approximately 130 kg), in 2011(34 kg), and in 2035 (18 kg). In 2011, soon after construction ends, the REM-0/0/3 alternative results in a 67 percent reduction in the Tri+ PCB load over Federal Dam compared to the No Action alternative and a 53 percent reduction in the load over Federal Dam compared to the MNA alternative. After a longer period of time, in 2035, the REM-0/0/3 alternative results in a 72 percent reduction in the Tri+ PCB load over Federal Dam compared to the No Action alternative and a 25 percent reduction in the load over Federal Dam compared to the MNA alternative.

The three active remedial alternatives (CAP-3/10/Select, REM-3/10/Select, and REM-0/0/3) also rely on natural attenuation processes such as burial by cleaner sediments, bioturbation, biodegradation, dispersion, dilution through advection and recharge, adsorption, and volatilization to further reduce the concentration of any contaminants that remain after construction is completed. However, modeling results predict that these three alternatives will not completely achieve the PRGs for the site within the modeled period, although RAOs are met in part or in full, as discussed in subsections 9.1.1 and 9.1.2. The limitation in meeting PRGs largely stems from the assumption of the upstream Tri+ PCB load at Fort Edward (Rogers Island) of 0.0256 kg/day in 2005. Greater achievement of the PRGs is estimated based on a 0 kg/day assumption. Thus, remediating PCB-contaminated sediment in combination with control of the upstream load can be expected to achieve more PRGs, and to approach the PRGs faster, than either approach alone.

9.3.2 Adequacy of Controls

The No Action and MNA alternatives do not provide for engineering controls on the river sediments. The MNA alternative assumes a separate source control NTCRA in the vicinity of the GE Hudson Falls plant. As noted previously in Chapter 8, the existing institutional controls, which rely on voluntary compliance, are not fully adequate in reducing exposure to PCBs due to consumption of contaminated fish. In addition, institutional controls are inadequate for protection of the environment (*e.g.*, ecological receptors).

The CAP-3/10/Select alternative provides for dredging of some contaminated sediments in target areas and placement of an engineered cap over the remaining target areas. Like the MNA alternative, this alternative also provides for institutional controls, such as the fish consumption advisories. The REM-3/10/Select and REM-0/0/3 alternatives provide for removal of contaminated sediments in target areas. These two alternatives also provide for institutional controls, such as the fish consumption advisories.

The planned post-construction fish, water column, and sediment monitoring program allows for tracking the natural recovery of the river after remediation is completed. It also provides data to confirm the need to continue the existing fish consumption advisories and to evaluate the possibility of relaxing the advisories.

9.3.3 Reliability of Controls

Sediment capping, dredging, backfilling and habitat replacement, and off-site disposal/ treatment of removed sediments are, individually, all reliable and proven technologies. However, for the CAP-3/10/Select alternative, proper design, placement, and maintenance of the cap in perpetuity are required for its effectiveness, continued performance, and reliability. This presents a challenge for the Upper Hudson River since the capping concept requires maintenance of nearly 12 miles of long, narrow strips of cap with a high perimeter-to-surface area ratio. A cap placed in a relatively sheltered embayment or cove would be easier to maintain, since it would not be subject to the significant variations in river conditions typical of a river channel. The cap integrity monitoring and maintenance program planned for the CAP-3/10/Select alternative provides for as reasonably reliable maintenance as could be expected, if consistently and thoroughly followed. The challenge lies in overcoming the natural human tendency to relax vigilance as time goes on, especially as the essential rationale for installation of the cap fades from public consciousness. The fish consumption advisories will continue to provide some measure of protection of human health until PCB concentrations in fish are reduced and the PRG for protection of human health is attained. However, even the attainment of acceptable levels in the fish may serve to undermine vigilance in maintaining the cap in the future.

In general, the REM-3/10/Select and REM-0/0/3 alternatives are the most reliable, as there is little or no longer-term maintenance or residual risk associated with the remedial work. Of the removal alternatives, REM-0/0/3 is the most reliable, as it permanently removes the greatest amount of sediment (leaving the least amount of PCBs in the river). The CAP-3/10/Select alternative does not achieve the same degree of reliability due to the potential for defects or damage to the cap, thereby reducing its effectiveness. This alternative would still require all of the sediment handling, processing, and disposal activities needed for the removal alternatives. The No Action alternative is the least reliable. Although the MNA alternative is more reliable than the No Action alternative, it relies more heavily on institutional controls than do the active remedial alternatives to limit exposure to PCBs. Also, the fish consumption advisories may be relaxed sooner under the active alternatives. Institutional controls do not address ecological receptors, and human health risk reduction relies on knowledge of and voluntary compliance with the fish consumption advisories.

9.4 Reduction of Toxicity, Mobility, or Volume through Treatment

The No Action and MNA alternatives do not involve any containment or removal of contaminants from the Upper Hudson River sediments. Because the MNA alternative assumes the separate source control NTCRA in the vicinity of the GE Hudson Falls plant, the upstream Tri+ PCB load to the water column is expected to be reduced from 0.16 kg/day to 0.0256 kg/day by January 1, 2005. The No Action and MNA alternatives rely on natural attenuation processes such as burial by cleaner sediments, biodegradation, bioturbation, and dilution to reduce PCB concentrations in sediments and surface water. Biodegradation processes may convert some of the more highly chlorinated PCB congeners (*e.g.*, tetrachlorbiphenyls) to less chlorinated congeners (monochloro- and dichloro-biphenyls) and biphenyl. The degree to which chlorination affects PCB toxicity remains uncertain and debated within the scientific community. Yet, animal studies supported by GE and reviewed in the 1996 PCB cancer reassessment (USEPA, 1996c) found tumors in lab animals for all Aroclor mixtures tested (Aroclor 1016, 1242, 1254 and 1260), spanning a wide range of chlorination. Thus, it is not clear the degree to which the transformation from more highly chlorinated PCBs to lesser chlorinated congeners would alter the PCB toxicity, if at all. In any case, dechlorination is not expected to continue to extensively modify the PCB inventory over time since it appears to occur only within the first few years of depositon (USEPA, 1997a). Natural dilution of the contaminated sediments will also reduce the toxicity, but the overall volume of contaminated sediments would increase as PCBs are contributed to the Upper Hudson from upstream. Concentrations of PCBs in fish will respond slowly over time to decreases in concentrations in sediments and surface water.

For the CAP-3/10/Select alternative, the mobility of the PCBs in capped areas (approximately 207 acres) is reduced because these PCBs are sequestered under the bentonite cap. However, capping does not satisfy the CERCLA statutory preference for treatment. In addition, there is no reduction in the toxicity or volume of the PCBs under the cap. Under this alternative, the mass of PCBs and the volume of contaminated sediments within the Upper Hudson River are permanently reduced because approximately 1.73 million cubic yards of sediment, containing an estimated 33,100 kg of PCBs, are removed from the ecosystem. Because the CAP-3/10/Select alternative also assumes the separate source control NTCRA in the vicinity of the GE Hudson Falls plant, the upstream Tri+ PCB load to the water column is expected to be reduced from 0.16 kg/day to 0.0256 kg/day by January 1, 2005. Additional reduction of the water column loads will result from sediment remediation. After construction of the alternative is completed, natural attenuation processes will provide further, but slower, reductions in the toxicity of PCBs in the remaining sediments and surface water.

For the REM-3/10/Select and REM-0/0/3 alternatives, the mass of PCBs and volume of contaminated sediments in the Upper Hudson River are permanently reduced because sediment volumes from 2.65 to 3.82 million cubic yards (REM-3/10/Select and REM-0/0/3, respectively) containing a mass of PCBs from 45,600 kg (REM-3/10/Select) to an estimated mass of greater than 63,500 kg (REM-0/0/3) are removed from the ecosystem (Appendix E). Because these removal alternatives also assume the separate source control NTCRA in the vicinity of the GE Hudson Falls plant, the upstream Tri + PCB load to the water column is expected to be reduced from 0.16 kg/day to 0.0256 kg/day by January 1, 2005. Additional reduction of the water column loads will result from sediment remediation. Also, as for the CAP-3/10/Select alternative, natural attenuation processes will provide further, but slower, reductions in the toxicity of PCBs in the remaining sediments and surface water after construction of the alternative is completed.

In all three active remediation alternatives, for the mechanical dredging option, the sediments that are removed undergo limited treatment (stabilization with Portland cement) prior to landfill disposal. For the hydraulic dredging option, the sediments that are removed are processed through hydrocyclones, coagulation, sedimentation, and belt filter presses to separate them from the water. However, these sediments do not undergo stabilization prior to landfill disposal. A different treatment process may be employed for the beneficial use option. However, due to the large volume of sediments that would be removed from the river under each of the active alternatives, none of the alternatives satisfies the statutory preference for treatment as a principal element of the remedy (CERCLA Section 121(b)).

9.5 Short-Term Effectiveness

The short-term effectiveness of each alternative is addressed through evaluation of the following criteria:

- Protection of the community during remedial actions;
- Protection of workers during remedial actions;
- Potential adverse environmental impacts during construction; and
- Time until remedial response objectives are achieved.

9.5.1 Protection of the Community During Remedial Actions

No construction activities are associated with the remediation of sediments for the No Action and MNA alternatives, so neither alternative increases the potential for direct contact with or ingestion and inhalation of PCBs from the surface water and sediments. The cancer risks and non-cancer health hazards to humans and the adverse effects to ecological receptors due to the PCB-contaminated sediments will persist throughout the short term. Due to the separate source control NTCRA in the vicinity of the GE Hudson Falls plant, the Tri+ PCB load to the water column is expected to be reduced from 0.16 kg/day to 0.0256 kg/day by January 1, 2005. As a result, cancer risks and non-cancer health hazards to humans and adverse effects to ecological receptors for the MNA alternative are slightly lower than those under the No Action alternative in the short term. For the MNA alternative, the fish consumption advisories will continue to be the only means for protecting human health. There are no such advisories in the No Action alternative.

Risks to ecological receptors and cancer risks and non-cancer health hazards to humans posed by consumption of PCB-contaminated fish will be reduced more rapidly under the active alternatives than under the No Action and MNA alternatives. The fish consumption advisories and restricted access to portions of the river undergoing remediation provides protection from risks to human health for the local community in the short term.

Transfer facilities and treatment areas present potential short-term risks to the community. Therefore, access to these areas will be restricted to authorized personnel. In addition, monitoring and engineering controls will be employed to minimize short-term effects due to material processing activities. Increased traffic will also present an incremental risk to the community. The potential for traffic accidents may increase marginally as additional vehicles are on the road. These effects are likely to be minimal because most transportation of sediments for disposal will be accomplished by rail. In addition to vehicular traffic, there will be increased river traffic. Work areas in the river will be isolated (access-restricted), with an adequate buffer zone so that pleasure craft and commercial shipping can safely avoid such areas. Finally, the increased in-river barge traffic will be monitored and controlled to minimize, to the extent possible, adverse effects on the commercial or recreational use of the Upper Hudson River.

9.5.2 Protection of Workers During Remedial Actions

For the No Action alternative, occupational risks to persons performing the sampling activities (for the five-year reviews) will be unchanged from current levels. A slight increase in occupational risk may be associated with the MNA alternative due to the greater degree of sampling involved in the river (and the separate source control NTCRA in the vicinity of the GE Hudson Falls plant). For the three active remediation alternatives (CAP-3/10/Select, REM-3/10/Select, and REM-0/0/3), potential occupational risks to site workers from direct contact, ingestion, and inhalation of PCBs from the surface water and sediments and routine physical hazards associated with construction work and working on water are significantly higher than for the No Action and MNA alternatives. For these alternatives, as well as the No Action and MNA alternatives, personnel will follow a site-specific health and safety plan and OSHA health and safety procedures, and will wear the necessary personal protective equipment.

9.5.3 Potential Adverse Environmental Impacts during Construction

No construction activities associated with the river sediments are conducted for the No Action and MNA alternatives. Neither continuation of the existing limited sampling activities for the No Action alternative nor the increased monitoring program for the MNA alternative is anticipated to have any adverse effect on the environment, beyond that already caused by the PCB contamination of the sediments in the Upper Hudson River.

For the three active remediation alternatives (CAP-3/10/Select, REM-3/10/Select, and REM-0/0/3), the release of PCBs from the contaminated sediments into the surface water during construction (dredging and cap placement), as well as the transport of PCBs over Federal Dam, will be controlled by operational practices (*e.g.*, control of sediment removal rates; use of enclosed dredge buckets; and use of sediment barriers). Although precautions to minimize resuspension will be taken, it is likely that there will be a temporary increase of suspended PCB concentrations, and possibly in fish PCB body burdens. Studies have shown that such effects are controllable, small, and transient, and that longer term improvement is seen (*e.g.*, WRI, 2000; MDEQ, 1999).

Remedial activities may also result in temporary impacts to aquatic and wildlife habitat of the Upper Hudson. Backfilling and habitat replacement measures will be implemented to mitigate these impacts. A monitoring program will be established to verify the attainment of the habitat replacement objectives. Although the degree of impact will be directly related to the area remediated and volume dredged, these differences among the alternatives are not considered to be substantial due to their transient nature and the mitigation measures that will be utilized.

As part of this evaluation, a semi-quantitative analysis of the possible increase in PCB loads and concentrations due to sediment resuspension was performed for the regions downstream and outside of the target areas. These areas in fact represent the largest portion of the Upper Hudson within the site boundaries. This calculation is intended to describe the mean increase in water column PCB concentration over each dredging season in these areas. The detailed description of the model and analysis to estimate resuspension losses is provided in Appendix E.6. The results of the analysis are summarized here.

Resuspension losses for the CAP-3/10/Select alternative apply only to the areas undergoing dredging. Areas undergoing capping only are assumed to yield minor additional resuspension. Since this alternative involves the least sediment removal of the three engineered alternatives, additional PCB loads are smallest. Only mechanical dredging, as represented by an enclosed bucket dredge, is considered for sediment removal under this alternative. For the REM-3/10/Select and REM-0/0/3 alternatives, the short-term impacts of a 12-inch cutterhead dredge and an enclosed bucket dredge are considered for sediment removal. For all comparisons between the two dredging methods, the production rate of dredge spoil material is the same for both methodologies. Specifically, the production rate of a 12-inch cutterhead dredge is comparable to that of three 4-cubic-yard enclosed bucket dredges, given productivity assumptions made for dredging concepts in this FS.

The resuspension rate calculated for the bucket dredge represents a relatively conservative estimate since the available data describe the impacts of a less sophisticated dredge than that selected for the engineering concepts for all active remedial alternatives. For this reason, although the results indicate somewhat greater PCB concentrations and loads due to mechanical dredges versus hydraulic equipment, resuspension will not be the major consideration in selecting one dredging concept over another. Rather, other engineering issues, such as sediment transfer, processing and handling, as well as operational logistics, will be more important.

The magnitude of the short-term impacts due to resuspension varies with the overall scope of the alternative, in terms of volume of material excavated. The table below shows a summary of the extensiveness of each alternative and the expected short-term impacts due to resuspension during dredging.

Summary of Sediment Resuspension Impacts

Metric	No Action	MNA	CAP-3/10/Select	REM-3/10/Select	REM-0/0/3
Implementation schedule	NA	NA	2004-2008 5 years	2004-2008 5 years	2004-2010 7 years
Sediment volume removed (10^6 cy)	NA	NA	1.7	2.7	3.8
Increase in average Tri+ PCB concentration (ng/L)	NA	NA	5 (mechanical)	4 (hydraulic) 7 (mechanical)	3 (hydraulic) 5 (mechanical)
Baseline Tri+ PCB load (kg) over FD: ●2004-2008 ●2004-2010	461 (92 ann.) 637 (91 ann.)	295 (59 ann.) 383 (55 ann.)			
Add'l. PCB load (kg) from resuspension	NA	NA	32 (6 ann.) (2004-2008)	28 (6 ann., hyd.) 47 (9 ann., mch.) (2004-2008)	29 (4 ann., hyd.) 48 (7 ann., mch.) (2004-2010)

It is important to place these estimated increases in the Tri+ PCB load in perspective. In particular, current concentrations of Tri+ PCBs in the water column at the TI Dam are in the range of 14.4 to 532 (mean of 66 ng/L) in May through November 1999, the period of the year corresponding to the proposed remedial operations. At the expected time of implementation, the mean concentration at the TI Dam during this period is expected to be 29 ng/L based on the HUDTOX forecast. Concentrations in River Section 2 are generally similar to those in River Section 1 while those in River Section 3 are reduced by about 25 to 50 percent, depending on distance downstream due to dilution from tributary flow. Thus, in all river sections, these expected increases represent relatively minor changes as compared to current or projected water column concentrations. Indeed, these additions are within the year-to-year and season-to-season variations regularly observed in the Upper Hudson. They are also well below the order-of-magnitude increase in mean water column concentrations seen in the early 1990s. The water column PCB concentration increases observed in the early 1990s resulted in an approximate doubling of some fish levels. Thus, by analogy, the PCB releases associated with dredging for any of the three active alternatives should have only a minor impact on fish body burdens in the Upper Hudson. It should be noted that total PCB concentration increases may be greater, perhaps two to three times higher than those for Tri+ PCBs. However, current and projected water column total PCB concentrations at the TI Dam are also two to three times higher than those for Tri+ PCBs. Thus the expected increase in total PCB represents the same percentage increase relative to projected conditions as anticipated for the Tri+ increase.

In addition to the examination of the increase in PCB concentration, the analysis also included an estimate of the Tri+ PCB mass released by dredging operations. Overall, depending on the alternative, the remediation would generate an additional 4 to 9 kg per year of Tri+ PCBs over the five- or seven year operation. This value should be compared to the estimated release of Tri+ PCBs during the remediation period in the absence of remediation (about 91 to 92 kg/yr for No Action and 55 to 59 kg/yr for MNA). The increase is only about 10 to 16 percent of the expected annual release under MNA and even less under No Action. In fact, the modeled PCB load increase is well within the range of year-to-year variability. The current annual release of Tri+ PCBs is 109 kg/year. This rate of release, which is largely unchanged over the last 10 years, would generate a load of 545 kg over a period equivalent to the remedial operations for the CAP-3/10/Select or REM-3/10/Select alternatives, and 763 kg over a period equivalent to construction for the REM-0/0/3 alternative.

The additional release from any of the three active alternatives is less than the PCB release estimated from a single 100-year flood event (*i.e.,* about 60 kg), as noted in the RBMR (USEPA, 2000a). As discussed in the RBMR, the 100-year flood was not expected to have a major impact on fish or river PCB levels, with associated increases not lasting more than one to two years. With the remedial releases spread out over five or seven years, the impact should be much smaller with a residual impact (after completion of construction) of even shorter duration than the 100-year flood.

Based on these analyses, it appears unlikely that the removal of sediments associated with any of the three alternatives will yield substantially higher levels of PCB in the water or fish of the Upper Hudson during dredging. For the REM-3/10/Select and REM-0/0/3 alternatives, water column concentrations may reach from 25 to 60 percent over those forecast using HUDTOX in River Sections 2 and 3 but the higher levels are short-lived. Based on the similarity to the release associated with the 100-year flood event, it is unlikely that the residual effects will last more than a few years after the construction is completed.

For the CAP-3/10/Select alternative there is a potential transient impact from the temporary exposure of deeper, contaminated sediments during the time interval between excavation and cap placement. It may be possible to reduce impacts associated with exposure of deeper sediments by detailed planning of all phases of the dredging and capping operations. However, the level of coordination between the different elements of this alternative will render the overall remedial program under CAP-3/10/Select particularly complex. In addition, it will not be possible to fully avoid water quality and related ecological impacts resulting from the temporary exposure of contaminated sediments that are targeted for capping. Due to the transient and variable nature of this exposure, the impact cannot be quantified. Nonetheless, barring a major flood event, it is unlikely to be greater than that originating from sediment resuspension.

9.5.4 Time until Remedial Response Objectives Are Achieved

For all five alternatives, the risk-based PRG for protection of human health of 0.05 ppm PCBs (wet weight) in fish fillets is not met in any of the river sections in the short term. The target concentration of 0.2 ppm PCBs (one meal per month) in fish fillets is also not met in any river section in the short term for all five alternatives. The alternate target concentration of 0.4 ppm PCBs (one meal every two months) in fish fillets is not met in River Sections 1 and 2 in the short term by any of the five alternatives, but is met in River Section 3 in the year 2010 for the three active remediation alternatives and in the year 2011 for the MNA alternative. The 0.4 ppm PCBs target fish concentration is not met in the short term in River Section 3 by the No Action alternative.

The risk-based PRG for protection of the environment is a range from 0.3 to 0.03 mg/kg in whole fish (this corresponds to a range from 0.13 to 0.013 mg/kg total PCBs in fish fillets), based on the LOAEL and NOAEL fish concentrations consumed by the river otter. The corresponding LOAEL and NOAEL whole fish target concentrations for the mink are 0.7 and 0.07 mg/kg PCBs. For the river otter, the PRGs are not met in River Sections 1, 2, and 3 in the short term for all five remedial alternatives.

For the mink, the LOAEL target concentration is not met in River Section 1 in the short term, but is met in River Sections 2 and 3 prior to 2010 for the three active remediation alternatives. For the mink, under the MNA alternative, the LOAEL target concentration is not met in River Sections 1 and 2 in the short term, but is met in River Section 3 prior to 2010. For the mink, the NOAEL target concentration is not met in River Sections 1, 2, and 3 in the short term for any of the five remedial alternatives.

9.6 Implementability

The implementability of the alternatives are compared through evaluation of the following criteria:

- Technical feasibility;
- Administrative feasibility; and
- Availability of services.

9.6.1 Technical Feasibility

Both the No Action and MNA alternatives are technically feasible.

Technical feasibility for the active remediation alternatives is discussed below in terms of the main components of the alternatives:

- Dredging (mechanical and hydraulic);
- Capping;
- Transfer facilities; and
- Rail transport and disposal.

9.6.1.1 Dredging Feasibility

Mechanical Dredging

Removal of targeted sediments solely by mechanical means has been evaluated for the CAP-3/10/Select, REM-3/10/Select, and REM-0/0/3 alternatives. Removal of targeted sediments by hydraulic dredging has also been evaluated for the REM-3/10/Select and REM-0/0/3 alternatives. With regard to mechanical dredging, the following are the principal distinctions between the capping and removal alternatives:

- Capping requires the least total dredging (about 35 percent less than REM-3/10/Select) and least annual output (about 35 percent less than REM-3/10/Select);
- REM-0/0/3 requires the most removal work (about 43 percent more than REM-3/10/Select);
- Annual removal rates for REM-3/10/Select and REM-0/0/3 are approximately equal; and
- REM-0/0/3 entails significantly more removal of sediments in shallow cuts (less than 2.0 feet) than does REM-3/10/Select.

Technical feasibility was discussed in Chapter 8 in terms of the capability of mechanical equipment to productively remove as little as one or two feet of sediment. As a result of recent advances in mechanical systems, buckets are now available that can efficiently remove sediments in wide, shallow cuts. Therefore, it has been concluded that efficient removal of sediments, as proposed under each of the three active alternatives, is technically feasible.

Feasibility was also evaluated in terms of the ability of mechanical dredging systems to maintain acceptably low rates of sediment resuspension. An analysis of sediment resuspension during dredging operations is presented in Appendix E, and (conservative) estimates of both total and annual increased Tri+ PCB loads to the water column is presented in Chapter 8. It is concluded there that substantial water quality impacts are not expected to occur as a result of mechanical dredging operations. Thus, from the perspective of sediment resuspension, each alternative that involves mechanical dredging is considered feasible.

Hydraulic Dredging

Hydraulic dredging has been evaluated for the REM-3/10/Select and REM-0/0/3 alternatives. Under these alternatives, most removal will be accomplished with a suction cutterhead dredge; dredging in River Section 3 will be accomplished by means of mechanical equipment. The principal differences between the use of hydraulic and mechanical systems, insofar as those systems have been evaluated in this FS, are as follows:

- Only one hydraulic dredge is needed to remove targeted sediments in River Sections 1 and 2, as opposed to several mechanical dredges;
- Hydraulically dredged sediments are conveyed to the transfer facility by means of a slurry pipeline and not in barges;
- Hydraulically dredged sediments are dewatered and not stabilized; and
- Hydraulic dredging entails operation of a substantial water treatment facility.

As was discussed in Chapter 8, hydraulic dredging is considered technically feasible for either active alternative to which it is being applied. One distinction between REM-0/0/3 and REM-3/10/Select is that REM-0/0/3 entails substantially more removal of sediments where contamination is limited to the upper 1.0 or 1.5 feet. Since it is not considered practical to dredge less than two feet of sediment with the selected hydraulic technology, it will be necessary to dredge 90,000 cubic yards of non-targeted sediments should hydraulic dredging be selected under the REM-0/0/3 alternative.

As for the mechanical equipment discussed above, sediment resuspension rates and water quality impacts have also been estimated for hydraulic dredging. Based on available data, it has been calculated that hydraulic dredging operations will resuspend 40 percent less sediment than will mechanical removal operations for the same production rate. This analysis, however, does not reflect a number of recent improvements made to mechanical systems which were specifically formulated to reduce resuspension and for which published data is not yet available. Therefore, the difference in performance between the two technologies (mechanical and hydraulic dredging), as estimated in Appendix E, is not expected to be a determining factor in equipment selection and the two technologies are considered equally feasible from the perspective of sediment resuspension.

9.6.1.2 Capping Feasibility

Capping involves considerably less dredging than does the corresponding removal alternative since principal reliance is being placed on an impervious cap to effectuate the remediation. As mentioned in Chapter 8, evaluation of the AquaBlok™ system is currently in progress at several sites and final feasibility of this technology must await results of those studies. However, the materials of which AquaBlok™ is composed have served reliably in other, similar applications, and, therefore, there is reasonable expectation that AquaBlok™ will ultimately prove to be technically feasible. The scheduling of in-river work (dredging and capping) and overall program logistics will be somewhat more complex under the CAP-3/10/Select alternative than under REM-3/10/Select or REM-0/0/3.

9.6.1.3 Transfer Facilities Feasibility

Each active alternative, as evaluated in this FS, requires that transfer facilities be established at two locations: one facility would be adjacent to River Section 1, and another would be in the Port of Albany area. Utilization of these sites is somewhat different under the capping and mechanical dredging alternatives. About 35 percent less dredged material would be processed annually at the transfer facilities if the capping alternative were selected. This suggests a substantially lower level of activity at the transfer facilities (and potentially smaller sites). However, capping also requires that large quantities of AquaBlok™ be manufactured and distributed throughout the river. Doing so may substantially increase the use of the transfer facility sites (or result in separate sites being set up for distribution of AquaBlok™). Consequently, establishing transfer facilities at two locations for either the capping or mechanical removal remedies is considered equally feasible.

Should hydraulic dredging be selected as the removal technology, establishing a transfer facility adjacent to River Section 1 will be somewhat complicated by the need to operate relatively large slurry processing and water treatment systems. Several acres may be needed to house these systems and any associated equipment. Nonetheless, as concluded in Chapter 8, it is expected that a transfer/processing site can be assembled should hydraulic dredging be the selected dredging technology.

9.6.1.4 Rail Transport and Disposal Feasibility

The capping alternative would result in least stabilized dredged material being shipped to off-site disposal facilities. The two removal alternatives generate approximately the same quantity of stabilized dredged material on an annual basis. Thus, the scale of rail operations for the REM-3/10/Select and REM-0/0/3 is approximately the same. However, REM-0/0/3 has a duration of seven years and REM-3/10/Select has a duration of five years. It is expected that railroads that serve the Upper Hudson area can handle the additional traffic that would be generated by any of the alternatives.

9.6.2 Administrative Feasibility

In general, the principal administrative task under the MNA alternative is the institutional controls, such as the fish consumption advisories. Fish consumption advisories and a "catch and release only" fishing restriction are currently in place, so institutional controls are considered administratively feasible.

For the active remediation alternatives (CAP-3/10/Select, REM-3/10/Select, and REM-0/0/3), it is expected that the two transfer facilities, constructed on land adjacent to the Upper Hudson River, will be considered "on-site" for the purposes of the permit exemption under CERCLA Section 121(e), although any such facilities will comply with the substantive requirements of any otherwise necessary permits. Since the requirements for these facilities are equivalent for all three alternatives, assuming mechanical dredging, there is little difference in the administrative feasibility among the three. The hydraulic dredging option for the REM-3/10/Select and REM-0/0/3 alternatives will require somewhat greater land area, but properties meeting the requirements appear to exist. Although procurement of appropriate properties with reasonably close rail access presents certain marketplace and administrative challenges, research conducted for this FS suggests that sufficient options exist to provide workable solutions under a variety of possible scenarios.

It is assumed that review and concurrence on siting and design of these facilities by the State of New York will be obtained in a reasonably expeditious manner. While it is possible that local opposition to permanent dredged sediment disposal in the vicinity of the Upper Hudson River may translate to concerns regarding (and possible local administrative opposition to) a temporary northern transfer facility, it is likely that the tangible concerns can be addressed by proper design and engineering controls. It is also expected that, for any of the active remedial alternatives, there will be substantial restrictions on construction activity, including controls on the types of dredging and capping equipment to be used, restrictions on the speed of operations, constraints on barge filling practices, and controls on temporary storage of contaminated dredge spoils. Construction activities will also have to be coordinated with the Canal Corporation, which operates the Locks on the Upper Hudson River from May through November.

The major difference among the three alternatives in regard to local administrative feasibility relates to the lengths of the respective construction programs. The CAP-3/10/Select and REM-3/10/Select alternatives are projected to require five years of construction each, while the REM-0/0/3 alternative is estimated at seven years. Compensating economic benefits (expected to be roughly proportionate to the overall cost of each alternative) to the labor force for both skilled and unskilled workers, as well as local businesses such as lodging and food services and equipment and raw materials suppliers, may mitigate potential local administrative opposition.

Since the concepts for these alternatives call for shipment of sediments to disposal by rail, local highways will not be required to carry substantially increased heavy truck traffic, although some increase will be experienced during mobilization activities and possibly for delivery of certain materials and commodities. If beneficial use of dredged sediments proves a reality during design and implementation, some options may entail additional truck traffic, but the possibility exists for moving the material to the southern transfer facility by barge for loading onto trucks so as to minimize impacts on the secondary, local highway systems.

9.6.3 Availability of Services

For the No Action and MNA alternatives, the necessary services are available. For the active remedies, the services and materials listed below appear to present the principal limitations.

Barges and Towboats

Since most commercial activity on the Upper Hudson has ceased, it is not likely that a sufficient number of barges and tow boats suitable for river work can be readily found in the project vicinity. Obtaining barges and towboats will necessitate early planning for procurement and may require that some equipment be fabricated for this program. The number of barges and towboats required for mechanical dredging related to the REM-3/10/Select and REM-0/0/3 alternatives is approximately the same since the volume of material being removed on an annual basis is approximately the same. With regard to the CAP-3/10/Select alternative, the quantity of material being removed is approximately 35 percent less than that under the REM-3/10/Select alternative. Even though the capping operation will also require barges and towboats, the amount of work required for capping and backfill under CAP-

3/10/Select is about the same as the amount of work required for backfill alone under REM-3/10/Select. Consequently, the difference in the number of barges and towboats required is not strictly proportional to the difference in dredging volume between the two alternatives. It is estimated that the number of barges and towboats will be about 20 to 25 percent less for CAP-3/10/Select.

Hydraulic dredging utilizes only three to four larger-capacity hopper barges (loaded to 1000 tons) to transport dewatered sediments from the northern to the southern transfer facility, while mechanical dredging utilizes about four hopper barges and seven or eight lower-capacity deck barges (loaded to 200 tons) for transport of sediments directly to the northern and southern transfer facilities. Since some of the deck barges can make more than one trip per day to the northern transfer facility for the REM-3/10/Select alternative, the number of barges required is somewhat lower than the daily barge loads shown on Table 8-10a. Because hydraulic dredging will require fewer barges and towboats than a comparable mechanical dredging program, there will be a substantially reduced requirement for procurement or fabrication of barges associated with hydraulic dredging.

Rail Cars

Availability of rail cars fluctuates with economic conditions. The number of cars required to support operations for any active alternative is directly proportional to the volume of material processed on an annual basis. Therefore, on an annual basis, CAP-3/10/Select will require approximately one-third fewer cars than either of the removal alternatives. Since the active remedial alternatives are relatively long-term projects, and will require considerable pre-planning, it is expected that the needed rolling stock can be obtained for any of the active alternatives.

Cement

The amount of Portland cement required varies with the volume of sediment processed for an alternative. Specifically, hydraulic dredging for either of the removal alternatives is projected to require no stabilizing agent due to the use of mechanical dewatering. The CAP-3/10/Select alternative requires about one-third less stabilizing agent than either REM-3/10/Select or REM-0/0/3 on an annual basis. Availability of this commodity also fluctuates with economic conditions. However, since there are several potential, less costly substitutes for Portland cement, it is not likely that adverse conditions in the Portland cement market would make project implementation infeasible, although, depending on the amount required, use of substitutes could conceivably be more costly due to the potentially higher volume to be disposed.

9.7 Cost

The present worth for all five alternatives has been calculated for the year 2000 using a 7 percent discount rate. The net present worth for all five alternatives, including the beneficial use option, is presented in Table 9-1.

9.7.1 Net Present Worth

The net present worth of the remedial alternatives ranges from $140,000 for No Action to $570 million for the REM-0/0/3 alternative. The net present worth of the REM-3/10/Select alternative is $460 million, which is $110 million less than the cost for the REM-0/0/3 alternative. For the active remedial alternatives (CAP-3/10/Select, REM-3/10/Select, and REM-0/0/3), these costs are estimated for the use of mechanical dredging techniques to remove PCB-contaminated sediments from the Upper Hudson River, and assume the disposal of the dredged materials at existing permitted TSCA and non-TSCA landfills, as appropriate.

For the beneficial use option for non-TSCA material, the net present worth of the active remedial alternatives ranges from $338 million for the CAP-3/10/Select alternative to $496 million for the REM-0/0/3 alternative. These beneficial use option costs are also based on the use of mechanical dredging techniques.

For the hydraulic dredging removal option and the dredged materials are disposed at TSCA and non-TSCA landfills, the net present worth costs are $448 million for the REM-3/10/Select alternative and $550 million for the REM-0/0/3 alternative.

9.7.2 Capital Costs

The No Action alternative has no capital cost. The MNA alternative has a present worth capital cost of $417,000 for further refining and recalibration of the mathematical model for the Upper Hudson River. The present worth of the capital costs for the active remedial alternatives ranges from $344 million for the CAP-3/10/Select alternative to $556 million for the REM-0/0/3 alternative. The net present worth of the capital costs for the REM-3/10/Select alternative is $448 million, approximately $108 million less than the net present worth of the capital costs for the REM-0/0/3 alternative. For these active remediation alternatives, the present worth of the capital costs includes the disposal of the stabilized dredged materials at TSCA and non-TSCA landfills, and assumes the use of mechanical dredging techniques to remove PCB-contaminated sediments from the Upper Hudson River.

For the option where the non-TSCA material is utilized for beneficial uses, the present worth of the capital costs for the active remedial alternatives ranges from $314 million for the CAP-3/10/Select alternative to $483 million for the REM-0/0/3 alternative. The net present worth of the capital costs of the REM-3/10/Select alternative under the beneficial use option is $399 million. These beneficial use option costs are also based on the use of mechanical dredging techniques.

For the option where hydraulic dredging techniques are utilized to remove PCB-contaminated sediments and the dredged materials are disposed at TSCA and non-TSCA landfills, the net present worth of the capital costs is $434 million for the REM-3/10/Select alternative and $536 million for the REM-0/0/3 alternative.

9.7.3 O & M Costs

Due to the varying frequency of different elements of the monitoring program, and the five-year period for NCP reviews, O&M costs will vary on an annual basis. The present worth of the O&M costs for the remedial alternatives ranges from $140,000 for the No Action alternative to $38 million for the MNA alternative. The net present worth of the O&M costs for the CAP-3/10/Select alternative is $24 million, for the REM-3/10/Select alternative is $13 million, and for the REM-0/0/3 alternative is $12 million. For the active remediation alternatives, this present worth of the O&M costs assumes the use of mechanical dredging techniques to remove PCB-contaminated sediments from the Upper Hudson River, and disposal of the stabilized dredged materials at TSCA and non-TSCA landfills.

For the option where the non-TSCA material is utilized for beneficial uses, the present worth of the O&M costs for the active remedial alternatives ranges from $12 million for the REM-0/0/3 alternative to $24 million for the CAP-3/10/Select alternative. These beneficial use costs are also based on the use of mechanical dredging techniques.

For the option where hydraulic dredging techniques are utilized to remove PCB-contaminated sediments and the dredged materials are disposed at TSCA and non-TSCA landfills, the net present worth of the O&M costs is $14 million for the REM-3/10/Select alternative and $13 million for the REM-0/0/3 alternative.

9.8 Cost Sensitivity Analyses

Sensitivity analyses have been performed to assess the significance that changing principal features of the CAP and REM alternatives will have on overall project costs. Based on results of the base case analysis, the parameters that influence the quantity of sediments needing to be stabilized, shipped, and disposed have the greatest impact on costs. In addition, disposal costs for sediments classified as TSCA-regulated materials are significantly greater than for those considered to be non-TSCA materials. A comparison of the costs for the base case alternatives (mechanical dredging and landfill disposal), beneficial use option (mechanical dredging and beneficial use), and the hydraulic dredging option (hydraulic dredging and landfill disposal) are presented in Table 9-1. Thus, the sensitivity analysis presented below addresses changes in several parameters that influence either the volume of sediment removed and the fraction of removed sediments considered to be TSCA-regulated.

The sensitivity of the cost estimates for the three active remediation alternatives to the assumed non-TSCA threshold PCB concentration is provided in subsection 9.8.1. Subsection 9.8.2 presents the sensitivity of the cost estimates for these three active remediation alternatives to an adjustment of the remediation boundary (*i.e.*, the areas targeted for remediation). Further, for the capping with select removal alternative, the sensitivity of the cost estimate to a reduction in the cap thickness was examined; the results of this evaluation are shown in subsection 9.8.3. Also, the sensitivity of the cost estimates for the two removal alternatives to the depth of sediments targeted for removal is presented in subsection 9.8.4. An analysis of the impact of the disposal site location (*i.e.*, distance from the Upper Hudson River is provided in subsection 9.8.5. A summary of these cost sensitivity analyses is included in subsection 9.8.6.

9.8.1 Cost Sensitivity to an Increase in the Assumed Non-TSCA PCB Threshold Concentration

As described in subsection 5.2.5.2, dredged sediments with PCB concentrations greater than 33 mg/kg will be managed by disposal in a TSCA landfill. The sediments with less than 33 mg/kg PCBs will be sent for disposal to a non-TSCA landfill. The 33 mg/kg threshold PCB concentration was used in this FS to provide a safety margin so that the non-TSCA landfill always receives sediments with PCB concentrations less than 50 mg/kg. A sensitivity analysis was performed to determine the change in the cost estimates of changing the threshold PCB concentration from 33 mg/kg to 50 mg/kg; *i.e.*, eliminating the safety margin. A summary of the quantity changes for each of the three active remediation alternatives as a result of making this change in the threshold PCB concentration is presented in Table 9-2. A summary of the corresponding present worth costs for the CAP-3/10/Select, REM-3/10/Select, and REM-0/0/3 alternatives are outlined in Tables 9-3a, 9-3b, and 9-3c, respectively.

The tabulation below shows the mass of TSCA material that will be targeted under the REM-3/10/Select alternative for the two assumed values for the non-TSCA threshold PCB concentration.

REM-3/10/Select Cost Sensitivity to Assumed Non-TSCA Threshold PCB Concentration		
Assumed Threshold Concentration	**TSCA Sediments Targeted (10^6 tons)**	**Present Worth Costs ($million)**
PCBs > 33 mg/kg	1.68	$460 million
PCBs > 50 mg/kg	1.39	$449 million

As shown, the present worth costs do decrease when the assumed non-TSCA threshold PCB concentration is increased from 33 mg/kg to 50 mg/kg. However, since less than 294,000 tons of sediments are excluded from being handled as a TSCA-regulated material (and need to be handled as non-TSCA material), the reduction in costs is only about 2 percent. A maximum cost reduction of $14 million occurs under the REM-0/0/3 alternative, and a minimum reduction of $9 million under the CAP-3/10/Select alternative, when the assumed non-TSCA threshold PCB concentration is increased to 50 mg/kg. For the CAP-3/10/Select alternative, a net present worth cost reduction of about 2 percent is obtained by increasing the assumed non-TSCA threshold PCB concentration.

9.8.2 Cost Sensitivity to Remediation Target Area Boundary Adjustment

The remediation target areas were defined for this FS using the criteria of Full-Section remediation (*i.e.*, in which the MPA targets are 0 g/m^2 or greater), Expanded Hot Spot remediation (*i.e.*, in which the nominal MPA targets are 3 g/m^2 PCBs or greater), Hot Spot remediation (*i.e.*, in which the nominal MPA targets are 10 g/m^2 or greater), and Select remediation (*i.e.*, in which the targets are roughly based on nominal MPA of 10 g/m^2 or greater, modified by potential for scour). Areas involving Full-Section remediation were not varied for this analysis because Full-Section remediation involves the entire river cross-section. The remediation target area boundaries for Select remediation, Hot Spot remediation and Expanded Hot Spot remediation were varied by plus or minus 50 feet. If the remediation target area is adjusted by plus 50 feet, additional sediment will have to be removed, transported, stabilized, and disposed of off-site. Additional backfill will also be required during site mitigation. The reverse is true for the minus 50 feet adjustment in the remediation target area.

A summary of the quantity changes for each of the three active remediation alternatives as a result of making this adjustment is shown on Table 9-4. The corresponding present worth costs for the CAP-3/10/Select alternative are outlined in Tables 9-5a (target area plus 50 feet) and 9-5b (target area minus 50 feet), respectively. The corresponding present worth costs for the REM-3/10/Select alternative are outlined in Tables 9-5c (target area plus 50 feet) and 9-5d (target area minus 50 feet), respectively. Similarly, the corresponding present worth costs for the REM-0/0/3 alternative are outlined in Tables 9-5e (target area plus 50 feet) and 9-5f (target area minus 50 feet), respectively.

The following table illustrates results of the analysis for the REM-3/10/Select alternative.

REM-3/10/Select Cost Sensitivity to Modified Target Area Boundaries		
Remediation Target Area	**Volume Targeted (10^6 cy)**	**Present Worth Costs ($million)**
Base Case	2.65	$460 million
Base Case + 50 feet	2.95	$503 million
Base Case - 50 feet	2.08	$378 million

As shown, a change in target area boundary of 50 feet has a significantly lower impact on overall project costs than does a one-foot change in dredging depth (applicable to REM alternatives only; see subsection 9.8.4, below). The impact on costs in this case results from the same factors that influence costs when dredge depth is modified, *i.e.*, a change in target area changes target volumes which, in turn, impacts dredging, transportation, and disposal costs.

Table 9-5b shows that for the CAP-3/10/Select alternative, reducing target area boundary by 50 feet reduces the net present worth costs by about $87 million (approximately 24 percent). Similarly, Table 9-5a shows that for the CAP-3/10/Select alternative, increasing the target area boundary by 50 feet increases the net present worth costs by $35 million (approximately 9 percent).

For the two removal alternatives, reducing the target area boundary by 50 feet reduces the net present worth costs by approximately 5 percent (for the REM-0/0/3 alternative) and 18 percent (for the REM-3/10/Select alternative). Similarly, for these two removal alternatives, increasing the target area boundary by 50 feet increases the net present worth costs by approximately 1 percent (for the REM-0/0/3 alternative) and 9 percent (for REM-3/10/Select alternative). The maximum change in costs occurs under the REM-3/10/Select alternative; costs increase by $43 million when the target area boundary is increased (plus 50 feet) and decrease by about $82 million when the boundary is reduced (minus 50 feet).

9.8.3 Cost Sensitivity to Reduction in Cap Thickness for Capping with Select Removal Alternative

As described in subsection 5.2.4.1, a one-foot-thick cap consisting of AquaBlok™ was used for the CAP-3/10/Select alternative. For the sensitivity analysis, a six-inch cap thickness was used instead. A summary of the quantity changes as a consequence of such a reduction in the cap thickness is shown on Table 9-6. A summary of the corresponding present worth costs is outlined in Table 9-7.

The outcome for the CAP-3/10/Select alternative is provided in the following table.

CAP-3/10/Select Cost Sensitivity to Modified Cap Thickness		
Cap Thickness	**Volume Removed (10^6 cy)**	**Present Worth Costs ($million)**
12" base case	1.73	$370
6" alternative	1.63	$342

The two factors which have the greatest affect on overall project costs when cap thickness is changed are the mass of river sediments being removed, and the volume of AquaBlok™ needed to complete the cap. For the CAP-3/10/Select alternative, it has been assumed that dredging of river sediments will be necessary to maintain pre- and post-remediation bathymetry approximately constant wherever water depths are less than six feet. Thus, a reduction in cap thickness translates into reduced removal of river sediments and, consequently, reduced transportation and disposal costs for those sediments. Also, a reduction in cap thickness results in lower costs for both capping material and cap installation work. Based on the sensitivity analysis conducted for this FS, it has been determined that the two factors (reduced removal costs and reduced capping costs) impact the present worth costs approximately equally.

Table 9-7 shows that for the CAP-3/10/Select alternative, reducing the cap thickness by six inches reduces the net present worth costs by $28 million (approximately eight percent).

9.8.4 Cost Sensitivity to Depth of Removal Adjustment for the Removal Alternatives

For the two removal alternatives, a sensitivity analysis was performed by varying the depth of sediment removed. The removal depth was varied by plus or minus one foot. The additional volume, referred to as the volume variance, was calculated by multiplying this area by one foot. This volume variance was added to the volume that was calculated previously to give the upper bound volume. Similarly, the lower bound volume was calculated by subtracting the volume variance from the original volume. A summary of the quantity changes for the two REM alternatives as a consequence of such a depth of removal adjustment by one foot is shown on Table 9-8. The corresponding present worth costs for the REM-3/10/Select alternative are outlined in Tables 9-9a (depth of removal plus one foot) and 9-9b (depth of removal minus one foot), respectively. Similarly, the corresponding present worth costs for the REM-0/0/3 alternative are outlined in Tables 9-9c (depth of removal plus one foot) and 9-9d (depth of removal minus one foot), respectively.

This analysis is applicable to only the removal alternatives, and results are illustrated in the following table for the REM-310/Select alternative.

REM-3/10/Select Cost Sensitivity to Modified Removal Depth		
Removal Depth	**Volume Targeted (10^6 cy)**	**Present Worth Costs (in millions)**
Base Case	2.65	$460
Base Case +1 foot	3.35	$552
Base Case -1 foot	1.96	$369

As can be seen in the example above, a substantial change in target sediment volume occurs when the depth of removal is increased or reduced by one foot. The increase and decrease in volume translates into increased and decreased costs for dredging, in-river transportation, quantity of sediment to be stabilized, transportation by rail, and off-site disposal. Costs increase by about 20 percent when removal depths are increased one foot and decrease by about 20 percent when removal depths are reduced by one foot for the REM-3/10/Select alternative. For other removal alternatives, Tables 9-9a and 9-9c show that increasing the depth of removal by one foot raises the net present worth costs by 20 percent (for the REM-3/10/Select alternative) to 30 percent (for the REM-0/0/3 alternative). Similarly, Tables 9-9b and 9-9d show that decreasing the depth of removal by one foot reduces the net present worth costs by 20 percent (for the REM-3/10/Select alternative) to 30 percent (for the REM-0/0/3 alternative). It is expected that the design phase sampling program described in subsection 5.2.7.2 will improve estimates of dredging depths. Thus, some change in removal cost estimates may occur upon completion of the design phase effort.

9.8.5 Cost Sensitivity to Disposal Site Location

Since transportation costs and tipping fees are such a large fraction of overall remedial costs (approximately 50 percent of the capital cost for the REM-3/10/Select alternative is related to transportation and disposal, exclusive of sediment stabilization), it is useful to provide context for these costs by considering alternate approaches. One possibility would be to reduce the distance that stabilized sediments must be hauled. In order to assess the cost implications of the landfill being closer to the Upper Hudson, rough cost estimates were generated for options not considered in development of alternatives in Chapter 6 (since they were screened out in Chapter 4 based on administrative infeasibility).

In one case it was assumed, for purposes of this analysis, that a lined landfill, dedicated to handling dredged material, could be constructed within a one-day round-trip (by truck) of one of the transfer facilities. A second option was also evaluated assuming that the distance to the landfill would allow a truck to make two round trips each day. An additional disposal option considered was the use of a Confined Disposal Facility (CDF) constructed adjacent to River Section 1. This concept would consist of a naturally lined landfill that would receive hydraulically dredged sediments from River Sections 1 and 2 and mechanically dredged sediments from River Section 3. In this case, essentially all off-site transportation costs would be eliminated as would the need for northern and southern transfer facilities (although a transfer operation would be needed immediately adjacent to the CDF).

Transportation (trucking) and landfill construction and operating costs were estimated from information in technical publications, cost estimating manuals, and personal communications. CDF costs were estimated based on the hydraulic dredging concept presented in Chapter 5 and Appendix H. The following tabulation presents a comparison of costs for the REM-3/10/Select alternative considering the various transportation and disposal options evaluated:

Option	Distance to Disposal Site (miles)	Estimated Capital Costs ($million)
Existing Permitted Landfills	250 to >1000	$660
New Landfill-one RT/day	< 200	$520
New Landfill-two RT/day	< 100	$460
Confined Disposal Facility	Near-River	$200 to $250

As can be seen from the table, capital costs associated with a CDF are lowest (by over $400 million) because all off-site transportation is eliminated and because neither the northern nor southern transfer facilities is necessary. Disposal in a new dedicated landfill would reduce project cost by about $130 million if the landfill were within 200 miles of the transfer facilities. If the landfill were situated within 100 miles of the Upper Hudson, capital costs for the REM-3/10/Select alternative could be reduced by about $200 million or approximately 30 percent. For disposal in a new dedicated landfill, much of the difference in the costs compared to more remote disposal is related to the TSCA-regulated material. Estimated costs for disposal of the non-TSCA material at a new landfill, including transportation, are only about 25 percent less than those for remote disposal, while costs for disposal of TSCA-regulated material are less than half (*i.e.*, about 60 percent less).

9.8.6 Summary of Cost Sensitivity Analyses

Of the several parameters that have been evaluated here, except for the landfill location analysis presented in subsection 9.8.5, changing dredging depth has the greatest cost significance. A change of one foot in targeted removal areas impacts the total present value of removal alternatives by up to 30 percent. One conclusion that can be drawn from this is that when additional data related to the vertical distribution of sediment contamination becomes available, project costs may be substantially altered. Varying other parameters, such as the assumed non-TSCA threshold PCB concentration and the targeted removal areas, results in considerably lower cost impacts. Table 9-10 presents a summary of the cost sensitivity analyses discussed.

It should be noted, however, that beneficial use of the sediments may markedly alter the outcome of the sensitivity analysis. Remedial costs, in the base case, are heavily influenced by the stabilization, shipping, and disposal of the PCB-contaminated sediments. As the shipping of sediments to TSCA and non-TSCA landfills is reduced, project costs will become more sensitive to factors such as the assumed TSCA PCB concentration threshold and potentially less sensitive to dredging depth. The full import of beneficial use cannot be assessed until a detailed strategy for its implementation is developed.

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400832

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400833

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