Appendix B

Sediment Technologies Memorandum

Sediment Technologies Memorandum for the Lower Fox River and Green Bay, Wisconsin

Prepared for:

Wisconsin Dept. of Natural Resources

♦ **The RETEC Group, Inc.**

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Executive Summary

Dredging of PCB-impacted sediment has received national and regional attention regarding its viability as an effective remedial alternative. To address these concerns and evaluate dredging as a potential remedial alternative for the Lower Fox River and Green Bay project, an independent review of 20 environmental dredging case studies was conducted. The objective of this review was to relate the effectiveness of dredging with achievement of short-term target goals (immediately after dredging) and long-term remedial objectives (e.g., reduced fish tissue concentrations) for each project.

Projects selected for detailed review were retained from a screening process involving an initial list of over 60 sediment remediation projects. The screening process included several requirements necessary for selection: the remedy is complete, and post-verification samples were collected; the chemicals of concern in site sediments were above protection levels to human health or the environment; at least 2,500 cubic yards of sediment were removed; and primary documentation is available. The 20 projects retained for detailed review include a geographic cross-section of sites from the west coast (five sites); midwest (seven sites); east coast/south (five sites); and international projects (three sites), all implemented in the past 12 years.

Review methods began with acquiring primary sources of information, interviewing site managers, and assembling monitoring results. Review parameters included types of equipment used, site characterizations, sediment cleanup goals, water quality impacts during dredging, monitoring conducted to verify achievement of goals, and project outcome. The lessons learned from this review can be directly applied to the Lower Fox River and Green Bay feasibility evaluations. Many of these findings and recommendations are consistent with the findings of the National Research Council in their recently released review document titled *A Risk Management Strategy for PCB-Contaminated Sediments* (NRC, 2001). The key conclusions and lessons learned from this review of dredging case study projects are summarized below.

Achievement of Short-term Target Goals. Short-term target goals are also referred to as performance-based criteria. Achievement of performance-based criteria was evaluated on the expectations defined by the projects themselves and the dredging goals defined for the contractor. Chemical-based performance criteria were used in only 10 out of 20 projects. Other removal criteria included mass removal, depth, horizon, and evaluation. The two projects that did not achieve performance goals lacked adequate site characterizations and engineered designs. Dredging can obtain target goals such as percent mass removal or removal down to a target elevation, depth, sediment horizon, or concentration (18 out of 20 projects) provided that the appropriate remedial technologies and expectations have been selected for the site conditions. Dredging of soft sediments can effectively remove PCB-contaminated sediments with minimal resuspension and downstream transport of contaminants and minimal impacts to air quality. Dredging may not be an effective tool for sediment remediation in areas with large quantities of wood and buried debris (sometimes removed with an excavator prior to dredging), cobbles covering the river/lake bottom, steep slopes, or restricted access. An adequate site

characterization (e.g., identifying the presence of wood debris, bedrock, slopes, buried concrete and rubble) can significantly influence the outcome and cost of dredging activities, and assist with the selection of an appropriate technology. Selection of experienced contractors coupled with good communication with the surrounding community can also influence the schedule, progress and costs of dredging activities.

For most of the projects, over 80% of the mass was removed and the average surface sediment concentrations were lower than pre-existing conditions. However, some projects noted post-dredge maximum concentrations that were the similar to the maximum pre-dredge surface concentrations. Many of the projects had elevated but localized concentrations in the water column, surface sediments ,and caged fish tissues during dredging, but these concentrations were significantly reduced after time in all media if adequate source control was in-place.

Achievement of Long-term Remedial Objectives. The measurement tools used to define long-term success are removal of fish consumption advisories, return of a site to beneficial use, or delisting of regulatory status. By these definitions, dredging has effectively reduced the risk to human and environmental health in six out of 20 projects reviewed. For several other projects (seven out of 20 projects) the initial long-term monitoring results suggest a decreasing trend towards improved environmental health (primarily assessed by fish tissue concentrations), however, more time is required to determine the significance of the observed downward trend. For the remaining seven sites reviewed, the long-term trends were inconclusive, either by inherent variability of the data or lack of a well-defined monitoring plan capable of detecting a trend. Variability in temporal site conditions, sampling protocols, and systematic sampling efforts are likely contributors to the variability observed between sampling events. In many cases, insufficient time has passed since completion of the dredging effort to verify the achievement of protection, or the site has not achieved source control immediately outside of the project area.

Projects Reviewed. The projects included in this detailed and independent review of contaminated sediment dredging projects were Bayou Bonfouca, LA; Black River, OH; Collingwood Harbor, Canada; Ford Outfall, MI; Lower Fox River Deposit N and SMU 56/57, WI; GM Foundry, NY; Grasse River, NY; Lake Jarnsjön, Sweden; Manistique River, MI; Marathon Battery, NY; Minamata Bay, Japan; New Bedford Harbor, MA; Port of Portland, OR; Port of Vancouver, WA; Puget Sound Naval Shipyard, WA; Sheboygan River, WI; Sitcum Waterway, WA; Waukegan Harbor, IL; and West Eagle Harbor, WA.

Recommendations. A summary of recommendations for the potential application of dredging as a remedial tool include:

- Develop clear target goals (e.g., source removal, no restrictions on fish consumption, time frame) to be used for selecting the appropriate dredging technology (if selected) and expectations;

- Obtain an adequate knowledge of site conditions and limitations before designing and selecting the final remedial technology;

- Determine acceptable levels of risk during implementation based on the knowledge of site conditions. There will always be some risk.

- Measure "achievement" by both the intended performance of the project and long-term risk reduction.

- Use a mass balance approach to determine potential contaminant transport during dredging and the extent of potential risk; and

- Develop an appropriate long-term monitoring plan designed to verify project success.

In addition, multiple metrics are needed to verify the implementability and effectiveness of dredging. A containment system and subsequent net transport of sediments off-site or residual surface sediment concentrations are valuable indicators but should only be one of many metrics used to evaluate short-term project success. Post-dredge fish tissue sampling (or other biota) can be valuable indicators of system health but careful and consistent methodologies should be developed to accurately quantify risk reduction.

Acknowledgments

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Other reviewers that contributed to the content and interpretation of specific case studies included: Bob Paulson, Ed Lynch and Bill Fitzpatrick of Wisconsin DNR and Mike crystal of Sevenson Environmental (Lower Fox River demonstration projects); Murray Brooksbank of Environment Canada (Collingwood Harbour project); Dick Gilmur of the Port of Tacoma (Sitcum Waterway project); James Hahnenberg of USEPA (Manistique Harbor); Mary Logan of USEPA (Grasse River project); and A. R. Winklhofer of USEPA (Black River project). Many thanks to other USEPA and state project managers; NOAA representatives (i.e., Todd Goeks and Jo Linse); USFWS (i.e., David P. Allen); project site managers; and other interested parties for improving the quality of this review by providing primary documentation of sediment remediation and monitoring activities.

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Table 14 Dredging Project Expectations and Outcomes
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List of Attachments - Case Studies of Sediment Dredging Projects

Attachment 1: Detailed Case Studies

Bayou Bonfouca - Slidell, Louisiana
Black River - Northwest Ohio
Collingwood Harbour - Ontario, Canada
Ford Outfall/River Raisin - Monroe, Michigan
Lower Fox River Deposit N - Kimberly, Wisconsin
Lower Fox River SMU 56/57 - Wisconsin
GM Foundry/St. Lawrence River - Massena, New York
Grasse River - Massena, New York
Lake Jarnsjön - Sweden
Manistique River and Harbor - Manistique, Michigan
Marathon Battery - Cold Springs, New York
Minamata Bay - Kyushu Island, Japan
New Bedford Harbor - Bristol County, Massachusetts
Port of Portland T4 Pencil Pitch - Portland, Oregon
Port of Vancouver Copper Spill - Vancouver, Washington
Puget Sound Naval Shipyard Pier D - Bremerton, Washington
Sheboygan River and Harbor - Sheboygan Falls, Wisconsin
Sitcum Waterway Commencement Bay/Nearshore Tideflat - Tacoma, Washington
Waukegan Harbor/Outboard Marine - Waukegan, Illinois
Wyckoff/West Eagle Harbor Operable Unit - Bainbridge Island, Washington

Attachment 2: Long-term Monitoring Plan Designs

Dredging Projects: Black River, Ohio
Dokai Bay, Japan
Ford Outfall, Michigan
GM Foundry, New York
Grasse River, New York
Lake Jarnjsön, Sweden
Minamata Bay, Japan
New Bedford Harbor, Massachusetts
Santa Gilla Lagoon, Italy
Shiawasse River, Michigan
United Heckathorn, California
Waukegan Harbor, Wisconsin

Capping Projects: Hamilton Harbor, Canada
New York Mud Dump, New York
Simpson Cap, Washington
Wyckoff/East Eagle Harbor Operable Unit, Washington

List of Attachments - Case Studies of Sediment Dredging Projects

Attachment 2: Long-term Monitoring Plan Designs (Continued)

Monitored Natural Recovery Projects: James River, Virginia
Sangamo-Weston, South Carolina

List of Acronyms

ACOE	United States Army Corps of Engineers
AET	Apparent Effects Threshold
AOC	Administrative Order by Consent
AOC	area of concern
ARARs	Applicable or Relevant and Appropriate Requirements
ARCS	Assessment and Remediation of Contaminated Sediments Program
ASRI	Alternative Specific Remedial Investigation
AVS	acid volatile sulfide
AWQS	Ambient Water Quality Standards
BAF	Bioaccumulation factor
BBL	Blasland Bouck and Lee Engineers
BBSS	Bayou Bonfouca Superfund Site
CAA	Clean Air Act
CAB	cable arm bucket
CAD	confined aquatic disposal
CB/NT	Commencement Bay/Nearshore Tideflat
CBOS	Center for Bio-Organic Studies
CCG	Canadian Coast Guard
CDF	confined disposal facility
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Register
CGLRM	Council of Great Lakes Research Managers
COC	chemical of concern
COI	constituent of interest
CRD	Columbia River Datum
CSL	Cleanup Screening Level
CTF	confined treatment facility
CWA	Clean Water Act
DEQ	Department of Environmental Quality
DGPS	Differential Global Positioning System
DMMU	dredged material management unit
DOFO	Department of Fisheries and Oceans
DOT	Department of Transportation
DWZ	dangerous waste zone
Ecology	Washington State Department of Ecology
EDC	Eastern Drainage Channel
EE/CA	Engineering Evaluation/Cost Analysis
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
EROD	ethoxynesorusin-o-deethylase
ESD	Explanation of Significant Differences
ESE	External Source Evaluation
EWQC	Ecology Water Quality Certification

List of Acronyms

FMC	Ford Motor Company
GLHS	Great Lakes Harbor Sediments
GLNPO	Great Lakes National Program Office
GLWQA	Great Lakes Water Quality Act
HAET	High Apparent Effects Threshold
HCB	hexachlorobutadiene
HDPE	high-density polyethylene
HPAH	high-molecular weight polyaromatic hydrocarbon
HPC	heavily polluted classification
IJC	International Joint Commission
IMP	Interim Monitoring Program
JTU	Jackson turbidity units
LDEQ	Louisiana Department of Environmental Quality
LDHH	Louisiana Department of Health and Hospitals
LEL	Lowest Effects Level
LOPH	Louisiana Office of Public Health
LSI	Liver Somatic Index
MCUL	Minimum Cleanup Level
MDEQ	Michigan Department of Environmental Quality
MDNR	Michigan Department of Natural Resources
MLLW	mean lower low water
MTCA	Model Toxics Control Act
NCGP	non-consumption for general population
NCP	National Contingency Plan
NCSP	non-consumption for sub-population
NGVD	National Geodetic Vertical Datum
NPDES	National Pollutant Discharge Elimination System
NPL	National Priority/Priorities List
NRDA	National Resource Damage Assessment
NSRAP	National Site Remedial Action Plan
NTCRA	Non-Time-Critical Removal Action
NTU	turbidity units
NWPA	Navigable Waters Protection Act
NYDEC	New York State Department of Environmental Conservation
OMC	Outboard Marine Company
OMEE	Ontario Ministry of Environment and Energy
OMMP	Operations Maintenance and Monitoring Plan
OMOE	Ontario Ministry of the Environment and Energy
PAH	polyaromatic hydrocarbon
PCB	polychlorinated biphenyl
PCP	pentachlorophenol
ppb	parts per billion
ppm	parts per million

List of Acronyms

ppt	parts per trillion
PS	Pilot Study
PSDDA	Puget Sound Dredge Disposal Analysis
PSEP	Puget Sound Estuary Program
PSMG	Provincial Sediment Management Guidelines
PSNS	Puget Sound Naval Shipyard
PSR	Pilot Study Report
PUC	polyurethane columns
PVC	polyvinyl chloride
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
RA	removal action
RAO	remedial action objective
RAP	Remedial Action Plan
RARA	Removal Action Recommendation and Action Memorandum
RCRA	Resource Conservation and Recovery Act
RGP	restricted, general population
RI/FS	Remedial Action/Feasibility Study
ROD	Record of Decision
RSP	restricted, sub-population
RTP	Remediation Technologies Program
SAB	Science Advisory Board
SAP	Sampling and Analysis Plan
SACM	Superfund Accelerated Cleanup Model
SCU	sediment containment unit
SedPac	Sediment Priority Action Committee
SEDTEC	Sediment Technologies, Environment Canada
SMF	sediment management facility
SMS	Sediment Management Standards
SMU	sediment management unit
SMWG	Sediment Management Work Group
SQOs	sediment quality objectives
SQS	Sediment Quality Standards
SRA	sediment removal area
SWD	surface water discharge
TDS	total dissolved solids
TOC	total organic carbon
TSCA	Toxic Substances Control Act
TSCS	Target Sediment Cleanup Standards
TSS	total suspended solids
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USFDA	United States Food and Drug Administration

List of Acronyms

VOC	volatile organic carbon
WDFHPA	Washington Department of Fisheries Hydraulic Project Approval
WDNR	Wisconsin Department of Natural Resources
WHOU	West Eagle Harbor Operable Unit
WQB	Water Quality Board
WQC	Water Quality Certification
WQMD	Water Quality Monitoring of Discharge
WSDNR	Washington State Department of Natural Resources
WWTP	wastewater treatment plant

1 Introduction

This document provides a review of case studies relating to the use of dredging as an excavation method for the removal of contaminated sediments. The objective of this review was to evaluate information regarding the effectiveness of environmental dredging as a potential remedial action for the sediment-bound polychlorinated biphenyls (PCBs) in the Lower Fox River and Green Bay. The information presented in this paper will be evaluated during the development of remedial alternatives for the Lower Fox River and Green Bay Feasibility Study, along with additional site-specific information generated for the Lower Fox River and Green Bay.

Source: EPA
Clamshell Dredge on Barge

The effectiveness of dredging as a tool for sediment remediation has recently been questioned by some groups (BBL, 1999; Lower Fox River Group, 1998 and 1999; Ortiz et al., 1998). Citing a limited number of cases, critics of dredging suggest that dredging has limited exposure reduction benefits, and may increase rather than decrease contaminant exposure. However, the underlying reasons for apparent short-term deficiencies (e.g., poor dredging design, contractor quality control) are not taken into consideration in these discussions, and the long-term positive effects of removal actions at other contaminated sediment sites are ignored. The purpose of this document was to independently review primary sources of information and present a summary of the effectiveness of dredging based upon a review of sediment project case studies.

This focused report examines 20 sediment dredging projects to assess both the short- and long-term effectiveness of dredging as a remedial alternative. Each case study discusses the type of equipment used, the sediment cleanup goals, water quality impacts during dredging, and monitoring of physical, chemical, and biological parameters for determining short-term effectiveness. Short-term effectiveness is defined as achievement of goals based on project expectations, not on expectations the reviewer may impose on the project. When available, the evaluation of long-term effectiveness towards the ultimate goals of habitat quality, reduced exposure to biota, protection of human health, rescinding of fish consumption advisories, and reduced bioaccumulation up the food chain are also discussed.

1.1 Background

Many of our nation's rivers, bays, and estuaries have been adversely impacted by historical point source and non-point source activities. Most of these impaired systems have been linked to maritime harbors and industrialized rivers and waterways (Fairey et al., 1998; NRC, 1997; Long et al., 1996; Swartz et al., 1989). Contaminated sediments may contain metals, petroleum hydrocarbons, polycyclic aromatic hydrocarbons (PAH), or more recalcitrant chemicals such as PCBs, dioxins, or pesticides that sorb to fine-grained particles and settle into and on the sediment floor of the water body. While typically these contaminant zones range from only a few inches to a few feet in thickness, these contaminated sediments cover wide areas and have the potential to affect human health and the environment.

Management of these contaminated sediments is complicated, as impacts to human health, the environment, and local or national economies must be considered in selecting strategies that balance environmental concerns with economic practicalities. How big is the problem? Under the Water Resources Development Act passed by Congress in 1992, the U.S. Environmental Protection Agency (EPA) undertook the National Sediment Inventory, and identified that as much as 10 percent of the sediment underlying the nation's surface waters was sufficiently contaminated to pose risks to humans and wildlife who eat fish (EPA, 1997 and 1998). This encompasses over 1,700 water body segments as potential areas of concern (AOC) nationwide (Demars et al., 1995). Within the Great Lakes area alone, the United States and Canada identified 43 AOCs where contaminants in sediments are elevated to the point where the beneficial uses of water (drinking, swimming, fishing, and boating) are significantly impaired. In addition, the National Research Council estimated that there are approximately 14 to 28 million cubic yards of contaminated sediments from navigation projects that must be managed annually (NRC, 1997).

Management of contaminated sediments has been the subject of multiple review documents (NRC, 2001; NRC, 1997; Demars, 1997; Cleland, 2000 for Scenic Hudson; Sediment Management Work Group, 1999; Sediment Priority Action Committee, 1997; SEDTEC, 1997; DOD, 1994; EPA, 1994a and 1994b; Averett et al., 1990). In the recently published document titled *A Risk Management Strategy for PCB-Contaminated Sediments* by the National Research Council (NRC, 2001), the review committee supported the conclusion that exposure to PCBs in sediment may pose long-term risks to public health and the ecosystem, and that risk

management should be the paramount consideration. Risk management should be site-specific and consider all available technologies (NRC, 2001). While there are numerous methods developed for the remediation of contaminated sediments, there are six generally accepted response actions that can be applied (EPA, 1994b):

- Natural attenuation (no action),
- Monitored natural recovery,
- Containment in place,
- Treatment in place,
- Excavation and containment, and
- Excavation and treatment.

Of those alternatives, this case study review focuses specifically on removal or excavation of subaqueous sediments (i.e., dredging by wet-excavation) (Averett, 1997). Results of the review will be applied to the Lower Fox River/Green Bay Remedial Investigation and Feasibility Study (RI/FS) to help the project team evaluate feasible remedial alternatives for the Lower Fox River and Green Bay. The other response actions listed above (natural attenuation, containment or treatment options) are explored in the feasibility study.

Excellent reviews of dredging technologies can be found in the ARCS Program *Remediation Guidance Document* (EPA, 1994b), *Removal of Contaminated Sediments: Equipment and Recent Field Studies* (Herbich, 1997) and in Environment Canada's Contaminated Sediment Removal Program (SEDTEC, 1997). The types of dredges suitable for work in the Lower Fox River are discussed in Section 7 of the Feasibility Study.

In general there are two types of subaqueous excavation that are germane to the discussions in this document: mechanical and hydraulic dredging. Mechanical dredges apply mechanical force to dislodge and remove sediment. A mechanical dredge consists of a suspended or articulated bucket lowered to the bottom that "bites" the dredge material and raises it to the surface. The dredged material is then deposited in a haul barge, or other contained conveyance, for transport and re-handling to final disposition. Hydraulic dredges applying mechanical agitation (such as with a cutterhead augers or high-pressure water jets) to dislodge sediment. The loosened slurry is essentially then "vacuumed" into the intake pipe by the dredge pump and transported over long distances through a dredge discharge pipeline.

Dredging as a remedial alternative is included in the evaluation of alternatives for the Lower Fox River and Green Bay. Critics of dredging have argued that while it may be feasible to dredge, effectiveness of dredging is limited by:

Christina River Dredging
Source: Sevenson

- Inability of dredging to remove all constituents from the sediment bed;
- Constituents left behind could be available to the food web in higher concentrations;
- Constituents of concern could be resuspended and subsequently released into the water body, to be deposited outside the dredge area or carried downstream;
- Dredging is too expensive when compared to other alternatives, and
- Removal of the sediment bed destroys existing habitat (BBL, 1999).

Critics of dredging in essence argue that the inability to remove all constituents of interest results in exposing or re-distributing contaminants at higher concentrations than existed at the surface prior to implementing the removal action. This argument assumes that the highest concentrations tend to be located at depth (2 to 3 feet below the sediment surface) and are naturally attenuating or are being buried by cleaner sediments. Based on this premise, the argument is that the action is counter-productive, and that the risks to aquatic receptors, or birds or humans that eat fish from that system, are exposed to higher levels of contaminants than would otherwise be encountered since the highest concentrations are at depth. On this basis, some have argued that dredging should not be considered as a remedial alternative for the Lower Fox River.

1.2 Purpose

The focus of this report is to review major environmental dredging projects for the purposes of evaluating:

- Achievement of proposed short-term performance-based target cleanup goals;

- Achievement or progress towards proposed long-term remedial objectives;
- Adequacy of site characterizations and engineering design components appropriate for the site;
- Effects on downstream and off-site transport of contaminated sediment during removal;
- Adequacy of monitoring to be able to assess goals, and;
- Determine if dredging is viable remedial alternative.

Each of these evaluations are discussed in Section 4.

1.3 Application to the Lower Fox River/Green Bay Project

An estimated 90,720 kilograms (kg) (200,000 pounds) of PCBs were released into the Lower Fox River between 1954 and the present (ThermoRetec, 1999). PCBs in the Lower Fox River pose a potential threat to human health and ecological receptors due to their tendency to sorb to sediments, persist in the environment, and bioaccumulate in aquatic organisms. General fish consumption advisories are currently in effect for 13 species of fish located within the project area from Little Lake Butte des Morts (upstream of the De Pere dam) and out into Green Bay. Fish consumption advisories have been in place since the 1970s.

Mouth of Lower Fox River to Green Bay
Source: WDNR

The intent of this technical memorandum is to apply the concepts, applications, and lessons learned from 20 contaminated sediment remediation projects towards the screening and development of the Lower Fox River/Green Bay remedial alternatives. Specifically, results of this paper will be used to evaluate the dredging alternative with respect to three criteria: technical implementability, effectiveness and cost (EPA, 1988). The lessons learned regarding site conditions, problems encountered, elements of the initial site characterization and engineering design, along with the ability to verify achievement of target goals from the monitoring programs will be directly applied to the Lower Fox River/Green Bay feasibility evaluations.

2 Project Selection and Review Methods

2.1 Project Selection

The process of selecting contaminated sediment dredging projects for review entailed a tiered screening of projects based on current status of the remedy, extent of monitoring programs, and type of dredging. Selection of case studies were determined *a priori* to provide as unbiased of a foundation for review as possible. The initial screening process involved accessing a full-breadth of readily available information on over 60 dredging projects (Table 1).

2.1.1 Initial Screening

Specific and general resources for the initial screening included:

- EPA regional websites, fact sheets, and publications;
- Dredging-related websites and journal articles;
- Proceedings from dredging conferences;
- Assessment and Remediation of Contaminated Sediments (ARCS) Program, EPA's Great Lakes National Program Office (GLNPO) publications;
- Sediment Priority Action Committee (SedPac) and International Joint Commission (IJC) publications;
- White papers published by research groups;
- Sediment Management Workgroup (SMWG) Publications;
- *Contaminated Sediments in Ports and Waterways Cleanup Strategies and Technologies* (NRC, 1997,);
- Conference Proceedings from the National Symposium on Contaminated Sediments (NRC, 1998);
- Western Dredging Association newsletters;
- Hudson Watch website (http:\\www.hudsonwatch.com) or (http:\\www.hudsonvoice.com);
- U.S. Army Corps of Engineers publications;
- Contacting dredging design engineers;

- Environment Canada's SEDTEC publication; and
- Personal experience.

SMU 56/57 Stockpile
Source: EPA

Dredging projects retained after this initial data-gathering phase had to meet the following criteria (to be applicable to the Lower Fox River/Green Bay project): 1) the purpose of the remedy was environmental dredging (as opposed to maintenance or navigational dredging); 2) the remedy was already implemented and not in the planning stages; 3) the contaminants of concern were PCBs, or other persistent chemicals such as PAHs or metals that tend to accumulate in site sediments; and 4) the remedy was a wet excavation project (standing water over the sediments and accessed by barge). A combination of technologies in which dredging was at least one of the implemented methods was also acceptable.

2.1.2 Secondary Screening

Dredging projects retained after the secondary screening process had to meet the minimum following requirements:

- Contaminated sediment with concentrations exceeding site-specific chemical levels determined to be protective of human health and the environment;
- Dredged in 1988 or later, to benefit from improved monitoring techniques and requirements;
- At least 2,500 cubic yards of sediment were removed;
- Verification monitoring after cessation of dredging operations; and
- Access to primary documentation.

Projects meeting the secondary criteria were selected for detailed review (Table 1).

The year of 1988 was selected as cutoff for review since the EPA guidance document for conducting remedial investigation/ feasibility studies (RI/FS) was published in 1988, providing a framework for consistency, methods of evaluating success, and defining short-term and long-term goals (EPA, 1988). Projects conducted outside of the U. S. were selected primarily on the

amount of primary documentation available for review. The volume of 2,500 cubic yards was selected to help focus efforts towards full-scale remediation projects as opposed to pilot studies. Some pilot studies were selected (greater than 2,500 cubic yards) if the volumes were large or if an intensive amount of monitoring was conducted around the pilot study. Many of the projects reviewed with less than 2,500 cubic yards were collected for laboratory and treatability testing with no intention of mass removal. The purpose of these small-scale projects was generally not to test the effectiveness of environmental dredging. Adequate baseline sampling and post-project verification sampling had to be included as elements of the project in order to verify achievement of project goals. Sediment remediation projects considered are summarized in Table 1.

2.2 Focus of Review

For each case study selected, the specific focus was to acquire and review primary references, including data results from sampling activities and documents stating the project objectives (usually defined in the Record of Decision). Primary references/resources likely included, but were not limited to the following documents (Table 2):

- Records of Decision (RODs);
- Project bid requests and specifications;
- Contractor project design submittals;
- Initial site investigation reports;
- Fish consumption advisories;
- Remedial design/remedial action work plans;
- Project completion reports;
- U.S. EPA Fact Sheets;
- Enforcement action memos;
- Sampling and analysis plans for verification sampling;
- Water and sediment quality monitoring reports; and
- Operation, maintenance and monitoring plans (OMMPs).

To fill in data gaps after the initial review of acquired primary resources, secondary references were also pursued, when appropriate, including journal articles, conference presentations, EPA summary fact sheets, Internet websites, and communications with site project managers. These documents were reviewed to assess dredging methodologies, monitoring results, problems encountered, lessons learned, and verification of achievement of target goals and long-term objectives.

2.3 Project Review Parameters

A total of 20 contaminated-sediment dredging projects were reviewed. Each case study was organized into the headings described below (see Attachment 1 for the complete writeups). The review parameters and types of information presented in each section are defined below. A brief summary of results and findings are discussed in Section 3. A checklist briefly describing the types of information reviewed is presented in Table 2.

2.3.1 Statement of the Problem

The "statement of the problem" briefly summarizes the nature and extent of the problem and impacted resources. The reason why remedial activities were conducted including the purpose, time frame, and intent of the dredging activities were are also mentioned. This section also defines the lead regulatory agency.

Round Cutter Head Dredge
Source: Terra et Aqua

2.3.2 Site Description

This section describes the physical environment of each site, including location; receiving water bodies; water body type; site access; average water depth; substrate type and thickness; surrounding property use; and industrial sources.

2.3.3 Site Investigation

This section describes the initial site investigations leading up to a site ranking or regulatory listing; and subsequent site investigations, risk assessments, and/or pilot studies leading up to remedial activities. It describes the regulatory framework of the decision-making process, identification of problem areas, and identification of guidelines for cleanup. The primary contaminants of concern of the site are identified including: the vertical and horizontal extent of contamination, constituents of concern (COCs), maximum concentrations detected at the site, and impaired resources. A summary of investigation studies, and the regulatory framework are also defined.

2.3.4 Performance-Based Target Goals and Project Objectives

This section describes the short-term target goals and the long-term remedial action objectives (RAOs) for each project. The target goals are defined as the performance-based criteria used to define completion of the dredging project and compensation costs to contractors. Performance-based target goals were usually related

to removal of sediment down to a measurable physical criteria such as: the residual chemical concentration, depth or elevation, or percent of contaminant mass removal. The performance-based criteria were based on site-specific expectations defined by each project. The RAOs are defined as the intended long-term benefits hoped to gain as a result of the dredging activity. Long-term objectives were usually related to risk reduction to humans and the environment. The remedial action implemented for each site was based on knowledge that contaminated sediments posed some unacceptable level of risk to the aquatic system, determined from baseline site investigations.

2.3.5 Project Design

This section summarizes the overall remedy for the project and how it was designed. It describes how the role of engineering and design played into the project planning and implementation and includes a review of bid package characteristics including type of payment, adaptive management strategies, quality assurance/quality control (QA/QC) requirements, and qualifications-based or low-bid selection criteria. Fate and transport modeling and bench-scale tests to predict effects of dredging activities on adjacent resources are also defined. The quality of design components and pre-planning strategy efforts used to maximize the likelihood of achieving target goals are described to the best extent possible from available resources.

Dewatering Activities
Source: Bill Fitzpatrick, WDNR

2.3.6 Remedial Actions

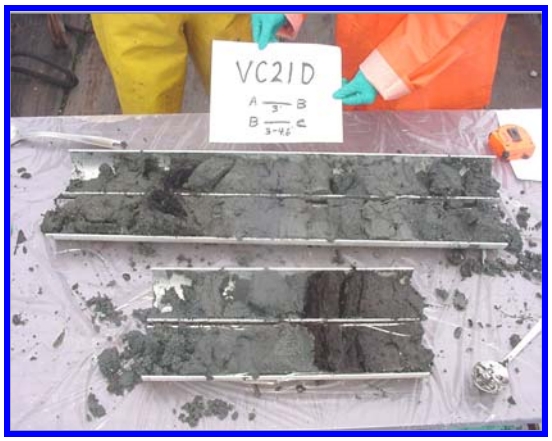
This section describes the dredging equipment, dewatering and treatment process, and disposal methods implemented for each project. Descriptions also include problems encountered, project limitations, the duration and schedule of removal action (number of hours per day and days per week), production rates, description of equipment used, and problems encountered. Site limitations that affected dredging production rates are also described. Limitations ranged from physical characteristics (water depth, restricted access, ice, currents) to policy decisions (shutdown during fish spawning windows, public outreach, special permits).

2.3.7 Environmental Monitoring Program

This section summarizes the monitoring program for each project including physical, chemical, and biological elements. Physical elements may include bathymetry, acoustic, lead-line, and sub-bottom profiling surveys. Chemical elements may include water column, sediment surface, sediment core, or air surveys. Biological elements may include sediment or water column toxicity testing, tissue analysis of plants, invertebrates, caged fish, resident fish, and benthic community structure analyses. Questions asked during the review included, but were not limited to:

- What parameters were measured during dredging activities and how were exceedances handled?
- What was the extent of baseline environmental data and were background concentrations known?
- Was the monitoring program modified to compensate for problems encountered?
- Was long-term monitoring designed into the remedial plan and if so, how many years were actually implemented?

2.3.8 Performance Evaluation



Core Sampling
Source: ThermoRetec

This section summarizes the degree to which each project met the stated performance-based target goals and long-term remediation objectives. During this review the questions asked included, but were not limited to:

- Was the project intended to be a full remediation project with 100 percent removal of contaminated sediment above a threshold criteria, or was it a focused removal project that considered site-specific conditions and limitations?
- What was the mass and volume of contaminants?
- What were the project expectations, and were acceptable levels of risk during implementation defined?
- Was overdredge allowed or designed into the program to ensure compliance with target goals?

- Were performance specifications modified during dredging activities to compensate for problems encountered?
- Was residual capping designed into the program to reduce exposure from contaminated sediment remaining in place, or as an afterthought because the target chemical criteria could not be achieved after several attempts?
- What was the residual risk after dredging?
- Were there concentration reductions in surface sediment (surface weighted average) or at depth?
- Were there reductions in surface water concentrations?
- Were the dredge design depths achieved and were post-verification samples collected?
- Can pre-dredging trends be established? If not, what trends could be generally expected?
- Were fish consumption advisories reduced or removed after project completion?
- Were other management-type actions implemented on the project (i.e., site delisting) based on observed results?

Sediment from Box Core
Source: ThermoRetec

This section also discusses how the design specifications may have influenced the outcome of the project, and the lessons learned for each project.

2.3.9 Costs

This section summarizes both the total dredging and disposal costs, when available, and calculates a cost per cubic yard. When cost breakdowns were not available, total remediation costs are presented. However, this review focuses primarily on effectiveness of dredging at meeting project expectations, not necessarily cost-effectiveness.

2.3.10 Contacts

This section provides the names of regulatory project managers to contact for more information. When

available, the lead design engineer, regulatory agency, and general contractor are also listed.

2.3.11 References

This section cites the primary references used to extract pertinent information. It also includes secondary references including websites, fact sheets, and personal communications when appropriate.

3 Results and Findings

3.1 Statement of the Problem Findings

All of the projects reviewed were under regulatory action to conduct environmental remediation (pilot or full-scale) of the site from observed impacts to human health and the environment ranging from fish consumption advisories to fish deformities and sediment toxicity. The distribution of the major contaminants of concern (out of 20 projects) included: PCBs (10 sites), PAHs (four sites), and heavy metals (six sites) (Table 3).

All of the projects reviewed have had fish consumption advisories posted in their project area (Table 4).

3.2 Site Description Findings

The projects reviewed were grouped into five major water body types: riverine (9), lake (3), marine (4), estuarine (2), and coves/ marshes (2). Average water depths ranged from intertidal (substrate exposed at low tide) up to 65-foot water depths with an average depth of approximately 15 feet.

Lower Fox River
Source: Great Lakes United

Physical constraints commonly encountered at many of these sites included winter storm and ice conditions, strong currents, tidal swings, hard bottom substrate (difficult to anchor silt curtains and difficult to implement overdredge), passing ships disturbing the silt curtains, access to sites from private land owners, shallow water depths, access under docks and pier structures, boating and fish spawning seasons (required downtime), and significant debris, wood, cables, and boulders buried in the substrate.

The stratigraphy in most of the riverine and lacustrine systems was a layer of silt/sand (less than 10 feet thick) over very dense, almost impenetrable glacial till (called hardpan) or bedrock layers. The stratigraphy in most of the marine systems was a layer of soft silt over medium dense sand (easy to penetrate), while the estuarine and marshes generally had thick soft silt/sand layers.

3.3 Site Investigation Results

The primary chemicals of concern driving the remedial cleanup projects were either PCBs, PAHs, or heavy metals. All of these analytes were found to accumulate in site sediments and served as a source of bioaccumulation and toxicity to benthic and aquatic organisms. The majority of contaminants were detected in the upper 3 feet of most systems with a few sites extending down to 5- and 6-foot depths below the mudline sediment surface.

3.4 Target Goals and Project Objectives Findings

The short-term performance-based target goals among the projects reviewed were generally grouped into four categories based on the type of metrics used to verify achievement and the purpose of the removal effort:

1. Mass removal of contaminated sediment for source control, prevention of downstream transport, or enhancement of natural recovery (three projects) (Grasse River, Port of Portland, and Collingwood Harbour);

2. Risk-based chemical criteria designed to be protective of human health and the environment (10 projects) (Marathon Battery, Port of Vancouver, GM Foundry, Lake Jarnsjön, Manistique, Minamata Bay, New Bedford Harbor, Sitcum Waterway and West Eagle Harbor and Waukegan Harbor); and

3. Physical criteria such as depth, elevation or horizon (seven projects) (depth: Bayou Bonfouca, Black River, Fox River Deposit N and SMU 56/57; elevation: Puget Sound Naval Shipyard (PSNS) and Sheboygan Harbor, and horizon: Ford Outfall).

Only 50% of the projects reviewed used chemical criteria as performance-based target goals. Elevated chemical concentrations were obviously driving the need for removal action, but other site-specific criteria were used as project expectations for the contractor (i.e., elevation). Residual surface sediment concentrations are presented in Table 5. The volume/mass of sediment removed for each project is presented in Table 6. These criteria serve as general categories recognizing that metrics from one category may have been used to develop target goals for another metric. For example, the New Bedford Harbor project established a concentration of 4,000 ppm as a target goal, however, elements of mass removal were considered as well since the concentration level was developed from a PCB mass/sediment volume curve.

Clamshell Bucket Dredge
Source: EPA

For many pilot demonstration projects or shoreline redevelopment projects, the target goals were often driven by elevation, depth or bedrock/hardpan requirements (Table 6). At these sites, contamination was correlated to sediment lithologies, and dredging to a physical design goal such as depth was assumed to be protective of the environment. For many projects an overdredge depth ranging from 0.5 to 1.0 ft below the maximum anticipated depth of impacted sediments was built into the remedial design (discussed below). Primary measurement methods for determining compliance with target goals were post-verification surface sediment grab/core samples.

The long-term RAOs could be categorized into three groups:

1. To protect human health (nine projects);

2. To protect the environment (six projects);

3. To provide physical source control and minimize downstream transport (five projects).

Many of the projects did not explicitly define long-term RAOs because they were either pilot studies, were only concerned with mass removal of sediments for source control, or assumed if chemical criteria were met, then long-term objectives would be met as well. For example, in Puget Sound the Washington State Sediment Management Standards are designed to be protective of

benthic and aquatic communities through Apparent Effects Thresholds (AETs). While there is not a direct measurable correlation between contaminant concentration and exposure, if chemical concentrations measured at a site are below the AET values then the site is determined to be protective of the benthic community.

3.5 Project Design Findings

A summary of the project designs and implemented remedies for each project are presented in Table 6.

3.5.1 Overdredge

Seven projects designed "overdredge" into the project plans. Four of these sites were located in the Pacific Northwest (Sitcum Waterway, West Eagle Harbor, Port of Vancouver, Puget Sound Naval Shipyard), while others included Lake Jarnsjön, Lower Fox River SMU 56/57 and New Bedford Harbor. The term "overdredge" refers to additional 0.5- to 1.0 ft lift of sediment removed from underneath the maximum known extent of contamination to ensure removal of all contaminated sediments. This technique can only be applied to site locations where contaminated material does not rest directly on top of an impenetrable layer such as hardpan or bedrock. In addition, the cost of dredging additional material can be costly and must be well managed and coordinated with the dredge contractor to manage costs. In cases where overdredge could occur, target goals were achieved.

Hydraulic Horizontal Auger Dredge
Source: D.C. Roukema, J. Driebergen, and A.G. Fase

A controversial exception to this finding is the SMU 56/57 demonstration project. Although a 0.5 ft overdredge was designed into the 1999 remedy, the target elevation was not achieved in most areas and the verification sampling had elevated PCB levels. However, a detailed review of the data by subunits revealed that the target elevation goals could be achieved. Contractors returned to the site in August 2000 to remove remaining sediment down to the targeted elevation. In New Bedford Harbor, the dredge design included an over-dredge allowance of 0.5 to 1.0 ft, but actual dredging depth exceeded the design depth to meet the targeted cleanup level. For the Sitcum Waterway project, an additional two feet of overdredge was added to the project beyond the vertical extent of impacted sediment for navigational needs.

3.5.2 Bench-Scale Tests/Modeling/Physical Testing

Bench-scale testing is generally conducted prior to implementing a dredging program to predict sediment performance during the dredging, pumping and dewatering process. Bench-scale treatability and physical testing is used to refine the selection of appropriate equipment sizes for removal and dewatering efforts. Based on the data reviewed, only about 50 percent of the dredging projects conducted laboratory testing to refine the project designs.

Transport modeling is generally conducted prior to implementing a dredging program to predict sediment resuspension and downstream transport effects during dredging. Many projects rely on literature values to predict off-site transport for the purposes of permitting, selecting environmental controls (i.e., silt curtains), and determining compliance boundaries. A few projects conducted site-specific modeling efforts to predict the magnitude of off-site contaminant transport. For example, the Sitcum Waterway project used computer models (EFQual and Plumes) to determine the dilution zone distances from the point of dredging and the appropriate compliance boundaries for water quality monitoring during dredging (silt curtains were not used).

The recently published sediment management report by the National Research Council (NRC, 2001) emphasized the need for better pre-remedy assessments of the processes governing the fate of PCBs, the impact of co-contaminants, and pilot scale testing. A full understanding of the hydrogeologic setting and the risk reduction potential of the management options are important predictors of effectiveness (NRC, 2001).

3.5.3 Site Characterization

All of the projects reviewed conducted subsurface sediment profiling to determine the horizontal and vertical extent of contamination and to evaluate the physical properties of sediments requiring remediation. Some of the projects used acoustic profiling equipment to determine additional physical characteristics of the site (i.e., refusal, bedrock, buried debris, density). Buried material such as boulders, concrete, bricks, scrap metal, discarded wood and lumber, or pier remnants often discovered at sediment sites can greatly impact the cost and schedule of a dredging project if not anticipated. Correlation of a contaminant with a particular stratigraphic unit, physical substructure, or sediment color can help the dredging contractor manage their activities more effectively.

For example, the Collingwood Harbour project used the presence of a bluish hue color in the excavated material as an indicator that

the underlying, clean clay layer was being dredged. This "early indicator" helped guide and improve the efficiency of the dredging effort. The pilot dredging project at Collingwood Harbour encountered numerous delays by large-size debris present from historical shipbuilding activities. Lessons learned from the demonstration project were considered when selecting the final dredging equipment. This resulted in significantly less frequent delays during the full-scale remediation project. In both the GM Foundry and Grasse River projects, large boulders and debris identified in the physical surveys were removed using an excavator bucket prior to initiation of hydraulic dredging activities. Unanticipated physical characteristics of the site sediment and bedrock influence the production rate and schedule of dredging activities. At the Manistique River/Harbor site, unanticipated rock and wood debris encountered during dredging contributed substantially to delays and cost increases and required a change in technologies. For the GM Foundry project, excavation of contaminated soft sediments down to "hardpan" material resulted in clogging of pumping equipment from the clayey or gravelly structure of the underlying clean substrate.

For the Bayou Bonfouca and Sheboygan River projects, contaminated sediment volumes encountered during dredging were significantly larger (up to three times more) than estimated sediment volumes requiring removal specified in the project ROD or design plans based on RI/FS sediment investigations. These findings support the argument that inherent limitations exist in sediment coring and poling activities when refusal is encountered.

A repeating theme for many projects is the necessity for a comprehensive understanding of the physical characteristics of site sediments. A clear understanding of site conditions can help formulate an appropriate dredging plan. For the dredging projects in Lake Jarnsjön and Marathon Battery, the dredging equipment was switched from hydraulic methods to clamshell buckets when coarse sand and gravel were encountered in selected areas. For sites where the side-slopes are known to be unstable and difficult to access, the remediation footprint can be designed around these limitations as was implemented in the Ford Outfall, Port of Vancouver, and Port of Portland.

3.5.4 Capping of Residuals

Three of the projects placed sand caps on residual sediments to isolate remaining sediments from risk and exposure to aquatic organisms. For the Sheboygan River, sand caps were purposely placed at several hotspots as part of the demonstration pilot project to assess the efficacy of placement based on site conditions. In the case of West Eagle Harbor, both thick and thin caps were designed into project plans. The thick cap was placed to isolate contaminants and reduce risk of exposure while the thin cap was placed to enhance natural recovery and return the sediment concentrations to below toxic thresholds within 10 years after remedial activities. In the case of GM Foundry, a sand cap was unanticipated and placed on one of six dredge quadrants after several attempts failed to remove residual contaminants. After the year 2000 dredging activities at Fox River SMU 56/57 a sand cap was placed over the entire dredge footprint, although not required by regulatory agencies, to isolate and prevent further downstream transport of residual impacted sediments.

Stockpiling Dewatered Sediment
Source: Bill Fitzpatrick, WDNR

3.6 Remedial Action Findings

3.6.1 Types of Dredging Technologies

The types of dredging technologies utilized at these sites can be grouped into five general categories: mechanical clamshell buckets with barge/scow (seven projects), a hydraulic cutterhead dredge with pipeline to shore (six projects), a hydraulic horizontal auger dredge with pipeline to shore (five projects), a hydraulic suction dredge without a cutter (one project), and other technologies such as the Pneuma airlift pump (one project). A few projects switched technologies during implementation after encountering site difficulties (usually debris and wood) (Lake Jarnsjön, Marathon Battery, Manistique). To access underpier and shoreline areas, several projects also implemented airlift vacuum pumps, backhoes, or diver-assisted smaller hydraulic pumps for difficult areas (Port of Portland, Manistique, Sitcum Waterway). A summary of dredging technologies used for the projects is presented in Table 7.

3.6.2 Containment Systems

Containment systems utilized during dredging to minimize downstream transport of suspended sediments included silt curtains (12 projects), sheetpile walls (three projects), oil booms (three projects), and no containment (two projects) (Table 8). In the case of GM Foundry, a silt curtain was initially installed, but did not work well in the strong river currents and wind. The silt curtain was removed and a sheetpile wall system devised. Additional information is needed to assess whether the silt curtain was not appropriate for the site or whether the design and installation were poorly implemented. In the case of New Bedford Harbor, silt curtains were initially installed, but later removed because of disturbance from tidal and weather conditions. Downstream transport was monitored by changes in chemical mass transport and bioassays using surface sediment chemistry. In the case of Bayou Bonfouca a combination of barrier systems was used, silt curtains and oil booms were installed around dredging activities, and a sheetpile wall installed along the shoreline banks for stabilization.

Bucket Dredge
Source: SAIC

On the other hand, experience at the Deposit N demonstration project has shown that the barrier containment system was redundant and unnecessary given the low resuspension of sediment by the environmental dredge. Extensive water column monitoring during the first phase of work showed little elevation of turbidity from the dredging operations, no significant difference between the inside and outside barrier samples, and therefore no apparent threat to the river water column. Based on the monitoring results, the second phase of the dredging proceeded without the barrier containment system with comparable results. No water quality exceedances were observed.

For the two projects that did not install containment systems (both in Puget Sound) an authorized, site-specific, chronic dilution zone was established around the dredging activities based on modeling results. The surface water compliance monitoring stations were established along the edge of the dilution zone and dredging activities were carefully monitored to minimize sediment transport. No significant exceedances were observed. In general, no significant water quality exceedances were noted in any of the projects reviewed, and no modifications to the dredge operations were noted based on water quality results (Table 8).

Monitoring Device
Source: SAIC

The significance and consequences of off-site loss of contaminants during environmental dredging have not been universally defined in the literature. For most projects, containment systems are installed either to: 1) prevent off-site exceedances of acute or chronic risk-based criteria, or 2) prevent mass transport of contaminants downstream. Monitoring requirements are determined by permit-based criteria which defines a particular regulatory decision on the allowable amounts of off-site concentrations (contaminant levels or surrogate parameter such as turbidity or suspended solids). The decision to install a barrier system should consider the purpose of the water quality permit balanced with the cost to install and maintain a containment system. The water quality permits should be based on site-specific risk management and judgement values that depend upon the valued endpoints of the project and site conditions. Overall, the effectiveness of a containment system and subsequent net transport of contaminants off-site should be only one metric with which to evaluate project success.

3.6.3 Problems Encountered

Common problems encountered during active dredging and processing can be grouped into seven general categories: 1) debris or unanticipated changes in physical material characteristics, 2) disturbance of containment systems, 3) difficulty dredging the underlying hardpan layer, 4) access to restricted areas (underpiers and side slopes) and sloughing of side slopes, 5) lower percent solids than anticipated in the dredge slurry and filter press cake, 6) public opposition to selected activities, and 7) seasonal restrictions to dredging activities (boating, fish spawning, ice during winter). Most of these problems are discussed in various discussions of Section 4 and detailed in each of the Appendix A case studies.

Physical Conditions. Problems encountered with debris, hardpan, side slopes and difficult access are discussed in Section 4.1. Problems encountered with containment systems and site characterizations are discussed in Section 4.3.

Low Percent Solids. The percent solids in the filter press cake of Lake Jarnsjön sediments was lower than expected. To meet the 35 percent solids content for disposal, the mechanically-dewatered sediment had to be remixed with sand and dewatered again to meet the landfill requirements. For the Lower Fox River SMU

56/57 project, the average percent solids in the dredge slurry during the year 2000 dredging activities was about 4.4 percent (40 percent lower than anticipated solids content). However, after mechanical dewatering, the dredged material was between 50 and 60 percent solids. For Waukegan Harbor, the sediment placed in the on-site nearshore containment cell required over two years to reach the target 90 percent consolidation despite dewatering and application of sand and coagulant efforts to "thicken" the material.

Barge Overflow
Source: SAIC

Public Opposition. Strong opposition to planned redevelopment activities or dredging and dewatering processes can influence the final design parameters for a sediment remediation project. For the New Bedford Harbor project, the surrounding community was opposed to incineration of contaminated sediments for fear of exposure to air emissions. As a result, contaminated sediments were placed in a nearshore confined disposal facility (CDF). For the West Eagle Harbor project, proposed shoreline redevelopment activities included the expansion of the Washington State ferry system facility which would result in the displacement of a local boatyard and haul-out facility for local boaters. The local community residents appealed the loss of their local boatyard. As a result, EPA amended the ROD, specified which off-site disposal, allowing construction of a nearshore CDF which would give the ferry system the additional space they needed and allow the adjacent boatyard to remain in-place.

Seasonal Restrictions. Almost all of the projects reviewed had seasonal limitations and permit restrictions associated with dredging operations. Many of these site-specific restrictions limited dredging operations to only six months of the year. Fish spawning restrictions often applied for three to five months a year to protect aquatic life. Boating season restrictions (when dredging activities could not limit passage of ships or recreational boats) were often in place during the summer months in many river and lake systems. Onset of winter conditions (ice, cold temperatures), especially in the Great Lakes region, limited dredging equipment operations to warmer months. The frozen surface ice limited the mobility of equipment and the cold temperatures compromised the effectiveness of equipment. Some projects, such as Lower Fox River SMU 56/57 and Manistique projects, struggled to meet the

project target goals before onset of winter conditions, often requiring demobilization before site activities had been completed.

3.7 Environmental Monitoring Program Results

A summary of the monitoring program elements and the results associated with each testing media are summarized at the end of each case study located in Attachment 1. Additional monitoring program designs for other case study projects are included for reference in Attachment 2. The monitoring programs utilized for the 20 case study projects are summarized in Tables 9 through 12. The most common monitoring parameters utilized at the dredging sites were sediment, water quality and fish tissue sampling (discussed below). However, the purpose of the sampling events were often different depending upon the phase of the remedy effort. Using the phase of the remedy effort as a guide, the monitoring program elements were easily divided into four groups:

- Baseline;
- Implementation during dredging (short-term);
- Post verification (short-term); and
- Long-term.

A summary of the results and types of monitoring used for each group is discussed below and presented in Tables 9, 10, 11, and 12.

Aerial photograph of River Mouth, Green Bay and Renard Island CDF
Source: B. Paulson, WNDR

Baseline monitoring was conducted to establish a level of comparison. Short-term monitoring during implementation was performed to ensure compliance with water quality requirements and minimize downstream transport of contaminants during dredging. Verification monitoring was conducted immediately after completion of dredging to ensure the actions were implemented as designed. Long-term monitoring was conducted to verify achievement and performance of the remedy.

The measurement methods used to verify achievement of short-term target goals and long-term objectives were dependent on the nature of the goal/objective. For example, all projects with chemical criteria target goals used post-project sediment samples to verify compliance. Projects with physical goals used bathymetry and mass reduction of contaminants to verify compliance. However, in some cases (Ford Outfall, Black

River, Lower Fox River - SMU 56/57 and Deposit N, Sheboygan River) where the target goal was to depth or horizon, verification sampling was conducted as a secondary measure to ensure that the site characterization adequately predicted hotspot depths and to use residual concentrations as baseline measures for future monitoring.

3.7.1 Baseline Monitoring

The results of the baseline monitoring review are summarized in Table 9. Physical, chemical, and biological data collected for baseline events generally included bathymetry, sediment, surface water chemistry, and fish tissue, respectively. Physical monitoring included bathymetry in 17 of 20 projects and surface water quality (e.g. turbidity, pH) in four projects. Sediment was analyzed for chemistry prior to dredging in each of the 20 projects reviewed. Analysis was on surficial sediment in six projects, cores in nine projects, and both in two projects. The sample collection technique was not specified in the three remaining projects. Surface water chemistry was analyzed in nine projects and baseline air monitoring was conducted in four projects.

Vibracore Sampling
Source: ThermoRetec

The most predominant biological monitoring was tissue analysis of fish and shellfish in six out of 20 studies. In one study where fish tissue analysis was conducted, vegetation, benthic algae, phytoplankton, and zooplankton tissues were also analyzed for COCs. Invertebrate toxicity and benthic abundance were also commonly measured during baseline monitoring.

Sediment samples were collected using cores at a much higher frequency than surficial samples in baseline monitoring when compared to other monitoring periods. This was due to the desire to measure concentrations of contaminants in sediment at various depth horizons. Sediment sampling in other monitoring periods were often only concerned with surface sediment concentrations. This observation did not apply to projects in which a cap was applied after dredging and sediment sampling was conducted to evaluate transport of contaminants through the cap.

3.7.2 Implementation During Dredging Monitoring

The results of the implementation during dredging monitoring review are summarized in Table 10. Physical, chemical, and

biological data collected for implementation monitoring generally included bathymetry, surface water chemistry, and caged fish/mussel tissue, respectively. In some cases, surface sediment samples were also collected between dredging passes to determine compliance with concentration-based cleanup goals. However, for the purposes of this study, these surface sediments samples used to describe current conditions after immediate dredging passes are described in the post-monitoring section.

Physical monitoring focused on surface water quality, which was measured in 16 of the 20 projects. Seven monitoring programs measured bathymetry during dredging to monitor progress. Surface water was the most commonly analyzed chemical parameter, being measured in 11 of the 20 projects. Air monitoring was also commonly measured, occurring in nine of 20 sites. Analysis of sediment chemistry was only noted in four projects during dredging (two surface, one core, and one not specified).

Hydraulic Auger Dredge
Source: EPA

Fish and shellfish tissue were the most common biological parameters analyzed (five of 20 projects). The shellfish studies generally utilized cased mussels at fixed locations. Although case studies sensitive indicators of sediment transport and uptake they are subject to significant confounding factors (such as passing vessel) that traffic render the results questionable (e.g., Lower Fox River SMU 56/57). Physiological parameters were monitored in fish at two projects, but no fish/shellfish toxicity tests were completed in any project. Invertebrate toxicity was measured in one project, however, no benthic abundance was conducted in any projects.

The focus of monitoring conducted during dredging was on the control of contaminant transport, rather than cleanup goals. This is illustrated by the predominant inclusion of surface water quality, surface water chemistry, air monitoring, and fish and shellfish tissue analyses in the monitoring program. Other than bathymetry, which was commonly used to measure progress of dredging, no monitoring parameter was included in more than three monitoring programs. Physiological responses in fish were measured in two monitoring programs as an inexpensive method to evaluate toxic effects. While only included in the Black River and Lake Jarnsjön monitoring programs, physiological responses were successfully used to determine project effects on receptors.

Programs which included other parameters, (e.g. sediment cores and invertebrate toxicity) did not apply the data to aid project evaluation or adjustments to design.

3.7.3 Post-dredging Monitoring

The results of the post-dredging monitoring review are summarized in Table 11. Physical monitoring included bathymetry in 14 of the 20 projects and surface water quality in two projects. Chemical analysis of sediment was conducted in 17 projects. Surficial sediment samples were preferred in post-dredge monitoring, being collected in 11 projects, while cores were collected at three projects, and the sampling method was not specified in three others. Surface water chemistry was only measured in four projects, and no air monitoring was conducted in any of the post-dredge monitoring programs. Biological monitoring included fish/shellfish tissue (five of 20) and benthic abundance and invertebrate toxicity (three of 20). Fish/shellfish were evaluated for physiological responses in two projects, although no toxicity testing was conducted on fish or shellfish in any project.

Deposit N Sand Drop Box
Source: Bill Fitzpatrick, WDNR

Either sediment chemistry or bathymetry was noted as a part of the post-dredge monitoring in each of the projects, except in Manistique River where monitoring data is not yet available. Monitoring of bathymetry and sediment chemistry are logical and direct methods to measure achievement of dredge depth and chemical sediment criteria. Although not used as commonly, fish tissue data also served to measure attainment of project goals in dredging projects.

3.7.4 Long-term Monitoring

The results of the long-term monitoring review are summarized in Table 12. Long-term monitoring was limited to chemical and biological analyses; no physical monitoring was noted in any of the projects. Commonly monitored parameters included sediment chemistry and biological tissue analyses. Sediment chemistry was analyzed on surficial samples in six projects, cores in two projects, and was not specified in one project. Biological analyses included tissue chemistry of fish and/or shellfish (seven projects) and plant, bird, and algae tissue (one project) and benthic abundance (five projects). No chemical air monitoring was conducted and surface water was only monitored at one project.

The extent of long-term monitoring and the parameters measured were considerably different compared to other monitoring periods. Compliance with long-term objectives is shown to be primarily measured through sediment chemistry, fish tissue, and benthic abundance. It is not surprising that emphasis is placed on fish tissue during long-term monitoring considering depuration rates for contaminants in fish require three to seven years, depending on the species (Thomann and Connolly, 1984).

3.8 Performance Evaluation Results

The performance evaluations for each project are discussed in Section 4.

3.9 Costs

Total remedial implementation management, monitoring and disposal costs ranged from approximately $0.5 to $44 million. Three out of 20 projects did not have costs available for review. The total costs per cubic yard ranged from $6 to $1,842 (Table 13). The dredging component alone ranged from approximately $6.20 per cubic yard to $507 per cubic yard (N = 11, other data not available). The dredging costs per cubic yard generally decreased as the volume of sediment to be removed increased (regardless of removal method). However, the total remediation project costs were variable and did not correlate to sediment volumes. This variability can be explained by site-specific differences in management plans, disposal options, site restrictions, monitoring, and redevelopment decisions.

3.10 Contacts

The EPA (or equivalent) was the lead agency on 17 of the 20 projects reviewed. The remaining three projects were conducted under state lead.

Deposit N Water Quality Monitoring
Source: Bill Fitzpatrick, WDNR

4 Data Analysis and Verification of Goals

Measures of success depends on the question being asked, and as such, there can be no single measure of success for all of these projects. Success is measured on a site-specific basis and for the purposes of this report, success is defined as the degree to which the remediation activity achieved the short-term target cleanup goals and long-term remedial action objectives (RAOs). Achievement of short-term performance-based

target goals were determined by comparing the results to the site-specific expectations defined by the project. Achievement of both target goals and long-term risk reduction is limited by the ability to verify the achievement and is solely dependent on a well-developed monitoring plan. The verification of achievement should also recognize dredging design factors, implementation difficulties, presence/absence of a decision-making framework, and the monitoring program design when evaluating each project. Each of these elements will be discussed separately below as they relate to the contaminated sediment dredging projects reviewed:

- Achievement of short-term performance-based target goals;
- Degree of progress towards long-term project objectives, as they relate to risk reduction;
- Application of a dredging design components; and
- Adequate design of monitoring methods used to verify achievement of goals.

4.1 Achievement of Short-Term Target Goals

4.1.1 Summary of Projects Reviewed

As previously summarized in Section 2, the performance-based target goals were grouped into four categories: 1) removal to a chemical criteria; 2) volume or mass removal; 3) removal to a physical horizon; 4) removal to an elevation; and 5) removal to a vertical depth below the sediment surface. Sites with no stated goals or assumed to be mass removal projects were generally pilot studies, focused time-critical removal actions, or combined with other objectives in mind. Removal of sediments to a chemical criteria were generally based on site-specific, risk-based models or regionally-developed sediment quality thresholds such as used in Puget Sound and Canada. Cleanups to a chemical criteria were designed to be protective of human health and the environment. Removal of sediments to a depth, horizon, or design elevation were also intended to be protective of the environment through previous site characterizations and knowledge of the distribution of

Box Core Sediment Sampler
Source: EPA Great Lakes National Program Office

contaminants. However, other physical performance-based criteria were used by design instead of a chemical concentration. Post-verification sampling of the residual sediments were used to determine residual chemical concentrations after remedy completion. In most cases, when other criteria were used for the contractors besides chemical concentration, the COCs were contained in the surficial/near-surficial soft, silty to silty sand sediment deposits overlying denser sand deposits or bedrock/ hardpan. Excavation to these identifiable and quantifiable horizons added a second tier of quality control to the dredging activities. The distribution of the target goal types and their relative percent success are summarized below:

Distribution of Performance Goal Types and Achievement

Short-Term Target Goal	Number of Projects	Number of Projects Achieving Performance-Based Criteria
Chemical Criteria	10	8
Mass Removal	3	3
Horizon (bedrock)	2	2
Elevation	2	2*
Vertical Depth	3	3
Total	**20**	**18**

* SMU 56/57 did not reach target elevation during year 1999 dredge activities, but did reach the target elevation in year 2000.

Residual surface sediment concentrations for each project are listed in Table 5, and the volume/mass of sediment removed is presented in Table 12.

4.1.2 Evaluation of Effectiveness and Implementability

Of the 20 case study projects reviewed, 18 projects met their stated target goals. The two projects that did not meet their stated target goals were GM Foundry and Manistique Harbor/River. The Lower Fox River SMU 56/57 project did not meet the target elevation during year 1999 dredge activities, but returned to the site in year 2000 and completed the sediment removal to project specifications. A fourth project, the Ford Outfall site, met 80 percent of its target goal and therefore was lumped into the "achieved goals" group.

Sampling
Source: ThermoRetec

The target goal of the Ford Outfall project was to remove soft overlying silt down to hardpan (glacially overridden silt/sand/ gravel, called till); however, verification sampling required residual sediments to measure less than 10 ppm PCBs. Verification sampling measured below 10 ppm in 11 of the 14 dredge cells (80 percent successful). In the case of GM Foundry, great care was taken to implement a successful project with extensive design elements, pilot testing, and modeling; however, post-project residual PCB concentrations were higher than the target chemical criteria. In the case of Manistique, PCB concentrations were also higher than the chemical criteria. For both projects, development of unrealistic target goals, lack of adequate understanding of site conditions, and the need for additional engineering design components, were likely contributors to dredging projects not achieving target goals.

In the case of the Lower Fox River SMU 56/57 demonstration project in year 1999, the initial contractor did not meet the target elevation criteria in 49 of the 53 dredge subunits, not because of limitations in dredging equipment, but because of the need to demobilize before onset of winter. A final cleanup pass was implemented in four subunits to assess dredging effectiveness and the ability to achieve target elevation goals at the site. In the four areas dredged to the design depth, the verification samples measured low concentrations of PCBs (below the anticipated goal of 1 ppm although not a specified design criteria). In areas where a final cleanup pass was not conducted to the design elevation, residual surface sediment concentrations higher than the chemical criteria (up to 280 ppm PCBs) were left exposed. However, in August 2000, a new dredge contractor returned to the site and continued removing impacted sediments. Sediments were successfully removed to the target elevation and confirmation samples were below the target criteria of 10 ppm PCBs (avg. = 2.2 ppm). In summary, the target goal is achievable based on well-planned implementation of dredging techniques.

Based on the review of primary reports and interviews with site managers, the most likely explanations for not achieving target goals included the following physical constraints: the unforeseen extent of wood and other debris (e.g., rock or construction materials) limiting the access to sediment removal, presence of an

impenetrable base layer (hardpan, bedrock) preventing removal of residual sediments resting on it, and recontamination of the dredge area from external sources (passing ships, sloughing side slopes, transport from other sediment sources). Each of these physical constraints is discussed below.

Presence of Rock, Wood and Other Debris. Dredging technologies had trouble effectively removing material located between rocks and debris. Often these materials clogged the dredging/dewatering equipment thereby slowing down production rates. Adequate characterization of site conditions were needed to develop realistic target goals and to select the most appropriate removal technology. Ford Outfall and Manistique both encountered cobbles, rocks, and debris which compromised the ability to remove contaminated sediments and limited the production/capacity of selected equipment to handle the site conditions. In the case of Manistique, some of these obstacles were not adequately characterized prior to mobilization for dredging, and thus were not anticipated. Therefore the appropriate technology and target goals for Manistique were not assigned. On the other hand, both the Grasse River and GM Foundry projects anticipated significant amounts of rocks and cobbles at the site and mobilized excavation equipment to specifically remove larger material before dredging equipment was mobilized, alleviating much of the burden during dredging.

Presence of Bedrock and Impenetrable Base Layers. In cases where overdredging was feasible, (Sitcum Waterway, Wyckoff/West Eagle Harbor, and Lake Jarnsjön) where the absence of hardpan or bedrock enabled the dredge to penetrate below the contaminated sediments, removal of all contaminated material was likely ensured (assuming source control). However, most of the river systems reviewed (Lower Fox River Deposit N, Manistique, Ford Outfall, GM Foundry) were not able to overdredge since the soft sediments generally rested on bedrock/hardpan. In the case of Lower Fox River Deposit N, the project was designed with this limitation in mind and sediments were dredged to within 3 inches of hardpan, recognizing that residual contaminants would be left in place. Although these sediments were newly exposed at the surface, a significant portion of the PCB mass was removed and the areal surface coverage of sediments exposed at the surface was significantly reduced. Built into the

Assembling Slurry Pipeline
Source: ThermoRetec

remedial design was the expectation that the residual PCBs would attenuate through burial by the natural river sediments load. Thus, the cost of the project was contained at approximately $4.3 million, saving the project time and resources to excavate the thin layer of sediment resting on top of the bedrock by incorporating an element of natural attenuation. This project met its short-term target goal of achieving a vertical depth below mudline (as opposed to a chemical criteria).

In summary, dredging equipment is limited at effectively removing excavate residual sediments resting on bedrock, but this limitation is often coupled with site conditions such as the percent solids of *in-situ* material and how easily the material is resuspended and resettled, along with the ability to control downstream transport of suspended material. However, overdredging is feasible when bedrock/hardpan is not present, and where site conditions allow overdredging, target cleanup goals can usually be achieved.

Recontamination and Source Control. Beyond the obvious potential for recontamination of dredge areas located within larger areas of concern, localized sources of recontamination included sloughing from side slopes, resettling of suspended solids from dredging activities, and river currents/passing ships disturbing the sediment bottom and transporting bedload sediments into the dredge area. In the case of the Ford Outfall removal project, the dredge prism extended below the navigation channel creating unstable side slopes that sloughed into the excavation underneath the silt curtain. At the Wyckoff/West Eagle Harbor site, the newly exposed intertidal sediments were sloughing from tidal action and required armoring to stabilize the slopes. At the GM Foundry site, the verification samples may have been collected from underlying glacial till that contained contaminated material when most of the overlying soft silts were removed.

4.1.3 Reduction of Surface Sediment Concentrations

A total of 17 out of 20 projects successfully reduced the maximum detected concentrations in surface sediments by 69 to 99.9 percent (Table 5). Three projects with post-verification concentrations similar to the baseline concentrations were the Black River, Puget Sound Naval Shipyard (PSNS) and Lower Fox River SMU 56/57 (1999) sites. For the Black River, however, the long-term remedial action objective of reduced fish liver neoplasm deformities was achieved. For the PSNS and 1999 SMU 56/57 projects, the majority of the dredge prism of contaminated sediments was removed; however, a small portion was left in place because of policy and field decisions, and not because of dredging equipment

limitations. As a result of these projects knowingly deciding to stop dredging before removing an entire deposits, sediments with elevated concentrations of contaminants were newly exposed. In the cases of Bayou Bonfouca and Collingwood Harbour, post-verification sample results were not available for review, but it was assumed that the target goals were achieved since the long-term goal of protecting human health was realized when the fish consumption advisories were lifted (Table 4).

4.1.4 Limitations of Target Goals

Critics of dredging (BBL, 1999) cite that although dredging projects have successfully reduced the volume and mass of contaminated sediments, these are not relevant measures of success, since by definition, each project achieved mass removal. They cite that only evidence of reduced chemical concentrations and reduced risk to the environment are viable measures of achievement. Furthermore, researchers argue that if reductions of risk are actually measured (e.g., lower bioaccumulation in fish, lower surface sediment concentrations), that the source of the effect cannot be quantitatively distinguished between different remedies such as source control, natural attenuation, dredging, or other isolation of contaminants. Other naturally-occurring site conditions may be confounding the interpretation of dredging effectiveness.

Silt Curtain
Source: ThermoRetec

How can we distinguish between the effects of source control or natural attenuation on the system and the effects of an implemented dredging program? Well-designed monitoring programs that are consistently implemented would help determine the natural variability of the system and be able to distinguish between a full-scale removal effort and natural attenuation. The relationship and direct exposure pathways between surface sediment concentrations and water column concentrations to bioaccumulation in aquatic organisms are well established; however, adequate post-project monitoring programs and sufficient time are required to observe long-term trends over time.

Finally, surficial concentrations only reflect a single “snapshot” in time and may not reflect longer term exposures. Dynamic and episodic deposition and scour patterns need to be evaluated when

determining residual risk. If deeper sediments with higher concentrations remain in-place, then the confidence in which these sediments will remain buried versus resuspend from physical disturbance events (i.e., storm events, ice scour, prop wash) is not always well defined.

4.2 Achievement of Long-term Project Objectives

4.2.1 Summary of Projects Reviewed

Long-term RAOs were grouped into three major categories: 1) protection of human health, 2) protection of the environment, and 3) physical removal of the contaminant mass for source control, with an implied intention of protecting the environment. The third category also includes pilot studies that generally do not have well-defined long-term objectives beyond mass removal. The distribution of the RAOs stated for each project are summarized below and in Table 14:

Distribution of Remedial Action Objectives and Status of Achievement

RAO	No. of Projects	Achieved [1]	Progress Towards [2]	Variable Results [3]
Protect Human Health	9	▸ Bayou Bonfouca ▸ Black River ▸ Minamata Bay	▸ GM Foundry ▸ Ford Outfall, Waukegan	▸ Marathon Battery ▸ Grasse River ▸ Manistique
Protect Environment	6	▸ Collingwood ▸ Lake Jarnsjön ▸ Sitcum Waterway	▸ Wyckoff/WEH	▸ New Bedford Harbor
Physical/Source Control	5	▸ None	▸ Port of Portland ▸ Port of Vancouver ▸ Sheboygan,	▸ New Bedford Harbor ▸ PSNS ▸ Fox River Deposit N ▸ Fox River SMU 56/57
Total	**20**	**6**	**7**	**7**

Notes:

[1] Fish consumption advisories have been removed, or site restored to functional use, or the sites were delisted from regulatory status.

[2] Some evidence of decreasing concentration in sediment and biota tissue, but no decision-making action taken based on results.

[3] No discernable trends observed.

Protection of human health in this context implies reduction of risk through dermal contact and fish consumption. Measurement endpoints used to assess protection of human health were usually surface sediment chemistry (isolation/removal of contaminants) and removal of fish consumption advisories. Protection of the environment in this context implies a reduction of risk to invertebrates, fish, birds, and mammals through sublethal and lethal toxicity, reproduction, bioaccumulation, and consumption. Measurement endpoints used to assess the protection of the environment included water column and benthic toxicity testing, benthic community structure (although hardly ever assessed for compliance because of inherent variability), and fish tumors and lesions.

Measurement endpoints used to assess the protection of the physical environment (minimized downstream transport of contaminants and isolation) were surface sediment chemistry, removal of contaminant, mass/volume, and downstream resident fish tissue sampling. Removal of contaminant mass is assumed to reduce the risk of downstream transport by eliminating the sediment source.

Lack of long-term objectives generally apply to pilot studies where the information gained would be applied to a larger scale remedy, and doesn't necessarily imply a "lack of planning" or that the project goals were not achieved. Basically, it means these projects cannot be evaluated solely by the metric of measurable risk reduction because there was no intent for long-term objectives to be measured (e.g., Sheboygan River) nor was risk reduction necessarily a major goal of the project. These projects sometimes do measurably reduce risk, but instead are intended to provide source control and to gather information on the ability to implement tested technologies.

4.2.2 Evaluation of Effectiveness and Implementability

Of the case study projects reviewed, six met their stated long-term project objectives (Bayou Bonfouca, Black River, Minamata Bay, Lake Jarnsjön, Sitcum Waterway, and Collingwood Harbour). In the first three cases, the fish consumption advisories have been rescinded from the project area (Table 4). Both Collingwood Harbour and Sitcum Waterway were delisted from regulatory status. Although a change in the regulatory status of the Lake Jarnsjön project was not specified, the project achieved its stated goals of reduced PCB levels in biota. For Waukegan Harbor, the fish tissue concentrations in carp fillets showed a significant

downward trend from pre-dredge conditions, but the data was considered by some reviewers to be inconclusive because of small sample sizes and large variability. Despite this variability, the fish consumption advisory for Upper Waukegan Harbor was rescinded. (However, recent 1999 fish data for Waukegan Harbor may require re-evaluation of advisory status; the chemical criteria selected for clean up may not have been protective enough.)

The fish consumption advisories were lifted from dredging projects completed between 1990 and 1995, and none of the projects completed during and after 1995 have had consumption advisories lifted. In addition, the two projects completed in 1993, Sitcum Waterway and Collingwood Harbour, have had regulatory closure for the sites. Since depuration rates for PCBs and other contaminants in fish tissue requires three to seven years (depending upon the species), projects completed after 1995 will likely require additional monitoring to observe consistent downward trends in fish tissue concentrations (assuming source control or mass reduction) (Thomann and Connolly, 1984).

4.2.3 Limitations of Long-term Remedial Objectives

Critics of dredging often state that dredging is often unable to remove all constituents from the sediment bed and that dredging destroys existing habitat. They state that dredging has limited effectiveness in reducing the amount of biologically available PCBs (in the surface sediments) and the contaminants of concern could be resuspended and released to a waterway during dredging only to be redeposited outside of the dredge area and carried downstream. Constituents left behind could be available to the food web at higher concentrations than if the dredge area was left to natural attenuation.

Research studies to assess the quality of long-term monitoring plans (NRC, 1990) found numerous limitations in the data sets including:

- Limited availability of long-term fish data monitoring results;
- Lack of comprehensive post-closure monitoring reports and documentation;
- Detailed descriptions of fish collection data are often missing (age, size, sex, season, weight, fillet vs. whole body, lipid-based corrections, collection location,

resident or caged, suspended in water column on substrate);

- Inability to distinguish between dredging effectiveness, source control, and recontamination; and

- Although reduction of PCBs in fish is a meaningful measure of risk reduction, inherent variability exists in the measurements. It is difficult to filter out confounding factors and determine the relationship between fish tissue concentrations (fish deformations) and reduction of sediment concentrations from dredging activities.

These limitations confounded the monitoring efforts and their ability to verify achievement of long-term remedial objectives.

4.3 Evaluation of Engineering and Design Components

4.3.1 Summary of Projects Reviewed

Design components of each remediation project were evaluated to determine the level and extent of pre-planning and site characterization prior to mobilization to a site. Site conditions and design factors that influenced the outcome of each project are summarized in Table 15. Some of the design components evaluated and considered to be useful for maximizing the likelihood of success included (EPA, 1994; Averett, 1995):

- An experienced dredging design consultant;

- Early identification of required approvals/permits, and ability to comply with them;

- Adequate baseline monitoring to verify achievement;

- Verification sampling before demobilization from site;

- A silt curtain/barrier to prevent downstream migration;

- A performance-based contract allowing contractor flexibility to meet objectives;

- Source control in place or at least considered;

- Long-term monitoring in place or considered;

- Physical constraints anticipated;
- Predictive modeling of contaminant releases;
- Adequate physical characterization of impacted sediments including design level informational studies;
- Remedy not limited by treatment or disposal constraints;
- Contingency plan for evaluating exceedances during dredging;
- Selection of equipment compatible with site conditions and the constraints of the project; and
- Realistic target goals for the site conditions and overall objectives.

Although design components were evaluated while reviewing project documents (Table 2), each case study had a unique set of variables, site conditions, and regulatory framework which made it difficult to categorize or group the results. However, a common theme resurfaced on many projects which included: 1) installation and maintenance of containment systems and realizing their limitations, 2) performance-based contracts to help ensure compliance with environmental monitoring and criteria, and 3) a complete understanding of site conditions to minimize unforeseen problems in the field and to select the most appropriate removal technology.

4.3.2 Evaluation of Effectiveness and Implementability

Containment Systems. A total of 15 out of 20 projects observed no significant exceedances of water quality (turbidity and total suspended solids [TSS]) during dredging activities (except from storm events and passing ships). One project (Sheboygan River) observed some turbidity and water quality exceedances in downstream samples. For the remaining four projects, data was not available for review. The Grasse River project had turbidity exceedances during the initial boulder removal activities, but water quality measurements further downstream were in compliance. Three projects (Sitcum Waterway, Port of Portland, Wyckoff West Eagle Harbor, and Port of Vancouver) did not install barrier systems around dredging activities. Compliance monitoring boundaries were established at the dilution zone boundaries and no exceedances were observed at these points. No exceedances were

measured in any of the water quality samples collected for chemistry, it seems turbidity was a more sensitive indicator of sediment transport. However, the significance of turbidity measurements should by reviewed based on to possible lack of correlation between turbidity and the chemical concentration of surface water. Caged fish samples were also sensitive indicators of resuspension showing elevated concentrations of contaminants during dredging activities in all projects used. However, the data had limited decision-making value and did not help determine net sediment transport rates or masses.

Air Quality. At least nine projects monitored air quality during dredging and dewatering operations. Samples were collected immediately around the operations and compared to ambient air quality samples collected further offsite. No major exceedances above safe human health levels defined for the project were observed. In general, no management action or remedy modifications were implemented based on measured air quality concentrations.

Performance-based Contracts. A time and materials contract may allow for large cost overruns without accountability by contractors to help achieve the project goals. The New Bedford Harbor project was a fixed price for hotspot removal that also included water treatment and incineration. Projects including Lower Fox River Deposit N, Sitcum Waterway, and Wyckoff/West Eagle Harbor, the contractor was aware of the project objectives, given flexibility to meet these objectives, and held accountable through performance-based contracting.

Disposal Site Liner Fabric
Source: ThermoRetec

Understanding of Site Conditions. Physical conditions of the site, physical properties of the sediment (obtained from testing and include grain size, specific gravity, percent solids, Atterberg limits, and WET testing methods), and the extent of contaminated sediments need to be adequately characterized to maximize the likelihood of success. At the GM Foundry site, although the soft sediments containing most of the contaminant mass were removed, the verification samples had elevated concentrations above cleanup criteria. One commonly perceived explanation for the elevated samples was that the underlying

glacial till layer (below the dredge design depth) had absorbed the PCB contaminant thereby confounding possible verification of sediment removal to the target cleanup goal. At the Manistique site, sediment core refusal to a hardpan layer was inappropriately confused with the buried slab wood and debris, when the actual stratigraphic horizon with clean material occurred much deeper in the profile at the bedrock interface. Most of the projects reviewed, however, conducted detailed bench-scale tests, laboratory physical testing and/or pilot studies (Sitcum Waterway, Lake Jarnsjön, Wyckoff/West Eagle Harbor, New Bedford Harbor, Collingwood Harbour, Bayou Bonfouca) which contributed to the observed success of achieving target goals for these projects.

4.3.3 Limitations of Design Components

Selection of specialty dredges designed for minimizing sediment resuspension or for maximizing performance does not guarantee superior results. The key to effective operations not only includes the selection of appropriate equipment, but also the use of highly skilled dredge operators that understand the constraints of the project and are managed by performance-based criteria and compliance monitoring (EPA, 1994).

Critics of dredging cite that dredging is too costly for removing well-distributed moderately contaminated sediments over a large area. A common criticism is that mass removal of contaminated sediment is not an important objective; only reduction of risk to human health and the environment is important (BBL, 1999). However, mass removal often serves as a method of source control to prevent further downstream migration and dispersion of contaminated sediments. Mass removal can serve to reduce risk by depleting the environmental reservoir of contaminants thereby accelerating the dilution of remaining contaminants. Mass removal may also change the depositional patterns of a sediment site by shifting from steady-state model to an area of deposition or accretion. By removing a volume of contaminated sediment, these newly vacated areas can capture suspended sediment particles leading to deposition and accelerated burial of residual contamination not potentially captured by the mass removal dredging efforts.

The intended purpose of the remedy and associated costs are policy decisions and not decisions that impact the use of dredging as a tool for source control and long-term benefit.

4.4 Evaluation of the Monitoring Programs

4.4.1 Summary of Projects Reviewed

Monitoring programs were developed to verify achievement of target goals, to verify improvement of valued resources, to determine the effectiveness of remedial activities, and to determine if adequate source control was achieved for the project area. Most of these elements were mentioned in earlier sections of this document and are briefly summarized here. The types of measurement endpoints used in the monitoring programs to verify achievement of target goals and recovery of impaired resources (long-term goals) were summarized into eight categories:

Measurement/Assessment Endpoints		
Measurement Endpoint for Assessing Impairment (SedPac, 1999)	**Used for Assessing Short-term Target Goals (N = 20)**	**Used for Assessing Long-term Objectives (N = 20)**
Sediment Chemistry	20	3
Water Column Chemistry	2	1
Caged Tissue - Fish, Invertebrates	6	2
Resident Tissue - Fish, Invertebrates	6	6
Fish Deformities	1	1
Benthic Community Structure	2	2
Water and Sediment Toxicity	3	3
Sediment Traps	1	0

4.4.2 Evaluation of Effectiveness and Implementability

Monitoring programs were used to evaluate project success and attainment of project objectives and goals as well as to gather information useful in project design and in process modifications. Projects often used bathymetry measurements, sediment chemistry, and fish tissue data to determine project success. Successful projects were often improved through the development of monitoring programs which throughly measured baseline physical and chemical site characteristics, developed consistent monitoring parameters, and considered short-term and long-term goals and objectives at all stages of the monitoring program. Those programs which did not develop consistent monitoring through selection of target species, sample type, or sample collection method, had difficulties developing trends and were viewed with scrutiny.

Evaluation of Baseline Conditions. The most commonly cited factor contributing to the failure of attaining project goals was

inadequate characterization of baseline conditions. Physical characteristics of the sediment and subsurface conditions including presence of buried rock, boulders, dense sand, and/or gravel were noted as a primary factor limiting the removal of sediment in the Grasse River, Lake Jarnsjön, Marathon Battery, and Port of Vancouver projects. Many of these characteristics were not revealed during pre-dredge monitoring studies. The presence of wood debris mistaken for bedrock inhibited sediment removal and contributed to miscalculations of contaminant distribution in the Manistique River and Harbor project. The failure to identify actual conditions led to significant increases to the volume removed and project cost. The extent of baseline contaminant distribution, however, was corrected during the Bayou Bonfouca dredging project, allowing the scope of work to be expanded prior to commencement of remedial activities.

Monitoring Program Development. Project success was usually evaluated through monitoring efforts designed specifically for the project goals. For example, bathymetry measurements were commonly used to evaluate success of projects to achieve the design depth, while sediment chemistry was measured to gauge success in achieving COC concentration criteria. Use of consistent monitoring parameters was necessary to evaluate the positive or negative effects of dredging. This is of particular importance in biological monitoring due to the variability of factors such as species, tissue type (whole body, fillet, etc.), and source of samples (caged vs. resident).

Monitoring was fairly consistent in most projects, although variability between pre and post remediation did exist. For example, the GM Foundry and Lake Jarnsjön projects consistently monitored fish with regard to analytical method, species, and timing throughout both projects resulting in data which was temporally comparable. In the Grasse River project, caged fish were consistently monitored the dredging program for measuring the effects of dredging. Resident fish, however, were only collected after completion of dredging and could not be used to gauge the effectiveness of dredging. In the case of Bayou Bonfouca, crab tissue samples were collected during the baseline event, but fish tissue samples were collected during the post-project sampling and therefore not comparable.

In the case of Ford Outfall and GM Foundry, no post-project resident fish were collected, and tissue monitoring started 1 to 2 years into the long-term monitoring plans. Tissues sampled in the Marathon Battery project varied considerably between monitoring

periods. During baseline monitoring, macroinvertebrates, and plant tissues were analyzed for cadmium, however, post-dredge analyses included benthic algae, plant, and bird tissues. Of the six tissues analyzed, only two were comparable, making the evaluation of dredging difficult. Although five projects used benthic community structure to assess impairment of resources, only two projects used this method for measuring beneficial reuse of habitat (Collingwood Harbour and Marathon Battery).

Evaluation of Post-Remediation Conditions. Many projects did not conduct any post-verification sampling, but began a long-term monitoring program three to four years after project completion.

Lake Kettelmeer Disposal Site
Source: Terra et Aqua

Monitoring programs need to consider the long-term objectives of a project prior to collection of baseline data so that results are comparable and dredging effects can be quantified. Changes in background exposure conditions over time also need to be taken into account when evaluating the success of remedial actions, or when evaluating natural decline in fish tissue concentrations without active intervention by dredging. In the New Bedford Harbor project, the long-term monitoring program was clearly outlined early in the project. Parameters measured and sampling methods followed the procedures set forth for baseline and post-dredge monitoring.

4.4.3 Limitations of Monitoring Programs

Monitoring programs need to adequately characterize the baseline conditions prior to remediation, develop consistent monitoring parameters, and formulate expectations prior to implementation. Most of the monitoring programs reviewed included sediment chemistry sampling and fish tissue sampling to determine compliance with project objectives. However, the frequency of sampling, the species selected over time, and the purpose of sampling are often unclear and inconsistent. Monitoring programs should be reasonable based on baseline data, and be designed to answer the question asked. The success of dredging projects and the applicability of the data used to evaluate success are largely determined by the monitoring program.

4.5 Lessons Learned

Common lessons learned from this review of case studies and summarized from other studies (SMWG, 1999; SPAC, 1999; BBL, 1999; IJC, NRC, 1997; Cushing, 1999; Cura et al., 1998) are summarized on Table 15 and include:

- The availability and quality of final post-project reports was limited.

- The role of sediment surface area on total load of PCBs into surface water (a primary route of exposure to fish and invertebrates) is very important (Ortiz et al., 1998). Removal of small hotspots may not significantly reduce the concentrations observed in surface water since low PCB contaminants may be contributing the bulk of PCB loads into surface water; however, mass removal to prevent downstream transport of contaminated material and dispersion of hotspots into widely distributed concentrations may be appropriate. The purpose of the remedy and the questions being asked must be carefully defined.

- Wastewater effluent requirements tend to be very restrictive. Contaminants returned to the site via treated wastewater are insignificant relative to existing site conditions, site risk, and contaminant mass.

- Defining the remedial goal as a surface-weighted average concentration over a moderate size area may be a useful way to evaluate dredging effectiveness.

- Dredging technologies typically cannot remove 100 percent of soft sediments down to bedrock or other impenetrable layers. At least 80 percent removal of the material can be expected, and some sediment residuals resting on bedrock should be expected. The amount of material left behind and the estimated percent concentration should be considered when designing a remedial program. Acceptable levels of short-term risk should be determined during the design phase.

- Experiences in the projects reviewed indicate that dredging-induced resuspension is typically not a significant source of off-site contamination. Dewatering-induced particulate matter is typically not a significant source of off-site air quality impacts.

- Barrier systems designed to contain suspended sediment worked very well with few water quality exceedances. Modifications were made efficiently to resolve problems encountered. Caged fish monitoring during dredging usually showed elevated levels of contaminants and therefore may be better, more sensitive, water quality monitors.

- Barrier systems may not always be necessary. Extensive monitoring on the two Lower Fox River pilot projects showed no significant resuspension during dredging activities. The extensive barrier system used on the Deposit N project was deleted from the contract and dredge permit about half-way through the project based on river monitoring.

- In river systems, the target goal of 1 ppm PCBs chemical criteria for post-verification surface sediment samples at discrete locations may not be achievable at all sites, depending upon source control and site conditions.

- Dredging has implementability limitations under site conditions with wood, cobbles and debris, impenetrable hardpan, sloughing from side slopes, shallow water, and difficult access (under piers).

Dredge
Source: Foth and Van Dyke

- Redundancy of critical equipment is a key factor in maintaining project schedules, achieving project goals and cost requirements. For example, the recent SMU 56/57 dredging project in the Lower Fox River had two "backup" dredges on standby which were frequently used during routine equipment breakdowns. Without sufficient spare equipment, breakdowns inevitably slow project progress and impede project goals.

- For hydraulic dredging projects, where feasible, installation of upland physical markers (e.g., sheet piles, concrete blocks) can serve as easy "low tech" survey markers for dredge location control and possibly serve as tie-down points for hydraulic cables.

- Good on-site project management cannot be overemphasized. Essential aspects include good communication between team members, adaptive management to resolve unforeseen site conditions, and proactive planning to modify project expectations at every stage of the operation. Obvious (but sometimes overlooked) activities should include daily progress meetings amongst team members and comprehensive monitoring of dredging operations. Monitoring should include daily tracking of specific targets such as: slurry solids, cubic yards removed, gallons of water treated, mass of contaminated material disposed, dewatering production, discharge water quality, bathymetric elevations, and sediment sampling results (if available). Improvements to the dredging operation need to be continually evaluated on an on-going basis.

- Surface sediment concentrations measurements are valuable and effective methods for determining achievement of target goals; however, this achievement should be coupled with reduction in the surface area of remaining contaminated sediments to ensure achievement of risk reduction and exposure pathways.

5 Conclusions and Recommendations

Based upon the in-depth review of 20 case study environmental dredging projects, several lessons were repeatedly observed in most of these projects. These lessons can be summarized into five key findings discussed below, many of which are similar to the recommendations put forth by the National Research Council in their recent review of similar dredging projects (NRC, 2001).

5.1 Risk Reduction Versus Source Removal

In order to evaluate the objective of reducing fish tissue concentrations and protecting human consumption of fish (typically a major risk driver), then it is necessary to examine the mass of contaminant material removed, the surface-weighted concentration of remaining material bioavailable to the food web, and reduction of the ongoing potential for sediment resuspension from storm events and scouring. These three factors will determine the extent of source control and magnitude of residual risk for a contaminated sediment deposit. Levels of risk reduction is a decision-making process. In some cases the maximum detected concentrations were the similar to the maximum pre-dredge surface

concentrations; although a significant portion of the mass was removed. Many of the projects had elevated concentrations in the water column, surface sediments and caged fish tissues during dredging, although these releases were a fraction of the losses that would occur annually, assuming no removal would take place. In almost all projects, the concentrations measured in the post-project verification and the long-term monitoring samples were significantly reduced in all media if adequate source control was in place.

Cutterhead Dredge
Source: SAIC

Projects designed for risk reduction by mass removal typically have incorporated site-specific and technology-specific limitations of dredging into the design. The projects focused on depletion of the environmental reservoir of contaminants, reduction of off-site contaminant loading, protection from potential disruption by storm events, and encouragement of depositional process at the site to reduce the net residual contaminant concentrations over time. Lowered surface sediment concentration will reduce biological and water column exposure and therefore reduce risk.

A few key findings to consider when developing a dredging program includes:

- Mass removal is a beneficial process of source control which likely leads to long-term risk reduction.

- Individual samples for chemical concentrations in residual surface sediments should be one of several considerations relative to risk reduction. The percent reduction in surface concentrations over the entire deposit/footprint in both the short-term and long-term should be considered.

5.2 Sediment Transport Downstream During Dredging

Excessive downstream transport of contaminants during dredging is an argument cited by some as a major limitation of dredging as a viable remedial alternative. It is undoubtedly true that dredging does cause some short-term resuspension of sediments into the water column and that some of these sediments are transported downstream. However, the prevailing question is whether this mass loading is significant when compared to the entire

contaminant mass, the entire contaminant load from non-point sources, and the long-term protection of the environment from episodic storm events that mobilize large quantities of normally acquiescent deposits. The allowable mass-based loading criteria that can be acceptably transported downstream without adverse risk to the environment can be difficult to quantify. These measures should not be based on a single metric unit, but instead should be risk-based values based on site-specific modeling efforts.

Monitoring. The purpose of water quality monitoring during dredging is to determine if sediments are being transported downstream in excess of criteria (e.g., turbidity) and to possibly quantify the amount of contaminant mass transported downstream. Over 60 percent of the projects reviewed monitored surface water quality during dredging using chemical concentration in addition to turbidity/TSS. The remaining projects monitored only TSS after developing baseline correlation studies with chemical concentrations. However, studies of the Lower Fox River Deposit N and Grasse River projects determined that TSS and turbidity did not completely characterize releases and did not correlate well with PCB mass as sediment properties changed. Although the number of particles suspended in the water column may not significantly change during dredging, the concentration of PCB molecules attached to each grain particle tend to increase during dredging. However, these measurements are expected to be good indicators of more significant releases from dredging operations.

Mass Loading. The New Bedford Harbor and Lower Fox River demonstration projects were the only projects reviewed that monitored surface water quality and transport in terms of mass loading. Results of the New Bedford Harbor dredging project showed that the calculated net total of PCB mass loading was only 24 percent of the total allowable mass transport during dredging (240 kg) to maintain an average downstream contaminant concentration that did not exceed 1 ppm PCB in surface sediment concentrations. The Lower Fox River Deposit N Demonstration Project estimated a net loss of 2.2 kg PCB during dredging operations, less than 0.01 percent of the total PCB mass found in Deposit N.

In summary, sediment remediation projects should consider the purpose and variables of interest when developing a monitoring plan. For example, if the primary variable of interest is contaminant transport, then surface water quality should be measured in terms of overall mass loading during the duration of

the dredging program and steer away from discrete chemical criteria. If the primary variable of interest is acute protection of aquatic life, then short-term measures of dissolved oxygen, temperature, turbidity, oil sheens that may have immediate and adverse impacts to the environment should be monitored.

A few key findings and recommendations to consider when developing a sediment remediation dredging project include:

- Dredging can be conducted without significant contaminant mass loading further downstream when compared to the overall mass of contaminant removed from the site;

- Containment systems were generally effective in over 90 percent of the projects reviewed based on TSS except for a very few short-term exceedances associated with passing ships or episodic storm events;

- Caged mussel and fish tissue analyses conducted during dredging almost always show elevated concentrations when compared to background levels;

- Passing ships, disturbed containment systems, and storm events can act as confounding factors when trying to interpret chemical and biological monitoring data;

- Turbidity and TSS do not completely characterize surface water chemical quality. The concentration of contaminant may increase per grain particle during dredging. However, turbidity and TSS measurements can be valuable indicators of "significant" contaminant releases during dredging;

- For assessing contaminant transport, monitoring plans should measure net mass transport of contaminants.

5.3 Cost-effective Management

Many regulatory and private interest groups are searching for answers to the same questions of how to cost-effectively manage contaminated sediments while ensuring protection of human health and the environment over the long term (Peterson et al., 1999; Hahnenberg, 1999; Krantzberg et al.; Zarull et al, 1999; SMWG, 1999; SPAC, 1997). A few key findings and recommendations to consider when implementing a remedial dredging program include:

- Greater emphasis should be placed on post-project monitoring of effectiveness of sediment remediation and restoration of uses (SedPac, 1999).

- Higher priority should be placed on monitoring of ecological effects and beneficial use restoration at remediation sites (SedPac, 1999).

- Dredging as a remedial tool depends not only upon an adequate site characterization and a clear understanding of impairments and risks, it also depends on policy decisions developed for the purpose of dredging rather than the effectiveness of the remedial tool.

- Projects typically benefit from performance-based contracts with flexibility for implementation by contractor. Contracts should require a scientific demonstration of the particular dredging technology and clearly establish performance and payment criteria. Retain an engineering design firm that has experience designing remedial dredging programs (Taylor, 1998).

- Permit requirements will greatly affect project costs. Overly stringent permit requirements will increase dredging and disposal costs, set unrealistic expectations for the contractor and project team, and may have no significant contribution towards managing residual risk. Examples of permit requirements that have affected costs include: low wastewater effluent requirements redundant or unnecessary environmental controls (in-water barriers, double-walled pipes), and excessive monitoring requirements.

- Dredging costs can be reasonable if appropriately designed and generally decrease (cost per cubic yard) with increasing volumes. The disposal method and costs are also important to cost-effective management.

5.4 Understanding Site Conditions

A repeating theme for most projects reviewed is the need for a comprehensive understanding of a site's physical characteristics to formulate an appropriate dredging plan. This step is often underestimated and it is not until equipment has been mobilized to a site and unforeseen site conditions are encountered that the need for more baseline data is realized. Unforeseen site conditions

encountered on many projects have ranged from buried cobbles and debris that prevent sediment removal, to unstable side slopes that slough into recently dredged areas, and the vertical extent of contamination extends deeper than originally believed, and varying grain sizes and clay content clog dredging equipment and exceed the design capacity of the dewatering system. Many of these unforeseen but preventable conditions have significantly increased remediation project costs and duration and decreased dredging productivity.

Adverse site conditions is an argument cited by some critics as a major limitation that dredging is not a viable remedial alternative. It has also been argued that dredging equipment currently used for full-scale sediment remediation projects cannot solve site condition problems, and therefore dredging is not a practicable solution. However, this can be addressed by ensuring that design engineers have an adequate understanding of site conditions prior to implementing a remedial action. Information that has been overlooked on some projects generally relate to site history and site conditions (e.g., human-generated debris) sometimes causing remediation to take longer and cost more than expected or budgeted. Therefore, in order to properly evaluate the efficiency of past projects, one has to determine whether the site conditions and limitations were adequately quantified in order to select the best and most appropriate technology, and select reasonable and attainable target goals that will provide long-term protection of human health and the environment. Undoubtedly some site conditions will hinder the performance of some dredging technologies, but these issues are decision-making criteria that balance the inherent limitations of dredging equipment with cost to implement the strategy and the long-term benefit associated with source control efforts.

In summary, a few key findings and recommendations to consider when developing a sediment remediation dredging project include:

- The goals of the project need to be clearly defined and balanced with the limitations of dredging equipment. Dredging projects should consider not only performance-based chemical criteria but also mass reduction of contaminants. This would save significant amounts of money trying to remove residual concentrations of contaminant material resting on bedrock, or other impenetrable layers when a significant amount of the mass and risk has already been removed.

- Sediment coring and bathymetry surveys do not always adequately define the vertical extent of contamination, especially if refusal (especially gravel or debris) is encountered at mid-depth. Site history can sometimes provide valuable information regarding human-generated debris and should be reviewed during the site characterization.

- The grain size and physical characteristics of underlying clean material (and not just the COI sediment) need to be considered when selecting appropriate dredging and dewatering equipment, since the material is often inadvertently or intentionally excavated as well.

5.5 Elements of Project Design

A few key findings and recommendations to consider when developing a remedial dredging program include:

Liner Installation for Disposal Site
Source: ThermoRetec

- Projects need well-defined measurement methods and well-defined target goals. The long-term goals for most remediation programs are loosely defined as "reduction of risk" and protection of human health and the environment. Clear objectives regarding how these goals will be evaluated should be determined during project design. Endpoint measures may include metrics such as: surface-weighted sediment concentration averages, discrete maximum exceedances for any individual measure, restoration or return of a given aquatic population, or removal of fish consumption advisories in a given period of time.

- Methods for post-verification surface sediment sampling should be specified and should be representative of aerial surface conditions. Specify the minimum residual thickness required to collect a sample and if residual sediment located between rocks and in crevasses is relevant. The goal should be to minimize sample bias by collecting sediment from localized hot spots.

- Target goals should be realistic based on site conditions and technologies without compromising the long-term objectives. The risk-based cleanup criteria values need to be implementable and protective of human health and the environment.

- Dredging can be an effective tool for achieving target goals depending upon the question being asked. When the goal is mass removal of sediment or source control to prevent downstream transport of contaminants, dredging is effective. When the goal is removal to a chemical criteria, then dredging can be partially to fully effective if source control measures are in place when needed. When the goal is risk reduction, dredging can achieve progress towards risk reduction for protection of human health and the environment.

5.6 Develop Long-term Monitoring Plans

A common theme encountered on many of the projects reviewed was the lack of comprehensive monitoring programs sufficient to verify long-term project success. Quantitative evaluations of the degree of success in meeting project objectives require well designed and implemented monitoring programs. Appropriate metrics must be identified and data collected with sufficient spatial and temporal dimensions to adequately characterize the variables of interest.

6 Limitations of This Review

Source: D. Breneman

Data presented in this memorandum has been reviewed to the best of ThermoRetec's and WDNR's abilities given the data available for review. Primary source documents, files, and reports were queried from many different sources and no information was intentionally omitted from this review. Interpretations may change/modify as each additional piece of information is revealed and as additional monitoring is conducted over time.

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Table 1 Dredging Projects Considered for Review

Contaminated Sediment Remediation Project	Summary of Activities	Reason Not Selected or Selected
Allied Paper/Portage Creek/Kalamazoo River, Michigan	Dry excavation in progress.	Dry excavation
Baird & McGuire, Massachusetts	1,500 cy wet excavated from banks in 1995.	Small volume (<3,000 cy)
Bayou Bonfouca, Louisiana	Mechanical dredging of 169,000 cy from 1993 to 1995.	Over 2,500 cy dredged after 1988 with verification monitoring
Black River, Ohio	Mechanical dredging of 99,700 cy from 1989 to 1990.	Over 2,500 cy dredged after 1988 with verification monitoring
Cherry Farm, New York	Hydraulic dredging of 50,000 cy in 1998.	No chemical post-monitoring
Collingwood Harbour, Ontario	Hydraulic dreding of 3,896 cy in 1992 and 1993.	Over 2,500 cy dredged after 1988 with verification monitoring
Convair Lagoon, California	Capping completed in mid-1998.	No sediment removal
Duwamish Waterway, Washington	Hydraulic dredging of 255-gallon PCB spill.	Prior to 1988
Ellicott Creek, Columbus McKinnon, New York	Auger dredged 2,349 cy in 1995 to landfill.	No post-monitoring; small volume (<3,000 cy)
Ford Outfall/River Raisin, Michigan	Mechanical dredging of 28,500 cy in 1997.	Over 2,500 cy dredged after 1988 with verification monitoring
Formosa Plastics, Texas	Hydraulic dredging of 7,000 cy in 1992 (ethylene dichloride spill).	PCBs not present
Lower Fox River Deposit N, Wisconsin	Hydraulic dredging of 8,175 cy from 1997 to 1999. Pilot Study	Over 2,500 cy dredged after 1988; relevant to the Fox River
Lower Fox River SMU 56/57, Wisconsin	Hydraulic dredging of 31,000 cy in 1999.	Over 2,500 cy dredged after 1988; relevant to the Fox River
Gill Creek DuPont, New York	Dry excavation of 7,000–8,000 cy in 1992.	Dry excavation; no verification sampling
Gill Creek Olin, New York	Dry excavation of 6,850 cy in 1998.	Dry excavation
GM Foundry/St. Lawrence River, New York	Hydraulic dredging of 27,000 cy in 1995.	Over 2,500 cy dredged after 1988 with verification monitoring
Gould, East Doane Lake, Oregon	Hydraulic dredging of 11,000 cy in 1998.	A lake system; PCBs not present
Grasse, River, New York	Hydraulic dredging of 3,500 cy in 1995.	Over 2,500 cy dredged after 1988 with verification monitoring
Hamilton Harbour, Ontario	Two mechanical dredging operations of 330 cy and 200 cy in 1996.	Small volume (<3,000 cy)
Hooker (102nd Street), New York	Dry excavation of 28,500 cy in 1996 and 1997.	Dry excavation
Housatonic River, Massachusetts	Dry excavation of 4,900 cy in 1997.	Dry excavation
Hudson River, New York	Small PCB hotspots removed in 1998 totaling 1,075 cy.	Mostly capped; small volume (<3,000 cy)
James River, Virginia	Natural recovery remedy selected.	No dredging action
Lake Jarnsjon, Sweden	Hydraulic dredging of 196,000 cy from 1993 to 1994.	Over 2,500 cy dredged after 1988 with verification monitoring
Lavaca Bay, Texas	Mass removal of 400,000 cy with mercury in 1998 from intertidal areas.	Difficult to access documentation
Lipari Landfill, New Jersey	Wet and dry excavation of 163,000 cy from 1994 to 1996.	Primarily dry excavation

Table 1 Dredging Projects Considered for Review

Contaminated Sediment Remediation Project	Summary of Activities	Reason Not Selected or Selected
Loring Air Force Base, Maine	Wet and dry excavation of 164,000 cy soil and sediment in 1997 and 1998.	A ditch system; no post-monitoring
Love Canal, New York	Dry excavation of 31,000 cy in 1989.	Dry excavation
Lower Rouge River, Double Eagle Steel, Michigan	Dredged 34,500 cy of zinc-contaminated sediment in 1997.	Prior to 1988
LTV Steel, Indiana	Hydraulic dredging of 109,000 cy with PAHs and oil from 1994 to 1996.	PCBs not present; difficult to access documentation
Mallinckrodt Baker (J.T. Baker), New Jersey	Dry excavation of 3,500–4,000 cy in 1993.	Dry excavation
Manistique River and Harbor, Michigan	Hydraulic dredging of 120,000 cy from 1995 to 1999.	Over 2,500 cy dredged after 1988 with verification monitoring; relevant to the Fox River
Marathon Battery, New York	Hydraulic and mechanical dredging of 100,200 cy form 1993 to 1995.	Over 2,500 cy dredged after 1988 with verification monitoring
Menominee River, Michigan	Dredging not conducted at time of review.	No action yet
Minamata Bay, Japan	Hydraulic dredging of 1,025,000 cy from 1983 to 1987.	Over 2,500 cy dredged with verification monitoring
National Zinc, Oklahoma	Dry excavation of 6,000 cy in 1998.	Dry excavation
Natural Gas Compressor Station, Mississippi	Dry excavation of 75,000 cy in 1996 and 1997.	Dry excavation
New Bedford Harbor, Massachusetts	Hydraulic dredging of 14,000 cy in from 1994 to 1995.	Over 2,500 cy dredged after 1988 with verification monitoring
Newbergh Lake and Upper Rogue River, Michigan	Mechanical and hydraulic dredging of 1,800 cy in 1997 from a small stream and dry excavation of 588,000 cy from lake in 1998.	A small system; small volume (<3,000 cy)
North Avenue Dam/Milwakee River, Michigan	Dredged 8,000 cy in 1997.	No post-monitoring
North Hollywood Dump, Tennessee	Hydraulic dredging of 40,000 cy for pesticides/metals in 1995/96, relocated to isolated oxbow and capped.	PCBs not present
Ottawa River, Ohio	Dry excavation of 8,039 cy in 1998.	Dry excavation
Pioneer Lake, Ohio	Hydraulic dredging of 2,100 cy with VOCs and PAHs in 1996 and 4,500 cy in 1997.	A lake system; PCBs not present
Port of Portland T4 Pencil Pitch, Oregon	Mechanical dredging of 35,000 cy from 1994 ot 1995.	Over 2,500 cy dredged after 1988 with verification monitoring
Port of Vancouver Copper Spill, Washington	Hydraulic dredging of 5,000 cy in 1990.	Over 2,500 cy dredged after 1988 with verification monitoring
Portland General Electric, Oregon	Removal of 14 cy.	Small volume (<3,000 cy)
Puget Sound Naval Shipyard Pier D, Washington	Mechanical dreding of 105,000 cy in 1994.	Over 2,500 cy dredged after 1988 with verification monitoring
Queensbury NMPC Site, New York	Dry excavation of 4500–5,000 cy in 1996.	Dry excavation
Ruck Pond, Wisconsin	Dry excavation of 7,730 cy in 1994.	Dry excavation
Sangamo - Weston, South Carolina	Natural recovery remedy selected.	No dredging action

Table 1 Dredging Projects Considered for Review

Contaminated Sediment Remediation Project	Summary of Activities	Reason Not Selected or Selected
Sheboygan River and Harbor, Wisconsin	Mechanical dreding of 3,800 cy from 1989 to 1991.	Over 2,500 cy dredged after 1988 with verification monitoring; relevant to the Fox River
Shiawassee River, Michigan	Mechanical dredging of 1,805 cy of sediment in 1982; pilot study.	Prior to 1988; small volume (<3,000 cy); additional dredging planned
Sitcum Waterway Commencement Bay, Washington	Hydraulic and mechanical dredging of 425,000 cy in 1993.	Over 2,500 cy dredged after 1988 with verification monitoring
Tennessee Products, Tennessee	Dry excavation of 13,222 cy in 1997.	Dry excavation
Thunder Bay, Canada	Capping chosen as remedial action in 1999.	Project to use capping
Town Branch Creek, Kentucky	Dry excavation of 17,000 cy sediment.	Dry excavation
Triana/Tennessee River, Alabama	Dewatering and capping of sediment.	No dredging action
United Heckathorn, California	Mechanical dredging of 108,000 cy with DDT and dieldrin in 1996.	PCBs not present; difficult to access documentation
Waukegan Harbor, Illinois	Hydraulic dredging of 38,300 cy from 1991 to 1992.	Large volume; PCBs; relevant to the Fox River
Welland River, Ontario	Hydraulic dredging of 13,000 cy with industrial mill scale in 1995.	PCBs not present; very little primary documentation
Willamette River, Oregon	Hydraulic dredging of 100 cy.	Small volume (<3,000 cy)
Willow Run Creek, Michigan	Dry excavation of 310,000 cy sediment in 1998.	Dry excavation
Wycoff/West Eagle Harbor Operable Unit, Washington	Mechanical dredging of 6,000 cy in 1997.	Over 2,500 cy dredged after 1988 with verification monitoring

Note:

Shaded projects were retained for detailed review.

Table 2 Project Checklist

Project Name: **Reviewed by:**
Project Location: **Checked by:**

Parameter	✓	Text Answer	Parameter	✓	Text Answer
Project Overview					
Minor water body			Duration of dredging		
Major receiving water body			Date action completed		
Water body type			Volume of material dredged		
Major COCs			Depth of contamination		
Average water depth			Schematic figure		
Access (good/poor)			Size of site		
Wet or dry dredging			Combined with other RAs		
Concentrations			Substrate type		
Permits/Conditions/Regulatory Program					
Regulatory program			Federal permits		
Regulating body			State permits		
Date ROD issued			Local permits		
Operational constraints			Permit restrictions		
Project Design Factors					
General dredge type			Dewatering required (equip.)		
Specific dredge type			Effluent treatment required (equip.)		
Dredge expert used in planning			Silt curtain/barrier required		
Contractor bid package			Hours of operation (hours, days)		
Type of payment			Daily dredge volume (t. solids)		
Contractor selection criteria			Daily water volume (liters/gals)		
Contractor plans and specs			Percent solids		
Problems encountered			Overdredge planned		
Material Treatment and Disposal					
General disposal alternative			Hours of operation/day		
Specific disposal alternative			Volume received (liters/gals)		
Beneficial use (yes/no)			Solids produced (meters/cys)		
Permit restrictions			Chem. analysis of treatment material		
Operational constraints			Water treatment - size/capacity/filters		
Material transport type			Water treatment - vol. sand/charcoal		
Landfill location/capacity			Frequency of filter replacement		
Landfill monitoring					
Baseline Monitoring			*Condition/Progress Monitoring*		
Physical			Physical		
Chemical			Chemical		
Biological			Biological		
			Duration		
Post-dredge Monitoring			Distance from operation		
Physical			Modifications		
Chemical			Distance from operation		
Biological			Exceedances handled		
# of years planned			Health and safety concerns		
# of years actual					

Table 3 Site Description and Statement of the Problem for Selected Projects

Project	Major Contam.	Receiving Water Body	Site Description	Statement of Problem
Bayou Bonfouca Slidell, Louisiana	PAHs	Lake Pontchartrain	Contaminated sediment found from 2.6 to 17 ft thick along 4,000-ft-long stretch of the bayou. Very shallow with standing water.	Designated as a Superfund site from former wood treating facility. Observed impact to fish; posted fish consumption advisories, but partially rescinded in 1998.
Black River Northwest Ohio	PAHs	southern Lake Erie	Freshwater tributary to southern Lake Erie.	Designated as a Great Lakes area of concern (AOC) from former steel facility, and effluent waste. Observed impact in aquatic organisms. Fish consumption advisories rescinded in 1997.
Collingwood Harbour Ontario, Canada	copper	Lake Huron	Dredge area is 2.45 acres surrounded by wetlands and shipyards. Shallow water and soft silts (2 ft thick) over clay then bedrock.	Soft surface sediments exceeded Ontario's chemical guidelines for protection of sediment quality. Moderately contaminated, but no open-water disposal.
Ford Outfall/River Raisin Monroe, Michigan	PCBs	River Raisin to Lake Erie	The hotspot around Ford Outfall is located within the larger River Raisin AOC. It is moderately sloped down to the main navigation channel with very soft silt (2 ft thick) over stiff clay (9 ft thick) over hardpan.	Designated as a Great Lakes AOC from motor plant industrial discharges. Observed impact to sediments and biota; posted fish consumption advisories. Emergency Superfund removal for source control of hotspot.
GM Foundry/St. Lawrence River Massena, New York	PCBs	St. Lawrence River	Entire study area includes 62,000 cy of sediments from the St. Lawrence River, Raquette River, and Turtle Cove. This focused St. Lawrence River project dredged approx. 13,800 cy (11 acres) located on a shallow shelf of the St. Lawrence River consisting of soft silt/sand over hardpan. Remediation of the Raquette River and Turtle Cove are planned.	Designated as a Superfund site from industrial discharges. Observed impacts to sediment and biota; posted fish consumption advisories.
Grasse River Massena, New York (pilot)	PCBs	St. Lawrence River	Entire study area (AOC) encompasses an 8.5-mile stretch of river. The pilot dredge project was a hotspot approx. 1 acre in size, in 2 to 14 ft of water within a larger study area. Substrate consists of soft sediment with loose cobbles over hardpan.	Designated as voluntary cleanup by ALCOA under Superfund from aluminum plant discharges. Sediments determined as unacceptable risk to environment. Posted fish consumption advisories.
Lake Jarnsjon Sweden	PCBs	Eman River to Baltic Sea	Entire study area (and dredge area) is a shallow 63-acre lake located along the Eman River (5- to 8-ft depth). Contamination was found across the lake in soft sediments up to 6 ft thick.	The lake was designated as a continuing source of contamination to the river sediments from historic paper mills and other industries by the Swedish EPA. Sediments were an unacceptable risk to aquatic organisms.

Table 3 Site Description and Statement of the Problem for Selected Projects

Project	Major Contam.	Receiving Water Body	Site Description	Statement of Problem
Lower Fox River Deposit N Kimberly, Wisconsin	PCBs	Fox River to Green Bay	The hotspot deposit is contained with the larger 39-mile Fox River AOC. Dredge area is 3 acres size, avg. 8-ft water depth, and 3-ft-thick soft sediments over bedrock.	Designated as a Great Lakes AOC from paper mill discharges. Observed impact to sediments and biota; posted fish consumption advisories.
Lower Fox River SMU 56/57 Wisconsin	PCBs	Fox River to Green Bay	The demonstration project is contained within the larger 39-mile Fox River AOC. Dredge area is 9 acres in size, avg. water depth 2 to 14 ft, and avg. 10 ft soft sediment over clay.	Designated as a Great Lakes AOC from paper mill discharges. Observed impact to sediments and biota; posted fish consumption advisories.
Manistique River Manistique, Michigan	PCBs	Lake Michigan	Entire study area extends 1.7 miles of river and a 97-acre harbor. Dredge area was a 15-acre hotspot in the harbor and several nearshore areas of the river in water depths of 15 to 20 ft.	Designated as a Superfund site from paper mills and other industrial discharges. Observed impact to fish; posted fish consumption advisories.
Marathon Battery Massena, New York (Areas I and III)	cadmium	Hudson River	Entire study area includes 340 acres of marshes and tidal flats, and over 200 acres of coves designated in 3 operable units. Areas are very shallow (5-ft depth) and tidally-influenced. Substrate is soft clay(1 ft thick) over clayey hardpan.	Designated as a Superfund site from battery manufacturing discharges. Observed impact to sediments and biota; posted fish consumption advisories.
Minamata Bay Kyushu, Japan	mercury	Yatsushiso Sea	The project reached dredging of 1,025,000 cy. Of contaminated sediment from 373 acres of a marine bay. A 143-acre reclamation area of isolated dredged material and an additional 950,000 cy of contaminated sediment. Dredge depth was up to 7 ft and water depths were up to 50 ft.	The bay posed serious risk to human health through ingestion of fish and shellfish. Contamination resulted in permanent health effects in several thousand people, the death of over 100 people, and eventual fish consumption restriction.
New Bedford Harbor Bristol County, Massachusetts	PCBs	Buzzards Bay	Entire study area includes 17, 950 acres of Acushnet River, upper and lower harbor, and Buzzards Bay sediments. The dredge area was a 5-acre hotspot removal project in the upper harbor. Substrate consists of soft sandy silt up to 4 ft thick.	Designated as a Superfund site from electronics manufacturing discharges. Observed impacts to sediments and biota; posted fish consumption advisories.
Port of Portland T4 Pencil Pitch Portland, Oregon	PAHs	Willamette River to Columbia River	Terminal 4 is an active port facility along the shorelines of the Willamette River. Area is acquiescent with limited disturbance from currents. Dredge area was in Slip 3 and underpier areas, with pencil pitch contained within the upper 15 cm.	Designated for cleanup as source control from off-loading spills of pencil pitch (coal tar) from vessels. Observed sediment concentrations and toxicity above state standards. Entire river is an AOC and currently under investigation; posted fish consumption advisories.

Table 3 Site Description and Statement of the Problem for Selected Projects

Project	Major Contam.	Receiving Water Body	Site Description	Statement of Problem
Port of Vancouver Copper Spill Vancouver, Washington	copper	Columbia River	Dredge area covers 0.8 acre along the shore slopes of the river in 5 to 40 ft of water. Substrate consists of slightly silty sand with contamination contained in the upper 18 cm.	Designated for cleanup as source control from copper spill associated with off-loading activities. Observed sediment concentrations and toxicity above state standards. Posted fish consumption advisories for lower river.
Puget Sound Naval Shipyard Pier D Bremerton, Washington	PAHs	Sinclair Inlet to Puget Sound	Dredge project area is approx. 7.2 acres to 9-ft depth below mudline in 43 ft of water. Substrate consists of soft silt and sand over dense sand (no hardpan). Area is tidally-influenced with weak tidal currents.	Project area designated for cleanup under MTCA and CERCLA from shipyard construction activities. Selected sediments within the operable unit needed immediate removal to expand vessel draft depths; however, sediment concentrations and toxicity measured above state standards.
Sheboygan River and Harbor Sheboygan Falls, Wisconsin (pilot)	PCBs	Lake Michigan	Entire study area includes 13 miles of upper, lower, and middle river sections and the harbor. Dredge area encompassed 18 small hotspots in the upper river section with avg. water depth of 2 to 4 ft.	Designated as a Superfund site from die-casting and other activities. Observed impacts to sediments and biota; posted fish consumption advisories.
Sitcum Waterway Commencement Bay/Nearshore Tideflats Tacoma, Washington	arsenic	Commencement Bay to Puget Sound	Project area is 52 acres with an avg. water depth of 25 ft. Substrate consists of soft silty sand with renewed deposition from Puyallup River. Area is tidally-influenced.	Designated a problem area within the Commencement Bay/Nearshore Tideflat Superfund Site from multiple sources. Observed impact to sediments and biota; posted fish consumption advisories. Remedy was a partial cleanup and navigational dredging project.
Waukegan Harbor/Outboard Marine Waukegan, Illinois (Upper Harbor)	PCBs	Lake Michigan	The harbor is approx. 37 acres with avg. water depths of 14 to 25 ft. The harbor is lined by A 20-ft sheetpile wall. Substrate consists of soft silt (7 ft thick) over sand (4 ft thick) over hardpan.	Designated as a Great Lakes AOC from die-casting discharges. Observed impact to sediments , biota, and community structure. Fish consumption advisories rescinded in 1996.
Wyckoff/West Eagle Harbor Operable Unit Bainbridge Island, Washington (OU-3)	mercury	Puget Sound	Entire study area is a marine embayment of 3 operable units totaling 500 acres and avg. water depths of 10 to 20 ft. Dredge area for OU-3 included tidally-influenced soft silt to gravelly sand with buried timber piles (minimal currents). OU-2 was capped.	Designated as a Superfund site from historical shipbuilding and wood treating activities. Observed impacts to sediment and biota; posted fish consumption advisories.

Table 4 Summary of Fish Advisories for Case Study Projects

Project	Status	Advisory Number	Extent	Pollutant	Number of Species/ Population	Issued By	Date Rescinded
Bayou Bonfouca, Louisiana	Rescinded	170	(7 mi) [040907]	Creosote	all fish: NCGP	State	12/10/1998
Black River, Ohio	Active	781	31st St. Bridge, Sheffield to Lake Erie	PCBs (Total)	brown bullhead, common carp, freshwater drum: RGP	State	NA
	Rescinded	781	31st St. Bridge, Sheffield to Lake Erie	PAHs	all fish: NCGP	State	6/30/1997
Collingwood Harbour, Ontario	Active	11856	Collingwood Harbour- harbor area only	Mercury	smallmouth bass, white sucker: UC	Province	NA
					yellow perch, walleye: UC, RGP		
Ford Outfall, Raisin River, Michigan	Active	279	Below Monroe Dam	PCBs (Total)	common carp: NCSP, NCGP	State	NA
					white bass: RGP, RSP, NCGP, NCSP		
GM Foundry, St. Lawrence River, New York	Active	748	Entire River	PCBs (Total), Mirex, Dioxins	all fish: NCSP	State	NA
					American eel, brown trout, channel catfish, Chinook salmon, common carp, lake trout: NCGP		
					brown trout, Coho salmon, rainbow trout, white perch: RGP		
		11833	St. Lawrence River from East of Iroquois to Cornwall	Mercury	American eel, black crappie, black perch, brown bullhead, northern pike, rock bass, smallmouth bass, walleye, white perch, yellow perch, yellow sucker: UC	Province	NA
					American eel, northern pike, rock bass, smallmouth bass, walleye: RGP		
					smallmouth bass: NCGP		
				PCBs (Total), Dioxins	carp: UC, RGP		
		11834	St. Lawrence River from East of Cornwall to Quebec Border	Mercury	brown bullhead, pumpkinseed sunfish, redhorse, rock bass, yellow perch: UC	Province	NA
					northern pike, smallmouth bass, walleye, white sucker: UC, RGP		
				PCBs (Total)	channel catfish: NCGP, NCSP, RGP		
Grasse River, New York	Active	2108	Mouth to Massena Power Canal (St. Lawrence County)	PCBs (Total)	all fish: NCSP, NCGP	State	NA
Green River, Wisconsin	Rescinded	915	Great Lake	PCBs	carp: NCGP	State	no date given
Hudson River, New York	Rescinded	3513	Niagara Mohawk Boat Launch down to Sherman Island Dam	PCBs	all fish: NCGP, NCSP, RGP	State	1/1/1998
Lake Michigan, Michigan	Rescinded	218	Little Bay de Loc- including Tributaries	PCBs	salmon, smelt, trout, yellow perch: RGP	Federal	4/1/1998
					brown trout: NCGP		
Lower Fox River, Deposit N, Wisconsin	Active	882	From mouth at Green Bay up to De Pere Dam	PCBs (Total)	12 species: RGP, RSP, NCGP, NCSP	State	NA

Table 4 Summary of Fish Advisories for Case Study Projects

Project	Status	Advisory Number	Extent	Pollutant	Number of Species/ Population	Issued By	Date Rescinded
Manistique River, Michigan	Active	219	Schoolcraft Co. Upstream of dam at Manistique	Mercury	northern pike: RGP, RSP	State	NA
		248	Schoolcraft Co. downstream from M-94/Old U.S. 2	PCBs (Total)	common carp: NCGP, NCSP, RSP	State	
Marathon Battery, New York	Active	3519	Bridge at Catskill South to and including upper bay of New York Harbor	PCBs (Total)	14 species: RGP	State	NA
					all fish: NCSP		
					shellfish: NCGP		
				Cadmium	shellfish: RGP, NCGP		
Menominee River, Michigan	Rescinded	3347	Below first dam	PCBs	bass, pike, salmon, trout, walleye: NCGP	State	1/1/1998
Milwaukee River, Wisconsin	Rescinded	892	Estuary to Estabrook Falls	PCBs	catfish: NCGP	State	no date given
Minamata Bay, Japan	Rescinded	NA	All Minamata Bay	Mercury	all fish shellfish	Ministry of Health and Welfare	10/1/1997
New Bedford Harbor, Massachusetts	Active	4948	NA	PCBs (Total)	shellfish: NCGP	State	NA
					all bottomfish, American eel, flounder, scup, tautog: NCGP, NCSP		
		4949	NA	PCBs (Total)	shellfish: NCSP, NCGP	State	NA
Ohio River, Ohio	Rescinded	2015	All waters	PCBs	bass, carp: NCGP	State	6/30/1997
Old North Harbor, Waukegan, Illinois	Rescinded	2150	NA	PCBs, Chlordane	alewise, carp: NCGP	State	12/31/1996
Bremerton Shipyard, Pier D, Sinclair Inlet, Washington	Active	4243	Port Washington narrows west to Gorst	PAHs	all bottomfish, rockfish, shellfish: NCGP	Local Health Dept.	NA
				Metals			
Port of Portland, Terminal 4, Oregon	Active	4573	Willamette River to Eugene	Mercury	largemouth bass, smallmouth bass, squawfish: RGP, RSP	State	NA
Port of Vancouver, Lower Columbia River, Washington	Active	4570	Length of the lower Columbia River from Bonneville Dam to the Pacific Ocean	PCBs (Total), DDT, Dioxins	common carp, largescale sucker, peamouth chub: RSP, RGP	State	NA
Sheboygan River and Harbor, Wisconsin	Active	890	From the dam at Sheboygan Falls to the mouth	PCBs (Total)	12 species: RSP, RGP, NCGP, NCSP	State	NA
Sitcum Waterway/Milwaukee Fill, Commencement Bay, Washington	Active	4246	Industrially developed waterways at South end	PCBs (Total)	all bottomfish, shellfish: NCGP	Local Health	NA
				Tetrachloro-ethylene			
Thunder Bay River, Michigan	Rescinded	1297	Upstream to first dam	PCBs	carp: NCSP	State	1/1/1998
Thunder Bay, Lake Huron, Michigan	Rescinded	4354	Thunder Bay	PCBs	walleye: RGP	Federal	4/1/1998
Waukegan Harbor, Outboard Marine, Illinois	Active	105	977,000 acres	Chlordane	lake trout: NCGP	State	NA
				PCBs (Total)	catfish, common carp, lake trout: NCGP		
					brown trout, Chinook salmon, Coho salmon, lake trout: RGP		
	Rescinded	105	977,000 acres	PCBs (Total)	brown trout, Chinook salmon: NCGP	State	12/31/1996
					brown trout, Chinook salmon, Coho salmon, lake trout: NCSP		
Wyckoff/West Eagle Harbor, Washington	Active	3339	Bainbridge Island	PAHs	shellfish, all bottomfish: NCGP	State	NA
				Mercury			

Notes:

Data obtained from the Listing of Fish and Wildlife Advisories Website: http://www.fish.rti.org/scripts/esrimp.dll?name=Listing&Cmd=Map. Last updated December 31, 1998. Query of database in April 2000.
Lower Fox River data obtained from Wisconsin Department of Natural Resources Website. Last queried May 2000
NA - Not applicable.
NCGP - No consumption, general population.
NCSP - No consumption, subpopulation.
RGP - Restricted, general population.
RSP - Restricted, subpopulation.

Table 5 Cleanup/Target Goals and Residual Chemical Concentrations In Surface Sediments

Project	Major Cont.	Approx. Dredge Depth (ft)	Detected Concentration in Surface Sediments		Cleanup Target Goal	Residual Concentration in Surface Sediment Post-Dredging		% Reduction		Factors Influencing Outcome
			Max (ppm)	Avg. (ppm)		Max (ppm)	Avg. (ppm)	of Max.	of Avg.	
Bayou Bonfouca, Louisiana (wet wt)	PAHs	3–17	60,000	—	depth verify = 1,300 ppm	47	achieved target depth	100%	—	Unknown
Black River, Ohio	PAHs	—	8.8	—	horizon	9.8	—	-11%	—	Long-term goals achieved in reduction of fish liver deformities.
Collingwood Harbour, Canada	copper	1.6	61	—	100% mass verify = tox	NA	NA		—	Chemical results not available, but claim significant reduction.
Ford Outfall/River Raisin, Michigan	PCBs	6	42,167	—	horizon verify = 10 ppm	20	~5	100%	—	80% of dredge cells met criteria.
GM Foundry, New York (pilot)	PCBs	—	5,700		1 ppm	27	—	100%	—	83% of dredge cells met criteria; cap placed over residuals.
Grasse River, New York	PCBs	2.5	11,000	1109	30% mass	260	75	98%	93%	Boulders prevented removal of residuals.
Lake Jarnsjon, Sweden	PCBs	5	30	5	0.5 ppm	0.85	0.06	97%	99%	Included overdredge material.
LowerFox River Deposit N, Wisconsin	PCBs	3	186	—	to depth	43	—	77%	—	Divers collected verification samples from cracks/crevices from lack of sediment.
LowerFox River SMU 56/57, Wisconsin	PCBs	10	710	—	elevation	17 (28)	—	94%	—	Demobilized from site before reaching design depth.
Manistique River, Michigan	PCBs	—	4,200	—	10 ppm	1300	—	69%	—	Repeated dredging to remove residuals on bedrock.
Marathon Battery, New York (Area I)	cadmium	1	171,000	27,799	100 ppm (Area I)	90	12	100%	100%	Background = 10 ppm.
Marathon Battery, New York (Area III)	cadmium	1	2,700	179	10 ppm (Area III)	50	14	98%	92%	Background = 10 ppm.
Minamata Bay, Japan	mercury	0-7	7,600	—	25 ppm	90	9.6	99%	—	Real-time bathymetry measurements
New Bedford Harbor, Massachusetts	PCBs	3.5	100,000	—	4,000 ppm	2,068	124	98%	—	Sampled the upper 2 cm.
Port of Portland Terminal 4, Oregon	PAHs	1	230,000; or 23%	—	mass 0.5% (wt)	0.0004	—	100%	100%	
Port of Vancouver, Washington	copper	2	70,000	—	depth verify = 1,300 ppm	5,240	1,200	93%	—	0.5 ft of overdredge.
PSNS Pier D, Washington	PAHs	8		—	elevation	NA	achieved target elevation		—	Combined navigational dredging; 1 ft overdredge.
Sheboygan River, Wisconsin (pilot)	PCBs	2	4,500	—	mass verify = 686 ppm	295	—	93%	—	Pilot cap placed over residuals.
Sitcum Waterway, Washington	arsenic	5	291	—	depth	0	achieved target depth	100%	—	Removed additional material for navigational depth; overdredge.
Waukegan Harbor/Outboard, Illinois (Upper Harbor)	PCBs	7	460	—	50 ppm	8.9	6.4	98%	—	Slip 3 sediments (<500 ppm) were left in-place (CAD site); maximum concentration was 16,400.
Wyckoff/West Eagle Harbor, Washington	mercury	3	32	—	5 ppm Hg	4	achieved target criteria	88%	—	Design plan called for capping of non-dredged areas; 1 ft overdredge.

Table 6 Contaminated Sediment Dredge Removal Volumes and Mass

Project	Major Cont.	Total Cont. in Prism		Proposed		Actual Removal		Remaining in Scoped Area		% Reduction		Factors Influencing Outcome
		Volume (cy)	Mass (kg)	Volume (cy)	Mass (kg)	Volume (cy)	Mass (kg)	Volume (cy)	Mass (kg)	Volume	Mass	
Bayou Bonfouca, Louisiana	PAHs	—	—	150,000	—	169,000	—	residual	—	113%	—	Unknown.
Black River, Ohio	PAHs	—	—	49,000	—	49,000	—	residual	—	100%	—	Unknown.
Collingwood Harbour, Canada	metals, PCBs	—	—	3,896	—	3,896	—	residual	—	100%	—	Dredged to underlying silt layer (clean).
Ford Outfall/River Raisin, Michigan	PCBs	—	—	28,000	—	28,000	—	residual	—	100%	—	Dredged to bedrock/hardpan.
GM Foundry, New York (pilot)	PCBs	—	—	13,800	—	27,000	—	residual capped	—	196%	—	Elevated residuals in Quadrant 3 on bedrock.
Grasse River, New York (pilot)	PCBs	—	—	3,500	—	2,600	—	550	—	74%	—	Boulders prevented removal of residuals.
Lake Jarnsjon, Sweden	PCBs	157,000	397	157,000	397	196,000	394	residual	2.9	125%	99%	Included overdredge material.
lower Fox River Deposit N, Wisconsin	PCBs	11,000	59	8,175	11	8,175	—	residual	—	100%	82%	Dredged to within 3 in of bedrock.
Lower Fox River SMU 56/57, Wisconsin	PCBs	80,000	—	80,000	—	31,346	—	49,000	—	39%	—	Demobilized from site before reaching design depth.
Manistique River, Michigan	PCBs	—	14,000	120,000	—	>120,000	—	residual	—	100%	—	Repeated dredging to remove residuals on bedrock.
Marathon Battery, New York	cadmium	100,200	50,000	86,000	—	100,200	—	residual	—	117%	—	Inaccurate initial estimate; dredge design depth of 1 ft.
Minamata Bay, Japan	mercury	—	—	1,025,000?		1,025,000?	—	residual	—	100%	—	Unknown.
New Bedford Harbor, Massachusetts (Hotspot)	PCBs	—	—	10,000	`	14,000	—	residual	—	140%	50%	Hotspot removal
Port of Portland Terminal 4, Oregon	PAHs, pencil pitch	35,000	10,654	35,000	10,654	35,000	—	residual	1,614	100%	85%	Difficult access under piers and riprap slopes.
Port of Vancouver, Washington	copper	1,900	—	1,900	—	1,900	—	unknown	—	100%	—	0.5 ft overdredge.
PSNS Pier D, Washington (pilot)	PAHs, PCBs	53,400	—	105,000	45%	105,000	—	residual	—	100%	—	Removed additional material for navigational depth; 1 ft overdredge.
Sheboygan River, Wisconsin (pilot)	PCBs	—	—	3,800	—	3,800	—	residual	—	100%	—	Few expectations.
Sitcum Waterway, Washington	metals, PAHs	127,500	—	425,000	—	425,000	—	residual	—	100%	—	Removed additional material for navigational depth; overdredge.
Waukegan Harbor/Outboard, Illinois	PCBs	—	300,000	38,300	136,000	38,300	136,000	residual	900	100%	96%	Sediments within Slip 3 CAD site (<500 ppm) were left in-place.
Wyckoff/West Eagle Harbor, Washington	mercury	9,200	—	3,650	—	3,650	—	capped	—	100%	—	1 ft overdredge.

Table 7 Summary of Project Designs and Remedial Actions

Project	Major Contam.	Removed Volume (cy)	Dredge Method	Project Design and Implemented Remedy	Problems Encountered
Bayou Bonfouca Slidell, Louisiana	PAHs	169,000	Mechanical by crane	Wet excavation using a mechanical custom-designed crane-mounted clamshell bucket on a barge. Material was pipelined to a holding pond then to an on-site incineration system. Leftover ash was placed in an on-site landfill. Full-scale remediation of the 4,000-ft-long project area.	Sheetpile walls surrounding the areas were left in-place to minimize disturbance of sediments and house foundations.
Black River Northwest Ohio	PAHs	49,700	Mechanical	Wet excavation using a mechanical clamshell bucket and hydraulic cutterhead dredge. Material was placed in an on-site CDF and capped. Full-scale remediation of study area.	Switched to a cutterhead dredge when bucket could not close from presence of debris.
Collingwood Harbour Ontario, Canada	copper	3,896	Hydraulic Pneuma pump	Wet excavation using a hydraulic Pneuma airlift pump. Material was pipelined to an onshore CDF. Dredged the contaminated surficial soft silt overlying a blue clay layer. Full-scale remediation of project area after an initial pilot study was conducted.	Large debris would plug the Pneuma pump cylinder.
Ford Outfall/River Raisin Monroe, Michigan	PCBs	28,500	Mechanical	Wet excavation using mechanical closed clamshell buckets with a barge and scow. Material was treated and transported to an on-site CDF. This was a focused removal project of hotspot sediments near the Ford Outfall. Cleanup criteria designed to be protective of biota. Remedy of the River Raisin is planned.	Passing cargo vessel generated prop wash and disturbed silt curtains. Sediment resuspension/settling on top of hardpan.
GM Foundry/St. Lawrence River Massena, New York	PCBs	27,000	Hydraulic horizontal auger	Wet excavation using a hydraulic horizontal auger dredge (dry excavation of nearshore areas). Boulders and debris were excavated before dredging. Material was pipelined to a settling basin and stored temporarily. Treated material will be sent to an on/off-site CDF depending upon the levels. Turtle Cove was not dredged; possible continued source. Full-scale remediation project of the St. Lawrence AOC. Remediation of Raquette River and Turtle Cove discussed in 1999 ROD. Capped residuals.	River currents required switch from silt curtains to sheetpile walls. A sand cap was required over Quadrant 3 from elevated residual concentrations. No permission to access Turtle Cove.
Grasse River Massena, New York (pilot)	PCBs	3,175	Hydraulic horizontal auger	Wet excavation using a hydraulic horizontal auger dredge (dry excavation around ALCOA outfall). Boulders were excavated prior to dredging. Material was dewatered and transferred to an upland landfill. Voluntary dredge cleanup project of hotspot area around outfall by ALCOA (25% of total mass).	550 cy of sediment left in-place because of boulders and cobbles. Silt curtain switched from screws to bottom weights.
Lake Jarnsjon Sweden	PCBs	157,000	Hydraulic horizontal auger [1]	Wet excavation using a hydraulic auger dredge and mechanical bucket for denser material. Material was dewatered and placed in nearby landfill. Full-scale remediation of lake sediments.	Pockets of dense sand and gravel required switch of dredge equipment.

Table 7 Summary of Project Designs and Remedial Actions

Project	Major Contam.	Removed Volume (cy)	Dredge Method	Project Design and Implemented Remedy	Problems Encountered
Fox River Deposit N Kimberly, Wisconsin (pilot)	PCBs	8,175	Hydraulic cutterhead	Wet excavation using a hydraulic cutterhead dredge. Material pipelined to an on-site treatment area. Dewatered material transported to off-site landfills. A pilot demonstration project to assist selection of remedial technologies for Lower Fox River project.	Winter shutdown conditions.
Fox River SMU 56/57 Wisconsin (pilot)	PCBs	31,346	Hydraulic horizontal auger	Wet excavation using hydraulic cutterhead and horizontal auger dredge. Material was dewatered and placed in off-site landfill. Was a demonstration project to gather information for Lower Fox River project.	Winter shutdown conditions.
Manistique River Manistique, Michigan	PCBs	120,000	Hydraulic cutterhead [1]	Wet excavation using hydraulic cutterhead dredges customized for the project. Material was pipelined to on-site treatment and settling tanks, then transported to off-site landfills. Full-scale remediation to 95% mass removal of sediments above chemical criteria.	Many site conditions compromised implementation: buried slab-wood and debris, winter weather and wind, and excavation to bedrock.
Marathon Battery Massena, New York (Areas I and III)	cadmium	100,200	Hydraulic horizontal auger [1]	Wet excavation of coves and ponds using a hydraulic horizontal auger and mechanical clamshell dredges (dry excavation of marshes). Material was placed in on-site settling basin, fixated then transported to off-site landfills. Full-scale remediation to 95% mass removal of sediment above chemical criteria.	Coarse sand and gravel required switch to clamshell bucket. Tidal conditions slowed progress.
Minamata Bay Japan	mercury	1,025,000	Hydraulic suction	Wet excavation using a hydraulic dredge (no cutterhead). Material pipelined to near shore containment facility which isolated additional contaminated sediment. Full-scale remediation to 100% mass removal of sediment above chemical criteria.	None specified.
New Bedford Harbor Bristol County, Massachusetts (Hotspot)	PCBs	14,000	Hydraulic cutterhead	Wet excavation using a hydraulic cutterhead dredge. Material pipelined 1 mile to a temporary CDF. Only a partial mass removal project of upstream sediments (45%) to control ongoing sources and prevent downstream transport during storm events. Modeled for the most benefit for the least cost. Remediation of lower harbor and Buzzards Bay planned.	Submerged power lines prevented access to a few areas. Tides/currents compromised silt curtains. Dredging operations/ strategy were adjusted in response to monitoring.
Port of Portland T4 Pencil Pitch Portland, Oregon	PAHs	35,000	Mechanical [1]	Wet excavation using shrouded clamshell bucket and bottom-dump scows. Nearshore areas excavated with airlift pump. Material transported to an in-water CDF. Capping not considered. Full-scale remediation to 100% mass removal of spilled pencil pitch (coal tar).	Difficult to access and dredge underpier and riprapped areas.

Table 7 Summary of Project Designs and Remedial Actions

Project	Major Contam.	Removed Volume (cy)	Dredge Method	Project Design and Implemented Remedy	Problems Encountered
Port of Vancouver Copper Spill Vancouver, Washington	copper	5,000	Hydraulic cutterhead	Wet excavation using a hydraulic cutterhead dredge, with diver assistance in underpier areas. Material pipelined to on-site settling pond then transported to disposal sites located on port property. Full-scale remediation project of 100% mass removal to eliminate source (spilled copper).	The heavier weight of copper concentrate prevented complete entrainment by dredge. Residuals redeposited and left behind.
Puget Sound Naval Shipyard Pier D Bremerton, Washington	PAHs	105,000	Mechanical	Wet excavation using clamshell buckets and dump scows. Material transported to either open-water disposal or off-site landfill. Only a partial cleanup of larger study area implemented by need to increase navigational depths near berths.	None specified.
Sheboygan River and Harbor Sheboygan Falls, Wisconsin (pilot)	PCBs	3,800	Mechanical	Wet excavation of 18 hotspots using clamshell buckets and land-based backhoes. Material placed in on-site CTF, some hotspots capped. A pilot study with main objective to assist future selection of full-scale remedial alternatives. Mass removal of hotspot sediments above 686 ppm PCBs. Also placed a pilot cap.	Winter shutdown and strong currents. Very shallow areas required backhoes. Permission to access areas from shoreline residents.
Sitcum Waterway Commencement Bay/Nearshore Tideflats Tacoma, Washington	arsenic	425,000	Hydraulic cutterhead [1]	Wet excavation using hydraulic cutterhead dredges and clamshell buckets for specialized areas. Material placed in an on-site, nearshore CDF used to expand port facilities. Full-scale remediation of waterway combined with a navigational dredge project caused by rapid sedimentation.	Significant debris on underpier armored slopes. Tide swings required horizontal and vertical control maintenance.
Waukegan Harbor/Outboard Marine Waukegan, Illinois (Upper Harbor)	PCBs	38,300	Hydraulic cutterhead	Wet excavation using hydraulic cutterhead dredge. Material <500 ppm placed directly in nearshore CDF located over the area of highest contamination (Slip 3) minimizing volume requiring excavation. Material >500 ppm stabilized then returned to containment cell. Full-scale remediation of upper harbor.	Activities halted during boating season. CDF required 2 years to consolidate before closure.
Wyckoff/West Eagle Harbor Operable Unit Bainbridge Island, Washington (OU-3)	mercury	3,650	Mechanical	Wet excavation using clamshell buckets and backhoes for underpier areas. Dredged material barged to on-site CDF used to expand ferry terminal facilities. Capped remaining sediments below state cleanup criteria, but still exposure risk. Cap used to enhance natural recovery. Full-scale remediation of OU-3.	Tide swings sloughed exposed sediment, armored areas for protection.

Note:

[1] Used clamshell, backhoe or diver-assisted methods for difficult areas.

Table 8 Containment Barrier System and Water Quality Monitoring Results

Project	Barrier System	Water Quality Monitoring Results
Bayou Bonfouca, Louisiana	silt curtains and oil booms, sheetpile for banks	Not specified.
Black River, Ohio	oil booms	Not specified.
Collingwood Harbour, Canada	unknown	Water quality turbidity criteria met during dredging.
Ford Outfall/River Raisin, Michigan	silt curtains (disturbed from passing ship)	No major exceedances of water quality (turbidity).
GM Foundry/St. Lawrence River, New York	silt curtains then switched to sheetpile wall	After modification to sheetpile wall, minimal turbidity exceedances which corresponded to a storm event. No PCB chemical exceedances.
Grasse River, New York (pilot)	silt curtains	Turbidity exceeded during boulder removal, but not 2,300 ft downstream. No PCB chemical exceedances. Caged fish had elevated PCBs during dredging.
Lake Jarnsjon, Sweden	silt curtains	No significant exceedances of water quality (turbidity).
Fox River Deposit N, Wisconsin	HDPE plastic barrier	No exceedances of water quality (turbidity).
Fox River SMU 56/57, Wisconsin	silt curtains	No exceedances of water quality (turbidity).
Manistique River, Michigan	silt curtains and oil booms, sheetpile walls for certain areas	Unknown water quality results. Caged fish had higher than background concentrations but no statistical differences between during and baseline conditions.
Marathon Battery, New York	silt curtains, earthen berm for dry excavation	Unknown.
Minamata Bay, Japan	none	No major exceedances of water quality
New Bedford Harbor, Massachusetts	silt curtains, but removed; surface booms and shroud on dredge	PCB mass transport was monitored. Unknown if turbidity was monitored, however, water column acute toxicity had minimal exceedances compared to reference. Deployed mussels were within seasonal variability.
Port of Portland T4 Pencil Pitch, Oregon	unsure if silt curtain was installed	Turbidity was within normal range of variability for the river. No exceedances of pencil pitch chemical criteria.
Port of Vancouver Copper Spill, Washington	none	No copper chemical exceedances detected at midpoint or downstream boundary of dilution zone.
PSNS Pier D, Washington	oil booms	Water quality samples were collected but results were not available for review.
Sheboygan River, Wisconsin (pilot)	silt curtains (occasionally toppled from currents)	Some turbidity and chemical water quality exceedances observed downstream. Caged fish had higher concentrations during dredging.
Sitcum Waterway, Washington	none	No significant exceedances of water quality (turbidity) measured 300 ft from dredge.
Waukegan Harbor/Outboard, Illinois (Upper Harbor)	silt curtains, sheetpile wall around CDF	No water quality exceedances measured during dredging (turbidity).
Wyckoff/West Eagle Harbor, Washington (OU-3)	silt curtains	Turbidity exceedances were within compliance criteria (less than 20% exceedances at 200-ft mixing zone boundary).

Table 9 Baseline Environmental Monitoring Program Measurements

Dredging Project	Physical		Chemical					Biological					Other
	Bathymetry	Surface Water	Surface Water	Surface Sediment	Sediment Cores	Ground Water	Air	Benthic Abundance	Invertebrate Toxicity	Fish/Shellfish Tissue	Fish/Shellfish Toxicity	Fish/Shellfish Physiological Responses	Additional Monitoring
Bayou Bonfouca, Louisiana			◆		◆	◆	◆						
Black River, Ohio				◆								◆	
Collingwood Harbour, Ontario	◆		◆	◆				◆	◆				
Ford Outfall/River Raisin, Michigan	◆				◆		◆			◆			
Fox River Deposit N, Wisconsin	◆	◆		◆						◆			
Fox River SMU 56/57, Wisconsin	◆		◆		◆					◆			
GM Foundry/St. Lawrence River, New York	◆			◆[1]			◆			◆			
Grasse River, New York	◆		◆		◆		◆	◆		◆			
Lake Jarnsjon, Sweden	◆	◆	◆		◆					◆		◆	
Manistique River, Michigan	◆		◆[4]		◆					◆			◆[2]
Marathon Battery, New York				◆						◆			◆[3]
Minamata Bay, Japan	◆		◆	◆[1]						◆			
New Bedford Harbor, Massachusetts	◆			◆				◆	◆	◆			
Port of Portland T4 Pencil Pitch, Oregon	◆	◆		◆	◆				◆		◆		
Port of Vancouver Copper Spill, Washington	◆			◆	◆			◆	◆				
Puget Sound Naval Shipyard Pier D, Washington	◆				◆				◆	◆			
Sheboygan River and Harbor, Wisconsin	◆		◆		◆					◆			
Sitcum Waterway Commencement Bay, Washington	◆	◆	◆		◆					◆			
Waukegan Harbor/Outboard Marine, Illinois	◆			◆					◆	◆			
Wycoff/West Eagle Harbor Operable Unit, Washington	◆		◆	◆[1]				◆					
Total	17	4	10	11	11	1	4	5	6	14	1	2	2

Notes:

[1] Sampling method was not specified as surface or core.
[2] Chemical analysis of material collected in sediment traps.
[3] Biological analysis of vegetation, benthic algae, phtoplankton, and zooplankton tissues.
[4] Available from published sources.

Table 10 Environmental Monitoring Program Measurements During Implementation

Dredging Project	Physical		Chemical					Biological					Other
	Bathymetry	Surface Water	Surface Water	Surface Sediment	Sediment Cores	Ground Water	Air	Benthic Abundance	Invertebrate Toxicity	Fish/Shellfish Tissue	Fish/Shellfish Toxicity	Fish/Shellfish Physiological Responses	Additional Monitoring
Bayou Bonfouca - Slidell, Louisiana							◆						
Black River - Northwest Ohio				◆								◆	
Collingwood Harbour - Ontario, Canada		◆											
Ford Outfall/River Raisin - Monroe, Michigan		◆	◆				◆						
Fox River Deposit N - Kimberly, Wisconsin		◆					◆						
Fox River SMU 56/57 - Wisconsin		◆	◆				◆						
GM Foundry/St. Lawrence River - Massena, New York		◆	◆				◆						
Grasse River - Massena, New York	◆	◆	◆				◆			◆			
Lake Jarnsjon - Sweden		◆	◆				◆					◆	
Manistique River - Manistique, Michigan	◆	◆	◆	◆	◆					◆			◆[1]
Marathon Battery - Cold Springs, New York													
Minamata Bay - Minamata City, Japan	◆	◆	◆							◆			
New Bedford Harbor - Bristol County, Massachusetts							◆		◆	◆			
Port of Portland T4 Pencil Pitch - Portland, Oregon	◆	◆	◆	◆									
Port of Vancouver Copper Spill - Vancouver, Washington		◆	◆	◆[2]									
Puget Sound Naval Shipyard Pier D - Bremerton, Washington		◆											
Sheboygan River and Harbor - Sheboygan Falls, Wisconsin		◆	◆							◆			
Sitcum Waterway Commencement Bay/Nearshore Tideflat - Tacoma, Washington	◆	◆	◆										
Waukegan Harbor/Outboard Marine - Waukegan, Illinois	◆	◆					◆						
Wycoff/West Eagle Harbor Operable Unit - Bainbridge Island, Washington	◆	◆	◆										
Total	**7**	**16**	**12**	**4**	**1**	**0**	**9**	**0**	**1**	**5**	**0**	**2**	**1**

Notes:

[1] Chemical analysis of material collected in sediment traps.

[2] Sampling method was not specified as surface or core.

Table 11 Post-dredging Environmental Monitoring Program Measurements

Dredging Project	Physical		Chemical					Biological					Other
	Bathymetry	Surface Water	Surface Water	Surface Sediment	Sediment Cores	Ground Water	Air	Benthic Abundance	Invertebrate Toxicity	Fish/Shellfish Tissue	Fish/Shellfish Toxicity	Fish/Shellfish Physiological Responses	Additional Monitoring
Bayou Bonfouca - Slidell, Louisiana	◆												
Black River - Northwest Ohio				◆								◆	
Collingwood Harbour - Ontario, Canada	◆			◆				◆	◆				
Ford Outfall/River Raisin - Monroe, Michigan	◆			◆									
Fox River Deposit N - Kimberly, Wisconsin	◆			◆									
Fox River SMU 56/57 - Wisconsin	◆		◆		◆								
GM Foundry/St. Lawrence River - Massena, New York	◆			◆[1]									
Grasse River - Massena, New York	◆	◆	◆		◆					◆			
Lake Jarnsjon - Sweden		◆	◆		◆	◆				◆		◆	
Manistique River - Manistique, Michigan [2]													
Marathon Battery - Cold Springs, New York				◆[3]									
Minamata Bay - Minamata City, Japan	◆			◆[3]						◆			
New Bedford Harbor - Bristol County, Massachusetts	◆			◆				◆	◆	◆			
Port of Portland T4 Pencil Pitch - Portland, Oregon	◆			◆									
Port of Vancouver Copper Spill - Vancouver, Washington	◆			◆[3]									
Puget Sound Naval Shipyard Pier D - Bremerton, Washington	◆			◆									
Sheboygan River and Harbor - Sheboygan Falls, Wisconsin			◆	◆						◆			
Sitcum Waterway Commencement Bay/Nearshore Tideflat - Tacoma, Washington	◆			◆				◆	◆				
Waukegan Harbor/Outboard Marine - Waukegan, Illinois													
Wycoff/West Eagle Harbor Operable Unit - Bainbridge Island, Washington	◆			◆									
Total	**14**	**2**	**4**	**14**	**3**	**1**	**0**	**3**	**3**	**5**	**0**	**2**	**0**

Notes:

[1] Surface sediment samples collected by hand-augered coring.
[2] Post-dredging monitoring data is not yet available.
[3] Sampling method was not specified as surface or core.

Table 12 Long-term Environmental Monitoring Program Measurements

Dredging Project	Physical		Chemical					Biological					Other
	Bathymetry	Surface Water	Surface Water	Surface Sediment	Sediment Cores	Ground Water	Air	Benthic Abundance	Invertebrate Toxicity	Fish/Shellfish Tissue	Fish/Shellfish Toxicity	Fish/Shellfish Physiological Responses	Additional Monitoring
Bayou Bonfouca - Slidell, Louisiana			◆		◆					◆			
Black River - Northwest Ohio				◆								◆	
Collingwood Harbour - Ontario, Canada								◆					
Ford Outfall/River Raisin - Monroe, Michigan					◆					◆			
Fox River Deposit N - Kimberly, Wisconsin [1]													
Fox River SMU 56/57 - Wisconsin [1]													
GM Foundry/St. Lawrence River - Massena, New York										◆			
Grasse River - Massena, New York								◆					
Lake Jarnsjon - Sweden [2]													
Manistique River - Manistique, Michigan [3]													
Marathon Battery - Cold Springs, New York				◆				◆					◆[6]
Minamata Bay - Minamata City, Japan										◆			
New Bedford Harbor - Bristol County, Massachusetts				◆				◆	◆	◆			
Port of Portland T4 Pencil Pitch - Portland, Oregon													
Port of Vancouver Copper Spill - Vancouver, Washington				◆[5]									
Puget Sound Naval Shipyard Pier D - Bremerton, Washington				◆									
Sheboygan River and Harbor - Sheboygan Falls, Wisconsin [4]										◆			
Sitcum Waterway Commencement Bay/Nearshore Tideflat - Tacoma, Washington				◆									
Waukegan Harbor/Outboard Marine - Waukegan, Illinois				◆					◆	◆			
Wycoff/West Eagle Harbor Operable Unit - Bainbridge Island, Washington								◆					
Total	**0**	**0**	**1**	**7**	**2**	**0**	**0**	**5**	**2**	**7**	**0**	**1**	**1**

Notes:

[1] No long-term monitoring program has not been developed at this time.
[2] No long-term monitoring data was available for review.
[3] The long-term monitoring program was not yet available at the time of this review.
[4] Additional long-term monitoring will be included along with full-scale remediation.
[5] Sampling method was not specified as surface or core.
[6] Biological analysis of vegetation, benthic algae, and bird tissues.

Table 13 Summary of Dredging and Disposal Costs

Project	Dredging			Treatment and Disposal Method	Additional Expenses	Total Cost[1]	
	Volume Removed (cy)	Cost per CY	Method			Cost per CY	Total Cost
Bayou Bonfouca Slidell, Louisiana	169,000	$125	Mechanical	Incineration and on-site landfill		$680	$21.1million
Black River Northwest Ohio	49,000	$25	Mechanical	CDF		$83	$5 million
Collingwood Harbour Ontario, Canada	3,896	$34	Hydraulic	CDF		$154 (CAN)	$0.6 million (CAN)
Ford Outfall/River Raisin Monroe, Michigan	28,000	—	Mechanical	On-site landfill		$220	$6 million
Fox River Deposit N Kimberly, Wisconsin (pilot)	27,000	—	Hydraulic cutterhead	Off-site landfill		$525	$4.3 million
Fox River SMU 56/57 Wisconsin (pilot)	2,600	$27	Hydraulic cutterhead	Off-site landfill		$286	$9 million
GM Foundry/St. Lawrence River Massena, New York	196,000	$230	Hydraulic horizontal auger	On-site storage and cap	Placement of cap	$370	$10 million
Grasse River Massena, New York (pilot)	8,175	$450	Hydraulic horizontal auger	Off-site landfill and cap		$1,534	$4.9 million
Lake Jarnsjon Sweden	31,346	—	Mechanical, Hydraulic horizontal auger	Off-site landfill		$40	$6.4 million
Manistique River Manistique, Michigan	>120,000	—	Hydraulic cutterhead	Off-site landfill		$300	$36 million
Marathon Battery Massena, New York (Areas I and III)	100,200	—	Hydraulic horizontal auger	Off-site landfill		$142	$11 million
Minamata Bay Japan	1,025,000?	$40	Hydraulic with suction	Nearshore CDF	New harbor construction	$487	$50 million
New Bedford Harbor Bristol County, Massachusetts (Upper Harbor)	14,000	$124	Hydraulic cutterhead	CDF	Wastewater treatment	$1,430	$20.1 million
Port of Portland T4 Pencil Pitch Portland, Oregon	35,000	$6.20	Mechanical	CAD		NA	NA
Port of Vancouver Copper Spill Vancouver, Washington	1,900	—	Hydraulic cutterhead	On-site landfill		$526	$1 million
Puget Sound Naval Shipyard Pier D Bremerton, Washington	105,000	—	Mechanical	Open-water and CDF		NA	NA
Sheboygan River and Harbor Sheboygan Falls, Wisconsin (pilot)	3,800	$450	Mechanical	On-site LTF		$1,842	$7 million
Sitcum Waterway Commencement Bay/Nearshore Tideflats Tacoma, Washington	425,000	$1.50–$25	Hydraulic cutterhead	Nearshore CDF	Habitat	$6.20	$17.5 million
Waukegan Harbor/Outboard Marine Waukegan, Illinois (Upper Harbor)	38,300	—	Hydraulic cutterhead	Thermal desorption and nearshore CDF		$552	$21 million
Wyckoff/West Eagle Harbor Operable Unit Bainbridge Island, Washington (OU-3)	3,650	—	Mechanical	Nearshore CDF	Habitat	$630	$3.8 million

Note:

[1] Total cost included dredging, disposal, treatment, project planning, and monitoring.

Table 14 Dredging Project Expectations and Outcomes

Project	Dredged Volume (cy)	Year Dredging Completed	Short-term Performance-Based Goal [1]			Long-term Objective [1]				Comments
			Defined Target Goal	Target Achieved	RAO Category	Defined Remedial Action Objective	Achieved	Progress Towards	Variable Results	
Bayou Bonfouca, Louisiana	169,000	1995	chemical	yes	HH	reduce PAH contact (HH)	yes			Advisories rescinded
Black River, Ohio	60,000	1990	horizon	yes	HH	reduce toxicity to biota	yes			Advisories rescinded
Collingwood Harbor, Canada	3,896	1992	mass	NA	E	reduce toxicity to biota	yes			Site redeveloped
Ford Outfall/ River Raisin, Michigan	28,500	1997	horizon	80%, yes	E	reduce PCBs in fish		yes		
Fox River Deposit N, Wisconsin	8,125	1999	depth	yes	M	mass removal			ND	Demonstration project
Fox River SMU 56/57, Wisconsin	50,000	2000	elevation	yes	M	mass removal			ND	Demonstration project
GM Foundry, Massena, New York	27,000	1996	chemical	no	HH	reduce PCBs in fish		yes		
Grasse River, New York - pilot	2,600	1995	mass	yes	M	mass removal			variable	
Lake Jarnsjon, Sweden	196,000	1994	chemical	yes	HH	reduce PCBs in biota	yes			Objectives met
Manistique River, Michigan	72,000	1999	chemical	no	HH	reduce PCBs in fish			variable	
Marathon Battery, New York	100,200	1995	chemical	yes	HH	reduce bio impacts			variable	
Minamata Bay, Japan	1,025,000	1987	chemical	yes	HH	reduce toxicity to HH (HH)	yes			Advisories rescinded
New Bedford Harbor, Massachusetts	14,000	1995	chemical	yes, but 4,000 ppm	HH	reduce PCBs in fish			variable	
Port of Portland Terminal 4, Oregon	35,000	1995	mass	yes	E	reduce toxicity to biota		yes		
Port of Vancouver Copper Spill, Washington	1,900	1990	depth	yes	E	remove all Cu seds		yes		
Pier D, Bremerton Shipyard, Washington	105,000	1995	elevation	yes	M	none			variable	
Sheboygan River, Wisconsin -pilot	3,800	1991	mass	yes	M	mass removal		yes		
Sitcum Waterway, Washington	425,000	1994	depth	yes	E	remove all contaminated sediments	yes			Site delisted
Waukegan Harbor/Outboard Marine, Illinois	38,300	1994	chemical	NV, depth	HH	reduce PCBs in fish		yes		Advisories rescinded, but status unsure
Wykcoff/West Eagle Harbor, Washington	3,650	1997	chemical	yes	E	reduce toxicity to biota		yes		

Notes:

[1] Remedial expectations were defined by the projects themselves.

E - Ecological Health

HH - Human Health

M - Mass

NV - No value available for review.

Table 15 Lessons Learned for Case Studies

Project	Factors Influencing Outcome	Lessons Learned
Bayou Bonfouca, Louisiana	Sheetpile walls surrounding the areas were left in-place to minimize disturbance of sediments and house foundations.	The incineration costs were hugely expensive and the majority of the $55 million costs (dredging was $125/cy). Adequate sediment investigation accurately defined volume of contaminated material and site conditions prior to remediation.
Black River, Ohio	Dredged to hard bottom. Switched to a cutterhead dredge when bucket could not close from presence of debris.	Although PAH concentrations post-project were similar to baseline levels (after plant closure) the incidence of fish liver tumors were <1% after dredging compared to 32% prior to dredging (but after plant closure). Fish consumption advisories lifted.
Collingwood Harbour, Canada	Large debris would plug the Pneuma pump cylinder.	A pilot study was useful in predicting dredging effectiveness. Site was delisted.
Ford Outfall/River Raisin, Michigan (hotspot removal)	Passing cargo vessel disturbed silt curtains. Mechanical Cable Arm dredged below depth of navigational channel resulting in side slope sloughing. Sediment resuspension/settling on top of hardpan.	Dredged to hardpan/bedrock. 80% of dredge cells met chemical criteria. Need to look at design depths relative to surrounding elevations and the potential for sloughing/recontamination of dredge area.
GM Foundry/St. Lawrence River, New York	River currents required switch from silt curtains to sheetpile walls. The silt curtain was poorly designed for river conditions, may have been implementable with different design. A sand cap was required over Quadrant 3 from elevated residual concentrations. No permission to access Turtle Cove. Dredged to hardpan.	Despite multiple attempts, elevated concentrations remained in Quadrant 3 requiring a sediment cap. PCB contaminant in the underlying glacial till was suspected. Other quadrants (5 of 6) averaged 5 ppm PCBs post-project (10-fold reduction) but did not achieve target goal of 1 ppm PCBs.
Grasse River, New York (pilot)	550 cy of sediment left in-place because of boulders and cobbles. The extent of these materials was not anticipated. Silt curtain switched from screws to bottom weights.	Horizontal auger did not work well with cobbles. Caged fish located along/outside the perimeter of contaminant system showed elevated PCBs during dredging, but significantly reduced immediately post-project.
Lake Jarnsjon, Sweden	Pockets of dense sand and gravel required switch of dredge equipment (from auger to bucket). Higher sand content required addition of more water for the suction dredge (lower % solids). Designed 0.5 ft of overdredge.	
Lower Fox River Deposit N, Wisconsin	Target goal was to dredge down to within 3 in of bedrock.	Development of realistic target goals helped maximize achievement of risk reduction for a reasonable cost. Plastic HDPE plastic barrier unnecessary to river water quality.
Lower Fox River SMU 56/57, Wisconsin	Demobilized from site before reaching target depth from onset of winter conditions. Actual sediment removal rates were one-third of targeted goal.	Elevated surface sediment verification samples were the result of incomplete dredging (did not reach target depth below PCB hotspot).
Manistique River, Michigan	Many site conditions compromised implementation: buried slab wood and debris, winter weather and wind, and excavation to bedrock.	Repeated dredging to removal residuals on bedrock.

Table 15 Lessons Learned for Case Studies

Project	Factors Influencing Outcome	Lessons Learned
Marathon Battery, New York (Areas I and III)	Coarse sand and gravel required switch to clamshell bucket. Tidal conditions slowed progress.	Discrete samples exceeded chemical criteria, however, the average concentrations met target goals. Background concentrations were 10 ppm.
Minamata Bay, Japan	Real-time bathymetry measurements during dredging used to gauge completion of dredging to design depth.	Surface sediment criteria easily achieved, however, fish tissue criteria were not met until six years later.
New Bedford Harbor, Massachusetts	Submerged power lines prevented access to a few areas. Tides/currents compromised silt curtains. Sampled the upper 2 cm for verification.	Designed as a mass removal project for source control (remove sediments >4,000 ppm PCBs) to prevent downstream transport. Target goal selected based on cost/benefit analysis. Target goal easily achieved. Observed daily low tides and project shutdown in winter (ice). Community opposed incineration. Many monitoring adjusts to comply with criteria, especially air emissions for DNAPL.
Port of Portland T4 Pencil Pitch, Oregon	Difficult to access and dredge underpier and riprapped areas. Combined with navigational dredge project. Designed 1 ft of overdredge.	Even with overdredge designed into project, exceeded chemical criteria in most cells, likely because of contaminated non-dredged areas.
Port of Vancouver Copper Spill, Washington	The heavier weight of copper concentrate prevented complete entrainment by dredge. Residuals redeposited and left behind. Designed 0.5 ft overdredge. No silt curtains installed because of deep water.	The post-project concentration averaged among all dredge cells met the 1.300 ppm copper chemical criteria although some discrete dredge cell measurements exceeded 1,300 ppm.
PSNS Pier D, Washington	Designed 1 ft of overdredge.	Combined navigational and source control dredging project. Chemical criteria was not met in numerous dredge cells, suspect recontamination from areas not dredged but in the AOC.
Sheboygan River, Wisconsin (pilot)	Winter shutdown and strong currents. Very shallow areas required backhoes. Strong currents toppled the silt curtains. Access restrictions from shoreline residents. A pilot cap was placed over residuals in hotspot areas (designed into project).	Sediment probing techniques used to assess sediment thickness underestimated actual volumes of material requiring removal. Dredge equipment was versatile and mobile.
Sitcum Waterway, Washington	Tide swings required horizontal and vertical control maintenance. Combined with a navigational project. Designed 1 ft overdredge.	Underpier areas had significant debris, cables, concrete, and boulders which proved difficult to access and dredge effectively.
Waukegan Harbor/ Outboard, Illinois (Upper Harbor)	Activities halted during boating season. Slip 3 sediments (<500 ppm) were left in-place (CAD site). CDF required 2 years to consolidate before closure.	Additional baseline sediment data needed (right before sampling) for comparison to post-project samples. Fish tissue samples collected yearly but few samples and variability is high.
Wyckoff/West Eagle Harbor, Washington (OU-3)	Design plan called for capping of non-dredged areas for enhanced natural recovery. Designed 1 ft overdredge. Tide swings sloughed exposed sediment, armored areas for protection.	Compliance with state sediment management standards chemical criteria is assumed to be protective of the benthic community based on AET tests.

Attachment 1

Detailed Case Studies

1 Statement of the Problem

- Dredged 1993-1995
- PAHs
- 169,000 cubic yards
- $125 per cy dredging ($680 per cy total)

Historic releases of creosote resulted in polyaromatic hydrocarbon (PAH) contamination at the Bayou Bonfouca site with 60,000 ppm (wet) maximum PAH concentration measured. The contamination presented human risk pathways through recreational exposure and fish consumption. The site was categorized as a public health hazard due to extensive soil, sediment, biota, surface water, and groundwater contamination. A written advisory and warning signs were posted against swimming and consumption of fish and shellfish by the Louisiana Department of Health and Hospitals and the Louisiana Department of Environmental Quality (LDEQ) for a 7-mile length of the bayou. Hotspots were dredged from November 1993 to July 1995. The lead agency for the project was Environmental Protection Agency (EPA) Region 6.

2 Site Description

The Bayou Bonfouca Superfund Site is an abandoned creosote wood treating facility located in Slidell, Louisiana, approximately 25 miles northeast of New Orleans. The dredging area is located along 4,000 linear feet of the bayou with a channel width of 250 feet. The bayou is lacustrine in nature consisting of shallow standing water and saturated soils. The nominal water depth of the bayou is 10 feet. The receiving water body is Lake Pontchartrain, located approximately 7 miles south of the site.

3 Site Investigation

Aerial of Bayou Bonfouca
Source: U.S. EPA Region 6

The site investigation included sediment, soil, groundwater, surface water, and air sampling to determine the horizontal and vertical extent of creosote contamination. EPA established the remedial action level for sediment removal at 1,300 ppm total PAHs. Because the remedial action took place before establishment of ecological risk, this level was established based on human risk criteria. Project oversight was provided by EPA Region 6 under Superfund (CERCLA) and the State of Louisiana. The ROD was signed March 31, 1987. The ROD stated an estimate of 46,500 cubic yards of sediment was to be removed along a 2,000-foot length of the bayou (EPA, 1987).

Sediment explorations were performed on three occasions to determine the extent of contamination and bank stability. The explorations were conducted from June 9 to June 27, 1988, December 1 to December 17, 1988, and May to June, 1990. In 55 sediment samples collected from within the bayou,

PAH concentration ranged from below the method detection limit to over 60,000 ppm (wet weight) (CH_2M Hill, 1990). Results of the 1988 and 1989 investigations showed a significant increase in the extent of contamination presented in the ROD. The dredge area was therefore expanded to include all areas of the bayou with greater than 1,300 ppm PAHs. The increase corresponded to an estimated volume of 150,000 cubic yards of sediment along a 4,000-foot length of the bayou. Elevated sediment contamination ranged from 2.6 to 17 feet in depth. An *Explanation of Significant Differences* report was released February 5, 1990 explaining the updated scope of the remedial action (Layton, 1990). Contamination levels above 1,300 ppm for total PAHs were also found in sediments located outside of the bayou including three of the four borings in the Eastern Drainage Channel, and one boring located in the Western Creek (see Figure 1) (CH_2M Hill, 1990). Because two borings located downstream in the Western Creek did not exceed contamination criteria, it was assumed that the creosote released was not of sufficient volume to flow into the bayou.

Evidence of creosote contamination was confirmed in upland soil waste piles and in two of the three groundwater aquifers of the site. The surficial (ground surface to -9 NGVD) and shallow artesian aquifers (-12 to -28 feet NGVD) had creosote contamination. No contamination was detected in the deep artesian aquifer that began at a depth of -34 feet NGVD and was at least 10 feet thick. Surface water samples from the bayou were collected and analyzed during the second remedial investigation and design investigation. PAH contamination ranged from 160 to 628 ppb in the bayou surface water (CH_2M Hill, 1990).

Based on remedial and design investigations, a comparison of alternatives was conducted to evaluate each of nine identified alternatives (CDM & F.P. Corp., 1989). Specific criteria considered in the evaluation included:

- Odor potential of remedial activities,
- Need for source control,
- Riverbank stability,
- Constructability,
- Need for long-term monitoring,
- Life expectancy of the remedial facilities, and
- Time required for remediation.

The use of mechanical dredging and on-site incineration was determined to be the most appropriate alternative for protection of human health and the environment. Dredging and on-site incineration remained the preferred alternative in the *Explanation of Significant Differences*, although the addition of a protective cap was included in the remedial action for all dredged areas. Long-term monitoring of the cap would be required. Incineration provided the greatest degree of risk minimization of sediment toxicity. Institutional considerations for the selected alternative included deed restrictions for on-site ash and soil disposal.

4 Target Goals and Project Objectives

The project was designed to remove hotspot PAH contamination in excess of 1,300 ppm. The 1,300 ppm PAH action level for sediments was imposed for sediment removal based on direct contact exposure and potential for ingestion of carcinogens in groundwater, surface soils, and in the food chain (EPA, 1997). This level was found to present lifetime increased cancer risk of less than 1×10^{-4} (EPA, 1987). The action levels conformed to the acceptable health risk criteria contained in the National Contingency Plan. Minimal volumes of residual contaminants were left behind due to the need to ensure stable excavations, but capped to minimize exposure.

5 Project Design

Pre-planning and Bid Documents. Data not available for review.

Summary of Remedial Action Plan. The remedial project design involved mechanical dredging with use of silt curtains and adsorbent booms to minimize silt and contaminant transport. Dredging without dewatering of the bayou was determined to be the best approach because of the depth of excavation required (up to 17 feet). Sheetpile walls were used to ensure stable conditions in deep excavation areas. After dredging, a protective layer of sand and gravel was installed to isolate and contain small areas of residual contamination and contamination below the criteria level. Sediments were to be dewatered on site and treated water discharged into the bayou. Dewatered sediment was to be treated by incineration then landfilled and capped on site (GE/AEM/BBL, 1999; Tetra Tech).

Dredging design accounted for minimal residual contamination remaining after excavation. As stated in the 1987 ROD, "Any excavation on slopes greater than what is considered safe could results in the undermining of trees along the bayou resulting in the possible loss of property and harm to the environment." Therefore, the design accounted for limited residual PAH contaminated sediments over 1,300 ppm to remain in some areas. Sheetpile walls were to be used in unstable excavation areas with significant volumes of contaminated sediment to allow sediment removal.

A protective layer was included in the 1990 *Explanation of Significant Differences* for protection of human health by minimizing contact with remaining contamination. The cap would also provide a stable substrate for restoration of aquatic life. The application of a protective layer was added in the 1990 update, "After dredging, the contaminated portion of the bayou will be backfilled with clean materials to reduce the chances of contact with any residual materials."

Short-term environmental considerations included the possibility of odor, noise, and bank stability problems during dredging, and dust control during capping. Air impacts were one possible long-term impact that was minimized with an emission control system. Disturbances to the bayou generally resulted in intense and relatively far-reaching creosote odor. An

attempt to minimize sediment disturbance was therefore attempted in the proposed remedies. Preference for dredging to take place only during daylight hours was stated in the remedial planning activities document.

Residual upland soils containing greater that 100 mg/kg PAHs and less than 1,000 mg/kg were collected and landfilled on site. Those with concentration of greater than 1,000 mg/kg PAHs were incinerated. Soils less than 100 mg/kg were left in place (Klink & Obert).

Incinerator specification for destruction and removal efficiency was established at 99.99 percent for all constituents of concern by RCRA incinerator regulations (40 CFR Part 264, Subpart O). All ash had to be less than 10 mg/kg before on-site landfilling.

Limitations and Permits. None specified.

6 Remedial Actions

6.1 Dredging

Computer Controlled Dredging
Source: U.S. EPA Region 6

The project involved removal of PAH contaminated sediments and soils derived from creosote. Approximately 169,000 cubic yards of sediment and 10,000 cubic yards of soils were excavated and treated by incineration. A crane-mounted clamshell dredge was used to excavate sediments to a barge. Dredging took place at a nominal depth of 10 feet (maximum depth of 17 feet) along a 4,000-foot length of the bayou. The nominal width of the dredge area was 250 feet.

Schedule and Duration. The completion of remedial action was scheduled for December 1996. The actual dredging activities were begun in November 1993 and completed in July 1995, approximately 18 months ahead of schedule. The total project time was 21 months, 15 months of which was active dredging. The daily schedule was 9 hours per day, 5 days per week.

Equipment. Mechanical dredging was completed using a custom-designed, crane-mounted clamshell on a barge. Dredging operations took place within silt curtains and absorbent booms. Sheetpile walls were installed on both sides of the bayou in some locations to provide bank stabilization.

Total Volume Removed and Production Rates. A total of 169,000 cubic yards of sediments were removed at a rate of 520 cubic yards per day based on days of active dredging.

Site-specific Difficulties. The initial project design specified driving sheetpile walls on either side on the bayou prior to dredging to ensure stability. The design called for removal of the sheetpile walls after backfilling was complete. Problems with liquefying of sediments, and damage to foundations of adjacent houses resulted from driving the

sheetpile walls. For this reason, the sheetpile walls were left in-place (Duane Wilson of LDEQ, 2000. Personal communication.).

6.2 Dewatering and Water Treatment Operations

Process water from dewatering operations was treated by clarification, bioreactor, granular-activated carbon system. A total of 171 million gallons of water were treated at a rate of 500 gallons per minute.

Water Quality Monitoring of Discharge. The effluent water was discharged into the bayou. A discharge criteria of less than 20 parts per billion of individual PAHs was established.

Groundwater Treatment. Groundwater treatment began in June 1991 and succeeded in reducing the volume of contamination and prevented further migration. Approximately 9 million gallons of contaminated groundwater were extracted and treated by August 1999 resulting in recovery of 26,000 gallons of creosote oil. Treated water was discharged into the bayou. Additional recovery and monitoring wells are being installed to address the creosote plumes found in the shallow artesian aquifer. EPA will continue long-term remedial action until July 2001, at which time the State of Louisiana will take over the long-term remedial action for the next 20 years.

6.3 Storage and Disposal

Sediments were transported to a holding pond by a 24-inch diameter floating pipeline. Sediment was then transported to an on-site incineration system consisting of feed system (filter press dewatering and blending), rotary kiln, secondary combustion chamber, and gas cleaning system. Following thermal treatment, incinerator ash was placed in an on-site landfill along with marginally contaminated upland material. An engineered cap constructed of high-density polyethylene geotextile material, Claymax, and native clay was then installed over the landfill (EPA, On-site Incineration).

7 Environmental Monitoring Program

The monitoring program included bathymetry surveys, sediment sampling, invertebrate tissue, and fish tissue sampling (Table 1).

7.1 Baseline

Physical. Field and laboratory tests were conducted to determine the necessary slope to maintain stable conditions upon excavation.

Chemical. Chemical air monitoring was reported in the Pilot Study Report. The ambient air monitoring characterized air quality conditions on site prior to remediation efforts. The air monitoring detected naphthalene in concentrations of 5 to 11 ppb in two of five sample stations.

Two phases of off-site sediment sampling were conducted in Bayou Bonfouca, and upstream areas located in the Western Creek and the Eastern Drainage Channel. Sediment sampling consisted of a total of 63 cores. The streambed of Bayou Bonfouca was cored in 55 locations ranging from approximately 300 feet upstream of the confluence of Western Creek and the Bayou, to approximately 4,000 feet downstream of the confluence of the Eastern Drainage Channel and the Bayou. Eight additional cores were drilled, four in the Western Creek and four in the Eastern Drainage channel (CH_2M Hill, 1990).

Extensive creosote contamination existed along approximately 4,000 feet of the bayou sediments. In 1981, pentachlorophenol (PCP) was detected in two sediment samples located downstream of the site at the boat landing. The low levels that were detected of PCP did not pose a health threat.

Biological. LDEQ posted an advisory against fish/shellfish consumption and swimming along a 7-mile length of Bayou Bonfouca on November 24, 1987. In 1981, the Center for Bio-Organic Studies at the University of New Orleans collected plankton, blue crabs, and clams from the bayou for metals and PAH testing (Louisiana Office of Public Health, 1994). Analyses of the bayou waters did not detect PAHs. Biota sampled had total PAH concentrations of 210 parts per million ($\mu g/g$) in plankton; 170 $\mu g/g$ in crabs; and up to 0.6 μg of benzo(a)pyrene per gram of wet tissue in the clams (8).

Three blue crabs were sampled in three different locations in Bayou Bonfouca: 1) 0.35 mile south of the turning basin, 2) 0.6 mile south of the turning basin, and 3) Bayou Bonfouca adjacent to Southern Shipyards (south of the site). The three blue crabs that were sampled had very low levels of PAH contamination, which did not pose a health threat. However, the blue crabs did contain elevated levels of mercury and lead (9). Mercury concentrations in the crabs ranged from 20 to 250 ppb while lead concentrations ranged from 560 to 16,400 ppb. These metals have not been associated with the study area.

7.2 Implementation During Dredging

Physical. No physical progress data were available for review.

Chemical. Continuous air monitoring was conducted by LDEQ during dredging to protect workers and community residents. Data were collected at three monitoring stations for volatile, semivolatile, and particulate readings. Air monitoring was designed to warn workers if federal health guidelines were exceeded and dredging would cease.

Biological. No biological progress data were available for review.

7.3 Post

Physical. The Corps of Engineers conducted post-remedial bathymetry surveys to determine the elevations following dredging and placement of the protective layer.

Chemical. No post-construction data were available for review.

Biological. No post-construction data were available for review.

7.4 Long Term

Data were collected as a part of the state annual monitoring program on September 16, 1997 for sediment, water, and fish testing. Sediments were analyzed for PCBs (3 samples) and semivolatiles (10 samples). Semivolatiles in sediment were detected at a maximum concentration of 47.7 ppm (di-n-butylphthalate). The highest detected PAH compound was fluoranthene at a concentration of 34.9 ppm. Water samples (10) were below the detection limit for semivolatiles. (Louisiana DEQ, 1998).

Fish were collected for analysis of arsenic, lead, PCBs, and semivolatiles. Fish collected included largemouth bass (15 samples), red ear sunfish (7 samples), freshwater drum (5 samples), white bass (1 sample), and channel catfish (5 samples). Maximum concentrations were 0.1 and 0.006 ppm for arsenic and lead, respectively (both in largemouth bass). PAHs were not detected above the quantitation limit in fish, although phthalates were detected in the semivolatile analysis. The maximum phthalate concentration was 37.6 ppm bis (2-ethylhexyl) phthalate (wetweight). However the majority of fish results were below detection limits for PCBs, encouraging the initiation of removing the fish consumption advisory (Louisiana DEQ, 1996 and 1998). PCBs were also analyzed in the fish and sediments samples; however, detected concentrations were in the ppb range.

Table 1 Summary of Monitoring Results

Testing Parameters	PAH Concentration (ppm)			
	Baseline 1988–1993	During Nov 1993 – July 1995	Post 1995	Long-term 1996 - 1997
Bathymetry	Yes	Unk	Unk	Unk
Sediment Cores	0 to 60,000 ppm wet	Unk	NA	34.9 ppm (fluoranthene)
Surface Water	0.160 to 0.628	Unk	NA	Non-detect
Air Monitoring	None	Conducted	None	None
Tissue	210 μg/g plankton (ppm) 170 μg/g crabs (ppm)	NA	NA	Non-detect fish

Unk - Unknown
NA - Not available for review

8 Performance Evaluation

The site was categorized as a public health hazard due to extensive soil, sediment, biota, surface water, and groundwater contamination (Louisiana, 1994). A written advisory and warning signs were posted

against swimming and consumption of fish and shellfish by the Louisiana Department of Health and Hospitals and the Louisiana Department of Environmental Quality (LDEQ) for a 7-mile length of the bayou in 1987. The non-consumption for general population (NCGP) fish advisory for all fish species with creosote pollutant was rescinded on December 10, 1998 (EPA, 2000). As stated by EPA, "the bayou has been restored for aquatic life, and approved for human residential and recreational use including installation of a public boat launch" (EPA, 1999).

8.1 Meet Target Objectives

No post-remedial sediment data were reviewed to determine attainment of target goals. However, the project is widely viewed as successful since the long-term remedial action objective, defined as the protection of human health and the environment was achieved through removal of the fish consumption advisory in 1998. The remedial action was successful in treating over 169,000 cubic yards of contaminated sediment and approximately 9 million gallons of site groundwater.

8.2 Design Components

The remedial action design was based on extensive sampling of sediment, groundwater, and surface water. Nine alternatives were evaluated for specific criteria to determine the most appropriate remedy. Mechanical dredging and on-site incineration were selected.

8.3 Lessons Learned

Sediment investigation determined the volume of sediment in excess of cleanup action levels was approximately three times greater than specified in the 1987 ROD. The investigation allowed the scope of work to be expanded and the Explanation of Significant Differences to be issued prior to commencement of remedial activities.

9 Costs

The project cost was estimated at $55 million in the 1987 ROD and updated to $100 million in the 1990 *Explanation of Significant Differences*. The total remediation cost was approximately $115 million ($680 per cubic yard). The cost of dredging was $21.1 million ($125 per cubic yard).

10 Project Contact

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11 References

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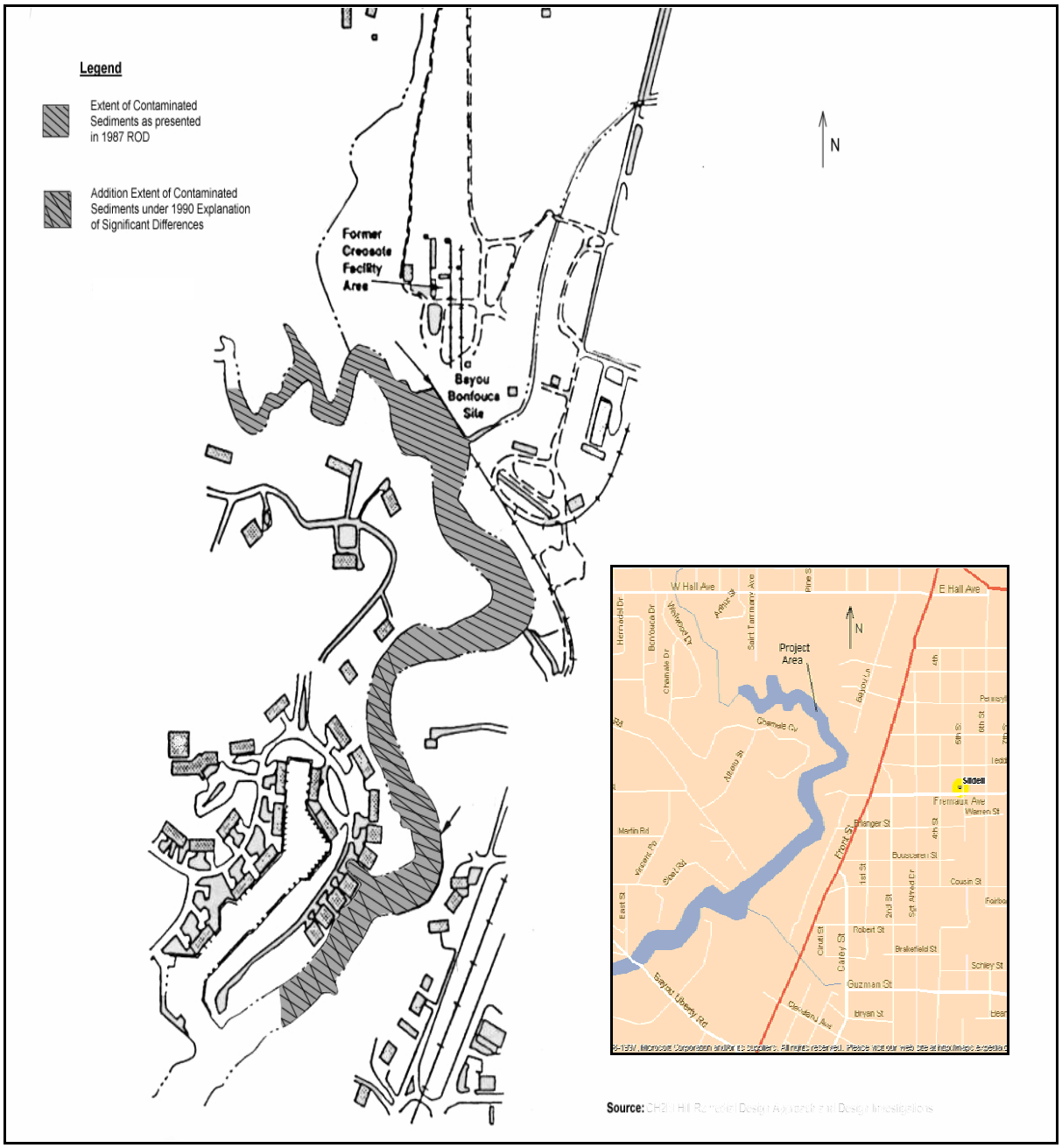
Figure 1 Remedial Dredge Plan - Bayou Bonfouca



1 Statement of the Problem

- Dredged 1989–1990
- PAH
- 60,000 cubic yards
- $83 per cy total

The Black River, Ohio was the site of a remedial dredging project in 1989 mandated by the Environmental Protection Agency (EPA) to remove high concentrations of contaminants, specifically polynuclear aromatic hydrocarbons (PAH). The nature and extent of the contaminated sediment, accumulated from continual industrial discharge, and the ensuing threat to ecological receptors, prompted the EPA to order the dredging project (Lesko *et al.*, 1996; Baumann and Harshbarger, 1998). The lead agency for this project was EPA Region 5.

2 Site Description

The Black River flows northwesterly through Ohio, draining into southern Lake Erie, the Great Lakes, at Lorain Harbor (Figure 1). This freshwater tributary is situated between the Huron River (to the west) and the Cuyahoga River (to the east), which also drain into Lake Erie. There are several major industrial facilities along the river.

3 Site Investigation

The International Joint Commission (IJC) for the Great Lakes defined the Black River as an Area of Concern (AOC) based upon the high level of contamination that has resulted from industrial discharge (Smith *et al.*, 1994). The primary industry along the lower Black River is USX-Kobe (formerly US Steel), with several other large industrial and municipal facilities located further upstream. Of the various industries that discharge waste to the river, the EPA considered the USX-Kobe coke facility to be the major contributor, discharging over 1 million gallons of industrial waste per day, until its closure in 1983. Effluent from this coke facility was considered to be the major source of high concentrations of PAH contaminants in the Black River (IJC, 1999). Although PAH concentrations in Black River sediment declined after the coke facility closed in 1983, levels remained of concern with regard to the health of brown bullhead catfish and other resident aquatic organisms.

Aerial of Black River
Source: U.S. EPA Region 5

In 1985, the EPA issued a Consent Decree to USX-Kobe mandating the removal of 38,000 cubic meters (or about 50,000 cubic yards) of PAH-contaminated sediment from the main stem of the Black River in the vicinity of the former coke facility (EPA, 1999). Remedial dredging activities were conducted between 1989 and 1990 using a mechanical clamshell dredge, and removed all sediments above 390 ppm PAHs. The remediation project was mandated to remove the high levels of PAHs from the river system to ultimately reduce the incidence of fish

abnormalities, such as liver and lip cancers and neoplasms, in resident brown bullhead populations. PAH concentrations in sediment and the incidence of liver cancers and tumors were measured and compared over a period of several years in an attempt to evaluate the effects of PAH contamination in the system, and the effectiveness of the sediment remedial dredging project.

4 Target Goals and Project Objectives

The primary cleanup goal was to remove all PAH-contaminated sediment in the main stem of the Black River near the former USX-Kobe coke facility to "hard bottom," or to the underlying shale bedrock. Specifically, the 1985 EPA Consent Decree mandated the removal of 38,000 cubic meters (49,700 cubic yards) of PAH-contaminated sediment. In removing contaminated sediment, it was anticipated that this remediation project would eliminate the high incidence of liver tumors and cancer in resident brown bullhead fish populations.

5 Project Design

USX-Kobe was required to comply with EPA's 1985 Consent Decree, which was initially issued to deal with violations of the Clean Air Act, but included the supplementary requirement of dredging the PAH-contaminated sediment. Once issued, the parties involved were not able to immediately agree upon a disposal site and, thus, dredging did not commence until 1989 (Baumann, 1998).

Black River Dredge
Source: U.S. EPA Region 5

Pre-planning and Bid Documents. None are available for review.

Summary of Remedial Action Plan. The remedial action entailed wet excavation of site sediments using a mechanical clamshell bucket and a hydraulic cutterhead dredge (for areas with debris since the bucket could not close) to "hard bottom" or bedrock. Excavated sediment was placed in an upland, on-site, lined containment cell landfill then subsequently capped.

Limitations and Permits. Required permits included the Clean Water Act for NPDES, Section 404, dredge and fill, and Section 401, water quality certification. Disposal of the dredged sediment had to comply with RCRA requirements (IJC, 1999). Dredging operations ceased during the fish spawning season, May through July.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. Remedial dredging activities commenced in the fall of 1989 and were completed in December 1990, at a cost of $1.5 million. Dredging hours of operation increased from one shift 5 to 6 days per week, to 7 days per week, then up to 24 hours per day through project completion on December 13, 1990 (GE, 1998).

Equipment. A watertight clamshell dredge was used during the dredging operations to reduce the loss of sediment to the water column. An oil boom was erected to prevent the potential spread of oil during operations. Upon removal, the dredged sediment was moved from the dredge barge into a lined containment cell on site of the steel facility, dewatered, capped in-place, and monitored. A contingency plan was defined in the event of a spill.

Total Volume Removed and Production Rates. The Consent Decree required removal of 49,700 cubic yards of contaminated sediment; however, 60,000 cubic yards were actually removed from two hotspots in the Black River.

Site-Specific Difficulties. None specified in review documents.

6.2 Dewatering and Water Treatment Operations

Once in the lined containment cell, the dredged sediment was allowed to dewater. The decanted water was then treated.

6.3 Storage and Disposal

Disposal of the dredged sediment, which exceeded the EPA's Heavily Polluted Classification for Great Lakes Harbor Sediments, was required to be placed in a confined disposal facility (CDF). After dewatering on site of the USX-Kobe facility, the sediment was capped in-place, and monitored following closure. Such careful disposal procedures were followed to prevent potential groundwater contamination, which would have violated EPA's RCRA requirements for cap closure. Leachate generated at the closed CDF is treated and discharged to the Black River through an outfall limited by the company's National Pollutant Discharge Elimination System (NPDES) permits.

7 Environmental Monitoring Program

Monitoring in the Black River was conducted over a period of several years to evaluate physical and chemical characteristics (i.e., PAH concentrations in sediment) and to evaluate biological characteristics (i.e., the incidence of liver cancer and neoplasms and the detection of PAH metabolites in liver and bile in brown bullhead populations).[1] Monitoring

[1] Fish tissues are not directly analyzed for PAH concentrations because organisms rapidly metabolize and excrete PAHs.

provided insight regarding the extent of contamination, the effects of contaminants on receptors, and the ultimate result of remedial dredging activities. Refer to Table 1 and Figure 2 for comparison of monitoring results before dredging, during dredging, and after dredging.

7.1 Baseline

Baseline conditions refer to the physical, chemical, and biological characteristics of the Black River between 1980 and 1989, prior to dredging operations. The USX-Kobe coke facility, which discharged high levels of PAHs (and certain metals) into the river, was in operation until 1983, at which point the facility closed and discharge of process-generated wastewater ceased. The company had high phenol and ammonia levels in its type 002 outfall (groundwater runoff) for a number of years after the coke plant closed.

Chemical. 1980 and 1981, during coke facility operations, sediment sampled in the Black River at the outfall of the USX-Kobe coke plant detected a total of 1,096 ppm of PAHs (dry weight), including the carcinogen benzo(a)pyrene at a concentration of 20 to 40 ppm (Table 1). There were also elevated levels of certain metals (e.g., cadmium measured at 30 ppm), pesticides, and oils and grease (Baumann, 1998; Baumann and Harshbarger, 1998; IJC, 1999).

Following the permanent closure of the USX-Kobe coke facility in 1983, PAH concentrations in Black River sediments declined due to the reduction of waste discharge, supplemented by natural sedimentation that buried the contaminated sediments. The PAH concentration measured in sediments was between 4.3 and 8.8 ppm (about two orders of magnitude less than concentrations during coke plant operations) (Baumann, 1998; Baumann and Harshbarger, 1998) (Table 1).

Biological. PAH profiles in the resident brown bullhead catfish (*Ameiurus nebulosus*) in 1980 and 1981 (metabolites detected in bile) corresponded to the high PAH concentrations in the sediment, confirming exposure. Additionally, the prevalence of liver cancer in brown bullhead populations ranged from 22 to 39 percent, and the frequency of all liver neoplasms (including non-cancerous tumors) was detected at 56 to 60 percent (Baumann, 1998; Baumann and Harshbarger, 1998) (Table 1; Figure 2). Incidence of liver neoplasms correlated positively with age (Folmar, *et al.*, 1995).

When PAH concentrations in the sediments declined following the facility closure, the frequency of liver cancer in brown bullheads declined to approximately 10 percent, and the frequency of all liver neoplasms decreased to between 21 and 32 percent (Baumann, 1998; Baumann and Harshbarger, 1998) (Table 1; Figure 2). Bioavailability of PAHs appears to have been reduced after the 1983 coke facility closing by natural sedimentation that covered PAH deposits (and by the export of PAHs out of the system), as evidenced by the reported decline in brown bullhead liver cancers.

7.2 Implementation During Dredging

Sediment and fish samples were collected from the Black River during dredging in 1989 and 1990; however, the data were not available for review.

7.3 Post

Sediment and fish samples were collected from the Black River during and immediately following the dredging operations that occurred in 1989 and 1990.

Haul Truck
Source: U.S. EPA Region 5

Chemical. In 1992, 2 years following dredging, PAH concentrations in the sediments had increased slightly to 16.6 ppm (Baumann and Harshbarger, 1998) (Table 1). Possible explanations for the observed increase include exposure to elevated levels of contaminant sediment from temporary resuspension and redistribution of sediments during dredging activities (despite all efforts to minimize disturbance), flow induced scour and redistribution of contamination, and other causes.

Biological. In 1992, the total percentage of brown bullhead with liver neoplasms also increased. The incidence of all neoplasms rose from 21 to 32 percent to between 56 and 58 percent) immediately following dredging. The same positive correlation was seen between age and tumor frequency rates (Baumann and Harshbarger, 1998; Folmar *et al.*, 1995) (Table 1; Figure 2). This increase in tumor incidence to levels as high as those during coke facility operations suggests an increased exposure of fish to PAHs in sediments that became naturally buried then temporarily resuspended and redistributed in the water column during dredging operations.

7.4 Long-term Monitoring

After dredging activities were completed and the PAH-contaminated sediments were removed, the PAH concentrations measured in the sediments and the incidence of neoplasms detected in brown bullheads both declined dramatically.

Physical/Chemical. After the sediment remediation project was completed, the total concentration of PAHs in Black River sediment declined from the 1980 levels (1,096 ppm) to 9.8 ppm in 1994, similar to concentrations found in the late 1980s after natural sedimentation occurred (Baumann and Harshbarger, 1998) (Table 1). Although PAH concentrations in the sediments were similar to those measured in the

early 1980s, the subsequent decline in biological effects was much more dramatic following the remedial dredging project. (Moloney, M.E., 1993).

Biological. A dramatic decline in the prevalence of liver cancer and neoplasms occurred in the first class of fish not present in the river during dredging (i.e., spawned after the dredging operations were complete). Fish liver neoplasm rates in age 3 fish declined to nearly 0 percent in 1994, with no incidence of cancer and the greatest increase in the percentage of completely normal livers (Baumann and Harshbarger, 1998) (Table 1; Figure 2). Any PAH exposure caused by dredging, therefore, was apparently restricted to the time frame of the activity itself, with the end result reaching the remediation goal of dramatically reduced PAH concentrations in sediment and the elimination of liver cancer and neoplasms in brown bullheads.

Table 1 Summary of Monitoring Results

Testing Parameters	Baseline 1 Operational Coke Plant 1980–1982	Baseline 2 Post-facility Close 1983–1989	During Dredging 1990–1992	Post/Long-term 1993–1994
Physical/Chemical PAH Concentrations in Sediment	1,096 ppm	4.3 to 8.8 ppm	16.6 ppm	9.8 ppm
Biological Liver Neoplasms in Brown Bullheads	56 to 60%	21 to 32%	46 to 58%	<1%

8 Performance Evaluation

8.1 Meet Target Objectives

Overall, this dredging project successfully met the target goals of removing the PAH-contaminated sediment to "hard bottom." Incidence of liver cancer increased in brown bullheads collected 2 and 3 years following dredging. This increase was associated with PAH redistribution during dredging. Liver cancer incidence decreased and normal tissue incidence increased 3 and 4 years post-dredging. Therefore, the long-term project objective of reducing the incidence of fish liver tumors was also met.

Data collected between 1980 and 1994 on the Black River support the hypothesis that high levels of PAHs in sediment cause such abnormalities as liver cancer and neoplasms in resident benthic brown bullhead catfish. When PAH concentrations were high in sediment (during coke facility operations and during dredging activities), the incidence of liver cancer and neoplasms was high. When the coke facility closed, eliminating the source of PAHs to the river and allowing natural sedimentation to effectively cover the PAH-contaminated sediments, rates of fish liver neoplasms decreased. It appears that remedial dredging activities briefly

caused an increase in PAH concentrations in sediment, and thus higher incidences of neoplasms, by temporarily resuspending buried contaminated sediments.

After contaminated sediment was dredged, PAH concentrations declined substantially and, subsequently, fish that spawned after completion of the dredging project showed no incidence of liver neoplasms and a dramatic increase in normal liver tissue. The decline in PAH concentrations in sediment, and the ensuing elimination of liver cancer in resident brown bullheads, as well as the most dramatic decline in liver neoplasms in general to the lowest levels measured since coke facility operations, provides evidence of the ultimate efficacy of dredging as a remedial measure for PAH-contaminated sediment at this site.

The state fish consumption advisory for "no consumption - general population" was rescinded on January 1, 1998 for all PAH-contaminated fish (EPA, 2000).

8.2 Design Components

None were available for review.

8.3 Lessons Learned

Adaptive management allowing the contractor to switch dredge types in the middle of the project when site conditions proved difficult (debris), helped maximize performance of this remediation project.

9 Costs

The estimated total cost for dredging, disposal and monitoring was reportedly $5 million ($83 per cubic yard) (GE, 1998). Dredging costs were estimated at $1.5 million. ($25 per cubic yard)

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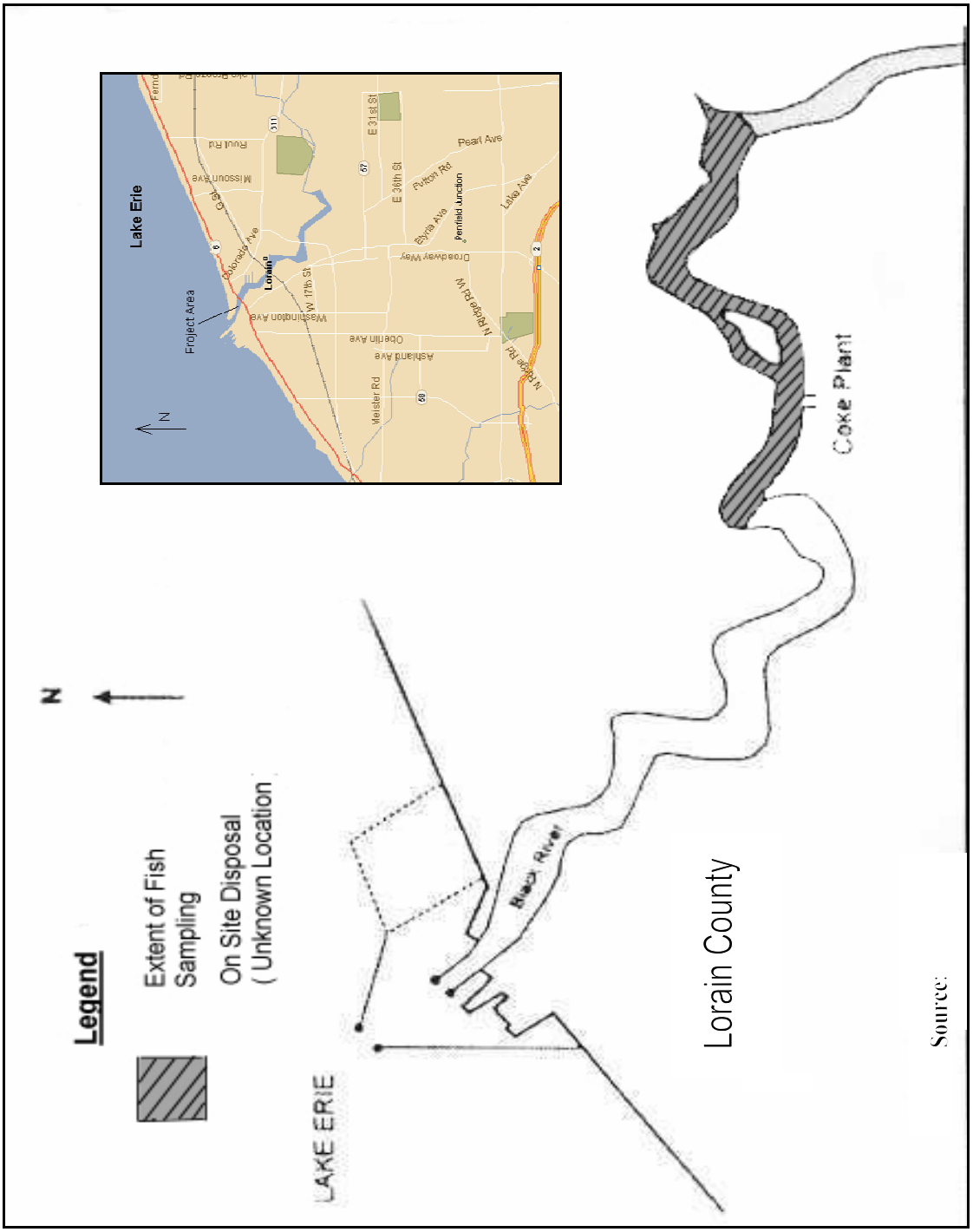
Figure 1 Remedial Dredge Plan - Black River



1 Statement of the Problem

- Dredged 1993
- Metals
- 3,896 cubic yards
- $154 per cubic yard

Sediment in Collingwood Harbour was contaminated with metals from historical shipbuilding activities. Navigational dredging was performed in the harbor in 1986 and a remedial demonstration dredging project was performed in 1992. After the pilot project, the cleanup action consisted of dredging a 2.45-acre area in 1993. Cleanup sediment removal was implemented in order to rehabilitate degraded benthos, remove chronic toxicity and lift restrictions on navigational dredging. The lead agency for coordinating remedial actions was the Ontario Ministry of Environment. Environment Canada and Public Works Canada were lead agencies for the dredging activity.

2 Site Description

Collingwood Harbour is located on the south shore of Nottawasaga Bay in the southern extension of Lake Huron's Georgian Bay in Ontario, Canada (Figure 1). The harbor is approximately 200 acres in area. The harbor is relatively shallow with maximum water depth of 21 feet (at datum). Sediments consisted of soft silt that overlaid a clay layer and bedrock. The harbor is surrounded by a wetland complex, wastewater treatment plant outfall, marina, grain terminal, former shipyards, and the town of Collingwood (population 16,000) (Gamble, 1998).

3 Site Investigation

Navigational dredging was conducted in Collingwood Harbour in 1986. Contaminant levels of chromium, copper, lead, zinc, and PCBs were found in excess of the LEL established by the Provincial Sediment Management Guidelines and subsequently led to restrictions on open-water disposal of dredged sediment. Similar maximum PCB and metals concentrations were observed in a 1987 investigation. A summary of maximum contaminant concentrations before and after the navigational dredging are given in Table 1.

Aerial of Collingwood Harbor
Source: Environment Canada

A sediment sampling survey was performed in April 1992 to determine the nature and extent of contamination for designing of the cleanup dredging plan. Contaminants in excess of the LEL cleanup criteria level included chromium, copper, lead, and zinc as shown in Table 1 (SEDTEC, 1993). PCB concentrations were below the detection limit in all samples collected in the 1992 investigation. The contaminated silt sediments were

present at thicknesses of 0.7 to 1.6 feet (IJC, Case Study). The sediment investigation concluded that contamination was contained within the soft silt layer and the underlying clay layer was deposited before industrial activity and was not contaminated. Results of the investigation indicated that an area of 2.45 acres required removal to meet biological requirements for healthy benthos and removal of chronic toxicity. (Figure 1)

Contaminants of Concern. The major contaminants of concern were trace metals including chromium, copper, lead and zinc. Maximum concentrations detected in a 1992 sediment sampling investigation were 31 ppm chromium, 61 ppm copper, 150 ppm lead, and 180 ppm zinc (Sedtec, 1993). However, conflicting values from a 1993 investigation found maximum concentrations of 300 ppm copper, 1000 ppm lead, and 4000 ppm zinc (Brooksbank 2000). All maximum concentrations from both investigations were above the LEL cleanup criteria. A summary of chemical cleanup criteria is provided below (OMOE, 1993).

Contaminant	LEL (ppm oc)	SEL (ppm oc)
Chromium	26	110
Copper	16	110
Lead	31	250
Zinc	120	820

4 Target Goals and Project Objectives

The principal goal of remedial activities was to remove sediment toxic to benthic organisms. One hundred percent removal of sediments causing toxicity was the target objective of the dredging action. Concentrations of metals, trace or organic contaminants and nutrients in surface sediments within the harbor turning basin had to meet Ontario Ministry of Environment sediment guidelines (IJC, 1999).

5 Project Design

Pre-planning and Bid Documents. A demonstration of contaminated sediment removal was conducted in 1992 using the Pneuma airlift pumping system. The demonstration involved removal of 1,800 cubic meters of marginally contaminated sediment from the west boat slip and the eastern dry dock. The percent solids of the dredged sediment slurry ranged from 15 to 30 percent (Environment Canada, 1998). Results of the demonstration project were used to design the 1993 remedial dredging plan.

Several contractors submitted competitive bids for the 1993 cleanup action dredging project. The selected contractor was the lowest proposal cost received for the cleanup.

Summary of Remedial Action Plan. Sediment was removed in the 1992 demonstration and the 1993 cleanup by a barge-mounted hydraulic dredge set up with guide cables that extended across the harbor channel. The dredge was advanced 13 to 16 feet per minute using a winch system. Dredged sediment was pumped through a 6-inch pipeline to a newly constructed confined disposal facility (CDF) located approximately 3,300 feet from the dredge area (C.B. Fairn, 1993).

Limitations and Permits. Regulatory approvals were required before proceeding with remedial activities. Approval to dredge in a navigable waterway under section 5(2) of the Navigable Waters Protection Act, RSC 1985, Chapter N-22 was granted by the Canadian Coast Guard and the Department of Transportation. The Department of Fisheries and Oceans gave approval under Section 33 of the Fisheries Act (SEDTEC, 1993).

6 Remedial Actions

6.1 Dredging

The dredging area was located in the inner section of the Collingwood Harbour adjacent to the east dock wall and immediately north of the east dry dock slip in the southern portion of the harbor (Figure 1). The water depth in this area ranged from 10 to 18 feet increasing toward the center of the channel.

Schedule and Duration. Dredging operation was conducted from November 24 to December 8, 1993, 6 days a week, 10 hours a day. The duration of active dredging was 66 hours. A total of 53 hours was spent on downtime activities, which included mobilization, demobilization, dredge relocation, and maintenance. The dredging crew consisted of five workers including a superintendent, dredge foreman, dredge operator, compressor operator, and laborer/boat operator.

Equipment. Hydraulic dredging was conducted using a Pneuma pump unit 150/30 including pump body, distributor, vertical inlet shovels, hoses, lowering and raising frame. The dredge was suspended from a 25-ton Crawler crane mounted on a floating flat barge (45 feet by 28 feet by 5 feet) equipped with steel spuds, anchors, four winches, generator, and lights. Dredged sediment was transported to the shore by a floating discharge pipeline where it connected to a 6-inch-diameter PVC pipeline. The PVC pipeline transported the dredged sediment approximately 3,300 feet to a CDF (C.B. Fairn, 1993).

The Pneuma pump uses static water head and compressed air inside special cylinders in a manner similar to a piston pump. The head creates a vacuum and sediment slurry is suctioned into the pump and attached pipeline (hydrostatic pump principle). Small debris (such as cobbles, bottles, tin cans) did not effect operation but larger items, however, (plate steel, timber) required removal through access ports before continuing operations.

Total Volume Removed and Production Rates. An estimated total volume of 3,896 cubic yards of sediment was removed from a 2.45-acre area. The resulting production rate was 59 cubic yards per hour. Percent solids of the dredge slurry was approximately 30 percent. Three passes were made over each section of the dredged area with overlap to ensure no areas were missed.

Site-specific Difficulties. Significant down times for Pneuma Pump cylinder cleanup were necessary during the 1992 demonstration project due to plugging by medium- and large-sized debris from historical shipbuilding activities (Environment Canada, 1998). Some minor delays were experienced due to debris encountered during the 1993 cleanup dredging. The frequency of such delays were significantly less than in the demonstration project.

Soundings indicated that contaminated silt sediment remained after two passes of the dredge. A third pass of the dredge was therefore conducted. A bluish hue observed during the third pass indicated that the underlying clay was being dredged, and all contaminated silt and sediment was presumably removed.

6.2 Dewatering and Water Treatment Operations

Dewatering, Treatment and Disposal. Dredged sediments were pumped via a 6-inch PVC pipeline to a CDF. Dewatering of the slurry was accomplished via passive dewatering in a CDF. Carriage water was separated from dredge solids through gravity settling, evaporation, and infiltration through the CDF sidewalls and bottom. Walls of the CDF were constructed with cobble, sand, and filter fabric (Brooksbank, 2000).

Water Quality Monitoring of Discharge. No water treatment of discharge was conducted. No monitoring data were available for review (unknown if collected).

6.3 Storage and Disposal

Evaporated sediment was capped with clean material in the CDF.

7 Environmental Monitoring Program

The monitoring program included bathymetry surveys, water quality sampling during dredging, sediment sampling, toxicity testing, and benthic community assessment (Table 1).

7.1 Baseline

Physical. A detailed pre-dredge survey of the dredging site was conducted on April 22, 1993 using an echo sounder to establish bathymetry of the harbor bottom and to determine the thickness of contaminated sediments to be dredged. Because only silt sediments were considered contaminated, this determination could be made using physical data. The soft silty sediment ranged from 0.7 to 1.6 feet in thickness and overlaid a native clay layer (C.B. Fairn, 1993).

Water quality monitoring conducted prior to dredging was used to establish ambient levels for turbidity, total suspended solids (TSS), temperature, and pH on October 26, 27, and November 3, 1992. Water samples were collected at two depths: 1 meter below the surface and 1 meter above the sediment surface. Ambient conditions were determined as 5 NTU turbidity and 5 mg/L TSS in both surface and bottom samples (SEDTEC, 1993).

Chemical. Chemical analysis conducted in 1992 and 1993 measured sediment contamination in excess of the LEL for chromium, copper, lead, and zinc (Table 1).

Biological. Benthic abundance/community structure analysis and sediment toxicity tests were conducted in 1992 and 1993 throughout the harbor (and outside) to determine baseline conditions. Oligochaetes were found to be abundant in areas of low-level toxicity in the benthic community structure analysis. Sediment toxicity tests provided evidence that sediment was the cause of toxic impact, rather than the water column or other factors. Chronic low-level toxicity was present in the shipyard slips and in an area northwest of the slips. No growth inhibition was demonstrated in sediment bioassays conducted in 1993 on areas outside of the dredge area.

7.2 Implementation During Dredging

Physical. Water quality monitoring was conducted during dredging for turbidity, total suspended solids (TSS), temperature, and pH at a frequency of two to eight times per day. The acceptance criteria for turbidity was established at an increase of less than 30 percent over ambient levels. The levels for turbidity averaged 6 NTU 1 meter from the surface and 8 NTU 1 meter from the bottom at a distance of 25 meters from the dredge. The acceptance criteria for TSS was established at an increase of less than 25 mg/L over ambient levels. Average TSS results were 5 mg/L at the surface and 10 mg/L at the bottom at a distance of 25 meters from the dredge with ambient levels of 5 mg/L at the surface and bottom. Acceptance criteria for turbidity and TSS (based on average levels) were met during dredging.

7.3 Post

Physical. A sounding survey of the dredged area was conducted using an echo sounder to determine depths of excavation and volume of dredged sediment. The average depth of excavation was 1.0 foot.

Chemical. Chemical analysis of post-dredging sediments was stated to demonstrate a sharp decline in metals concentrations; however, the sediment chemical data have not been received for review at this time (IJC, 1999).

Biological. As stated in the Collingwood Harbour RAP, State 3 Document, “in locations where the LEL is marginally exceeded, concentrations are comparable to background values, or biological

responses, in terms of community composition and bioassay endpoints, are not statistically different from reference values."

7.4 Long Term

Routine monitoring will be conducted to determine the rate of benthos recolonization; however, monitoring data are not available to date. A status survey is scheduled for year 2000.

Table 1 Summary of Monitoring Results

Contaminant	Concentration (in ppm dry-weight)			
	Pre-baseline 1992 (after navigation dredging)	During 1992	Post-1993	Long Term
Bathymetry (echosounder)	Soft sediment 0.7 to 1.6 ft thick	Unknown	Avg. depth of dredge = 1 ft	—
Surface Sediment	Chromium - 31 ppm max Copper - 61 ppm max Lead - 150 ppm max Zinc - 180 ppm max PCBs - 160 ppm max (SedTech, 1993)	Unknown	NA, but stated as "decreased"	—
	Copper - 300 ppm max Lead - 1000 ppm max Zinc - 4000 ppm max (Brooksbank, 2000)			
Surface Water Column	TSS, temperature, pH, turbidity	TSS, temperature, pH, turbidity; criteria met	None	—
Sediment Toxicity Tests	Sediment is cause of toxicity	None	Not statistically different from reference	—
Benthic Community	Oligochaetes abundant	None	Not statistically different from reference	Planned

8 Performance Evaluation

Collingwood Harbour was delisted as an Area of Concern in November 1994. The project was successful in reducing ecological risk. The project also demonstrated successful use of an innovative technology, the Pneuma pump, during remediation.

Since completion of remedial activities, additional fish and wildlife habitat rehabilitation and restoration activities have taken place in the harbor. The community has been involved with the Greening of Collingwood program and the Environment Network of Collingwood to continue environmental restoration work and environmental education begun by

the Collingwood Harbour Public Advisory Committee and the Remedial Action Plan Team.

8.1 Meet Target Objectives

Sediments that demonstrated toxicity to benthic organisms have been removed from the harbor.

8.2 Design Components

A sediment removal demonstration was conducted in the fall of 1992, prior to the full-scale remedial cleanup. The demonstration evaluated the Pneuma airlift pumping system during the removal of 5,200 cy of sediment. Results of the demonstration proved useful in selected an appropriate dredge technology and determining sediment characteristics before the cleanup dredging.

Adequate baseline chemical characterization helped equate visual characteristics (blue hue of the clay material) as general confirmation of dredge success during the 1993 cleanup dredging without waiting for post-verification sampling.

Environmental quality monitoring was conducted for chemical and biological condition of sediment prior to and after dredging activities. Water quality monitoring was conducted during dredging to ensure sediment dispersion was minimized.

8.3 Lessons Learned

A pilot study was useful in predicting effectiveness of dredging and foreseeing potential problems and parameters. Public involvement through education and restoration activities also contributed to the success of the project. Contaminated sediment can be successfully removed using environmental dredging technologies. Beneficial use, measured via biological and chemical testing, can be restored in an industrial harbor.

9 Costs

The cost of the 1992 demonstration and 1993 cleanup dredging (9,548 cubic yards) was $635,000 with a unit cost of $67 per cubic yard.

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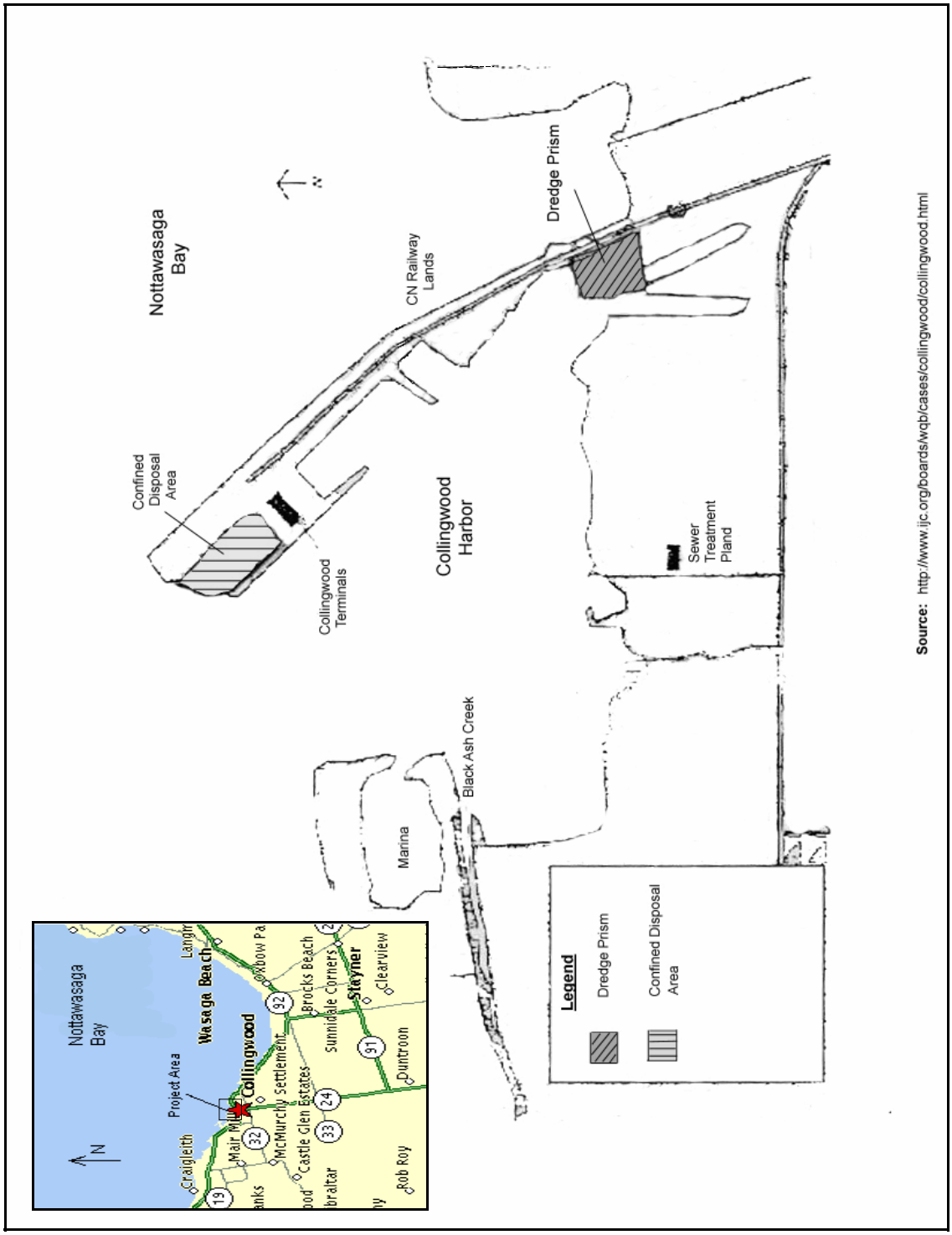
Figure 1 Remedial Dredge Plan - Collingwood Harbour



1 Statement of the Problem

- Dredged 1997
- PCBs
- 27,000 cubic yards
- $220 per cubic yard

The Ford Motor Company dredged approximately 27,000 cubic yards (20,520 cubic meters) of PCB-contaminated sediment in 1997 from a "hotspot" located near their 48-inch discharge outfall adjacent to the shipping channel of the River Raisin. The EPA-selected remedy was to dredge the hotspot sediments to below the risk-based chemical criteria of 10 ppm polychlorinated biphenyls (PCBs). Contaminated sediment was stabilized with Portland cement and disposed of in a Toxic Substances Control Act (TSCA) landfill located on site. The lead agency for this project was U.S. Environmental Protection Agency (EPA) Region 5.

2 Site Description

The entire River Raisin Area of Concern (AOC) is a 2.6-mile section of the lower River Raisin located near the city of Monroe, Michigan, in the southeastern portion of the state (Figure 1). It extends from the Winchester Bridge (Dam #6) downstream to the receiving water body of Monroe Harbor and Lake Erie extending 0.5 mile out from shore. The Ford outfall site is located within the AOC. Although the site is located in the industrial center of Monroe on Ford Motor Company property, the adjacent terrain is relatively flat with a large portion composed of wetlands, woods, and Sterling State Park. The Ford outfall project site consists of the sewer system at the Ford plant and the River Raisin sediments in the proximity to the closed 48-inch and 36-inch outfalls at the plant (outfalls closed since 1972). The sediment removal area is located in proximity to the closed 48-inch discharge pipe, in an embayment adjacent to the River Raisin just downstream of the turning basin.

View of River Raisin

The river has an annual mean discharge of 728 cubic feet per second. Water depth ranges from 4 to 6 feet nearshore, sloping to 18 feet on the side slopes, then 30 feet in the navigation channel. River sediments consist of soft silty clay surface deposits with no cohesion (up to 2 feet thick) over soft to stiff organic silty clay (up to 9 feet thick) over hard glacial till (Metcalf and Eddy, 1994).

According to the U.S. Environmental Protection Agency (EPA), the Ford Monroe Stamping Plant manufactured automotive parts at the site starting in 1949 and discharged wastewater directly into the River Raisin via outfalls until the 1970s. In 1972, the old outfalls were closed and new ones constructed further downstream. The majority of wastewater was generated by cleaning, painting and plating processes containing PCBs.

3 Site Investigation

Both EPA and the Michigan Department of Environmental Quality (MDEQ) detected elevated PCB concentrations in samples collected from wastewater, fish, and sediment surrounding the wastewater discharge pipes between 1973 and 1992. After a Michigan State University Research team detected high concentrations of PCBs in sediments near the former Ford outfall pipe in 1991, the EPA issued an Administrative Order of Consent (AOC) to the Ford Motor Company (EPA, 1993). With EPA oversight, Ford conducted a remedial investigation to define the lateral and vertical extent of PCB contamination in this area known as the "hotspot." In 1993, sediment samples collected near the 48-inch outfall ranged from 1.5 to 29,000 ppm PCBs, and samples collected near the 36-inch outfall ranged from 5.8 to 180 ppm PCBs. Samples collected 300 feet downstream of the 48-inch outfall measured up to 120 ppm PCBs (EPA, 1995). In 1995, EPA conducted sediment sampling to determine if any hotspots were present in the river in addition to the hotspot located near the Ford outfall discharge pipe. Chemicals detected in these surface sediment samples included: PCBs, dioxins, furans, chromium, nickel and zinc. In 1997, MDEQ conducted additional sampling to further define the extent of sediment contamination at certain locations. Based on PCB contamination and perceived impact to fish and wildlife habitat, a Remedial Action Plan was issued by the Michigan Department of Natural Resources (MDNR) in 1987 for the River Raisin Area of Concern.

The Ford Outfall Site was identified for a Superfund Emergency Removal Action under the direction of EPA Region V using the Superfund Accelerated Cleanup Model (SACM). A final remedy plan was selected in August 1996. The SACM was intended to provide EPA with greater flexibility to clean up NPL-caliber sites with more efficiency. In 1998, after the 1997 remediation effort, MDEQ conducted sediment sampling to determine the success and extent of the PCB cleanup, and to determine if contamination was present further upstream.

Contaminants of Concern. The major contaminant of concern driving the cleanup actions was PCBs. The highest PCB concentrations were detected in sediment samples collected near the outfall pipe in 1991 measuring 42,167 ppm PCBs. Baseline sediment samples collected in 1995 measured maximum concentrations of 52 ppm and 140 ppm PCBs immediately downstream and 2 miles further downstream of the hotspot area, respectively. PCB-contaminated contaminants of concern included dioxins and trace metals measured in concentrations above the Ontario Ministry of Environment and Energy (OMEE) potential severe effects levels.

4 Target Goals and Project Objectives

The remedial project goals were to remove all contaminated sediment from a hotspot located near the outlet of the Ford plant's wastewater discharge pipe. The proposed hotspot measured 600 feet long to 200 feet wide and totaled 28,000 cubic yards of sediment. The target goals were

twofold: 1) to dredge all sediment down to hardpan from within the dredge prism, and 2) monitor residuals for compliance with 10 ppm PCB cleanup criteria based on EPA risk-based cleanup criteria designed to be protective of fish and wildlife. Post-verification sediment sampling was used to measure dredging success. As stated in the AOC, the target goals were "respondent shall dredge and dewater all sediment that contains PCBs above 50 ppm"; however, this chemical criteria was changed to 10 ppm PCB based on EPA's streamlined risk assessment.

Long-term Project Objectives. Following redeposition from nearby areas, EPA expected residual hotspot concentrations to range between 10 and 30 ppm PCBs. These concentrations were considered protective of the larger fish exposure zone of the River Raisin AOC. As stated in the 1995 AOC, the long-term remedial action objective (RAO) was to reduce PCB concentrations in fish and to protect human health:

Filter Cake
Source: WDNR

> "A proposal to remove sediments down to the clay layer within the defined removal area was reviewed and recommended by the Sediments Group (EPA) to be accepted based on the estimates showing PCB levels left behind would likely reduce PCB contamination in biota to acceptable levels for human consumption." (EPA, 1995)

The amended 1997 removal decision document stated the long-term RAO was to:

> "Reduce potential threat to human health and the environment by reducing the mass of chemical constituents in the river sediment, sewer material, and soil at the site available for bioaccumulation via ingestion of contaminated fish." (EPA, 1997)

5 Project Design

Pre-planning and Bid Documents. The remedial design activities included environmental physical, chemical, and biological studies, physical characterizations, and subsurface sediment sampling to refine the horizontal and vertical extent of contamination. The AOC required an engineering evaluation/cost analysis (EE/CA) plan, a statement of work, a monitoring program, corrective action plan, contingency plans, performance standards, a completion of removal action report, pre-construction inspections, and a field sampling and analysis plan (SAP) and quality assurance project plan (QAPP). An EE/CA for the Ford Outfall Site was conducted in 1994 by Metcalf and Eddy that outlined the remedial alternatives, stated how each RAO would be performed to maximize success, operational steps to minimize resuspension of sediment, compliance with ARARs, sediment handling, and monitoring plans. The EE/CA recommended using the cable arm bucket based on site conditions (Metcalf and Eddy, 1994).

EPA contracted the U.S. Army Corps of Engineers (ACOE) to conduct oversight of the remediation effort. A district oversight work plan was approved to be used by the ACOE in conjunction with the bid documents and other contractors submittals to assure the PRPs performance was in compliance with the ROD.

Summary of Remedial Action Plan. In 1996, EPA selected a final remedy plan for the Ford outfall hotspot that included: dredging of contaminated sediment exceeding 10 ppm PCBs using a mechanical closed-bucket clamshell dredge, containing sediment resuspension with a silt curtain, transfer sediment to treatment area by barge and scow, solidifying/stabilizing the sediment with Portland cement, uploading and hauling of treated sediment to a TSCA-approved on-site disposal facility (sediment containment unit), monitoring air quality during dredging, establishing baseline conditions before dredging, and conducting post-verification sediment sampling. The remedy also called for additional upland plant and sewer investigations (IJC, 1999; EPA, 1998).

Limitations and Permits. None specified. However, all aspects of the water and sediment treatment system were tested prior to beginning full-scale remedial activities.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. Remedial dredging activities operated from mid-July through the end of September 1997 (55 actual dredging/redredging days out of 88 calendar days). Hours of operation were 8 hours per day, 5 days per week.

Equipment. A derrick barge equipped with a 6-cubic-yard environmental cable arm clamshell bucket with a vibrator and a 4-cubic-yard conventional clamshell bucket (when warranted) were used to dredge sediments from a 2.6-acre hotspot around the 48-inch outfall. A silt curtain was installed with anchor weights and “no wake” buoys. The clamshell bucket dumped dredged sediment into an 800-cubic-yard-capacity three-compartment scow barge, then wet sediments were transferred into sealed tandem dump trucks by an overhead crane and slim-profile cable arm bucket. Bobcat loaders, front-end loaders and excavators were used to transport sediments from different upland areas. A silt screen made of geotextile fabric was placed around dredging operations from the water surface own to a few feet above mudline to minimize sediment transport downstream. The curtain was installed with anchor weights and “no wake” buoys.

Total Volume Removed and Production Rates. Approximately 27,000 cubic yards of contaminated sediment (34,724 tons) was removed and treated from the Ford outfall hotspot in 1997.

Site-specific Difficulties. In August 1997, a 634-foot-long cargo vessel generated prop wash while turning around in the burning basin causing

damage to the silt curtain. The silt curtain required repair before resuming activities. Resuspension caused sediment to remain in the center of the river despite numerous dredging attempts to remove all sediment down to native material. According to MDEQ, possible explanations for dredging difficulties included: 1) operator carelessness, and 2) cargo ships passing through the dredging area disturbing the water column.

6.2 Dewatering and Water Treatment Operations

Wastewater from the scow was pumped into a holding tank before processing at the on-site wastewater treatment facility (WWTP) equipped with sand filters. Treated water was released back to the River Raisin after passing water quality testing of PCBs. As of 1997, the wastewater treatment plant remained on site to continue treatment of leachate water pumped from the sump area of the sediment containment unit (SCU) (ACOE, 1998).

Air Monitoring Equipment
Source: B. Paulson, WDNR

6.3 Storage and Disposal

Wet sediments were temporarily stockpiled on land-based pads. An excavator transported sediment into a shaker/screen then conveyored to a pugmill power screen, which fed directly into a pugmill hopper. The pugmill homogenized the PCB-contaminated sediment with reagent. Treated sediments were stockpiled for curing then disposed of in a 3-acre TSCA cell that was built on the property of the Ford Monroe Plant. The TSCA cell was located within a larger 32-acre on-site landfill. The sediment containment unit (or TSCA cell) was covered with a geotextile cap and leachate will continue to be collected and treated on site through the WWTP.

7 Environmental Monitoring Program

The environmental monitoring program included baseline sediment sampling, air and surface water quality sampling during dredging, and post-verification sediment sampling. Bioaccumulation studies in caged and resident fish were also conducted after the 1997 dredging. Verification of monitoring success was based on sediment sampling chemical criteria. The monitoring program also included a corrective action plan, a contingency plan, and field SAP and QAPP.

7.1 Baseline

Physical. According to the EE/CA, "hydrography surveys will be performed prior to sediment removal to locate the river bottom and the underlying clay layer."

Chemical. In 1995, EPA collected 22 sediment cores from the River Raisin AOC to depths of 2 to 6 feet below mudline to determine if any

additional hotspots (beyond Ford Outfall) were present in the larger AOC. In May/June 1997 (a few months before remediation of the Ford Outfall hotspot), MDEQ collected 27 sediment cores to refine the extent of PCB contamination in the River Raisin AOC identified in the 1995 study. Samples collected from both the 1995 and 1997 study were analyzed for a multiple classes of analytes in addition to PCB Aroclors; however, none of these samples were collected within the Ford Outfall hotspot area. The downstream sediment sample collected closest to the hotspot area measured 52 mg/kg PCB Aroclor 1242 in the surface interval while the average downstream concentration for all samples was 14.9 mg/kg PCB Aroclor 1242 in 1995. The maximum detected concentration in the upstream samples was 9.0 mg/kg PCB Aroclor 1242 with an approximate average of 1.0 mg/kg PCB 1242. The 1997 samples are not discussed because the detection limits were an order of magnitude higher than the 1995 samples and comparable to neither the 1995 nor 1998 data (MDEQ, 1999).

Air monitoring for PCB particulates was conducted at three ambient stations placed upwind and downwind from the exclusion zone. Five 24-hour samples taken at 6-day intervals were collected prior to the removal action for determining background concentrations.

Biological. Caged fish monitoring was conducted in 1988 and 1991 by MDEQ. Details of the sampling events were not available for review.

7.2 Implementation During Dredging

Physical. A turbidity monitoring program was established to monitor potential resuspension of sediments during dredging. Turbidity in the water column was measured twice per day at one upstream and one downstream location of the sediment removal area (SRA) at two vertical depths (mid-depth and just above mudline). Water column samples were also analyzed for PCBs, but discontinued because the action levels to trigger additional monitoring were not exceeded. There were reportedly no major violations of the compliance parameters and no adjustments to the dredging plan were made based on compliance measurements.

Chemical. As specified in the remedy, air and water column monitoring was to be conducted during dredging, but no details were available for review. No biological testing was performed during dredging.

As stated at the hudsonwatch website, "as soon as re-dredging in a dredge-cell was completed, re-sampling of the cell floor and/or sideslopes was performed for confirmation. In a few dredge cells, re-dredging and re-sampling were performed several times. Post-verification surface ponar grab samples were collected from the dredged area, and confirmatory sample results from all 14 dredge-cells indicated the AOC target cleanup goal of 50 ppm PCBs was met. Confirmation sideslope sample results also indicated that the U.S. EPA target cleanup goal of 10 ppm was met (specifically the sideslopes)."

"The redredging effort went essentially to bedrock. Often the remaining sediment being dredged consisted of a 2- to 6-inch layer of highly liquid sediment. The redredging effort was assisted by diver inspections."

Water quality monitoring for turbidity was conducted twice daily upstream and downstream of the dredging activities (collected mid-depth).

Air monitoring for PCB particulates consisted of daily collection of 24-hour composite samples over a 2-week period, then every third working day, from three ambient stations. No significant exceedances of the 0.01 $\mu g/m^3$ PCB action level were reported. Action levels were determined by readings above the Threshold Limit Value (TLV) set by the American Conference of Governmental Industrial Hygienists (ACOE, 1998).

A wastewater treatment plant was used at the site for water treatment during the project. Analytical results indicated that effluent met discharge requirements for the project before discharge to the River Raisin (ACOE, 1998).

7.3 Post

Physical. Final pole soundings were conducted in all areas after redredging. According to the ACOE on-site representative, sediment was dredged to the design depths and dimensions indicated on the remediation drawings (ACOE, 1998).

Chemical. After completion of redredging (September 26, 1997), a verification sediment sample for lab analysis was collected near the center of each of the 14 dredge-cells that constituted the 2.6-acre target area. Surface grab samples were collected using a ponar sampler and compared to the 10 ppm target cleanup level. In seven of 14 cells, insufficient sediment remained for sample collection. In four of 14 cells, the final sample was less than 10 ppm PCBs (0.5 to 7 ppm range). In three of 14 cells, the final sample was greater than 10 ppm (12 to 20 ppm range).

In 1998, MDEQ collected sediment samples from 20 stations to determine post-dredge conditions. Two surface sediment samples (0 to 6 inches and 0 to 18 inches) were collected from within the dredged hotspot area with measured concentrations of 64 mg/kg and 110 mg/kg PCB Aroclor 1242. The sediment samples located downstream of the hotspot removal area ranged from non-detect to 32 mg/kg PCB Aroclor 1242 with an average of 6 mg/kg. The 1998 average downstream concentration of PCB Aroclor 1242 is 2.5 times lower than the average 1995 sediment concentration. All other Aroclors were non-detect (MDEQ, 1999).

Biological. Habitat or benthic abundance was not monitored in the River Raisin immediately after dredging.

7.4 Long Term

Post-monitoring activities are ongoing by MDEQ and include sediment cores, caged fish bioaccumulation studies, and resident fish tissue analysis for PCB concentrations (MDEQ, 1998a and 1998b; GE/AEM/BBL, 1999). Caged fish were placed at three locations in the Raisin River in 1998 to evaluate results of the removal project. Cages were placed at the Grand Trunk Railroad Bridge (upstream), downstream of the turning basin (near dredging site), and at the mouth of the river. Total PCB concentrations in tissue were highest at the mouth (0.01 to 0.67 ppm). Concentrations were significantly different ($p < 0.05$) between sites (MDEQ, 1998).

Table 1 Summary of Monitoring Results

Test Parameters	Monitoring (maximum concentration of PCB Aroclor 1242 in ppm)				
	Baseline 1988	Baseline 1991/1993	Pre-dredge 1995	Post-dredge 1997	1998
Physical				met design depth	
Surface Sediment (maximum)		29,000 ppm		20 ppm (all below 50 ppm)	110 ppm (average 10 ppm)
Fish Tissue (net uptake) [1]	4.06	1.07			0.6678

Note:
[1] Net contaminant uptake in caged fish from mouth of river (MDEQ, 1998).

8 Performance Evaluation

8.1 Meet Target Objectives

The target goal of mass removal of contaminated sediment down to the clay horizon (native) with verification sampling to 10 ppm PCBs was achieved in 80 percent of the dredge cells. Progress towards risk reduction of PCBs to human health and the environment was observed by a 263-fold reduction in maximum PCB concentrations from baseline conditions and a 0.6-fold reduction in fish tissue concentrations. Design elevation was achieved based on physical and chemical monitoring data. The post-verification sediment sample chemical concentrations were below the compliance criteria, therefore the remedial dredging objectives were met.

As stated in the Hudsonwatch website, "Confirmatory sample collection activities in many dredge-cells were revealing that sediment remained, even through prior dredging to refusal had occurred. A review of information from dredging, sampling, and the dive inspection of the silt curtain, identified the following suspected sources of remaining sediment:

- Sediment deposited due to passage of unauthorized lake freighter;

- Recent sediment deposition following resuspension during dredging;
- Sloughing of sediment outside of the dredge prism along the base of the silt curtain into the dredge area; and
- Sloughing of sediment along the slope from the nearshore shelf to the deeper dredged channel" (GE/AEM/BBL, 1999).

As stated in a letter from Mike Collins of the EPA to the Ford Motor Company, "Based on agency oversight, final reports, and inspection reports, I concluded that the Ford Motor Company has completed the following work required by the AOC..." (EPA, 1999). However, Roger Jones of MDEQ collected two samples on September 22, 1998 that exceeded the target goal of 50 ppm PCBs. MDEQ believes the extent of remaining contaminated sediment should be quantified.

8.2 Design Components

During preliminary negotiations, EPA did not consider other options besides dredging as a remedial alternative. They were interested in source control and minimizing downstream transport of PCB hotspots further downstream and into Lake Michigan. With this in mind, the project engineers considered different dredging technologies, site conditions, limitations, and existing data. However, based on the 1997 post-project sediment sampling (N = 14) where results ranged from 0 to 20 mg/kg PCBs, when compared to the 1998 sampling event (N = 2) where results were 64 and 110 mg/kg PCBs, it appears that: 1) source control has not been achieved, or 2) ridges and furrows exist within the former hotspot with patchy concentration distributions. It is likely that source control was not achieved, since resuspension, redeposition, sloughing of sideslopes, and potential upstream sources of PCBs were anticipated. This dredging project may have proceeded in haste (to show significant progress within the Superfund framework) without adequate consideration of site conditions in the project design. However, the target goal was to remove all hotspot sediments down to native horizon, which was achieved and implementable within the framework of the larger AOC (River Raisin).

8.3 Lessons Learned

After initial dredging to refusal, confirmation sediment samples revealed thin layers of sediment remained on the bedrock resulting in several additional passes with dredge equipment. Other sources of sediment deposition included: passage of an unauthorized lake freighter, resuspension during dredging, and sloughing of material from adjacent sideslopes.

As dredging activities approached the hardpan layer, dredged material consisted of a mixture of sediment, rock and hard clay. These harder materials clogged the treatment system and slowed the treatment process. A comprehensive understanding of site conditions and sediment

properties is necessary to adequately design a dewatering and treatment system capable of handling the dredged material.

Communication with surrounding industries, interest groups, and nearby residents is essential to completing a successful dredging project within the vicinity of multiple land uses. The unauthorized passage of a lake freighter that utilized the turning basin immediately upstream of the dredging activities and passed over the silt curtain, thereby disturbing the silt curtain, may have been avoided through public awareness and coordination with local industries.

9 Costs

The total cost for dredging, treatment and disposal on site was projected to be $5.17 million and the actual cost was approximately $6 million ($220 per cubic yard). Estimated cost for out-of-state disposal at a TSCA landfill was $15.29 million (not implemented).

10 Project Contact

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Design Engineer: Metcalf and Eddy
General Contractor: Sevenson Environmental Services
Dredge Contractor: Luedtke Engineering Company
Oversight: ACOE and MDEQ

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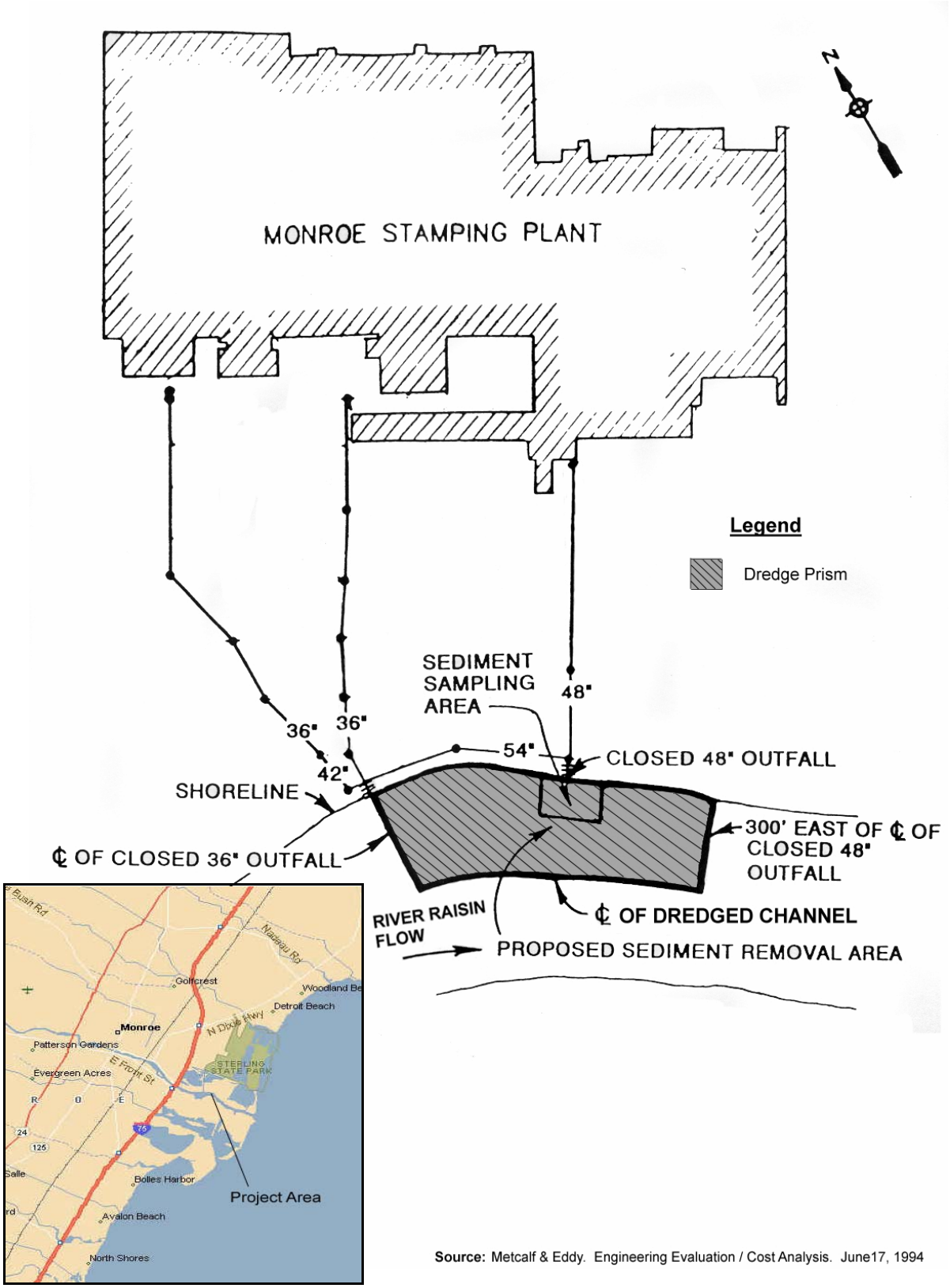
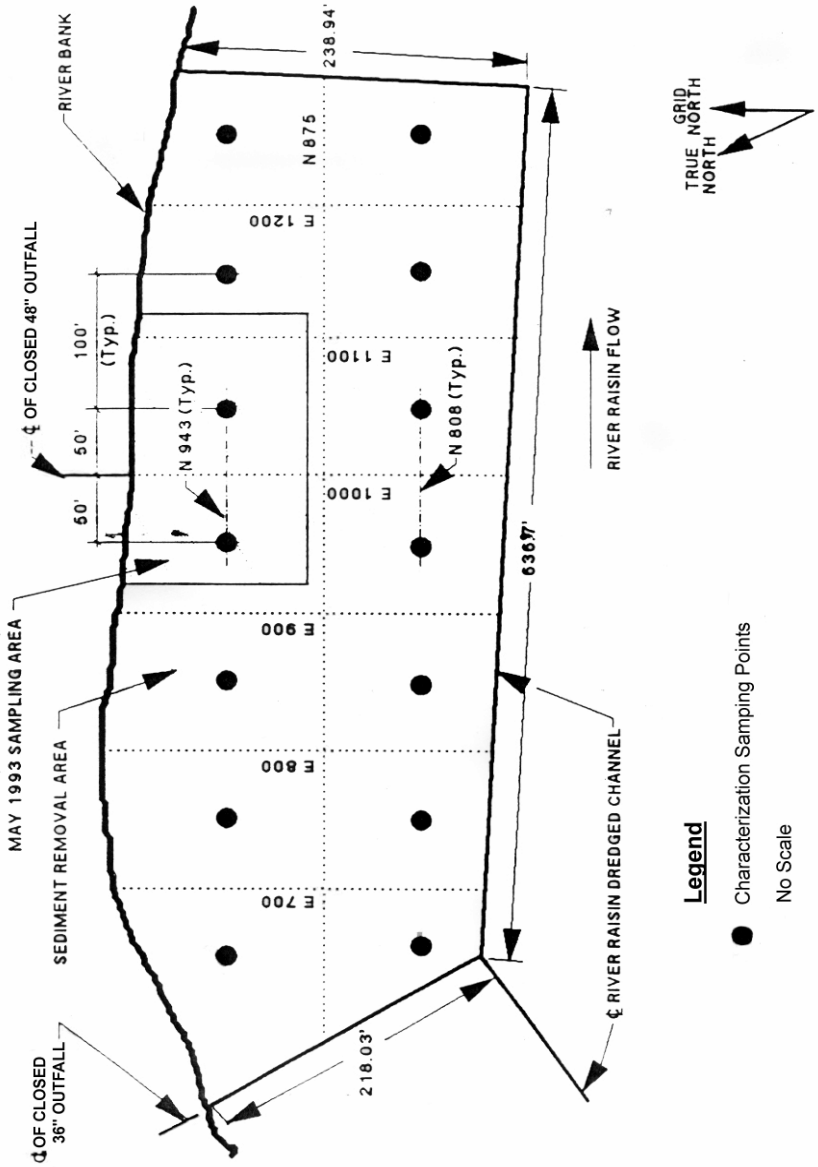
Figure 1 Ford Outfall Dredge Prism



Source: Metcalf & Eddy. Engineering Evaluation / Cost Analysis. June17, 1994

Figure 2 Ford Outfall Dredge Prism/Sampling Locations



Source: Metcalf & Eddy. Engineering Evaluation / Cost Analysis. June17, 1994

1 Statement of the Problem

- Dredged 1998–1999
- PCBs
- 8,175 cubic yards
- $525 per cy total

Deposit N, located in the Lower Fox River near Kimberly, Wisconsin was contaminated with polychlorinated biphenyls (PCBs) from multiple industries and paper mill facilities. Maximum concentrations detected in surface sediment samples were 186 mg/kg dry-weight PCBs. Deposit N, along with other deposits in the Lower Fox River, resulted in fish consumption advisories for the Fox River. This priority deposit, approximately 3 acres in size and 11,000 cubic yards in volume, was identified by Wisconsin Department of Natural Resources (WDNR) for a pilot demonstration removal project for the larger Fox River RI/FS project. The selected remedy was 100 percent removal of contaminated sediment to a design depth of 3 to 6 inches above bedrock using a hydraulic cutterhead dredge. Remedial activities were conducted in 1998 and 1999. As a pilot study, the target goal of the dredging project was to achieve mass removal of PCB-contaminated sediment down to the design elevation and to assess the protectiveness of environmental dredging in removing PCB contamination. The project objective was to use the information gained to assess appropriate remedial technologies, effectiveness and implementation of the selected technology and costs for a large-scale remedy of the Lower Fox River.

2 Site Description

Deposit N is part of the Lower Fox River/Green Bay remedial investigation/ feasibility study (RI/FS) project located in Wisconsin on the western shores of Lake Michigan. The Lower Fox River extends 39 miles from Lake Winnebago to Green Bay, Wisconsin, draining 2,445 square miles. Twelve dams impound the once navigable river as it drops approximately 158 feet in elevation from the lake down to the De Pere dam. The Deposit N project area is approximately 3 acres in size, 0.25 mile wide, and 11,000 cubic yards in volume. The surrounding area is a mixture of paper mill industries, residential, and undeveloped land. Water depths at the location are generally 8 feet deep and the average sediment thickness prior to removal was 2 to 3 feet. The mean annual Fox River discharge recorded in 1994 was 4,252 cubic meters per second (120 cubic feet per second). Site sediments were generally soft, silty clay in the western lobe and sandy in the eastern lobe averaging 2 to 3 feet thick over fractured bedrock with scattered boulders near the shorelines (ThermoRetec, 2000).

3 Site Investigation

In 1995, an RI/FS investigation characterized Deposit N as an elongated point bar deposit just offshore in Inter Lake Papers Company Site (SAIC, 1996 and 1997). A final Record of Decision (ROD) for remedial action will be addressed after release of the river and bay-wide RI/FS data reports. The lead agency is WDNR with financial support from the U.S. Environmental Protection Agency (EPA).

Contaminants of Concern. The primary contaminant of concern was PCBs from the production of carbonless copy paper by the paper mill industries located along the shoreline of the Fox River. Other contaminants include mercury and heavy metals. PCBs were measured as high as 186 ppm and mercury was measured up to 4.7 ppm. Contaminated sediment was contained primarily in the soft silts (0 to 3 feet thick) overlying fractured bedrock.

4 Target Goals and Project Objectives

The target goals of the pilot study were to achieve sediment removal by hydraulic dredging down to a design depth of 3 to 6 inches above bedrock. No target chemical cleanup criteria was required in the project specifications since detectable PCB concentrations were expected from residual sediment resting on the hard fractured bedrock after dredging activities. The thin residual layer was considered during the design phase to gain the highest removal efficiency for the cost. Without the ability to overdredge and remove residual sediments, the target goal of sediment mass removal within the dredge prism was a viable design. No long-term project objectives were specified except to aid in the future refinement of remedial alternatives for the Lower Fox River project.

5 Project Design

In late 1997, the pilot study was initiated on behalf of WDNR and EPA.

Dredge and Silt Curtain
Source: B. Fitzpatrick, WDNR

Pre-planning and Bid Documents. Extensive physical and chemical laboratory testing was conducted to simulate dredging and filling activities and to predict the fate and transport of site chemicals. Tests included: sediment dewatering bench tests, water treatment, filter press, stabilization bench tests, whole effluent toxicity tests and TSS/turbidity correlation tests (Foth and van Dyke, 2001). The pre-design project work provided the foundation for the construction performance specifications for Deposit N. A design engineer prepared and issued competitive bid specifications and bid documents. The contracting strategy centered on a performance-based contract that contained specific performance criteria, but allowed the contractor flexibility to modify remedial strategies while maintaining performance standards. The lowest qualified bidder was awarded the contract. A project quality assurance project plan (QAPP) was developed by the contractor that provided the field and laboratory quality objectives for monitoring work, and defined sampling procedures, equipment, and corrective action responsibilities.

Pre-removal activities also included acquiring state and federal permits, access agreements, and an environmental assessment. Permits included: a Wisconsin Chapter 30 permit for dredging, an ACOE nationwide permit for dredging and barrier construction in federal waters, a WPDES permit for effluent discharge back to the river and solid waste disposal plan modification approval for TSCA-level waste disposed to approved Wisconsin state solid waste landfills (approved by EPA) (Foth and Van Dyke, 2001).

Summary of Remedial Action Plan. Overall, the remedial action entailed construction of a special containment system around the deposit to prevent transport of resuspended sediments, wet excavation of subtidal sediments using a hydraulic cutterhead dredge, treatment of extracted sediment slurry with sieve screens, hydrocyclones, and filter presses, stabilization of sediments with polymer, and off-site disposal of material to an upland landfill. Water separated during the sediment treatment process was discharged back to the river after chemical testing (Foth and Van Dyke, 2000).

Limitations and Permits. Dredging activities ceased during the winter months because of ice and freezing weather conditions.

6 Remedial Action

6.1 Dredging

Schedule and Duration. Equipment was mobilized to the site in October 1998 and work continued until December 31, 1998 (holiday off) when operations ceased for the winter from sub-zero weather conditions. Dredging operations resumed the following summer from August 20, 1999 to October 14, 1999. Dredging operations occurred for 104 days. Operation hours were 24 hours per day during the 1998 activities and 10 hours per day during the 1999 dredging activities. Dredging time averaged an aggregate of 3 to 5 hours per day (Foth and Van Dyke, 1999, 2000 and 2001; ThermoRetec, 2000).

Hydraulic Cutterhead Dredge
Source: B. Fitzpatrick, WDNR

Equipment. Sediment removal was conducted using an 8-inch Moray/Utra hydraulic cutterhead dredge with a swinging ladder configuration, rotating, variable speed cutter, and an intake/suction line. The slurry material was pumped from the dredge to the onshore treatment facility through an 8-inch-diameter, double-walled (1998 only), high-density polyethylene (HDPE) pipeline (Foth and Van Dyke, 2000). Percent solids of dredge slurry ranged between 0.4 and 6 percent with an average of 2 percent based on 1998 data (ThermoRetec, 2000). Sediment resuspension and transport

Dewatered Filter Cake
Source: B. Fitzpatrick, WDNR

was minimized by placement of a perimeter turbidity containment barrier consisting of 80-mil HDPE anchored to the bottom, weighted to the bottom with rail lengths placed in manufactured pockets and suspended at the water surface with 12-inch-diameter floats. In addition to the perimeter barrier, two other barriers were also installed: a deflection barrier and a silt curtain. During the 1999 operations, the perimeter curtain was not deployed; only the silt curtain and deflection barrier were used during the 1999 dredging work.

The summary report stated "for final dredging cleanup work close to the bedrock, the dredge was modified by extending the suction pipe mouth inside the cutterhead and reducing the area of the mouth opening by 15 percent to increase vacuum pressure." With additional funds and time leftover after meeting project design requirements, additional supplemental dredging was conducted in the western lobe to remove additional soft sediments resting on bedrock (Foth and Van Dyke, 2000).

Total Volume Removed and Production Rates. A total of 8,190 cubic yards of sediment were removed (6,470 tons of dewatered sediment and removal of 112 pounds of PCBs from the Fox River). The estimated dredge prism volume was approximately 11,000 cubic yards, but the target volume was 7,060 cubic yards to allow for the residual volume left on the riverbed as specified in the removal contract. A small area adjacent to the shore was not dredged due to the presence of coal and large boulders resting on the riverbed. Of the volume removed by the project, 7,160 cubic yards was removed from Deposit N and 1,030 cubic yards was removed from Deposit O.

Following the removal to specifications at Deposit N and the supplemental dredging of the western lobe, the contractor was authorized to perform additional sediment removal of an adjacent deposit called Deposit O. Additional work at Deposit O was approved to take advantage of the mobilized equipment and existing permits for the work. Approximately 1,030 cubic yards of low level PCB contaminated sediment was removed from Deposit O over a three-week period. Approximately 1 pound of PCBs were removed in the sediment from Deposit O.

Site-specific Difficulties. None that impacted the overall success of the project. The presence of shallow bedrock was a known factor that was anticipated in the project design and as expected did slow production. To collect post-verification samples, divers had to look in cracks/crevices of the fractured bedrock and underneath boulders to find adequate sample volume for testing.

6.2 Dewatering and Water Treatment Operations

Extracted sediment slurry from the barge was screened through a 0.375-inch shaker screen to remove debris and gravel fractions. Remaining slurry was pumped into a settling tank then pumped into two hydrocyclones to remove the sand fraction (greater than #200 sieve). The remaining material was conditioned with a polymer in mixing tanks to increase percent solids, and pumped into two 200-cubic-foot filter presses for compression at 200 pounds per square inch (psi). Project specification requirements for 50% solids in the dewatered sediment were achieved by the treatment process (Foth and Van Dyke, 2001). The compressed solid material was stockpiled and tested for PCBs, mercury, and percent solids. Water separated during filter presses was treated through solid sand filtration and liquid-phase carbon adsorption prior to testing and discharge back to the Fox River.

Water Quality Monitoring of Discharge. Prior to discharge back to Fox River, water was tested for PCBs, TSS, ammonia, mercury, priority pollutants, and whole effluent toxicity testing. The discharge pipe was configured to satisfy a Wisconsin Pollutant Discharge Elimination System (WPDES) zone of discharge requirement. Monitoring demonstrated no exceedances of WPDES permit requirements.

6.3 Storage and Disposal

Dewatered sediment and debris were loaded into haul trucks using a front-end loader. Based on the PCB concentrations of dried sediment relative to TSCA standards, the material was transported to either Winnebago County Landfill (PCBs less than 50 ppm) located 28 miles from the site, or the Wayne Disposal Landfill in Bellevue, Michigan (PCBs greater than 50 ppm). During 1999, all dredged sediments were transported to the Winnebago County Landfill.

7 Environmental Monitoring Program

The environmental monitoring program included surface sediment sampling, water quality monitoring during dredging, and post-verification surface sediment sampling (FRRAT, 2000) (Table 1).

7.1 Baseline

Physical. Bathymetric surveys were conducted during the RI/FS investigations to determine sediment stratigraphy, topography, and soft sediment thickness. Surveys were also conducted prior to mobilization to the site to determine compliance criteria for dredging activities. Turbidity meters were placed at six locations to monitor water quality during dredging operations and establish baseline turbidity conditions

Chemical. Both prior to and shortly after dredging in both the west and east lobes of the deposit, surface sediment samples were collected by divers to provide data on PCB mass removal. Although PCB target concentrations were not required in the project specifications, the average pre-dredge PCB sediment concentration in Deposit N was 11.7 ppm, with

a maximum of 85.4 ppm and approximately 82 percent of the PCB mass was removed. A plot of PCB mass at Deposit N over a defined area (PCB pounds per square yard) showed considerable reduction in available mass of PCBs to the aquatic environment.

Biological. Caged fish studies were conducted in October and November 1997 for PCB Aroclors. Numerous resident fish tissue bioaccumulation studies have occurred between 1988 and 1996 including the 1989/1990 Green Bay mass Balance Study, the WDNR fish contaminant advisory study, the USGS water quality assessment program, the 1996 RI/FS WDNR fish tissue data collection, the 1996 BBL fish tissue data set, and the NRDA 1996 fish tissue collection study by the USFWS. Results of these studies are currently being folded into an ecological and human health risk assessment in support of remedial alternatives for the RI/FS Lower Fox River project. Nine species of fish (carp, walleye, yellow, perch, alewife, common shiner, emerald shiner, gizzard shad, golden shiner, and rainbow smelt) were analyzed for total PCBs, PCB congeners, and other constituents of concern and are included in various food web models developed for each river reach.

7.2 Implementation During Dredging

Physical. Turbidity meters were placed at six locations to monitor water quality during dredging operations and establish baseline conditions. Turbidity results in the vicinity of operations showed a range averaging less than 2 to 4 NTUs above the background upstream stations and showed that on average, dredging produced little change to river turbidity.

Chemical. No sediment sampling was specified. Air quality monitoring was conducted during the 1998 activities with four real-time, particulate monitors surrounding the land-based treatment operations. Air sample results complied with site standards.

Biological. No biological testing was conducted during dredging.

7.3 Post

Physical. A bathymetric survey was conducted to document the final topography of the project area using similar methods described in the progress section.

Chemical. Post-verification sediment sampling was conducted immediately after dredging before equipment was demobilized. The average PCB sediment concentration in Deposit N was 7.5 ppm, with a maximum of 43 ppm. After the supplemental dredging effort to try and remove the residual layer of soft sediment resting on bedrock (before demobilization, but not required in the project plans), sample collection was difficult at many stations since bedrock was exposed. Divers had difficulty collecting adequate sample volume and had to look in cracks/crevices and underneath boulders to find sediment. The maximum PCB concentration detected was 130 ppm.

Biological. No biological testing was conducted after dredging.

7.4 Long-Term

Long-term monitoring of the dredging activities at Deposit N will be developed as part of the overall remedial design program for the Lower Fox River and Green Bay project. A long-term monitoring plan for Deposit N has not been developed yet.

Table 1 Summary of Monitoring Results

Testing Parameter	PCB Concentration (in ppm)		
	Baseline 1988–1997	**During Dredging 1998–1999**	**Post 1999**
Bathymetry	Conducted	None	Met target depth 3 in above bedrock (west) 6 in above bedrock (east)
Surface Sediment	Avg = 11.7 ppm Max. = 85.4 ppm 1994 max. = 186 ppm PCB mass = 130 lbs (60 kg)	None	Avg. = 7.5 ppm Max. = 43 and 130 ppm PCB mass = 24 lbs (11 kg)
Treated Water Effluent	None	No exceedances of WPDES parameters	None
Water Column [2]	Detectable PCB concentrations up and downstream	Daily during dredging, 20–28 NTU Non-detects up and downstream	None
Air Quality	Yes	Daily at treatment site; no exceedances	None
Caged Fish [1] N=9	Collected upstream, downstream, and on deposit	None	None

[1] Caged fish data collected in 1997 only.
[2] FRRAT, 2000; B. Paulson, 2000.

8 Performance Evaluation

8.1 Meet Target Objectives

The pilot dredging project met the depth and volume target goals specified in the design specifications. The target goal was to remove all sediment (7,065 cubic yards) with the dredge prism to within 3 to 6 inches of the hard bedrock. The actual depth achieved in some areas was to less than 3 inches of bedrock and the actual volume removed was 7,149 cubic yards. Overall, 82 percent of the PCB mass (49 kg) was removed from Deposit N. Post-verification sediment samples from the dredge prism measured elevated PCB concentrations; however, a chemical compliance criteria was not a specified target goal for this project. Long-term project objectives were defined as engineering and design components that will assist in the selection of the final remedial design. Long-term objectives were not evaluated in this review.

8.2 Design Components

Several design components including performance-based dredging contract, adaptive dredging management and flexibility enabling the contractor to specialize their approaches, bench-scale tests to determine sediment properties prior to dredging, allowing a thin layer of soft sediments to remain on top of the bedrock, and positive communication and outreach to the public community, all likely contributed to the success of this remedial pilot project.

8.3 Lessons Learned

Cost management. Dredging costs were controlled in the planning stages by reviewing site conditions, current dredging technologies, and bench-scale tests, and then pooling these results into a cost/benefit analysis. Dredging efforts and costs were managed by defining realistic project goals (i.e., significant reduction in PCB mass at the surface exposed to the aquatic environment). If PCB concentrations in surface sediments were the primary method for determining dredging success (as opposed to mass reduction), then contractors would have been compelled to spend significant time, money, and effort to vacuum up residual sediments resting on bedrock that often prove too difficult to isolate and remove.

Verification sampling. In addition, when residual sediments were successfully removed to bare bedrock, it was difficult to acquire a sediment verification sample. In response to the difficulty of obtaining post dredge samples, divers were allowed to deviate from the original sampling plan and QAPP by moving off predetermined sampling stations to search the cracks and crevices for adequate sample volume thereby adding "bias" to the surface-weighted residual concentrations. It retrospect, verification sampling methods that stayed with the original sampling plan would have avoided some of the sample collection bias and probably yielded lower overall post project PCB results.

Mass balance approach. The Fox River Remediation Team (FRRAT, 2000), evaluated the effectiveness of environmental dredging at Deposit N using multiple mass balance approaches (deposit mass balance, process mass balance, river transport) with the following results:

Process	PCB Concentration [1]		
	Median µg/g	Load (kg)	% of slurry
(Initial) Dredge Slurry	192 µg/l	17	NA
Press Cake	19	16.5	16.5/17
Sand Pile	5	0.55	0.55/17
Debris Pile	1.2	0.21	0.21/17
Filter Bags	37.5	0.005	0.005/17
Sand/Carbon	0.95	0.09	0.09/17
Effluent	4.5 µg/l	0.0002	0.0002/17
Estimated Net Loss Downstream	2.2 kg out of dredge area		
Estimated Upstream Loading into Area	0.8 kg PCBs		

[1] FRRAT, 2000. Measured between Nov 26, 1998 - Dec 30, 1998.

Conclusions and recommendations presented in the Deposit N project reports that will be useful during development of remedial alternatives for the Lower Fox River/Green Bay project included:

- Turbidity monitoring was not an accurate measurement of downstream PCB transport during dredging. Low suspended solids concentrations did not correlate well with PCB concentrations in the water column. Monitoring required actual measures of PCB levels in the water column and a mass balance study of PCB residuals to obtain accurate measurements of net transport (Fox River Remediation Advisory Team, 2000). The mass balance study estimated that the resulting press cake material contained 96 percent of the PCBs removed from the deposit and that less than 0.01 percent of PCBs from the slurry concentration was discharged back to the river. The mass balance model did not measure an overall increase in mass of particles transported downstream during dredging (TSS), however, the PCBs transported on the particles did increase (increased net load of 2.2 kg PCB during the active dredging period).

- Due to the presence of a hard bedrock substrate located beneath the soft sediments, the target goal of the demonstration project was to remove contaminated sediment down to a design depth of 7.5 to 15 cm (3 to 6 inches) above bedrock. Approximately 5,475 m^3 (7,160 cy) of sediment and 50.3 kg (112 pounds) of PCBs were removed from Deposit N during 1998/1999 (F&VD, 2000). Overall, 82 percent of the PCB mass was removed from Deposit N and approximately 31 kg (68 pounds) of PCB remained in the sediments that were not accessible to dredging activities. (F&VD, 2000).

- The Deposit N pilot dredging project met the depth and volume target goals specified in the project plans (dredge to within 3 inches of bedrock). Over 82 percent of the PCB mass was removed from Deposit N. The post-dredge average

residual PCB concentration was 7.5 ppm (40 percent reduction from 11.7 ppm avg). Sediment removal to bedrock (from 3 inches to bedrock) was time-consuming and inefficient with very low percent solids content in the dredge slurry.

- Standard water treatment technologies were capable of meeting effluent requirements.

- The silt curtains at Deposit N were occasionally disturbed by passing ships and required immediate repair. Elevated PCB levels were measured in the water column downstream of dredging during this occasions. However, overall the silt curtains were effective barriers minimizing downstream transport of PCBs to a net load of 2.2 kg during dredging operations (<2 percent of the 142 kg mass in the entire deposit).

9 Costs

The dredging, monitoring, treatment, disposal, public outreach, and extra 1999 mobilization costs for this pilot study were approximately $4.3 million ($525 per cubic yard). This disposal costs totaled $654,000 and the specific unit cost in the construction contract for dredging was $20.70 per cubic yard. A post project analysis of the project costs noted that Deposit N as the first of the PCB cleanup projects on the Fox River, had incurred significant a typical project costs that are not likely representative of what a similar future project of this scale would cost (Foth & Van Dyke, 2000). The report noted that expenses for a public visitor area and outreach ($150,000), redundant in-river environmental controls (e.g., $500,000 plastic containment system used in 1998) that one would likely avoid in a more routine project results in an estimated cost for a future sized project of about $250 per cubic yard. Foth & Van Dyke also estimated that a larger 100,000 cubic yard project at a similar site could be expected to be performed for $200 per cubic yard under the type of conditions encountered at Deposit N.

10 Project Contact

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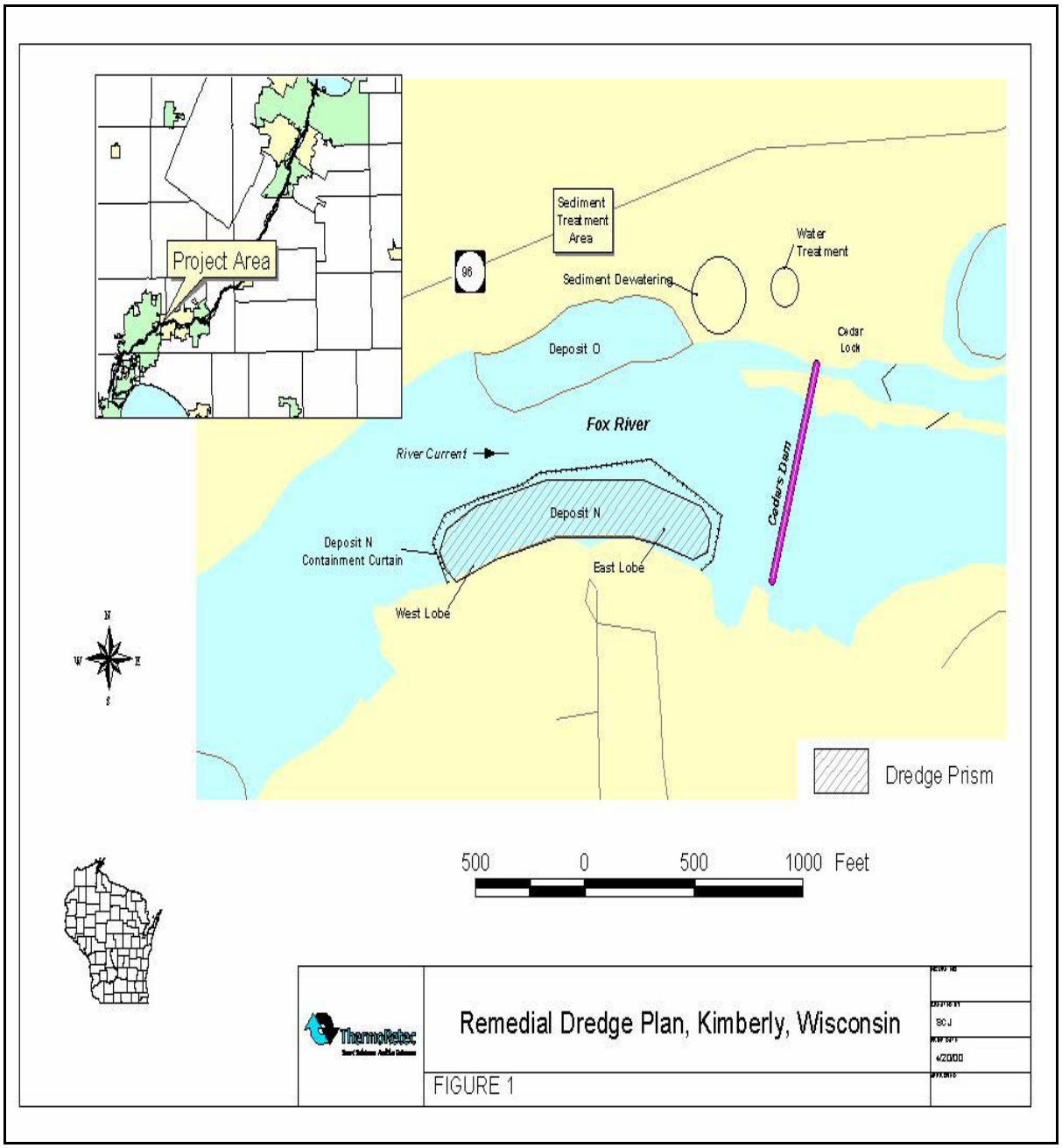
Figure 1 Remedial Dredge Plan - Lower Fox River Deposit N



1 Statement of the Problem

- Dredged 1999 & 2000
- PCBs
- 31,346 cubic yards 1999
- 50,316 cubic yards 2000
- $286 to $296 per cy

The Fox River Sediment Management Unit (SMU) 56/57 Demonstration Project Site is located in the Lower Fox River in Green Bay, Wisconsin. Sediment polychlorinated biphenyl (PCB) contamination is present from multiple industries and paper mill facilities. PCB concentrations up to 710 ppm have been detected in sediment. The selected remedy was removal of approximately 80,000 cubic yards sediment to a design elevation of 565 feet (Mean Sea Level, NGVD29) in 1999. This was expected to remove all sediment with PCB concentrations greater than or equal to 1 ppm. However, the dredge prism was only partially removed by December 1999, when the equipment was demobilized. Additional sediment was removed in August, 2000 to a targeted volume.

2 Site Description

The Fox River SMU 56/57 Demonstration Project Site is located in a 7-mile stretch of the Fox River from below the De Pere dam to the mouth of Green Bay. SMU 56/57 is approximately 9 acres in area and is located in the City of Green Bay on the west shore of the river in an area adjacent to the Fort James turning basin and shipping dock (ThermoRetec, 1999a and 1999b).

View of Fort James Corporation
Source: WDNR

Continuous soft sediment deposits present in the river bottom ranged from 1 to 16 feet in thickness (average 10 feet). Soft sediments are primarily soft organic silt overlying firmer native clay. The water depth in the project area ranged from 2 feet at the shoreline to 14 feet at the outer edge. Normal flow velocity ranges from +2.5 feet per second (fps) to -2.5 fps. Flow reversal occurs in the river during periods of strong and prolonged winds from the northeast. Flow velocity measurements collected from within the project area on 1 day ranged from 0 to 0.6 fps.

3 Site Investigation

In a 1995 investigation conducted by the Wisconsin Department of Natural Resources (WDNR) and U.S. Environmental Protection Agency (EPA), approximately 100 cores were collected at various depth intervals and analyzed for PCBs and other constituents. Results of the investigation were used with other data as input variables into a water and fish quality model that established a total of 115 sediment management units (SMUs) for the lower reach of the river below the De Pere dam. SMU 56 and 57 were contaminated with the highest concentrations of PCBs found to date, with a maximum concentration of 400 ppm measured at a depth interval of 3 to 5 feet. The maximum surface (0 - 10 cm) concentration was 99 ppm.

On January 31, 1997, the State of Wisconsin and the Fox River Group (a consortium of seven paper mill companies) entered into a state agreement for a sediment restoration project in the SMU 56/57 demonstration project area. In November 1997, WDNR and EPA took 32 cores in the SMU 56/57 focus area. PCB concentrations of the sediment ranged between non-detect and 710 ppm with the highest concentrations present in the top 2 to 5 feet. Sediment with PCB concentrations of at least 1 ppm were present at thicknesses of 2 to 16 feet with an average of approximately 10 feet (Montgomery Watson, 2000).

Contaminants of Concern. The primary contaminant of concern was PCBs from wastewater discharges to the river during the manufacture and recycling of carbonless copy paper. Although concentrations and mass removal of mercury were also discussed, it was not identified as the focus of the hotspot removal project.

4 Target Goals and Project Objectives

1999 Removal Activities

The project was intended to remove hotspot sediment from SMU 56/57 and to generate as much information as possible towards the design of larger-scale remediation project for the lower Fox River. The target goal was to dredge sediments to a design elevation of 565 feet (Mean Sea Level, NGVD29). Selection of this target elevation assumed that sediments with concentrations of PCBs greater than or equal to 1 ppm would be removed from the dredge prism. The dredge footprint called for removal of approximately 80,000 cubic yards of sediment (Paulson, 2000).

Silt Curtain and Dredge
Source: WDNR

2000 Removal Activities

The project goals were to complete the removal of contaminated sediment from SMU 56/57 to a pre-determined maximum *in situ* sediment volume of 50,000 cubic yards. The target goal was to continually dredge hotspot sediments until the surficial sediment PCB concentration was less than 1 ppm or the designated volume was met (maximum concentration of 10 ppm), whichever came first. The volumetric extent of dredging was pre-determined by 1) the need to preserve stable side slopes, 2) avoid leaving elevated PCB concentrations above 1 ppm in surface sediments, and 3) not exceed the remaining capacity in Fort James Green Bay Landfill Cell 12A (WDNR, 2000 Statement of Work). The SOW also called for surface sediment concentrations to be less than 10 ppm in 90% of the subunits and the maximum concentration in a subunit to be less than 25 ppm. Target dredge elevations were used to achieve project goals. A 6-inch clean sand cap would be placed over remaining surface sediments with average PCB

concentrations in a subunit between 1 and 10 ppm (Fort James et al., 2001).

5 Project Design

Investigation and design for the demonstration project was conducted between September 1997 and May 1998. Procurement and permitting began in June 1998 and was completed in June 1999.

Pre-planning and Bid Documents. Three separate requests for bids were prepared for dredging, water treatment, and dewatering with performance-based specifications. Performance-based specifications allowed use of contractor expertise and available equipment, and provided flexibility. The project planning was completed using a public review process (Montgomery Watson, 1999a, b, and c).

Summary of Remedial Action Plan. Overall, the remedial action entailed installation of a silt curtain, hydraulic dredging of sediment in 53 dredge cells within the dredge prism, and transport of sediment slurry to an onshore treatment process area on Shell Oil's Property (agreed access). The sediment slurry was fed into equalization (settling) basins. Water was treated with dual-media filters and granular activated carbon prior to discharge to the river. Sediments were dewatered and disposed at an off-site landfill. The SMU 56/57 focus was divided into 53 subunits measuring approximately 100 feet by 100 feet each and the initial target elevation for the entire area was 565 feet elevation with a 6-inch overdredge (actual elevation 564.5 feet).

Limitations and Permits. Dredging activities were designed to be protective of intake access and boat slip access for continued operations of the paper mill. Major permits and approvals required for the remedial activities included an Environmental Assessment, WDNR Dredging Permit, U.S. Army Corps of Engineers Dredging Permit, and WPDES Permit (Four Seasons Environmental, 1999a, b, and c).

In 1999, the onset of winter resulted in freezing water in pipelines and process equipment and formation of river ice. Due to time constraints, the dredge design elevation was raised to 567 feet in the northern half of the dredge area. The design elevation was raised again to 568 feet in subunits 2 and 23. A cleanup pass initially planned for all areas was only conducted only in a 30-foot by 30-foot area in the center of 4 dredge cells. The target goal of the cleanup pass was 6 inches below the 565-foot elevation. No limitations were noted during the 2000 dredge activities.

6 Remedial Action

6.1 Dredging

1999 Removal Activities

Schedule and Duration. Construction of the Fort James landfill PCB disposal cell was performed between middle June and late August 1999. The construction phase of the sediment removal lasted from July to late August 1999, and included mobilization of dredging, water treatment, and dewatering systems and personnel. Dredging was conducted between August 30 and December 15, 1999.

Dredging was discontinued on December 15, 1999 due to the onset of winter conditions. Project demobilization took place between December 15, 1999 and January 19, 2000. Additional activities, including general site cleanup and removal of equipment and dredged material, was scheduled to take place during spring 2000. Dredging was conducted during 96 of 108 calendar days of the project, averaging 4.3 hours per day. The total dredging time of the project was 464.5 hours. The dredging crew consisted of a dredge operator, a laborer stationed onshore, and a laborer at the equalization basin (Montgomery Watson, 2000)

Equipment. A 1,700-foot silt curtain was installed around the entire dredge area prior to commencement of dredging. The silt curtain skirt was a black, woven polypropylene, monofilament geotextile fabric with a 40–50 U.S. Standard sieve equivalent opening size and a percent open area of 15 percent. The silt curtain was anchored with "Manta Ray" anchors and concrete weights. Closed cell foam flotation was used to hold the curtain at the water surface.

A hydraulic dredge with a 12-inch pump and round cutterhead was used initially, beginning on August 30, 1999. After approximately one week of dredging, the dredge was replaced with an IMS 4010 Versi horizontal auger dredge in an attempt to increase solids of the dredge slurry. The IMS 4010 dredge operated in conjunction with an inline booster pump to transport the slurry to the equalization basins. On September 10, the dredge was replaced with an IMS 5012 Versi horizontal auger dredge with a 12-inch pump and a larger booster pump, and on September 22–23, a wider cutterhead (9 feet) was placed on the 5012 dredge. A number of dredge passes were necessary to achieve target elevations. Dredge passes were made by advancing the dredge along cables.

Dredge slurry was transported to equalization basins through a 2,800 linear-foot pipeline. The pipeline consisted of a single-walled 12-inch-diameter high-density polyethylene (HDPE) slurry pipe within the silt curtain. For the 1,860-foot portion of the hydraulic pipeline outside of the silt curtain, the 12-inch-diameter slurry pipe was double-walled within a 16-inch containment pipe (Montgomery Watson, 2000).

Total Volume Removed and Production Rates. Dredging was conducted in 96 of the 108 calendar days of the project, resulting in the

removal of a total of 31,346 cubic yards of sediment. The average hourly dredging rate (60 cubic yards per hour) and the average daily dredging rate (294 cubic yards per day) were less than the project goals (200 cubic yards per hour and 900 cubic yards per day). The average percent solids of the dredge slurry was 4.4 percent. A goal of 7.5 percent solids was established prior to dredging. Dredging resulted in the removal of 1,326 pounds of PCBs from the Fox River (Montgomery Watson, 2000).

Site-specific Difficulties. Dredge equipment was changed on multiple occasions in an attempt to increase the solids content of the dredge slurry. Onset of winter conditions required demobilization before completion of dredging effort.

2000 Removal Activities

Schedule and Duration. The construction phase of the sediment removal lasted from July to late August 2000, and included mobilization of dredging, water treatment, and dewatering systems and personnel. Dredging and sand cap placement were conducted between August 23 and November 8, 2000. An aggressive schedule allowed the project to be completed two weeks ahead of schedule and before the onset of cold weather (Fort James et al., 2001).

Equipment. A new, deeper silt curtain was placed around the entire dredge area and anchored through a series of sheet piles, screw anchors, and chains. Inside the perimeter curtain, three additional temporary silt curtains were used to separate the dredge footprint into four areas. Once an area was dredged, it was separated from the rest of the site to avoid re-contamination.

Three hydraulic dredges were available on-site to remove sediment from the dredge prism. All dredges were horizontal auger style, equipped with submersible pumps. The pumps transported dredge slurry (excavated sediment mixed with water) through a pipe system to a booster pumping station which, in turn, pumped the slurry to the land-based dewatering facility. Multiple dredges helped to ensure continuous dredging throughout the construction period, although only one dredge was used at any given time.

The onshore dewatering facility operated on a site adjacent to the Fort James mill. The sediment was separated from the water and trucked off to a waste disposal landfill, owned and operated by Fort James, located near Austin Straubel International Airport in Ashwaubenon.

Total Volume Removed and Production Rates. Dredging averaged 24 hours per day throughout the project, removing a total of 50,316 cubic yards of sediment. The average daily dredging rate was 833 cubic yards per day. The highest production day was October 20, 2000, removing 1,599 cubic yards of material. The average percent solids of the dredge slurry was 8.4 percent with a range from 3.5% to 14.4%. Dredging resulted in the removal of 670 pounds of PCBs from the Fox River during the year 2000. Combining the amount of PCBs removed during 1999

and 2000 yield a total of 2,111 pounds of PCBs removed from the Fox River (Fort James et al., 2001).

Placement of Sand Cap. After completion of dredging, a 6-inch layer of clean sand was placed over the dredge footprint covering approximately 7.4 acres (although not required in areas with surface concentrations less than 1 ppm PCBs). Thicker sand layers were placed in side slope areas. Sand placement was conducted by Buffalo Divers of New York using clam bucket located on a barge from September 23 to November 8, 2000. The sand was deployed in a radial pattern around each barge set-up location. A total of 13,500 cy of cover sand was placed with an average thickness of 8 inches (Fort James et al., 2001).

Site-specific Difficulties. The required dredging production rate was not met early in the project because of dredge downtime and filter cake pressing capacity. The contractor brought another dredge to the site and replaced the smallest press (94 cu ft) with two larger presses (22 cu ft each) (Fort James et al., 2001), which increased the daily dredge production rates to performance expectations (max rate of 1,599 cy per day).

6.2 Dewatering and Water Treatment Operations

1999 Removal Activities

Dewatering of sediment was conducted using recessed chamber filter presses to allow effective handling and disposal of sediment. The average percent solids of the filter cake was 53.1 percent based on laboratory analysis. The dewatering system was operated 24 hours per day, seven days per week by a crew of six to seven people working each 12-hour shift.

Process water generated for the treatment system were primarily from the equalization basin supernatant and press filtrate. Treatment consisted of adding polymer for total suspended solids (TSS) reduction and acid for pH reduction followed by flocculation and settling, filtration through two dual-media (sand/gravel) filters, and polishing through a granular activated carbon vessel. Treated water was discharged back to the river. Water treatment operations were conducted 24 hours per day, seven days per week except for breakdowns. The water treatment staff consisted of two people per 12-hour shift. Operation of the water treatment system was ended three days after completion of dredging (Montgomery Watson, 2000).

Water Quality Monitoring of Discharge. Effluent from the water treatment system was analyzed for a number of parameters prior to discharge. Concentrations of PCBs, mercury, and oil and grease were below the WPDES limit in all samples. The TSS WPDES daily limit (WDNR, 1999) was exceeded eight times during the project. BOD results exceeded the weekly average limit of 2 mg/L in all except for three samples. The results of effluent analytical testing are summarized in Table 1 (Montgomery Watson, 2000).

2000 Removal Activities

The dredge and booster pumps transported the slurry from the river to a shore-based vibrating shaker screen set on a V-bottom tank. The shaker screen was used to remove debris, stones, and vegetation from the dredge slurry. The dredge slurry was further circulated in the V-bottom tank and pumped through hydrocyclones to remove a portion of the sand. The dredge slurry then flowed into a 20,000-gallon agitated pump tank that transferred slurry to agitated mix tanks where polymer was added. These tanks fed the mechanical presses (Fort James et al., 2001).

Plate and frame mechanical presses dewatered the sediment to meet the specifications of 50% solids with a compressive strength of 0.4 tons per square foot. Average percent solids of slurry entering the mechanical presses was approximately 7.3%. Dried sediment was discharged to a conveyor system (press drop), which transported the dewatered sediment to the work area storage pad. The average percent solids of the filter cake was 59% with 11.0 ppm PCBs based on laboratory analysis. The dewatering system operated 24 hours per day, seven days per week working 12-hour shifts (Fort James et al., 2001).

Dewatered and stabilized sediments were to be separated into batches of 20,000 cubic yards or less, sampled for PCBs, and tested for free liquids (RCRA paint filter test) and other relevant geotechnical characteristics as needed. The average concentration of PCBs was 11 ppm and the concentration of PCBs ranged from 0.48 ppm to 32 ppm. Batches were transported to and disposed of in Cell 12A of the Fort James Green Bay Landfill.

The water treatment system processed up to 2,400 gallons per minute, and consisted of an untreated water surge tank, cloth bag filters, sand filters, carbon absorption system, and a final set of cloth bag filters. The treated water was sampled prior to discharge. Effluent flow rates were measured through a magnetic flow meter, and the water was discharged into the Fox River. Water treatment operations were conducted 24 hours per day, seven days per week. Approximately 66,329,000 gallons of water were treated and returned to the Fox River (Fort James et al., 2001).

Water Quality Monitoring of Discharge. Effluent from the water treatment system was obtained and analyzed as directed by the On-Scene Coordinator and the WDNR On-Scene Representative. On October 13, 2000, with USEPA and WDNR approval, the frequency of testing effluent for PCBs and mercury was changed from twice weekly to once a week. This change was based on the data, which showed that the previous six weeks of monitoring resulted in no detects of these parameters in the effluent. Over 66 million gallons of treated water was discharged back the river (WDNR, 2000b).

Table 1 Water Treatment Effluent Test Results (Fort James et .al., 2001)

Parameter	Units	Average	Minimum	Maximum	WPDES Limit
PCBs	μg/L	0.02	0	0.37	1.2
Mercury	ng/L	16.5	0	101.8	1,700
TSS	mgL	7.3	0	280	10
Oil & Grease	mg/L	3.4	0	8.3	10
pH	su	7.5	6.0	10.8	6–9
Turbidity	NTU	1.2	0	22	—
BOD_5	mg/L	11.5	0	27	2.0
Ammonia-N	mg/L	16.7	1.6	49	—
Dioxins	Pg/L	0	0	0	—

6.3 Storage and Disposal

1999 Removal Activities

Dewatered sediment was transported by truck to an off-site landfill. Tri-axle and semi trucks were loaded with cake material using a front-end loader. A total of 1,240 loads of dewatered sediment and project wastes were taken to the Fort James landfill between September 9, 1999, and January 17, 2000. The total sediment mass disposed to date has been 26,927 wet tons. Additional dredged sediment remaining in the equalization basins was to be removed in spring 2000 (Montgomery Watson, 2000). Approximately 1,441 pounds of PCBs were removed.

2000 Removal Activities

Dewatered sediment was transported by truck to an off-site landfill, owned and operated by Fort James near Austin Straubel International Airport in Ashwaubenon. A total of 2,484 loads of dewatered sediment and project wastes were taken to the Fort James landfill(Cell 12A) between August 2000, and November, 2000. Dewatered sediment had an average solids content of approximately 59%. The total dewatered sediment material disposed during the project was 51,613 dry tons (Fort James et al., 2001) with 670 pounds of PCBs removed.

7 Environmental Monitoring Program

The environmental monitoring program included analysis of sediment cores at various depths (including surface intervals), bathymetry measurements, water and air quality measurements, and caged and resident fish bioaccumulation data (Table 2).

7.1 Baseline

1999 Removal Activities

Physical. The Corps of Engineers performed a baseline bathymetric survey on August 23,1999 using single-beam sonar on range lines spaced at 50-foot intervals. Sediment cores were collected by Blasland Bouck & Lee (BBL) for physical characterization on August 19 to 21, 1999.

Chemical. As discussed in the site investigation section, WDNR and EPA took 32 cores in the SMU 56/57 focus area in November 1997. PCB concentrations of the sediment ranged between non-detect and 710 ppm with the highest concentrations present in the top 2 to 5 feet. Sediment with PCB concentrations of at least 1 ppm were present at thicknesses of 2 to 16 feet with an average of approximately 10 feet. Additional cores were collected from 40 locations on August 19 to 21, 1999 by BBL to provide additional analytical characterization of sediment for comparison with post-dredge sampling. The maximum concentration was 650 ppm at a depth of 4 to 5 feet (Paulson, 2000).

Aerial View of Silt Curtain and Dredge
Source: B. Paulson, WDNR

Baseline surface water data were collected, but were not available for review.

Biological. Caged fish studies were conducted in October and November 1997 for PCB Aroclors. Numerous resident fish tissue bioaccumulation studies have occurred between 1988 and 1996 including the 1989/1990 Green Bay Mass Balance Study, the WDNR fish contaminant advisory study, the USGS water quality assessment program, the 1996 RI/FS WDNR fish tissue data collection, the 1996 BBL fish tissue data set, and the NRDA 1996 fish tissue collection study by USFWS. Results of these studies are currently being folded into an ecological and human health risk assessment in support of remedial alternatives for the RI/FS Lower Fox River project. Nine species of fish (carp, walleye, yellow perch, alewife, common shiner, emerald shiners, gizzard shad, golden shiner, and rainbow smelt) were analyzed for total PCBs, PCB congeners, and other constituents of concern and are included in various food web models developed for each river reach.

2000 Removal Activities

Physical. A pre-dredge bathymetry survey was completed by Baird and Associates on August 14, 2000 as sloughing and siltation in the area may have occurred after completion of the 1999 Demonstration Project. Based on this survey approximately 49,600 cubic yards of sediment needed removal to obtain an average residual sediment concentration of 1 ppm PCBs. This volume would include redredging of some 1999 dredge units.

Six additional geotechnical borings were collected to further define grain size, degree of consolidation and other geotechnical characteristics within the disturbed side slopes of adjacent cells.

Chemical. No additional chemical testing was undertaken prior to dredging.

Biological. No additional biological testing was undertaken prior to dredging.

7.2 Implementation During Dredging

Environmental quality monitoring conducted during the dredging activities included river and velocity monitoring, water and air quality monitoring, bathymetric surveys, dredge slurry and dewatered filter cake sampling, water treatment monitoring (discussed above) and sediment confirmation sampling.

1999 Removal Activities

Physical. Turbidity measurements were taken at 15-minute intervals, 24 hours per day at two locations inside of the silt curtain and four locations outside of the silt curtains. Average monthly turbidity ranged from 16 to 49 NTU inside the silt curtain and 11 to 46 NTU outside of the silt curtain. Average turbidity measurements outside of the silt curtain were not appreciably different between upstream and downstream locations. The average turbidity inside the silt curtain was slightly higher than outside the silt curtain (range 3 NTUs lower inside to 11 NTUs higher inside). The downstream "trigger" level was never exceeded during dredging.

Optical surveys were performed by sightings along a baseline of wooden hubs along the shoreline to check for potential slope instability caused by dredging. No lateral movement was detected, and only slight vertical movement was measured during the dredging period.

Chemical. No sediment chemical data were collected from the 53 dredge cells, or subunits, during dredging. Surface water data were collected during dredging, but was not available for review. Extensive air monitoring data were collected from 25 onsite stations and several offsite locations up to 1.25 miles from the site. Samples were collected as 24-hour and 72-hour composites for total PCBs and aroclors from the landfill area, the dredging area, and systematic offsite distances away from activities. Air samples were locally elevated onsite but achieve background levels at a distance of 1250 meters (24 hour) and 750 meters (72 hour). No samples exceeding the health risk level of 100 ng/m^3. Total possible loss of PCBs via volatilization was 10.7 lb PCBs (0.8% of PCBs removed) at an emission rate of 0.01 to 0.1 lbs per day during dredging and dewatering activities (WDNR, 2000).

Biological. Not collected during dredging.

2000 Removal Activities

Physical. Dewatered and stabilized sediments, in batches of 20,000 cubic yards or less, were sampled for relevant geotechnical characteristics. Turbidity measurements were taken in the river at one station upstream (M1), at the water intake, and two stations (M2 & M3) 10 feet and 50 feet downstream, respectively, of the work. When turbidity measured at M2 or M3 was twice the turbidity measurement of M1, downstream water column samples were to be colleted and analyzed for PCBs. Sampling frequency decreased from twice daily to once per day, to every other day with USEPA approval as no elevated turbidity readings were reported.

Chemical. No sediment samples were from the dredge cells, or subunits, during dredging. Dewatered and stabilized sediments were sampled for PCBs and tested for free liquids (RCRA paint filter test). In accordance with the approved monitoring plan, river water quality testing for PCBs was not performed since there were no exceedances of turbidity as a result of dredging.

Biological. Not collected during dredging.

7.3 Post

1999 Removal Activities

For clarification, each of the dredging subunits was 100 ft by 100 ft. The SMU 56/57 area was divided into 53 units, but only 19 subunits were within the dredge area. Only four of these subunits received a final cleanup pass. The cleanup pass that attempted to reach the final elevation (565 ft) plus 1/2 foot of overdredge in these four subunits, focused only in the center portion of the 100 ft by 100 ft square. This area was approximately 30 ft by 30 ft. The cleanup pass did not remove 100% of the material in these four subunits.

Physical. A post-dredge acoustical bathymetric survey was conducted by Superior Special Services. The final elevation in areas that did not receive the final cleanup dredge pass contained sediment ranging from 1 to 7.5 feet thick above the final design elevation (Paulson, 2000). The final target elevation was achieved in four areas measuring approximately 30 feet by 30 feet.

Chemical. A summary of achievements included:

- Only 13 of 19 subunits had post-dredge verification core samples collected (the other five subunits had less than 1 foot of sediment removed and therefore were not sampled).

- Only one of 19 subunits achieved the target depth. The average post-dredge sediment concentration of this subunit was less than 1 ppm PCBs.

- Only three of the 19 subunits were below 1 ppm PCBs (average concentration). These three subunits were included

in the four final "cleanup pass" subunits attempting 100 percent mass removal of contaminated sediments down to target depth (75 percent success in cleanup areas).

A post-dredge core was collected from each subunit in which the sediment elevation changed by more than 1 foot (13 locations). The maximum PCB concentration measured was 330 ppm at a depth interval from 0.3 to 1.0 foot. In areas where a cleanup pass was not performed, post-verification sediment concentrations at the surface increased considerably from baseline concentrations. The post-dredge surface sediment concentrations ranged from 32 to 280 ppm, with corresponding baseline concentrations of 2 to 5 ppm. In three of four areas where a cleanup pass was performed surface PCB concentrations declined from pre-dredge concentrations. The final concentrations ranged from non-detect to 2.0 ppm. Duplicate surface samples collected from the fourth area measured 4.5 and 17 ppm PCBs compared to a pre-dredge concentration of 2.7 ppm (Montgomery Watson, 2000).

Post-dredging surface water data were collected, but was not available for review.

Biological. None collected as part of this demonstration project.

2000 Removal Activities

Physical. Post-dredge top-of-sediment surveys were performed using sonar surveys for each of the four completed sections to confirm that target elevations had been achieved. In areas were the dense, native river bottom (clay) was encountered above the target elevations, dredging was considered complete. All sonar surveys were supplemented with Foth & Van Dyke poling surveys conducted on the non-side slopes of each section.

Chemical. Surficial sediments (upper 4 inches) were collected from each subunit and analyzed for PCBs. One to five samples were collected from each 100 ft by 100 ft grid cell. Concentrations ranged from "no detect" to 9.5 ppm and averaged 2.2 ppm (Fort James et al., 2001). The *in situ* percent solids of surface sediments ranged from 33% to 68%. After verification sampling, all dredged areas were covered with 6-inches of sand (even though the AOC stated that surface sediments below 1 ppm PCBs need not be contained). Surface grab samples were used to verify placement of sand, and hand-push cores (2-inch CAB liners) were used to verify the thickness of the sand cap.

All effluent PCB results were non-detect values below established discharge limits. All effluent BOD results were below the daily maximum target concentration of 30 mg/L. Effluent pH values were all within target concentrations during the project. There were three low-level detects of mercury in the effluent, but all levels were well below the project target concentration of 1.7 ppb.

Biological. None collected as part of this project.

7.4 Long-Term

Long-term monitoring of the post- dredge conditions and recovery at SMU 56/57 will be developed as part of the overall remedial design program for the Lower Fox River and Green Bay project.

Table 2 Summary of Monitoring Results

Testing Parameter	Total PCB Concentration (in mg/kg)				
	Baseline 1989–1999	During Dredging Aug. - Dec. 1999	Post Dec. 1999	During Dredging Aug. - Nov. 2000	Post Dec. 2000
Bathymetry	Collected	Shoreline stability	Met target depth in four 30-ft × 30-ft areas; ranged from 1 to 7.5 ft above target depth in rest of study area	NC	Collected
Sediment Cores from Subunits 25, 26, 27 & 28 [(1) (2) (5)]	Surface = 2.3 to 3.1 Max = 330 ppm	NC	Surface= 0.01 to 4.5 ppm Max = 49 ppm	NC	NC
Sediment Cores All other Subunits [(1) (2)]	Surface= 0.35 to 5.3 1999 Max = 650 ppm 1997 Max = 710 ppm	NC	Surface= 32 to 280 ppm Max = 330 ppm	NC	Surface= ND to 9.5 ppm (avg = 2.2 ppm) before capping
Water Quality	NA	NA	NA	NA	NA
Caged Fish Data [(3)]	Non-detect to 310 μg/kg PCB Aroclors	Detectable	NA	NC	NC
Air Quality	Unk	Non-detect to very low levels 0.7-79.7 ng/m^2 total PCBs	Unk	NC	NC

[(1)] The surface interval is approximately 0 to 0.3 ft. depth. The maximum depth for sediment cores was about 14 ft. for baseline and about 4 ft. for post sampling.
[(2)] The max. concentrations are the highest values detected in core.
[(3)] Caged fish data collected in 1997, also had the suspended inside and outside silt curtain during dredging.
[(5)] Subunits received final cleanup pass to design depth.
NC = Not collected
ND = Non detect
NA = Not available
Unk = Unknown

8 Performance Evaluation

8.1 Meet Target Objectives

1999 Removal Activities

The target goal of removing contaminated sediment down to a target elevation of 565 feet with verification samples compared to a 1 ppm PCB goal was partially achieved. Due to time and weather constraints, the target elevation was raised 2 feet (to 567 feet) in the northern half of the dredge area in mid-November 1999. The design elevation was raised again to 568 feet in subunits 2 and 23 (a total of 53 subunits) at the end of November 1999, when it became evident that contractors could not complete the proposed plan before cost overruns accrued and before the onset of ice conditions. The final elevation in the southern 565-foot target area ranged between 562 and 568 feet. The final elevation in the northern area ranged between 567 and 572 feet. A cleanup pass initially planned for all areas was only conducted in four 30-foot by 30-foot areas. The target goal of the cleanup pass was 6 inches below the 565-foot target elevation. Only 31,346 cubic yards of the estimated 80,000 cubic yards of sediment slated for removal were actually removed.

Post-dredge PCB concentrations in surface samples were considerably higher than pre-dredge surface concentrations where a cleanup pass was not performed. The results are not unexpected because dredging was not completed to the design depth in most areas. However, the post-dredge results were less than the maximum concentrations detected in pre-dredge core samples, indicating that a significant mass for contaminated sediment was successfully removed.

Water quality and air quality monitoring during the removal operations determined that the majority of PCB mass (>95%) could be entrained in the treatment process and disposed as filter cake. Less than 1% was released as air emissions and only 5% was released downstream in the river.

2000 Removal Activities

The target goals for the 2000 removal project were generally met. The target elevations were achieved and all discrete sediment samples were below the 10 ppm PCBs (maximum allowable concentration) within the pre-determined removal volume of 50,000 cy. The project objectives called for the removal of 50,000 cubic yards of contaminated sediment from SMU 56/57, assuming that remaining surface sediments would have PCB concentrations less than 1 ppm PCBs. Approximately 41% of the post-dredge verification samples were below 1 ppm PCBs (80% were below 3 ppm PCBs) with an average of 2.2 ppm PCBs. It was expected that some residual surface sediment concentrations may be above 1 ppm PCBs.

Areas with PCB concentrations of less than 1 ppm were considered to be completed, requiring no further work. Areas with PCB concentrations between 1 and 10 ppm were to be covered with at least a six-inch layer of clean sand. Fort James Corporation chose to cover the entire dredged area with sand to further reduce exposure to PCBs. Sand covering most of the 6.5 acre dredge area ranged from 6 to 14 inches thick, averaging 8 inches.

This helped to cover any exposed PCBs left in the surface sediment and in the side slopes along the edges of the dredged area. All the clean- up objectives were met for this project. Confirmation samples taken from the site ranged from non-detect to 9.5 ppm prior to capping.

Monitoring of water quality, effluent, and filter cake conducted during dredging operations confirmed that dredging operations did not cause significant sediment resuspension or releases during removal operations. No significant exceedances were observed.

8.2 Design Components

Performance-based specifications were used to select the contractor for each component of the demonstration project. A public review process was included in the project design. The contractors quickly identified deficiencies in the dredging performance and brought in additional equipment to improve daily production rates.
The filter presses successfully dewatered the dredged sediment to an average solids content of approximately 59%, eliminating the need for further solidification prior to disposal.

8.3 Lessons Learned

1999 Removal Activities
Actual sediment removal rates achieved in the demonstration project were less than one-third of the projected goal. Less than 40 percent of the sediment was removed before the onset of winter forced the stop of remedial activities. Elevated PCB concentrations in surface sediments were the result of incomplete dredging. Partial dredging of the contaminated sediment prism resulted in newly exposed surface sediments with PCB concentrations higher than expected if the entire hotspot had been successfully removed. In the four subunits where the target elevation was achieved, residual PCB concentrations were less than 1 ppm in three of the four subareas. These elevated post-dredge concentrations and elevations do not imply that horizontal auger dredges are not effective tools for removing contaminated sediment.

Results of the PCB water column analysis and mass balance study conducted by USGS (Stever, 2000; USGS, 2000), showed that approximately 95% of the PCB mass contained in the dredged material was entrained in the dewatering and treatment process, and only 5% (24 kg) was lost downstream. A summary of the mass balance includes:

PCB Mass Balance Table (Stever, 2000 of USGS) September 1 - December 15, 1999			
Process	**Rate**	**Total Mass (kg)**	**% of Dredged Material**
Total mass of SMU 56/57 deposit	-	2,086 - 2,722 (80,000 cy)	
Total dredged material	-	654 (1441 lb)	100%
Effluent back to river	82 - 676 μg/l	0.14 kg	0.015%
Dewatered sediments			95%
Transported downstream during dredging	226 gm/day	24 kg	5%
Volatilized		2.6 kg	0.4%
Annual load from the LFR to Green Bay	186 kg/year	20.9 kg	

Conclusions and recommendations presented in the SMU 56/57 project reports that will be useful during development of remedial alternatives for the Lower Fox River/Green Bay project included:

- The SMU 56/57 pilot dredging project did not meet the depth and volume target goals specified in the project plans (dredge to 565 feet elevation). Only 18 to 24% percent of the PCB mass was removed from SMU 56/57. The contractors demobilized from the site before completion to target elevation because of unexpected site conditions and onset of winter conditions. In areas where the contractor did not achieve the target depths, surface sediment concentrations were similar to pre-dredge conditions or higher. However, in areas where the target depth was achieved, the post-dredge surface sediment concentrations were below the 1 ppm PCB comparison criteria in most areas.

- The horizontal auger produced a sediment slurry with 4.5 percent solids, much lower than the design specifications. Another method of hydraulic dredging may increase the percent solids content and lower the overall production costs.

- Debris was encountered at SMU 56/57 during dredging, which hindered progress and production rates. The dredge needed shorter cables, better positioning, and more overlapping transects to remove residual sediment ridges.

- Post-dredge average residual PCB concentration at SMU 56/57 was 7.5 ppm (40 percent reduction from 11.7 ppm avg).

- Partial cleanup left significantly higher PCB concentrations in some surface sediments where the target elevation was not achieved.

- Dredging activities should be completed before onset of winter conditions. Winter conditions adversely affected project costs and performance.

2000 Removal Activities
Sediment removal rates met project objectives and goals illustrating that horizontal auger dredges are effective tools for removing contaminated sediment. A key component of implementing a dredging project is selection of a qualified contractor with experience and good equipment. Good communication between parties and realistic expectations are also important variables to consider when implementing an aggressive construction schedule to ensure that project goals would be met before the onset of winter conditions. The apparent differences between the success of the 1999 and 2000 removal activities conducted at the same site with the same sediments, reemphasizes the influence of pre-planning, communication, expectation, and qualified contractors on the success of a project.

9 Costs

1999 Removal Activities
The total cost of the project was approximately $8.97 million including construction, dredging, treatment, disposal, and operational monitoring and construction management ($286 per cubic yard). The cost of the dredging component was approximately $27 per cubic yard. There was a $2 million difference between contract terms and payment versus penalties (Montgomery Watson, 2000). Disposal costs were not part of the contract since sediment was disposed on-site, however, estimated costs for off-site disposal were included in the total project costs for future planning purposes.

56/57 Upland Landfill
Source: B. Paulson, WDNR

2000 Removal Activities
The total direct cost of the project was $8.18 million, yielding a cost of $159 per cubic yard of *in situ* sediment (Fort James, et al., 2001). Direct costs included site improvement ($0.4 M); dredging, dewatering and treatment ($5.5 M); estimated disposal to dedicated onsite landfill ($1.1 M at $21/ton); operation of landfill ($0.1 M), and project management ($1 M). Additional project costs that were required to implement this project included rental of the former Shell Terminal Property for dewatering ($0.4 M), value of Cell 12A disposal cell ($5.9 M), and Fort James project team ($0.4 M). Therefore, the total project cost required to implement this project was approximately $14.9 million ($296 per cubic yard).

10 Project Contact

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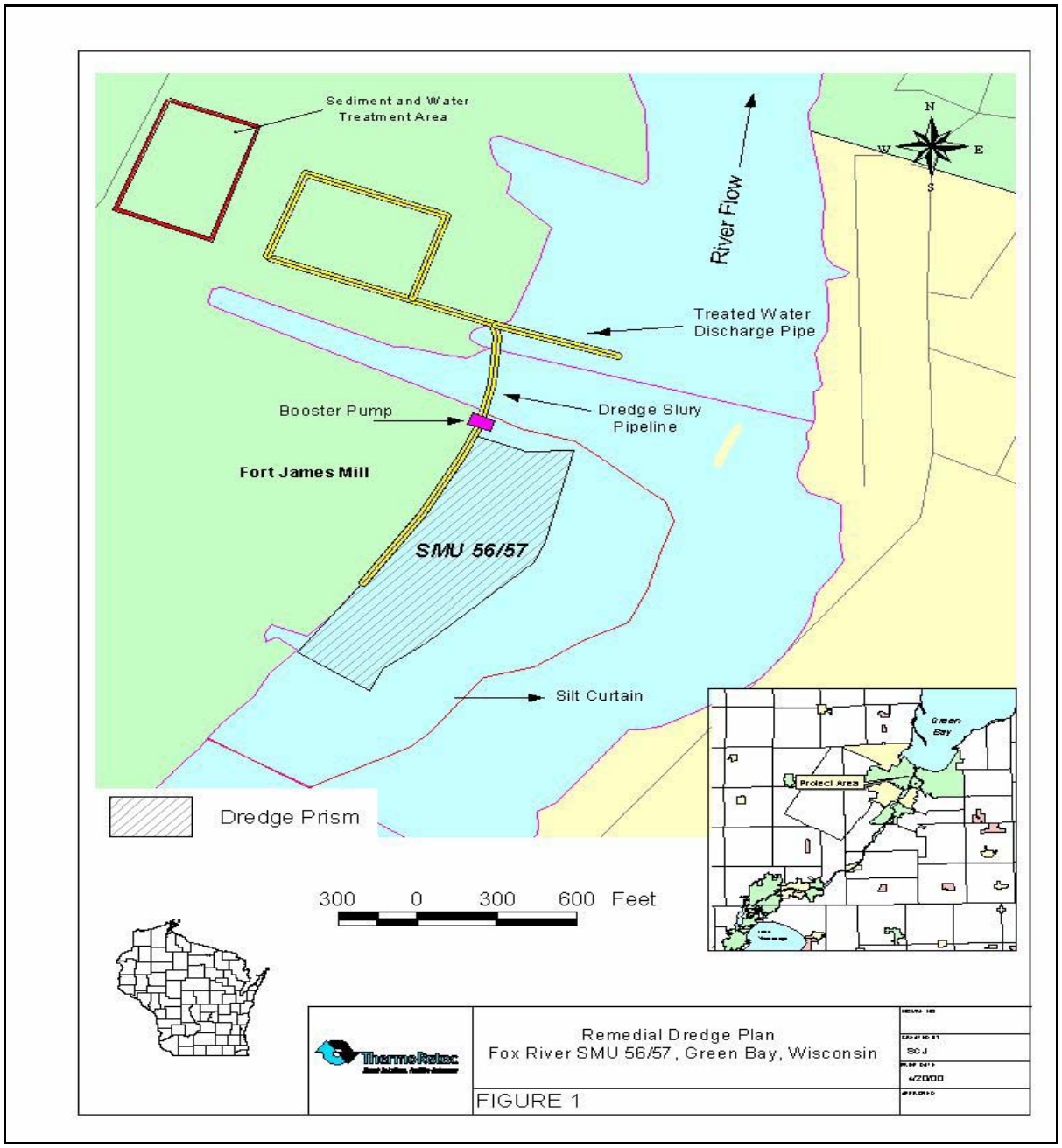
Figure 1 Remedial Dredge Plan - Fox River SMU 56/57



1 Statement of the Problem

- Dredged in 1995
- PCBs
- 27,000 cubic yards
- $680 per cy total

The General Motors (GM)/St. Lawrence River site generated an estimated 30,000 cubic yards of PCB-contaminated sludges from hydraulic oil used for aluminum casting from 1959 to 1973. PCB-contaminated sediments measuring up to 5,700 ppm polychlorinated biphenyls (PCBs) were present in the St. Lawrence River, the Raquette River, and Turtle Cove near the GM Foundry Plant (Figure 1). Over 11 fish consumption advisories were posted for the entire river.

The site was added to the National Priorities List (NPL) in 1984. Records of Decision (RODs) were issued in 1990 and 1992. The RODs were modified in the 1999 ROD to address changes in the treatment and disposal plans. The scope of remedial activities included excavation of sediment with PCB concentrations greater than 1 ppm, and on-site (<10 ppm) and off-site (>10 ppm) disposal. Dredging took place in the St. Lawrence River in 1995, removing 27,000 cubic yards of in situ contaminated sediment from an 11-acre nearshore site adjacent to the GM facility. The target concentration of 1 ppm PCBs was not reached. Average PCB concentration ranged from 3 to 27 ppm in six sampling areas. Concentrations significantly greater than the target goal remained in one 1.72-acre area and resulted in the addition of a protective cap to the remedial design (EPA, 1998). Contaminated sediment in the Raquette River and Turtle Cove are addressed in a 1999 ROD. The lead agency for this project was U.S. Environmental Protection Agency (EPA) Region 2 under Superfund.

2 Site Description

The site is located in the St. Lawrence River adjacent to the GM Foundry facility in Massena, New York. The river and adjacent lands provide habitat for a number of New York State-listed endangered, threatened, and special concern fish species and nesting for a variety of waterbirds and shorebirds.

Aerial view of GM Foundry
Source: St. Regis Mohawk Tribe

The portion of the river addressed in the remedial activities consists of a shallow bay shelf that extends approximately 250 feet into the river. The shelf sediments are primarily fine-grained clay, silt, and sand with high levels of organic matter. Dense glacial till underlies the sediment. Areas containing large rocks and boulders were also present.

Water velocity in the main channel of the river ranges from 2.75 to 4.42 feet per second. Lower velocities were observed on the shelf where remedial activities took place. The regulated flow ranges between 258,000 and 289,000 cubic feet per second in the St. Lawrence River.

3 Site Investigation

The GM Foundry site was proposed for the NPL on September 1, 1983. The final NPL listing date was September 1, 1984. PCB contamination existed in sediments of the St. Lawrence River, the Raquette River, and Turtle Cove and in other areas of the site including an industrial landfill, the east disposal site, and site groundwater and surface water. The 1990 and 1992 RODs (EPA, 1990; EPA, 1992) examined six alternatives for treatment of contaminated materials including biological destruction, chemical destruction, chemical extraction, incineration, and thermal extraction, and solidification. The 1990 ROD estimated removal of 62,000 cubic yards of sediment from the St. Lawrence River, the Raquette River, and Turtle Cove. Maximum PCB concentrations measured in the sediment of the St. Lawrence River, the Raquette River, and Turtle Cove were 5,700, 390, and 48 ppm, respectively. The actual dredging was conducted only in the St. Lawrence River and included the removal of 27,000 cubic yards of material. Sediment removal from the Raquette River and Turtle Cove are addressed in an amended March 1999 ROD (EPA, 1999).

4 Target Goals and Project Objectives

Criteria for removal of sediment from the St. Lawrence River was based on requirements of the Toxic Substances Control Act (TSCA), a baseline human health risk assessment conducted by EPA, and an ecological risk assessment conducted by the New York State Department of Environmental Conservation (NYSDEC) and the St. Regis Mohawk Tribe. Removal of sediment with PCB contamination in excess of 1 ppm was established as the target objective for the remedial action to protect human health and the environment. As stated in the 1990 ROD, "The 1 ppm PCB cleanup in the St. Lawrence and Raquette Rivers was based on interim federal and State sediment quality criteria guidance as well as on EPA's risk assessment."

5 Project Design

Pre-planning and Bid Documents. A horizontal auger dredge was selected after an assessment of five different dredging techniques based on sediment removal efficiency and sediment suspension.

Summary of Remedial Action Plan. The remedial action plan consisted of the installation of a sediment containment system, removal of sediment from six established quadrants in the study area, and on-site dewatering and water treatment. A sediment cap was added to the remedial action within Quadrant 3 after dredging was completed due to high residual PCB concentrations (Figure 1).

The initial containment system consisted of double barrier silt curtains placed at the perimeter of the dredge area. The silt curtain containment system was installed in 1994, but was determined to be unacceptable due to installation difficulties and swift river currents (Cushing, 1999). In 1995, GM changed contractors and a revised containment system was designed (GE/AEM/BBL, 1984). The revised design consisted of interlocking sheetpile walls that were driven to an average depth of 6 feet into the river bottom. The tops of some individual sheets were driven below the water surface to reduce stress during storm events by allowing water flow to pass through the containment area.

Mechanical removal of debris and rock was conducted prior to dredging using a barge-mounted backhoe. The barge was anchored with spuds located on each side of the barge. Larger material was rinsed of residual fines by agitating the bucket in the water column, then transported for storage in a sediment stockpile located south of the dredge area (Figure 1). Mechanical excavation of sediment located in shallow areas near the shoreline was conducted after dewatering using a Portadam System. The Portadam is a portable dam structure composed of upright steel frames that support an impermeable liner.

Waste Pile Sampling
Source: B. Paulson, WDNR

Hydraulic dredging was conducted using an 8-foot horizontal auger dredge winched along a cable guide. Areas with PCB concentrations in excess of 500 ppm were dredged first and confirmed with sediment sampling. Dredging resumed, removing sediments within the 1 to 500 ppm range. Sediments in excess of the 1 ppm PCB were dredged after the removal. Residual PCB concentrations in Quadrant 3 remained elevated after several dredging and sampling events. Alternative dredging methods were therefore implemented in Quadrant 3 with limited success. The alternative methods included a vacuum head dredge fitted with a metal shroud, and mechanical removal of sediment with the barge-mounted backhoe (BBL, 1996b). A sediment cap (75,000 square feet) was placed over Quadrant 3 residuals to isolate contaminated sediments.

Limitations and Permits. No remediation has occurred in Turtle Cove due to difficulties with access to the property (Fox River Group, 1999). Remediation of Turtle Cove and the Raquette River are addressed in a 1999 ROD.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. An ineffective silt curtain containment system was installed and removed in 1994. Remedial activities were reinitiated and conducted from March 29, 1995 to January 9, 1996. The sheetpile containment system was installed between May 8, 1995 and July 21, 1995, after the silt curtains were removed. Hydraulic dredging was conducted between June 29, 1995 and November 6, 1995. The initial schedule called for dredging eight to 10 hours per day, six days a week with dewatering and water treatment operation 24 hours per day. Due to additional available capacity at the water treatment plant, the dredging schedule was increased to 24 hours per day between September 11 and October 16, 1995. The sediment cap was installed in Quadrant 3 between November 9 and December 7, 1995.

Equipment. Equipment utilized in the installation of the containment system included a 30-foot by 90-foot barge, tug boat, material barge, 100-ton crane, and a vibratory hammer. The sheetpile wall consisted of American Institute of Steel Construction designated AZ-13 interlocking sheets and W 16 × 89 or HP 14 × 89 piles. Mechanical debris removal was conducted using a barge-mounted backhoe anchored with spuds with assistance from divers.

Hydraulic dredging was conducted using an 8-foot horizontal auger head moved by winching along a cable guide anchored at the shore and the sheetpile wall. The dredge advanced approximately 2 to 4 feet per minute and cut a depth of 3 to 12 inches on each pass. After a series of passes (typically four to six) the dredge was moved laterally 7 feet, allowing a 1-foot overlap, and dredging resumed.

Dredging in St. Lawrence
Source: K. Martin

Total Volume Removed and Production Rates. A total of 27,000 cubic yards of contaminated material was removed from the St. Lawrence River, which included 3,000 cubic yards of rocks and 13,800 cubic yards of residual filter cake requiring disposal (Crystal, 2001 personal communication). Production rates are not available for review.

Site-specific Difficulties. The sediment containment system in the initial 1994 project consisted of a double barrier of silt curtains placed along the perimeter of the dredge area. However, the silt curtains did not work well and in 1995, GM changed contractors and a revised sheetpile containment system was designed. Modifications were made to the sheetpile containment system during dredging due to turbidity measurements in excess of action levels between July 10 and August 14, 1995 (outside the system). Modifications included installation of filter fabric, installation of short steel sheets over low sheetpiles, and mechanical raising of low sheetpiles (ones driven further into sediment).

The changes proved to be effective in reducing turbidity outside of the containment system. Quadrant 3 had elevated PCB concentrations above cleanup criteria after several dredging attempts utilizing different techniques, therefore a sediment cap was placed over the residuals (surface area of 75,000 square feet). Reasons for the exceedances were summarized in the project completion report (BBL, 1996b).

> "...The solids content within the dredge slurry had dropped considerably, apparently due to exposure of the underlying till. Further removal work was technically impractical, given that all methods of sediment removal had been used in this area, sediment probing indicated only a thin layer of remaining sediment, mechanical removal activities were removing more underlying materials than modern sediment, sampling results were not significantly improving with each sampling round, and there were only a limited number of work days remaining before the winter season. Therefore a sediment cap for Quadrant 3 was designed...and approved by the USEPA."

Shoreline booster pumps were commonly clogged with rocks and debris so an intermediate 0.25-inch shaker screen was added between the hydraulic dredge and booster pump (BBL, 1996b).

6.2 Dewatering and Water Treatment Operations

Dewatering, Treatment and Disposal. Dredged sediment was pumped (with shoreline booster pumps) via a pipeline through on-site tandem vibrating 0.25-inch and #10 screens and into an equalization basin (approximately 350 to 1,000 feet distance). An additional 0.25-inch shaker screen was installed between the hydraulic dredge and booster pump due to problems with blockages in the pipeline formed by debris and large rocks.

Sediments were mixed with lime and dewatered using three recessed filter presses. Dewatered sediment was separated into two stockpiles based on pre-dredge PCB concentrations. Stockpile cell #1 received sediment with greater then 500 ppm PCBs and stockpile cell #2 received sediment less than 500 ppm PCBs. Large debris and rocks were stockpiled in cell #3.

Water pumped from the equalization basin and generated from dewatering was pumped to the water treatment plant. The treatment plant consisted of an oil-water separator, clarifier, mixed media filters, cartridge filters, and carbon filters. Treated water was held in a finished water tank until composite samples were collected. Treated water meeting water quality criteria was discharged to the St. Lawrence River.

Water Quality Monitoring of Discharge. A total of 43,285,316 gallons of water were treated between July 7 and November 21, 1995. Discharge criteria for treated water were 10 mg/L total suspended soilds (TSS), 15 mg/L oil and grease, and nondetectable concentrations of PCBs. Criteria for individual PCB Aroclors was set at 0.065 μg/L. If any or all PCB Aroclors were greater than the target detection limit but less than 0.3

μg/L, an evaluation of the pretreatment units was conducted to ensure optimum performance. If any or all PCB Aroclors exceeded 0.3 μg/L, the discharge of treated water was halted or recycled to the basin until corrective action had taken place and plant performance could be demonstrated (BBL, 1995).

Composite samples were collected daily from the finished water tank. A total of 91 samples were collected for PCBs, oil and grease, and TSS. PCBs were in excess of the detection limit, but less than 0.3 μg/L in 16 of the samples. PCB concentrations in excess of 0.3 μg/L were measured in three samples on July 8, July 11, and October 26, 1995. Discharge of treated effluent to the St. Lawrence River was immediately halted and recycled to the equalization basin until corrective actions were implemented and discharge criteria were met. High flow and resultant short retention times were responsible for exceeding discharge criteria on July 8 and July 11. The corrective action included reducing flow and the addition of 20,000 pounds of activated carbon to the treatment system. Conversion of the carbon filter system from a series to parallel alignment was responsible for exceeding criteria on October 26. The problem was corrected by returning the carbon filter system to a series alignment.

Except for three oil and grease samples not analyzed due to a shortage of sample preservative, all oil and grease results were less than the detection limit. TSS results were in excess of 10 mg/L in 14 of the 91 samples with a maximum concentration of 87 mg/L. When TSS criteria was exceeded, the pretreatment units were analyzed and subsequent corrective actions were reviewed and approved by GM and the on-site EPA representative.

6.3 Storage and Disposal

Dewatered sediments were stockpiled on site until 1999 awaiting a decision for final disposal. In a release dated March 25, 1999 (EPA, 2000a) the EPA stated, "sediments have been stored on the site pending the resolution of the strong public opposition to a Post-Decision Proposed Plan released by EPA in 1995 that called for the on-site treatment of PCB-contaminated materials below 500 ppm. EPA withdrew that plan this past summer and replaced it with another plan, which formed the basis of this modification. Materials with PCB concentrations of 1 to 10 ppm will be contained on the site in the East Disposal Area, which will be covered with an engineered cap. Materials with PCB concentrations above 10 ppm will be disposed of at licensed out-of-state facilities."

A second EPA statement dated June 10, 1999 (EPA, 2000b) explained details of the final disposal. "The U.S. Environmental Protection Agency (EPA) announced today that 23,000 cubic yards of contaminated sediments and soil will be removed this summer from the General Motors (GM) Superfund site in Massena, New York for disposal at a licensed facility in Utah. The total includes 13,000 cubic yards of contaminated sediments dredged from the St. Lawrence River and stored on the site since 1995, and 10,000 cubic yards of contaminated sludge from the active wastewater treatment plant on the GM property."

7 Environmental Monitoring Program

Monitoring parameters included in the dredging action included bathymetric surveys, chemical PCB analysis of sediment and the water column, and air monitoring. The monitoring and maintenance plan included measurements of PCB bioaccumulation in spottail shiner samples, and inspection and maintenance of the protective cap. Juvenile spottail shiners were chosen as the target species due to the presence of previously collected data in the St. Lawrence River; they have a limited home range and a typical life span of 3 years (BBL, 1996a).

7.1 Baseline

Physical. A pre-dredging bathymetric survey was conducted to document mudline elevations. Depths were measured along 50-foot transects located perpendicular to the shore.

Chemical. Sediment PCB concentrations measured from non-detect to 5,700 ppm with a median value of 74 ppm in investigations conducted during the remedial investigation.

Baseline air monitoring was conducted for PCBs between May 23 and June 20, 1995, prior to dredging. Samples were collected from Turtle Cove and from the future site of the sediment stockpiles. The results measured PCBs in two of 17 samples collected at the Marina location at concentrations of 0.2 $\mu g/m^3$. All other results for the Marina location and all 14 samples from the sediment stockpile locations were non-detect.

Biological. Annual PCB bioaccumulation was measured in spottail shiners from the St. Lawrence River prior to dredging from 1986 to 1992 and in 1994. Lipid normalized PCB concentrations ranged from 4 to 2,917 ppm (BBL, 1999). The results are summarized in Table 1 along with post-dredging results.

7.2 Implementation During Dredging

Physical. Turbidity was measured in water samples collected throughout the remedial activities. The criteria for turbidity outside of the containment system was established at 28 NTU. During installation of the sheetpile wall, measurements ranged from 0 to 13 NTU. From July 10 to August 14, 1995, the turbidity criteria was exceeded in 18 of 923 measurements with results ranging from 31 to 127 NTU. Modifications were made to the containment system including installation of filter fabric, installation of short steel sheets over low sheetpiles and mechanical raising of low sheetpiles. In the period (August 17 to December 5, 1995) following the modifications, only one turbidity measurement in excess of the 28 NTU criteria was measured (49 NTU). This sample corresponded with a storm event and high waves on October 14, 1995.

Chemical. Water column samples were collected from one location outside of the containment system and analyzed for PAHs and PCBs. A total of 38 samples was collected over 19 days and analyzed for PAHs.

Results were non-detect and PAH sampling was discontinued July 15, 1995. A total of 146 samples collected over 73 days was analyzed for PCBs. Only one sample, collected during mechanical removal activities, exceeded the 2 μg/L action level (BBL, 1996b). A sheetpile wall was subsequently installed resulting in no exceedances of performance criteria.

Air monitoring samples for PCBs were collected between June 21 and December 15, 1995 from a location adjacent to the sediment stockpiles and Turtle Cove. A total of 50 of the 98 samples collected from the sediment stockpile area exceeded the 0.1 $\mu g/m^3$ action level. Samples exceeding criteria ranged from 0.11 to 4.7 $\mu g/m^3$ PCBs. A total of 24 of the 82 samples collected from the marina exceeded the criteria concentration, ranging from 0.11 to 0.55 $\mu g/m^3$. Air monitoring samples for particulate dust were also collected throughout the project. Measurements exceeded the 150 $\mu g/m^3$ criteria in samples collected in 21 of 142 days. Watering of gravel roads and/or work areas was immediately implemented as a dust control measure after exceeding the dust criteria.

Biological. Biological monitoring was not conducted during the remedial activities.

7.3 Post

Physical. A post-dredge bathymetric survey and sediment probing were conducted immediately following dredging to determine the topography of the riverbed and depth of remaining sediment. The volume of sediment removed during dredging was calculated to be 13,800 cubic yards based on comparison of the initial and final bathymetric surveys.

Chemical. Residual PCB concentrations in river sediments were measured following each of the multiple removal attempts conducted in each of six quadrants. Average residual PCB concentrations in quadrants 1, 2, 4, 5, and 6 ranged between 2.5 and 3.9 ppm. Residual PCB concentrations in Quadrant 3 measured less than 100 ppm with an average residual PCB concentration of 27 ppm after eight rounds of dredging and sampling. The U.S. Army Corps of Engineers (ACOE) representative (observing site activities) requested the collection of a single sample at the western end of Quadrant 3 prior to installation of a sediment cap. The sample was collected November 8, 1995 and measured 6,281 ppm PCBs (BBL, 1996b).

Table 1 Summary of Monitoring Results

Testing Parameter	PCB Concentration (in ppm)			
	Baseline ≈1986 - 1995	During Dredging March 1995 - Jan 1996	Post November 1995	Long Term 1997 - 2001
Bathymetry	Yes	None	Removal of 13,800 cy	None
Sediment Core	Non-detect to 5,700 ppm with median of 74	To check progress	Average range 2.5 to 2.9 in five quadrants; average 27 ppm in one quadrant	None
Water Quality	None	Turbidity: 0 to 127 NTU: 19 exceedances, N >1,000 PCBs: one exceedance, N = 146	None	None
Biological - Resident Fish	Lipid-normalized PCB concentrations ranged from 4 to 2,917 ppm in spottail shiners	None	None	Average Lipid-normalized PCB concentrations = 22 ppm (1997) = 79 ppm (1998) = 27 ppm (1999) in spottail shiners (composite)
Air Quality	Non-detect to 0.2 $\mu g/m^3$ (N = 31)	Range from non-detect to 4.7 $\mu g/m^3$, 74 of 180 samples exceeded 0.1 $\mu g/m^3$ criteria	None	None

Table 2 Summary of Sediment PCB Concentrations

Location	PCB Sediment Concentration (in ppm)					
	Baseline			Post		
	Minimum	Maximum	Median	Minimum	Maximum	Average
	non-detect	5,700	74			
Quadrant #1				0.079	8.22	2.6
Quadrant #2				0.076	7.9	3.8
Quadrant #3				0.57	91.0	27.0
Quadrant #4				0.16	5.52	2.7
Quadrant #5				0.073	8.41	3.9
Quadrant #6				0.036	6.35	2.5

Biological. Following completion of dredging activities, fish tissue samples were not collected for another 1.6 years and are discussed in the long-term monitoring section. Since dupuration rate of PCBs in fish tissue often takes three to seven years depending on the species, this is not inappropriate. Sampling is expected to continue annually for five years.

7.4 Long Term

Annual PCB bioaccumulation measurements began in 1997 for the St. Lawrence River 5-year long-term monitoring plan (OMMP). Fish tissue samples for whole body and lipids were collected using spottail shiner if available, or else emerald shiner and longnose dace (BBL, 1999). Table 3 represents fish tissue data from pre- and post-dredging activities. Average lipid-normalized concentrations dropped from 620 ppm pre-project to 50 ppm PCBs after dredging.

In 1999, the fourth year of sediment cap inspections and third year of resident biota sampling was conducted in accordance with the OMMP. The integrity of the stone armor cap for all areas inspected appeared to be undisturbed and in good condition (following minor restoration with new armor materials after minor disturbance observed in previous yearly inspections). Resident spottail shiner fish were collected and analyzed as whole-body young-of-year composites for PCBs and percent lipid. Wet-weight total PCB concentrations ranged from 0.79 to 6.8 mg/kg PCBs (average = 2.4) and lipid-normalized concentrations ranged from 8.4 to 75 mg/kg lipid PCB (average = 27) (BBL, 2000). The mean total concentration in 1999 is lower than in 1998, and similar to levels in 1997. Collectively, the data appear to indicate a general downward trend in spottail shiner PCB concentration since the late 1980s.

Table 3 Resident Juvenile Spottail Shiner PCB Tissue Data (BBL, 1999 and 2000)

	Collection Date	Number of Samples	Lipids (%)	Average Total PCB (ppm wet-weight)	Average Lipid-Normalized PCBs (ppm)[2]	
Pre-dredge	1986 (Aug.)	9	1.41	1.22	87	Avg. = 620
	1987 (Sept.)	7	1.44	1.26	89	
	1988 (Sept.)	7	1.97	21.5	1,202	
	1989 (Sept.)	5	4.58	22.6	489	
	1990 (Sept.)	7	1.40	1.54	105	
	1991 (Sept.)	7	4.26	3.06	69	
	1992 (Aug.)	2	1.33	35.3	2,917	
	1994 (Sept.)	5	2.42	0.09	4	
Post-dredge	1997 (Oct.) LT[1]	7	5.58	1.20	22	Avg. = 64
	1998 (Oct.) LT[1]	7	4.54	3.59	79	
	1999 (Oct.) LT[1]	7		2.4	27	

Notes:

[1] Each sample is a 15-fish whole-body composite.

[2] The average PCB lipids for pre-dredge samples is 620 ppm and 50 ppm for post.

8 Performance Evaluation

8.1 Meet Target Goals and Objectives

Sediment removal was not successful in achieving the target PCB concentration of 1 ppm. Average residual PCB contamination ranged between 2.5 and 3.9 ppm in quadrants 1, 2, 4, 5, and 6. Residual contamination in Quadrant 3 averaged 27 ppm after eight rounds of dredging and sampling. A sediment cap was therefore designed and installed over Quadrant 3. The cap consisted of a 6-inch sand and activated carbon layer and a 6-inch armor stone layer.

Although the target goal of 1 ppm PCBs was not achieved, the project made progress relative to achieving human health and ecological endpoints by reduction of PCB concentration and mass. The average sediment PCB concentration dropped from 74 (median) to 27 ppm (before capping) with post-project average concentration of 7.1 ppm for all quadrants (10-fold reduction).

The average fish tissue concentrations dropped from 620 to 64 ppm PCBs since remedy completion (lipid normalized) (10-fold reduction). Additional long-term fish tissue monitoring samples should be, and will be, collected to verify this observed downward trend. Based on tissue results from 8 years of baseline data, the results can be highly variable.

Variability in certain years of the data may be due to several factors, including different fish lengths, sizes, species mobility, sample sizes, and sampling locations.

Sediments in Turtle Cove containing PCBs at concentrations up to 48 ppm were not included in the remedial dredging program and may continue to serve as a source of PCBs to fish.

8.2 Design Components

The horizontal auger dredge was selected after an assessment of five different dredging techniques based on sediment removal efficiency and sediment suspension.

Because residual contamination in Quadrant 3 averaged 27 ppm (above the 1 ppm cleanup criteria), a sediment cap was designed and installed over Quadrant 3. The cap design consisted of a 6-inch sand and activated carbon layer, a 6-inch gravel bedding layer, and a 6-inch armor stone layer. In 1999, the armored cap appeared intact with minimal disturbance. No routine maintenance was required; however, additional armor material was added in 1998 to restore minor nearshore areas.

8.3 Lessons Learned

The target removal criteria established for dredging was not achieved in any of the six quadrants of the removal action. Possible reasons for not meeting compliance criteria may include inadequate site characterizations, selection of removal methods, and selection of unrealistic cleanup criteria. However, significant reductions in fish tissue concentrations (12-fold) and surface sediment concentrations (10-fold) were observed. Although cleanup criteria of 1 ppm was not achieved, progress was made towards risk reduction.

Other lessons learned included:

- Silt curtains did not work well in fast-moving rivers.
- Installation of sheetpile walls need careful consideration. If the tops were placed above waterline, they were subject to disturbance, but placement below waterline resulted in turbidity exceedances outside the containment system.
- The cleanup criteria of 1 ppm PCBs was likely not a realistic target goal for post-verification sampling efforts based on site conditions and dredging method selected (horizontal auger). An average of 12 to 21 subsamples were collected in each of the six quadrants and less than 40 percent of the subsamples measured less than 1 ppm PCBs dry-weight. However, none of the discrete samples exceeded 10 ppm PCBs (except in Quadrant 3).
- The number of dredge passes varied by area, averaging approximately 15 dredge passes across all areas with certain

areas exceeding 30 dredge passes (BBL, 1996b). A vacuum head was placed on the end of the auger and every attempt was made to remove residual sediment resting on top of glacial till. A lot of effort was expended for residuals with little return under these site conditions.

9 Costs

The cost of the 1995 dredging of 27,000 cubic yards of in situ sediment was approximately $7 million based on a firm fixed-price contract. A total of 13,800 cubic yards of filter cake required disposal. This figure did not include cost of the sediment cap or disposal. The cost including the sediment cap was approximately $10 million. Based on these values, dredge and cap costs were $680 per cubic yard.

10 Project Contact

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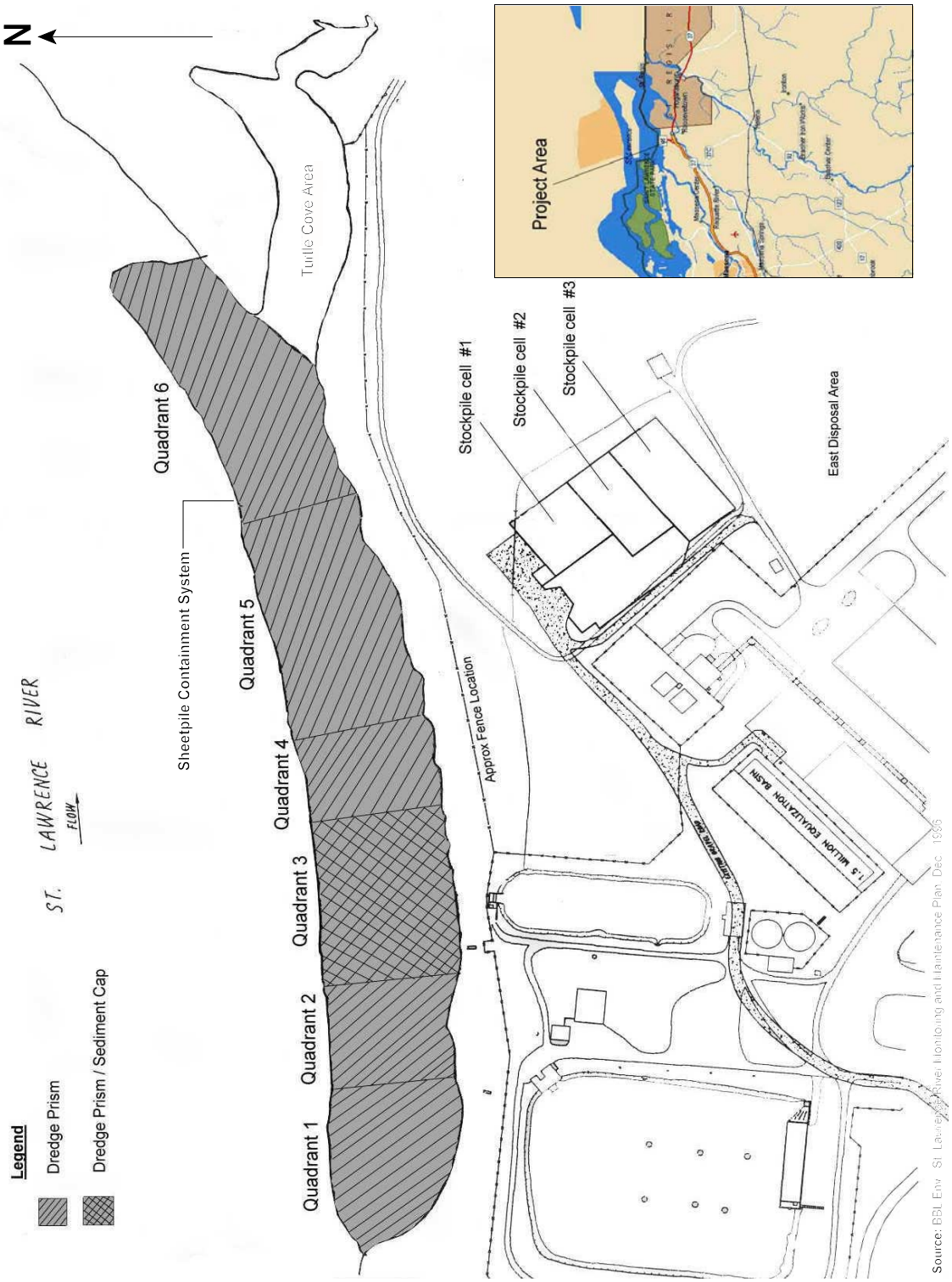
Figure 1 Remedial Dredge Plan - GM Foundry/St. Lawrence River



Source: BBL Env. St. Lawrence River Monitoring and Maintenance Plan Dec. 1995

1 Statement of the Problem

- Dredged 1995 (pilot)
- PCBs
- 3,800 cubic yards
- $450 per cy for dredging

PCB contamination was present in Grasse River sediments at concentrations up to 11,000 mg/kg. Approximately 2,600 cubic yards of sediment were dredged in 1995 as a pilot study to gain site-specific information/experience and to remove highly contaminated sediment from a major hotspot. A *Draft Analysis of Alternatives* was completed in December 1999 to address future remediation of the site. The lead agency for this project was U.S. Environmental Protection Agency (EPA) Region 2.

2 Site Description

The Grasse River area of concern, located in Massena, New York, is an 8.5-mile stretch extending upstream from the confluence with the St. Lawrence Seaway. The river bottom consists of glacial till containing large boulders, cobbles, and rock overlain with a soft sediment layer containing loose gravel and cobbles. The water level in the project area ranges from 2 to 3 feet near shore to a maximum depth of approximately 14 feet. The width of the river channel is approximately 400 feet. The dredging area was approximately 1 acre in size and measured approximately 100 feet wide by 500 feet long.

3 Site Investigation

A grid sediment sampling investigation, conducted in September 1993, found PCBs at concentrations up to 11,000 mg/kg. PCBs were the contaminant of interest at the Grasse River site and are primarily derived from historic discharges of the ALCOA aluminum product production plant. Contamination was present in sediment up to depths of 1 to 2.5 feet.

Hydraulic Horizontal Auger Dredge
Source: D.C. Roukema, J. Driebergen, and A.G. Fase

A Non-Time-Critical Removal Action (NTCRA) was proposed by ALCOA as a voluntary cleanup of Grasse River sediment located adjacent to the ALCOA Outfall No. 001. Final approval of the NTCRA, which included dredging, mechanical dewatering, and disposal in the ALCOA Secure Landfill, was granted by EPA in May 1995 under Superfund. To date, the site is not on the National Priorities List (NPL) nor has a Record of Decision (ROD) been issued (EPA, 2000).

4 Target Goals and Project Objectives

A 1993 EPA baseline risk assessment concluded the study area presented unacceptable risk due to ingestion of fish, ingestion of and dermal contact with sediment, and dermal contact with surface water (GE/AEM/BBL, 1995). The pilot remedial action was intended to remove only highly contaminated sediment from a 1-acre hotspot within the 8.5-mile study

area. This entailed proposed removal of approximately 3,550 cubic yards of contaminated sediment from a dredge prism in the immediate vicinity of ALCOA Massena Facility permitted Outfall No. 001. By removing 3,550 cubic yards, it was expected that 25 to 30 percent of the total polychlorinated biphenyl (PCB) mass from the entire study area would be removed. No target contaminant concentration criteria was established for the pilot removal.

5 Project Design

Pre-planning and Bid Documents. An engineering evaluation/cost analysis (EE/CA) was conducted to analyze removal action alternatives for the NTCRA. The EE/CA also defined the objectives of the study including volume and contaminant mass removal. A monitoring plan was instituted to determine the effects of remedial activities and to apply these findings to future designs. Underwater geophysical and diver surveys conducted in September 1993 and July and November 1994 provided information for the removal of boulders from the project area to assist in dredging.

Summary of Remedial Action Plan. The NTCRA was conducted as a voluntary action by ALCOA with oversight provided by EPA Region 2. In chronological order, remedial design included a helical screw-anchored silt curtain containment system, boulder removal, and dredging with a horizontal auger dredge. Dredged sediments were then dewatered, filter pressed, and transferred to a permanent upland landfill facility. Environmental monitoring was conducted prior to, during, and after dredging activities by an independent quality assurance contractor. During installation of the silt curtain, concrete blocks were used as anchoring devices due to the inability to drive helical screws into the river bottom.

In the immediate outfall area (Area B), an additional 200 cubic yards of sediment was removed by dry excavation from a dewatered area of the outfall. Dewatering of Area B was accomplished using a diversion pipe, a sheetpile wall, and submersible pumps. Manual removal of sediment was performed using two suction lines attached to an augerhead dredge pump manifold. The Area B dry excavation is not discussed further in this case study.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. The remedial action took place from June 19, 1995 to October 3, 1995 (110 days). Boulder removal took place from July 17, 1995 to August 9, 1995. Dredging was conducted from August 9, 1995 to September 6, 1995. The work schedule for the project was eight to 10 hours per day and five days per week.

Equipment. A silt curtain was installed surrounding the dredge area to contain sediments suspended during dredging. Redesign of the silt curtain

anchoring system was necessary due to the inability to drive helical screw anchors into the river substrate. Helical screws were therefore replaced with large concrete blocks to anchor the silt curtains. Prior to dredging activities, boulders, cobble, and debris identified in an underwater physical survey were removed from the dredging area. A Caterpillar 320L long-stick excavator with a riprap and rock removal bucket was used for removal (OHM, 1995).

Boulder removal resulted in significant suspension of sediment and failure of PCB and total suspended solids (TSS) water quality monitoring criteria. Initially, boulders were manually pressure washed within the bucket immediately after being lifted from the river. Modifications were made to wash the boulders beneath the waterline by agitating the loaded bucket. This allowed boulder removal to proceed with fewer elevations in TSS/PCB concentrations.

Sediment removal was conducted using a horizontal auger dredge operated with low-speed, high-torque hydraulic motors. During dredging, cobbles and rocks greater than 4 inches in diameter were removed from the dredge using a grappler. Consecutive dredge traverses were overlapped 12 to 24 inches to ensure all areas were covered.

Total Volume Removed and Production Rates. A total of 3,550 cubic yards of sediment were slated for removal. Although two dredge passes were made in some areas, approximately 550 cubic yards of sediment remained after dredging. The total sediment removed for this project was 3,175 cubic yards resulting in a removal efficiency of 85 percent. A summary of the dredged material includes:

- Boulders removed prior to dredging - 390 cubic yards,
- Sediment removed (average of two measurements) - 2,585 cubic yards,
- Dry excavation from Area B - 200 cubic yards,
- Sediment left in-place - 550 cubic yards, therefore
- Total = 3,725 cubic yards.

Sediment remained in-place due to accessability issues with the dredge resulting mainly from the presence of boulder and cobble material. The volume removed was calculated from production was 2,526 cubic yards and volume removed calculated from geophysical investigation was 2,643 cubic yards. These figures did not include the removed boulders. The solids content of dredged material ranged from 2 to 5 percent. The average daily pumping rate was 720,000 gallons.

Site-specific Difficulties. The proposed silt curtain anchoring system was replaced with large concrete blocks due to inability to drive helical screws into the river bottom.

Although 390 cubic yards of boulders and cobbles were removed from the site prior to dredging, additional boulders and cobbles were discovered during dredging and were left in-place. The presence of this material and the hard and dense conditions of the river bottom (glacial till) inhibited the efficient operation of the horizontal auger, resulting in reduced sediment removal efficiency. Sediment remained in the dredge prism at thicknesses between 0 and 14 inches (average of 4 inches).

6.2 Dewatering and Water Treatment Operations

Dewatering, Treatment and Disposal. Sediments were dewatered using four 100-cubic-foot recessed chamber filter press units. The water treatment system consisted of sand filters, dual bag filters, and dual cells of liquid-phase granular activated carbon (OHM, 1995). The water treatment system operated 24 hours a day from August 9, 1995 until September 19, 1995 (42 days) treating a total of 11,667,211 gallons. Treated water was discharged back to the Grasse River.

Water Quality Monitoring of Discharge. A discharge water grab sample was collected and analyzed daily for PCBs, TSS, total dissolved solids (TDS), polyaromatic hydrocarbons (PAHs), and fluoride. PCBs in excess of the discharge criteria (detection limit) were detected in two samples collected August 12 and August 18 at concentrations of 0.911 and 0.309 μg/L, respectively. PCB concentrations entering the granular activated carbon unit ranged from 6.5 to 8.3 μg/L (BBL, 1995).

6.3 Storage and Disposal

Following screening and dewatering, the filter cake, sand, and gravel residuals were disposed of in the ALCOA on-site secure landfill along with boulders and cobbles. A total of 169 cubic yards of gravel, 1,215 cubic yards of sand, 1,142 cubic yards of filter cake, and 390 cubic yards of boulder and cobble material were disposed in the landfill.

7 Environmental Monitoring Program

Physical, chemical, and biological monitoring was conducted prior to, during, and following dredging operations. The results of the monitoring program were presented in the NTCRA documentation report (BBL, 1995) and are summarized in Tables 1 and 2.

7.1 Baseline

Physical. Underwater geophysical surveys were conducted using magnetometry, side-scan sonar, and ground-penetrating radar to determine sediment stratigraphy and bathymetry in September 1993. Supplementary physical data were provided by diver surveys conducted in July and November of 1994.

Chemical. A gridded sediment sampling program was conducted within the hotspot excavation area in September 1993, with PCB results ranging between non-detect and 11,000 mg/kg. The average PCB concentration

was 1,109 mg/kg. The average PCB concentration in the top one foot of sediments (bioavailable zone) was 518 mg/kg.

Site-wide water column PCB analysis of filtered and unfiltered samples were conducted at 13 fixed transect locations between July 1993 and May 1994. PCB concentrations were less than the practical quantitation limits for all samples (0.5 and 0.7 μg/L, depending on the Aroclor). Results were less than the method detection limits (0.05 and 0.07 μg/L, depending on the Aroclor) in 92 percent of samples.

Baseline air monitoring for particulate- and vapor-phase PCBs was conducted on July 13 and 15, 1995. PCBs were not detected in any samples.

Biological. PCB bioaccumulation was tested in caged and resident fish at two locations upstream and two locations downstream of the removal area. Results of caged fish studies conducted between October and November 1993 detected PCBs in all sampling locations with higher concentrations in locations downstream of the outfall (Figure 1 and Table 2).

Ambient Air Monitoring
Source: B. Paulson, WDNR

Resident fish from locations including background, upper, middle, and lower stretches of the river, and the mouth of the river were tested for PCB bioaccumulation in 1991 and September and October 1993. A total of 58 smallmouth bass, 72 bullhead, and 12 spottail shiner samples were analyzed in the 1993 sampling. PCBs were detected in all samples. Although actual analytical data were not reviewed, the NTCRA Documentation Report stated that results did not show strong spatial trends and that there was no statistical difference in PCB concentrations between the 1991 and 1993 studies.

A benthic community assessment was conducted between August and November 1993 measuring the presence, abundance, and diversity of the macroinvertebrate benthic community. Samples from seven transects were taken at each of two sites (background and downstream of the remedial site). Based on the results, one downstream community transect was impaired.

7.2 Implementation During Dredging

Physical. The water column was monitored for TSS, TOC, DOC, temperature, pH, conductivity, and turbidity during dredging operations. Due to difficulties in removal, an average of 4 inches of sediment was left behind. This correlates to approximately 550 cubic yards. Weak correlation was observed between turbidity, TSS, and PCB concentration. Sediments were probed after each dredge pass to determine completeness of dredging to the base soft sediment in the dredge prism. A second

dredge pass was required in some areas that did not meet the progress survey requirements.

Chemical. Filtered and unfiltered PCB concentrations were measured daily in the water column during boulder removal and dredging. Samples were collected from two upstream locations and three locations immediately outside of the containment system. Concentrations ranged from non-detect to 13.3 μg/L at the perimeter locations. The 2 μg/L water quality criteria was surpassed on July 20, 21, 25, 26, 28, August 1, and 9 during boulder removal and August 10, 11, 12, 15, 16, and 17 during sediment removal. In the events exceeding criteria, additional sampling was conducted at a point 2,300 feet downstream. PCB concentrations in these samples ranged between non-detect and 1.38 μg/L. Because the concentration never exceeded 2 μg/L at this sampling point, the corrective action procedure was never implemented.

Filtered and unfiltered water column PCB samples were also collected from 13 fixed transect locations spanning a 4.5-mile length of the river during boulder removal and dredging. Two rounds of samples were collected daily throughout removal operations (July 17 through September 6, 1995). The results showed no detectable concentrations of PCBs during boulder removal. PCBs were detected during dredging in four of the transect samples at concentrations up to 1.1 μg/L. No PCBs were detected in any of the filtered samples.

Air monitoring was conducted daily from July 13, 1995 to September 6, 1995 for particulate- and vapor-phase PCBs. No PCBs were detected.

Biological. PCB bioaccumulation was tested using caged fish studies in the same four locations used in the 1993 baseline monitoring (Figure 1). PCB concentrations were significantly increased in upstream and downstream samples. See the post-monitoring section for concentrations and comparisons.

7.3 Post

Physical. A bathymetric survey was conducted to document the final topography of the river following dredging. A physical description of remaining sediments was also conducted. The water column was monitored for TSS, TOC, DOC, temperature, pH, conductivity, and turbidity.

Chemical. Two rounds of water column testing for PCBs (filtered and unfiltered) were conducted site-wide at the 13 transect locations. One sample had detected concentrations of PCBs in the first round of sampling at 0.7 μg/L. No PCBs were detected in the second round of sampling.

Sediment sampling within the excavation area was conducted two days after dredging on September 8, 1995, to document residual PCB concentrations. Results of sediment sampling for pre- and post-dredge sampling are given in Table 1. In the bioavailable zone, post dredge PCB

sediment concentrations decreased 88 percent when compared with pre-dredge 1993 maximum concentrations and decreased 86 percent when compared to 1993 average concentrations, with measured concentrations varying from non-detect to 2,200 ppm in surface sediments (ALCOA, 1999) prior to dredging.

Table 1 Pre- and Post-Dredge Sediment Sampling Results

Sampling Events	PCB Concentrations (in ppm)		
	Pre-dredge (1993)	Post-dredge (1995)	Percent Decrease (1993–1995)
All Sample Depths			
Minimum	non-detect	1.1	—
Maximum	11,000	260	99.9%
Average	1,109	75	93%
Bioavailable Zone (top foot)			
Minimum	non-detect	1.1	—
Maximum	2,200	260	88%
Average	518	75	86%

Biological. PCB bioaccumulation was tested on caged fish samples collected October 17, 1995 and November 7, 1995 from the four locations used in baseline and progress monitoring (Figure 1). Monitoring showed an increase in PCB concentrations measured in cage fish during dredging and at least one month following dredging (Table 2). PCB bioaccumulation increases were higher in downstream locations than upstream locations; however, the PCB concentrations in the upstream samples were also higher than respective baseline conditions.

Post-dredge PCB bioaccumulation samples of resident brown bullhead, smallmouth bass, and spottail shiner were collected between October 11 and October 18, 1995. PCBs were detected in resident fish from all sampling locations. Samples were collected from the same locations as the 1991 and 1993 pre-dredge sampling events. Although actual analytical data were not reviewed for baseline samples, the NTCRA Documentation Report concluded that statistically significant increases from baseline 1993 samples were shown only in spottail shiner samples from the upper stretch of the river. No significant increases were demonstrated in smallmouth bass or brown bullhead samples compared to pre-dredge samples. Results of 1995 post-dredging fillet samples for smallmouth bass and brown bullhead are presented in Table 2. While significantly elevated concentrations of PCBs were shown in downstream samples relative to the background (upstream) samples, no significant difference was shown between the three downstream regions of the river, below the dredging area.

7.4 Long Term

A benthic community assessment was scheduled to be completed in the summer of 1996. Data were not available for review and is not included in this case study.

Table 2 Caged/Resident Fish PCB Bioaccumulation in Fillet Samples (mg PCBs/kg lipid)

Testing Parameter	Stage	Baseline (Oct/Nov 1993)	During (Aug/Sept 1995)	Post (Oct/Nov 1995)
Caged Fish [1, 2]	Cage #1 (upstream, nearshore)	9.7	129	60.5
	Cage #2 (upstream, farshore)	5.2	76.2	20.4
	Cage #3 (downstream, nearshore)	110	2,736	388
	Cage #4 (downstream, farshore)	24.7	667	152
	Average Downstream Relative to Upstream	**8.0 ×**	**15 ×**	**7.0 ×**
Resident Fish [3] (Bass)	Background Stretch (upstream, above dam)	NA	NA	3.9
	Upper Stretch (downstream)	NA	NA	1,134
	Middle Stretch (downstream)	NA	NA	943
	Lower Stretch (downstream)	NA	NA	1,043
	Mouth of River	NA	NA	NA
Resident Fish [3] (Bullhead)	Background Stretch (upstream, above dam)	NA	NA	3.0
	Upper Stretch (downstream)	NA	NA	607
	Middle Stretch (downstream)	NA	NA	756
	Lower Stretch (downstream)	NA	NA	465
	Mouth of River	**NA**	**NA**	**NA**

Notes:

[1] Results presented are from 3-week sampling events.
[2] All cages were located along the perimeter of the containment system and below the dam.
[3] PCBs were detected during baseline, but apparently no significant temporal or spatial trends were observed.
NA - Data not available for review.

8 Performance Evaluation

8.1 Meet Target Objectives

Short-term Target Goals. Only 84 percent of the proposed 3,550 cubic yards of contaminated soft sediment was removed from the hotspot because of impediments from rocks and boulders and underlying glacial till. The competent glacial till acted as refusal to dredge penetration. The 8-foot horizontal augerhead could not remove all sediment under these conditions. Although the total mass of PCBs at the site was not available for review, measurements based on site-wide and hotspot sediment sampling determined that approximately 27 percent of the total PCB mass for the entire site was removed by the hotspot dredging. This was within the project goal of 25 to 30 percent mass PCB removal. Although no chemical criteria was established, the average PCB concentration in sediment decreased from 1,105 to 75 ppm (93 percent) from pre- to post-dredge samples. The dredging project was partially successful meeting the

volumetric cleanup goals and was completely successful meeting the mass reduction criteria.

Long-term Remedial Objectives. Elevated concentrations (15 times above background) were measured in caged fish during dredging activities. The 1995 post-dredge results collected one and two months after dredging demonstrated a marked decline in the average PCB concentration when compared to measurements collected during dredging, but not a significant improvement from baseline conditions. These sample results were likely influenced by residual dredging disturbance. Caged fish locations were located outside, but within 150 feet of the perimeter containment system (Figure 1). Overall, one data point showed a slight reduction in downstream tissue concentrations, relative to the reference site, when pre-dredge conditions (eight times reference) to post-dredge (seven times reference) sample results. Subsequent caged fish studies were proposed for 1996 and 1997; however, data were not available for review. Data are inconclusive

Although the largest hotspot of PCB contamination was removed from the Grasse River, resident fish show continued exposure to residual PCB-contaminated sediments remaining in the area of concern (73 percent mass remaining after hotspot dredging).

8.2 Design Components

Geophysical and diver surveys were conducted to determine site conditions as an aid for boulder removal prior to dredging. The surveys failed to supply necessary information regarding the nature of subsurface sediment and the presence of subsurface boulders. Not enough pre-planning project data were collected and the project designers did not properly respond to the information they had.

8.3 Lessons Learned

The selection of the horizontal augerhead dredge was based primarily on the ability to operate with minimal suspension of sediment. The dredge was not capable of achieving the desired sediment removal efficiency due to insufficient project planning. Contingency plans and potential modifications to project target goals should have been considered if difficult substrate conditions were anticipated.

9 Costs

The total project cost was $4.87 million, resulting in a unit cost of $1,534 per cubic yard (for 3,175 cubic yards). The cost breakdown for various aspects of the action was $675,000 for design and design support, $2,895,000 for construction, $425,000 for transportation and disposal, $575,000 for monitoring and documentation, and $300,000 for management. The costs do not include agency oversight or preparation of the EE/CA (BBL, 1995).

10 Project Contact

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11 References

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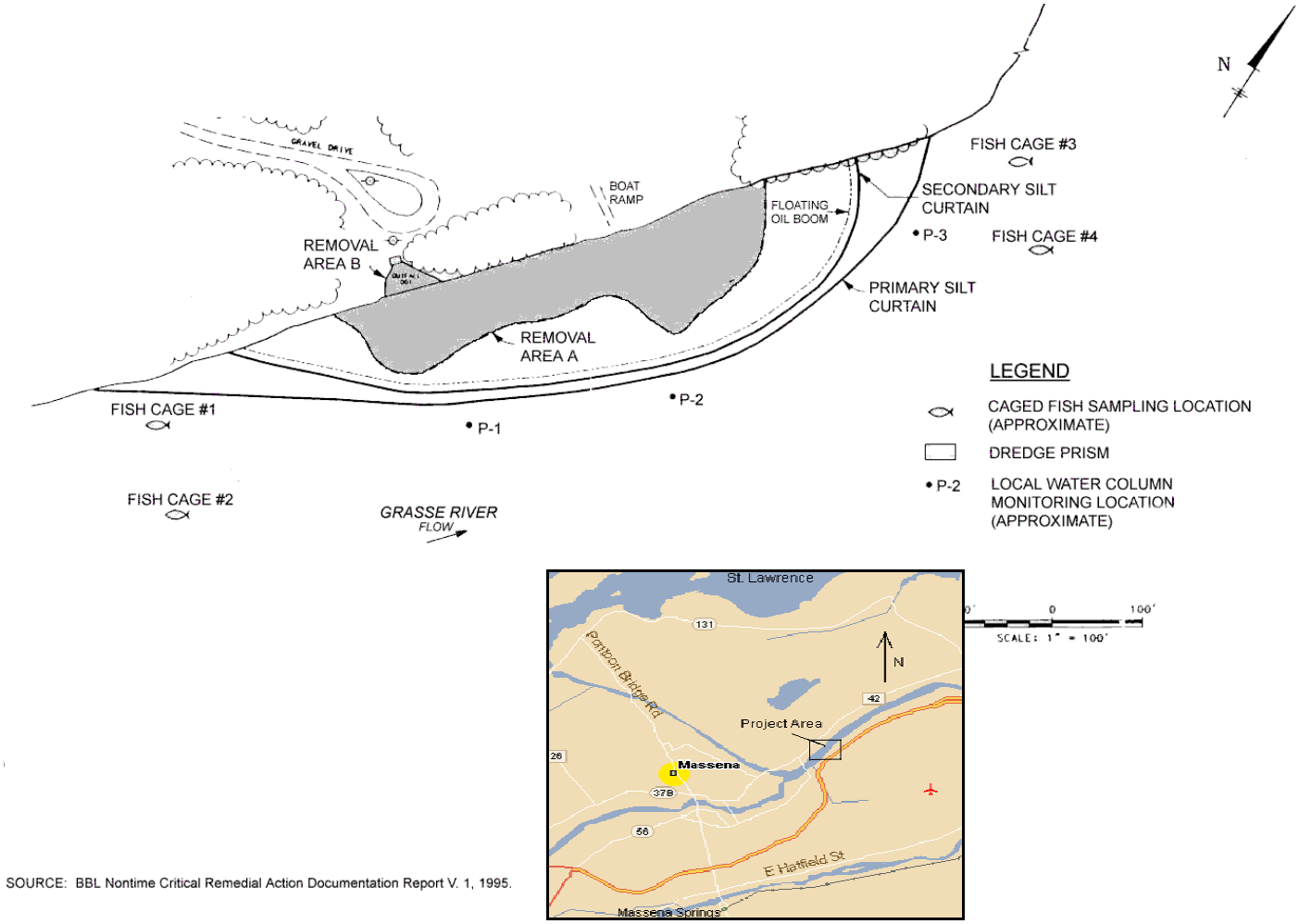
Figure 1 Remedial Dredge Plan - Grasse River



SOURCE: BBL Nontime Critical Remedial Action Documentation Report V. 1, 1995.

1 Statement of the Problem

- Dredged 1993/1994
- PCBs
- 157,000 cubic yards
- $40 per cubic yard

At the Lake Jarnsjön site on the Eman River in Sweden, the primary constituents of concern were polychlorinated biphenyls (PCBs) with a maximum detected concentration of 30.7 mg/kg dry-weight (average 5.0 mg/kg). The cleanup remedy was to dredge from 0.4 to 1.6 meters of sediments from the lake bottom and dispose of the dewatered contaminated material in a nearby landfill. Dredging took place during the fall of 1993 and the summer of 1994. The lead agency for this project was the Swedish Environmental Protection Agency (EPA).

2 Site Description

Lake Jarnsjön is a 62-acre lake located 72 miles upstream from the mouth of the Eman River in Sweden (Figure 1). Eman River is the largest watercourse in southeastern Sweden and it discharges waters into the Baltic Sea. Lake Jarnsjön is a shallow lake, with typical depths ranging from 1.8 to 2.8 meters (5 to 8 feet depth), with a maximum depth of approximately 4.5 meters (13.5 feet). The flow rate through the lake ranges from less than a few meters per second to over 100 meters per second, creating a rapid exchange rate of water volume in the lake. Lake sediments are characterized as very soft organic sediments, mixed with mineral silty sediments and scattered sand pockets (Elander and Hammar, 1998).

3 Site Investigation

In the 1980s, elevated PCBs were found in the mouth of the Eman River. Large quantities of PCBs were found in paper fibers that had accumulated in Lake Jarnsjön. The lake was pinpointed as the primary source of ongoing contaminant discharges into the river system. The PCB-contaminated sediments were contained in a layer that covered the entire 62-acre lake bottom. The thickness of this contaminated layer varied from less than 0.4 meter to as great as 2 meters of contaminated sediments. The most highly contaminated sediments were primarily located in the eastern part of the lake, with the lesser contaminated sediments located in the remainder of the lake.

View of River Eman
Source: Emåprojektet website
www.emaprojecktet.h.se/

PCBs were the primary constituent of concern in the Lake Jarnsjön remediation project, with approximately 400 kilograms present in the lake. Elevated concentrations of metals were also found at the site; however, they were not specifically addressed in this cleanup. Historical discharges have been documented upstream from Lake Jarnsjön, including waste from paper mills (PCBs, metals), a battery factory (metals) and an accumulator factory (metals). However, the primary responsible party, a paper mill

using recycled self-copying paper as raw material, caused the most extensive damage (Bremle and Larsson, 1998, Fox River Group, 1999, Gullbring *et al.*, 1998).

Remediation at Lake Jarnsjön was governed by the Swedish EPA and was part of the Swedish National Site Remedial Action Plan. The Swedish EPA was in charge of project planning and the local municipality was responsible for remedial action. A formal decision to undertake cleanup was made in 1992 (Gullbring *et al.*, 1998).

4 Target Goals and Project Objectives

The primary objective to the dredging project at Lake Jarnsjön was to protect human health and the environment. This would be done by removing contaminated sediments without harming the ecosystem. This project was a full-scale remediation project to be used as a national pilot cleanup, demonstrating that dredging was an ecologically and economically feasible cleanup option in Sweden. This project would expand knowledge about the cleanup of contaminated sediments and the decreasing PCB exposure in lakes and downstream areas.

5 Project Design

Pre-planning. Based on a pre-dredging Feasibility Study, a few options for remediation were explored. One option included capping the entire lake bottom with a clean material. This option did not seem feasible due to the already shallow nature of the water body. A second option included diversion of the Eman River via a new channel. This option was very expensive and would destroy nearby habitat. A third option, and the one chosen for implementation, was to hydraulically dredge the lake within a barrier of geotextile screens, mechanically dewater the contaminated sediments, and to dispose of them in a nearby landfill (Bremle, 1997, Bremle *et al.*, in press).

The Swedish EPA was in charge of planning remediation activities, and the local municipalities implemented the dredge plan and monitoring. A time schedule and cost estimate was agreed upon and was continually revised as the project progressed. The cost estimate was based upon unit costs and quantities (time and materials method) and performance-based environmental dredging criteria. The entirety of the cleanup was carried out within the agreed time frame and cost estimate.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. Dredging was scheduled from May to November of 1993, and during the summer of 1994. These months were chosen for the low water discharge at this time of year.

Equipment. A hydraulic dredge with an auger head was used to dredge Lake Jarnsjön. The dredge was specially designed with an advanced positioning system to work with high precision and in turn reduce the

amount of suspended sediments. In areas of denser, more coarse sediments, a bucket dredge was utilized. Geotextile screens (silt curtains) were used in the highly contaminated eastern portion of the lake to reduce spread of suspended solids. The screens were kept in place in the eastern portion of the lake until August of 1994 and were not utilized in the western portion of the lake.

Total Volume Removed and Production Rates. During 1993, the highly contaminated eastern area of the lake was dredged. One to four layers of sediments were removed in 0.4-meter-thick dredge lifts to a depth of 1.6 meters in some locations (approximately one-third of the lake surface area). Geotextile screens were used to localize turbidity and confine suspended solids to the eastern portion of the lake (Figure 1). In 1994, in the lesser contaminated western area of the lake was dredged. Only one layer of sediments was removed in a 0.4-meter-thick dredge lift. The geotextile curtain was removed during dredging of this western area due to low percent solids suspended during dredging. By the completion of the project in 1994, 157,000 cubic yards of contaminated sediments were removed. An additional 39,000 cubic yards of sediment were removed as "overdredge" material, pushing the total sediments removed to 196,000 cubic yards. Within this dredge volume, a total of 394 kg PCBs were removed from the lake. This equated to approximately 99 percent of total PCBs in the lake. Of the approximate 2.9 kg PCBs which remained in the lake after dredging, nearly all the contaminants were located near the lake shores, in areas which were not included in the remediation plan (Bremle and Larsson, 1998; Gullbring *et al.*, 1998).

Site-specific Difficulties. The auger dredge used for cleanup was specifically designed for the soft sediments of the lake. However, in the southern area of the lake, sediments were dominated by dense sand and gravel, and could not be cut by the dredger. In some instances these sediments had to be removed with a bucket dredge. In other instances, the sandy layers could be dredged by suction auger, but required the addition of more water to the sediments, consequently increasing the load at the dewatering plant (Elander and Hammar, 1998).

In order to reduce the risk to aquatic life in the lake, dredging was halted during the winter months, from December to April.

6.2 Dewatering and Water Treatment Operations

Dewatering, Treatment and Disposal. Mechanical dewatering was carried out on the dredged sediments from Lake Jarnsjön. In consideration of landfill stability, the dry solids requirement for dewatering was 35 percent. The dry sediment was disposed of in a landfill. One difficulty with this requirement was that with the filter presses used for dewatering, as they could not achieve 35 percent solids with the quantity of fine-grain fraction of sediments from the lake. Instead, the fine fraction had to be remixed with sand and then dewatered again. Water was treated by flocculation chemicals to settle suspended solids and PCBs before the water was returned to the lake (Gullbring *et al.*, 1998).

Water Quality Monitoring of Discharge. After dewatering, water returned to Lake Jarnsjön was not allowed to exceed more than 50 mg/L suspended matter. This equated to approximately 2 kg of PCBs being allowed to return to the lake during the dredge project (Bremle *et al.*, 1995).

6.3 Storage and Disposal

After dewatering, the residuals were deposited in a nearby landfill. The highest contaminated sediments were placed at the bottom of the landfill, on top of a geotextile liner and with the more contaminated sediments on the bottom. These different layers of contamination were separated by a geotextile screen so that in the future, it would be easier to remove specific sediments if better remedial technologies became available. The landfill was covered with a 1.2-meter layer of uncontaminated sand and gravel, and then the entire landfill was covered with uncontaminated soil and restored to pastureland (Gullbring *et al.*, 1998).

7 Environmental Monitoring Program

The monitoring program included water column sampling, surface sediment sampling, air monitoring, and caged and netted fish tissue analysis (Bremle, 1997; Bremle and Ewald, 1995; Bremle *et al.*, 1995; Bremle *et al.*, 1998; Bremle and Larsson, manuscript 11; Bremle and Larsson, in press-a; Bremle and Larsson, in press-b; Engwall, *et al.*, 1998, Forlin and Norrgren, 1998; Gullbring *et al.*, 1998).

7.1 Baseline

Physical. Turbidity and total suspended solids (TSS) were measured prior to dredging. TSS were measured both upstream and downstream of the lake.

Bathymetry surveys were also conducted in the summer and autumn of 1991.

Chemical. In 1990, the lake was divided into 12 operable units and studied for sediment PCB values. In each unit, five to nine cores were collected by core sampler from 0 to 0.4 meter depth. All cores were collected with a core sampler, composited within each unit, and analyzed for a composited average value for the area. The overall average PCB values ranged from 0.4 to 30.7 mg/kg dry-weight, with an average of 5.0 mg/kg.

PCB concentrations in water were measured in Lake Jarnsjön during the summer and autumn of 1991 at five locations (two upstream, one in the lake, and two downstream). The methodology for collection included pumping approximately 100 liters of river water through polyurethane columns (PUCs) at a flow rate of 10 ml per minute. Samples were frozen until analysis. The average value of PCBs in the waters of and around Lake Jarnsjön in 1991 was 8.6 ng/L, with PCB values declining with distance from the upstream paper mill source.

Biological. Netted fish studies were conducted in 1991 to look at PCB concentrations in adult fish. Perch were caught by netting at five locations, as close to the water sampling stations as possible. At each location, five male and five female one-year-old perch were caught. Whole fish were weighed, pulverized, and frozen for PCB analysis. The average value of PCBs in the fish in Lake Jarnsjön in 1991 was 34 mg/kg.

A 1991 caged fish study, using perch and trout, determined a baseline value at various locations upstream, in and downstream from Lake Jarnsjön. Liver Somatic Index (LSI), ethoxyresorufin-O-deethylase (EROD) activity, plasma parameters, and histopathological characteristics were all analyzed. The results for 1991 showed no significant differences between different locations.

7.2 Implementation During Dredging

Physical. Turbidity and TSS were measured on a regular basis during dredging as a control instrument for dredging activities. TSS were measured both upstream and downstream of the lake, in the discharge and dewatering zone, and within the protective dredging screens. At each location, two samples were taken per each shift by the contractor. Additionally, weekly monitoring was conducted immediately above the lake, 10 kilometers below the lake, and 80 kilometers below the lake. Results showed that the dredge equipment worked well and the overflow was less than 0.5 percent. Turbidity measurements were taken to daily to supplement TSS data.

Chemical. PCB concentrations in water were measured weekly from 1993 to 1995. The range of PCB values during the period of 1993 to 1995 was 1.7 to 30.2 nanograms per liter (ng/L), with an average of 7.8 mg/L. No significant changes were observed during dredging when compared to baseline water column concentrations.

PCBs were measured for air quality during dredging and disposal in the landfill. Eleven stations were located between 5 and 1,000 kilometers from the disposal site and at one reference station located 12 kilometers from the disposal facility. For each sample, 1,000 cubic meters of air was pumped through PUC columns at a flow rate of 40 liters per minute. Samples were frozen until analysis. Although air quality was elevated from background at 2.5 ng per cubic meter during dredge activities, it was still within an acceptable range of national average metropolitan background volumes in Sweden. After remediation was completed, PCB air quality returned to normal background levels.

Biological. In 1993 and 1994, caged fish studies were repeated upstream, downstream and in Lake Jarnsjön. The results showed reduction in the LSI value, elevation in EROD activity, similar histopathological lesions, and reduced plasma electrolytes as compared to the 1991 data.

7.3 Post

Physical. TSS was measured at 10-week intervals from the end of dredging until 1996. Sampling locations included two stations upstream of the lake, one station at the outlet of the lake, and two stations downstream of the lake. The results were not presented in the given documentation.

Chemical. In 1996, 54 areas were studied for sediment PCB concentrations in Lake Jarnsjön. In each area, five surface cores were collected from 0 to 0.2 meters depth. All cores were collected with a core sampler, composited at each location, and analyzed to give an average value for each area. The average PCB concentrations ranged from 0.01 to 0.85 mg/kg dry-weight, with an overall average of 0.06 mg/kg. This was a 97 percent decrease in maximum concentration and 99 percent decrease in the average from the 1991 results.

PCB values in water continued to be measured weekly from May 1995 to 1996 at locations in and below the lake. The range of PCB concentrations during the period of 1995 to 1996 was 0.4 to 8.2 ng/L, with an average of 2.7 ng/L. This was a 30 percent decrease from the 1991 data.

In the PCB sediment and water studies monitored for two years after completion of dredging, contaminant concentrations decreased over time from values recorded prior to and during dredging. Besides the overall decrease in PCB values, a seasonal variation was noted. The highest PCB values were recorded during the lowest discharge months (i.e., summer) and the lowest PCB values were recorded during the highest discharge months (i.e., winter). This effect has been contributed to a dilution factor, with high discharges diluting PCB values during the winter months and emphasizing values in the summer (Bremle *et al.*, manuscript 3).

Eight groundwater wells and six drinking water wells within the vicinity of the disposal site were tested for PCBs through 1997. The median PCB concentration was found to be 0.5 ng/L in the groundwater and drinking water over time.

Biological. Following the methods of the 1991 netted fish study, perch were caught in 1996 by netting at four locations, as close to the water sampling stations as possible. At each location, five male and five female one-year-old perch were caught. Whole fish were weighed, pulverized, and frozen until analysis. The average value of PCBs in the fish in Lake Jarnsjön in 1996 was 16 mg/kg. This was a nearly 53 percent decrease from the 1991 results.

In 1996, caged fish studies were repeated. Compared to results from the previous years, the LSI was reduced, but the EROD was elevated. The decrease in the LSI was probably due to reduction of available food supplies or changes in metabolism before and during dredging causing depletion in energy reserves. Conversely, the EROD activity is one of the most sensitive biomarkers and results showed that in 1996, even with the

decrease in PCBs in sediments and water, caged fish continued to indicate effects from PCB exposure.

7.4 Long Term

No long-term studies were documented in the reports.

Table 1 Summary of Monitoring Results

Testing Parameters	Monitoring Periods (average PCB values in mg/kg dry-weight)			
	Baseline (1990/1991)	Progress (1993/1994)	Post (1996)	Percent Change (1991–1996)
PCBs in Sediment	5.0 mg/kg (max = 50 mg/kg)	—	0.06 mg/kg (max = 0.85 mg/kg)	99% reduction
PCBs in Water	8.6 ng/L	7.8 ng/L	2.7 ng/L	30% reduction
Netted Fish [1]	34 mg/kg	—	16 mg/kg	53% reduction
Caged Fish [2]	no differences between sites	NA	NA	
Air Quality	—	2.5 ng/L	—	
Groundwater	—	—	0.5 ng/L	
EROD (caged fish)	NA	Values not available; elevated levels	Values not available; reduction noted	
LSI (caged fish)	NA	Values not available; reduced levels	Values not available; reduction noted	

Notes:

[2] Caged fish collected in 1991; data not available.

[1] Netted fish co-located with surface water sampling stations, concentrations based on extractable fat.

NA - Data not available for review.

8 Performance Evaluation

8.1 Meet Target Goals and Project Objectives

Although not specified as a target goal, remedial dredging at Lake Jarnsjön was able to remove 99 percent of PCB contaminated sediment from the site. From data collected during the two years post-dredging, results show a decline in PCBs in the sediments, lake water, and in fish. As the remedial action primary objective of the cleanup was to protect human health and the environment, it can be concluded that Lake Jarnsjön succeed in its project objectives. In supplement to these findings, one of the review authors noted that changes in background exposure over time need to be taken into account when evaluating the success of remedial actions.

From the results of this cleanup, Lake Jarnsjön can be considered a successful remedial action project, fulfilling the secondary objective of the cleanup: to expand knowledge and provide an example for future Swedish cleanup actions.

8.2 Design Components

Little was documented about the design components of the Lake Jarnsjön cleanup. One success in the planning of the project is that the project was financed as a "time and materials" method of remediation rather than a "lump sum" method. This allowed for a more thorough cleanup process.

8.3 Lessons Learned

A better understanding of bottom sediments may have prepared dredge planners for more technologically-suited dredge equipment. Dense, coarse-grained sediment challenged the dredging equipment (equipment selected for the fine-grained material) resulting in some project delays and increased costs. These delays and extra costs may have been avoided if properly anticipated.

9 Costs

The estimated costs for planning the remediation at Lake Jarnsjön from spring of 1990 through the detailed planning phase in 1992 was approximately $770,000 US. Total remediation costs are estimated to be approximately $6.4 million US. This equates to an approximate cost of $40 per cubic yard.

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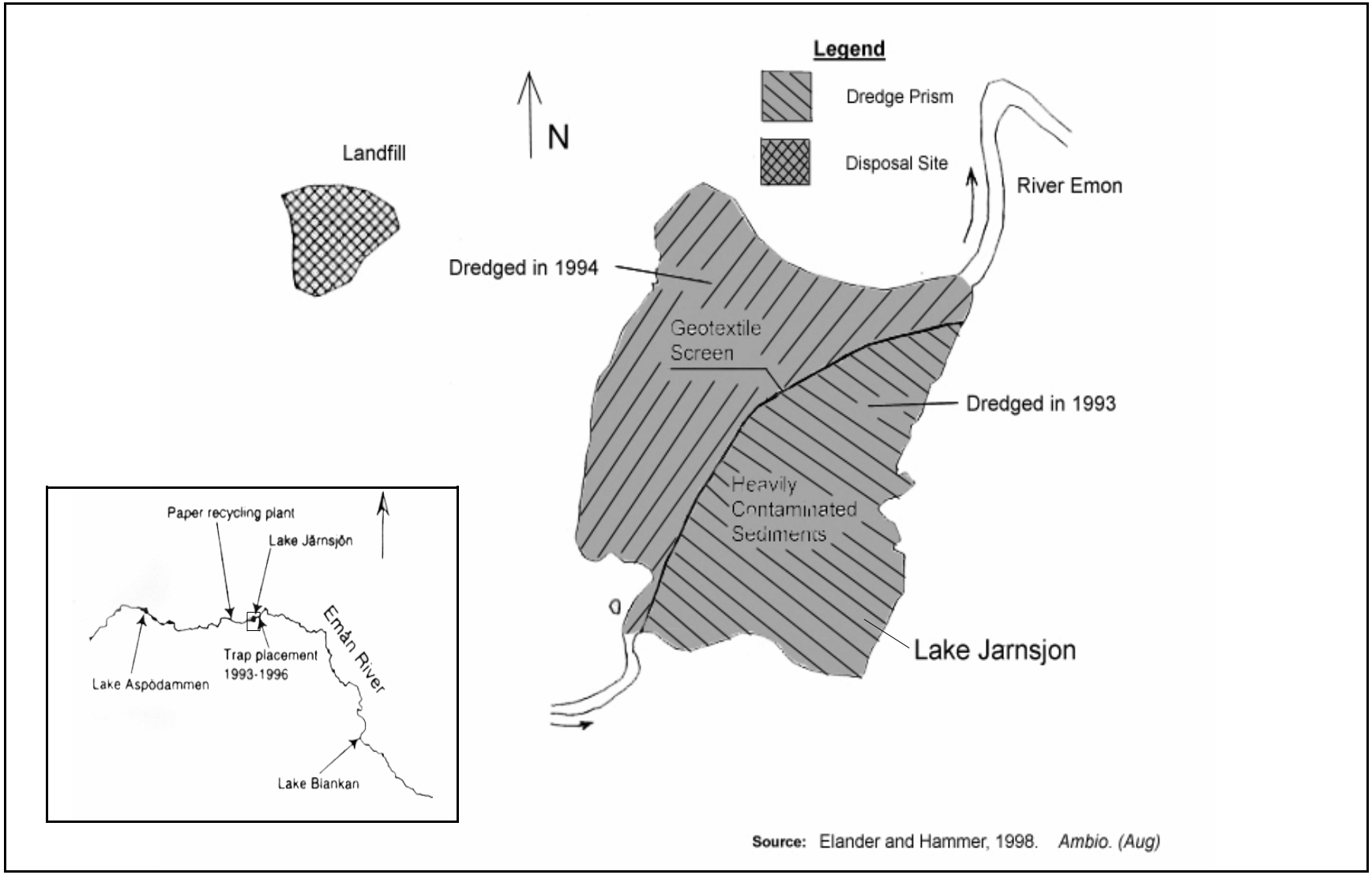
Figure 1 Remedial Dredge Plan - Lake Jarnsjön



Source: Elander and Hammer, 1998. *Ambio. (Aug)*

1 Statement of the Problem

- Dredged 1995-2000
- PCBs
- 120,000 cubic yards
- $300 per cubic yard

At Manistique River and Harbor superfund site in Michigan, the primary constituents of concern were polychlorinated biphenyls (PCBs). The cleanup remedy was dredging of three hotspots within the river and harbor. The cleanup goal was 95 percent removal of sediments contaminated with greater than 10 ppm PCBs (Blasland, 1999). Dredging began in 1995 and PRPs executed a buy-out in 1996 (Blasland, 1999). The lead agency for this project was U.S. Environmental Protection Agency (EPA) Region 5.

2 Site Description

The Manistique River and Harbor is located in the city of Manistique, on the southern shores of Michigan's Upper Peninsula. The project area is bounded to the east and west by the banks of the Manistique River, to the north by the Manistique Dam, and to the south by the outer boundaries of Manistique Harbor in Lake Michigan. Average water depth within the harbor is 18 to 20 feet, with average river depth ranging from 15 to 20 feet. The harbor is subject to sieche and storm-induced weather from Lake Michigan, especially in the winter months. The average sedimentation rate throughout the site is approximately 1.5 inches per year. The area of concern extends 1.7 miles downstream from the Manistique Dam, and includes both riverine and harbor sediments. The site is primarily used for recreational boating and fishing within the harbor, and for industrial and commercial use within the river.

3 Site Investigation

The Manistique site is composed of several nearshore and backwater hotspots, as well as an approximately 15-acre hotspot within the 97-acre harbor. PCBs are the primary constituents of concern, with approximately 14,000 pounds present in the river and harbor sediments (Blasland, 1999; EPA, 1995a; EPA, 1995b). Historical discharges have been documented upstream from Manistique Harbor, including waste from sawmills, a paper mill, industrial plants, a wastewater treatment plant, and navigation for shipping lumber. Wastes include paper, wood, and various industrial chemicals, with large quantities of sawdust and wood chips remaining in waters through time (Blasland, 1999; Garbaciak and Averett, 1999; GE/AEM/BBL, 1993).

Manistique Dredging
Source: B. Paulson, WDNR

In June 1995, an action memo was signed authorizing time-critical dredging removal of PCB-contaminated sediments at Area B. In October 1995, an action memo was signed authorizing capping of Areas C and D. After successful demonstration of dredging in Area B during the

summer 1995, EPA Region V proposed dredging Areas C and D to the local public and PRPs. In December 1995, the public and PRPs supported the modification from capping to dredging and a revised action memo was signed on September 10, 1996.

In 1996, EPA issued a Removal Action Recommendation and Action Memorandum in lieu of a ROD, and the site is regulated by CERCLA (Interagency Review Team, 1995). Applicable or relevant and appropriate requirements (ARARs) complied with included: TSCA, CWA, Fish and Wildlife Coordination Act, Endangered Species Act, State of Michigan ARARs, Environmental Response Action, Water Resource Act, Great Lakes Submerged Lands Act, Soil Erosion and Sedimentation Control Act, Solid Waste Management Act, Air Pollution Act, Goemaere-Anderson Wetland Act, Inland Lakes and Streams Act, and Shoreline Protection and Management Act (Interagency Review Team, 1995; Hahnenberg, 2000).

Target sediment cleanup standards (TSCSs) were generated by calculating fish target levels and a bioaccumulation model (BASF) biota to a sediment accumulation factor. From this model a TSCS was established for PCBs at an accumulation level of 10 mg/kg (Interagency Review Team, 1995). In addition to establishing a protective action level, health advisory signs and fish advisories on carp were put into effect for local residents.

4 Target Goals and Project Objectives

The primary objective of the dredging project at Manistique was the long-term protection of Lake Michigan. A secondary objective was to reduce health risks to humans and wildlife consuming fish from the Manistique River and Harbor. By using the 10 mg/kg action level determined by the BASF model, the goal of the Manistique dredging was to remove all PCBs above this action level, based on a 95 percent removal of contaminated sediments (Interagency Review Team, 1995).

5 Project Design

Pre-planning and Bid Documents. EPA's position on sediment removal at Manistique has changed over the span of this project. When dredging was being planned in 1994, erosion-prone areas were to be dredged to the 10 mg/kg PCB action level. Other locations having 10 to 50 mg/kg PCBs were to be capped. In 1995, an interagency review team concluded that dredging alone has a much longer-term performance record than capping and therefore all sediments above the 10 mg/kg action level were to be dredged (Interagency Review Team, 1995). The capping remedy was removed altogether from the cleanup plan.

Superior Special Services was the primary contractor for the Manistique dredging project. Environmental Quality Management provided oversight contracting. Costs were calculated on a "time and materials" method and performance-based criteria. No dredge design engineering was done; however, the contractor was given adaptive management flexibility. Three hotspots were targeted for dredging: a dead-end lagoonal hotspot (Area

B), a nearshore river hotspot (Area C), and a 15-acre hotspot in Manistique Harbor (Area D). Once hotspots were removed, the entire target area was anticipated to meet target PCB concentrations.

Summary of the Remedial Action Plan. The remedial project design at Manistique River and Harbor was a full-scale dredging project for the long-term protection of Lake Michigan. The operation included mechanical dredging, on-site treatment, and off-site disposal. A sheetpile cutoff wall, silt curtains and a floating boom were installed midway through the dredging to limit spread of contaminants.

Limitations and Permits. Because EPA was managing this dredging project, there were no specific permits required for cleanup. However, the site did need to comply with Surface Water Discharge restrictions, and later, the U.S. Army Corps of Engineers Dredging Permit Process. Dredging was limited to the non-winter months, from approximately April to October, and was dependent on weather conditions and partial freezing of water bodies.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. The Manistique dredge plan was implemented in 1995 and is continuing into 2000. Dredging is being completed in 2000. Dredging occurred during three months in 1995, six months in 1996 and 1997, five months in 1998, and has just been completed for the 1999 year. In 1997, a temporary HDPE cover, originally placed in 1993 over contaminated sediments in Area C, was removed prior to dredging.

Equipment. Dredging was completed by several sizes of hydraulic dredges, depending upon site conditions. Equipment included a custom hydraulic dredge with twin suction pumps and a modified head (some diver assistance), a diver-assisted hydraulic dredge with hose/pump, a diver-assisted vacuum removal hydraulic auger dredge, and a hydraulic cutterhead dredge with a 10-inch hoseline, pump and twin suction pumps added later. Site conditions dictated which equipment was best suited for removal operations (i.e., the slab-wood encountered at depth required diver assistance for removal). The variety in dredge equipment used over the years was based on knowledge gained the previous years and adopting adaptive management to improve dredge performance. To limit the spread of contaminants, a plastic sheetpile steel cutoff wall, with silt curtains and floating booms, was installed midway through the dredging removal portion of the Area B project. A plastic sheetpile was constructed instead of steel wall to alleviate concerns about fracturing the bedrock and disturbing bridge pilings.

Total Volume Removed and Production Rates. The total volume removed from Areas B, C, and D at the end of 1998 was estimated at 120,000 cubic yards of contaminated sediments, based on the proposed *in-situ* dredge prism (Zweibel, 2000). It was difficult to estimate the total *in-situ* volume removed through 1999 due to the necessity of redredging

areas to remove residual contaminated material. However, the *ex-situ* volumes removed in 1998 were estimated to be 22,000 cubic yards and in 1999 were estimated to be 25,000 cubic yards (Hahnenberg, 2000). This difficulty of comparing *in-situ* and *ex-situ* dredge volumes accounts for the discrepancy between reports of dredged sediments and final volumes disposed.

Manistique Dredging
Source: EPA

Through the course of the project and weather permitting, the dredging schedule of seven days per week, and six hours per day was typically achieved.

Site-specific Difficulties. On-site constraints included slowdowns due to wood and debris in the dredging areas, wind-driven waves causing extensive downtime, dredge production rates exceeding land-based handling and water treatment capacity, and rough weather causing shutdowns due to disruption of barge spuds. As well, it was impossible to overdredge due to contamination extending down to bedrock. Thus 100 percent removal of contaminated sediments was not possible by an overdredging technique, and areas had to be redredged multiple times, over multiple years. The EPA plans to use a diver-assisted vacuum removal in the spring of 2000 to remove residuals which have settled on the bedrock (Hahnenberg, 2000).

6.2 Dewatering and Water Treatment Operations

Dewatering, Treatment and Disposal. Prior to 1997, dredge material was pumped directly to an onshore treatment facility. Beginning in 1997, dredge material was pumped onto a barge and then transported to the onshore treatment facility. Following the removal of dredged material, sediment was sieved through a coarse screen, a vibrating screen, and then a rotary screen to remove large material. Remaining sediments were then sent to a FRAC tank for gravity settling. In 1996, hydrocyclones were added and material was then directed into four settling basins and a belt filter press. All waste and water treatment was done on-site (Blasland, 1999).

Water was treated through a dual-media filter (sand and coal), and then passed through activated carbon. All treated water met the 0.5 ppb PCB criteria and was then returned to Manistique Harbor.

6.3 Storage and Disposal

The majority of contaminated sediments dredged at the Manistique site have been disposed of in off-site landfills. In 1995, sediments containing less than 50 ppm PCBs (97 percent of sediments) were sent to a RCRA Subtitle D landfill (non-TSCA). Those sediments above 50 ppm (3 percent) were sent to an in-state TSCA landfill. From 1996, approximately 70 percent of sediments (less than 50 ppm) were sent to in-state commercial Subtitle D landfills, and approximately 30 percent (greater than 50 ppm) were sent to an in-state TSCA landfill (EPA, 1999).

7 Environmental Monitoring Program

The environmental monitoring program included bathymetric surveys, side-scan sonar surveys, sediment cores, caged fish tissue analysis, and sediment traps (BBL, 1998).

7.1 Baseline

Physical. Prior to dredging, bathymetry was collected by U.S. Army Corps of Engineers. Data were collected via sediment cores in 1993, 1997, and 1998, and caged fish studies in 1995 and 1998. Bathymetric and side-scan sonar bottom surveys were also conducted in 1998 to develop a picture of bottom sediments as dredging progressed.

In 1993, EPA installed a temporary sediment cap in the Manistique River (approximately 100' x 240') in water depths between 5 and 25 feet deep. The mat fabric was a 40-mil, high-density polyethylene (HDPE) plastic liner, anchored around the perimeter with concrete traffic-style barricades and attached to the mat by braided steel cables. The temporary cover was placed in an upstream area (between turning basin and Route 2 overpass) over sediments exceeding 124 ppm PCBs. A 1994 underwater diver inspection of the sediment cap revealed recent sedimentation up to six inches thick on the mat. The divers noted several areas where the fabric mat was deformed, stretched taut, or had lifted off the bottom from venting gas bubbles (Lopata, 1994). Sediment samples collected over the plastic cap contained <10 mg/kg PCBs in all 10 samples (and below 1 mg/kg in nine samples).

Chemical. Sediment cores collected in 1993 were used to assess PCB distribution in Manistique Harbor sediments.

Biological. A caged fish study was conducted in 1995 to provide a pre-dredge baseline. Four fish cages were deployed within the Harbor area and fish were analyzed for PCBs and TOC. The results from the sediment cores and the caged fish study were later paired to calculate a site-specific estimate of bioaccumulation factor (BASF), which was then used to establish the TSCS and the 10 mg/kg PCB action level.

7.2 Implementation During Dredging

Physical. In tracking mudline elevation at the Manistique site, bathymetric monitoring was done using standard bathymetric survey techniques. Side-scan sonar was also used to characterize the Harbor bottom and to determine if dredging has increased potential for exposure to PCBs by creating additional bottom topography. Both the bathymetric and the side-scan sonar surveys were conducted in 1998, after dredging had been completed for the season. Other ancillary data were collected at that time to provide on-site environmental conditions, and included available flow, meteorological, and lake level data for the sampling period.

Chemical. Chemical monitoring at Manistique included downstream water quality samples (1997 and 1998), sediment cores (1997 and 1998), and sediment trap studies (1998). Sediment PCB concentrations were

reported on a dry-weight basis and all fish PCB concentrations were reported on a wet-weight basis.

During dredging, water quality was monitored by turbidity monitoring. When spikes were observed in the turbidity monitoring, water samples were collected and analyzed. Locations for water quality monitoring included samples taken immediately downstream from the dredge area, approximately 100 to 150 feet downstream from the dredge area, and within the dredge area.

Sediment cores were collected by divers at five locations in Area B and 24 locations in the Harbor (the same locations for both the 1997 and 1998 studies). At each location, cores were driven to refusal, depth was measured, cores were segmented and analyzed for PCB and TOC. In Area B, two of five cores exceeded the target limit of 10 mg/kg PCBs. In the Harbor (Area D), 50 percent of the sample cores exceeded the target limit (Blasland, 1999).

Four sediment traps were deployed by divers downstream of each dredge prism and at the downward most extreme of project area. Each trap contained 16 Lexan tubes to collect settling particulate matter. The sediment traps were deployed during the winter months, when dredging was not in progress and after silt curtains had been removed for the season. All samples were analyzed for PCBs and TOC. Most sample results had PCB concentrations below 2 ppm, with the exception of three samples which ranged from 9 ppm to 84 ppm. These samples exceeding criteria of 10 ppm were from locations immediately below Area B and below the entire dredge area (Blasland, 1999).

Biological. In 1998, caged fish were deployed and suspended at three locations downstream of dredging activities in Area B and the harbor, and in one location upstream of dredging (used for background). Each cage was stocked with 30 juvenile fish, deployed by divers, and checked midpoint in each exposure period for mortality and proper positioning within the water column. After completion of the exposure period, whole fish composites were analyzed for PCB and lipid analysis. Results of this study showed that PCB levels remained higher than background levels, however there was no statistically significant difference between the 1995 data and the 1998 data (Blasland, 1999).

7.3 Post

Since dredging activities at the Manistique site lasted from 1995 to present, post-monitoring for the entire project has not yet taken place. However, progress monitoring occurred every year at the end of each dredging season (approximately October). Post-verification sampling was done after each dredging season, and if exceedances were found, the area was marked for redredging. Eventually, post-dredge sampling data should be replaced with the data collected during year 2000.

As of 1998, cleanup in Area B was labeled as complete. Thirty-five cores were collected and analyzed for PCB concentrations. Twenty-six of the

30 samples showed no detectible PCB concentrations. Overall, sampling showed a 40-fold reduction compared to pre-dredge concentrations (Blasland and Lee, 1998; Blasland, 1999; Hahnenberg, 1998).

7.4 Long Term

As of March 30, 1999, a long-term monitoring plan for the Manistique site has not yet been developed. According to the EPA, one should be in place by the finish of the dredging project in 1999.

Table 1 Summary of Monitoring Results

Testing Parameters	Monitoring Periods (ppm PCBs)		
	Baseline 1993/1995	Progress 1995–1999	Post 1999/2000
Bathymetry	collected	collected	NA
Side-scan Sonar	not collected	collected	NA
Sediment Cores	non-detect to 90 ppm (1993)	0.34 ppm to 65 ppm (1997) 0.14 ppm to 4,200 ppm (1998 - Area D)	non-detect to 1,300 ppm (1998 - Area B)
Caged Fish	0.25 ppm to 10 ppm (1995)	non-detect to 28 ppm (1998)	NA
Sediment Traps	not collected	<2 ppm to 84 ppm (1998)	NA
Water Quality (surface water samples)	NA triggered by TSS		

NA = not available for review

8 Performance Evaluation

8.1 Meet Target Objectives

The target goal for the Manistique cleanup was to remove 95 percent of sediments contaminated with 10 ppm or greater PCB concentrations. As the project is still being completed, a final evaluation is not yet possible for all three dredge areas. Dredging in Area B was completed in 1998 and shows the volume goal removal of all contaminated sediments above 10 ppm PCBs was met. However, it has not been possible to verify that the target volume of 95 percent mass removal was met in Area B.

8.2 Design Components

Implementation of the dredging project was compromised by an incomplete site characterization prior to starting dredging activities. Design components were constructed from sediment cores that supposedly hit refusal when the cores actually hit buried wood and debris, and not bedrock. The dredging equipment was selected based on this

premise. The difficulty of dredging wood, sawdust, rock, and gravel, was not fully considered when estimating the cleanup effort. Due to site conditions, most dredged areas were not initially cleaned up to meet target objectives and subsequently needed to be redredged, sometimes multiple times. Overdredging was not an option because contamination extended down to bedrock.

In addition, volumes were miscalculated prior to dredging. This occurred when some cores were driven into slab wood rather than to bedrock (Zweibel, 2000). From these incorrect depth estimates, a more conservative contaminated sediment volume was estimated than was later discovered. To create a further discrepancy between original volume estimates and actual volume of contaminated sediments, it was originally assumed that the bulk of contamination was limited to the sawdust and wood chip waste in the river and harbor. It was later discovered, in the midst of the dredging project, that the sediments were equally contaminated and also needed to be removed. These greater actual dredge volumes increased both the time and money required to reach cleanup goals.

One positive component to the dredge program was the flexibility given to the dredge contractors. Because the clean-up was controlled by an "environmental dredging" mind-set, the dredge program was periodically revised and more efficient techniques and equipment were adapted into the cleanup plan over time.

8.3 Lessons Learned

In conclusion, a better understanding of site conditions, as well as a more thought-out dredge plan, would have allowed for a timelier and less costly site cleanup.

9 Costs

Through the end of 1999, a total of $36 million has been spent on dredge and disposal activities at the Manistique site ($300 per cubic yard). Approximately $3.9 million was spent in 1995, approximately $3.8 million was spent in 1996, and approximately $7.8 million was spent in 1997. Approximately $9.5 million was spent in 1998, and an additional $11 million was spent in 1999 (Hahnenberg, 2000).

10 Project Contact

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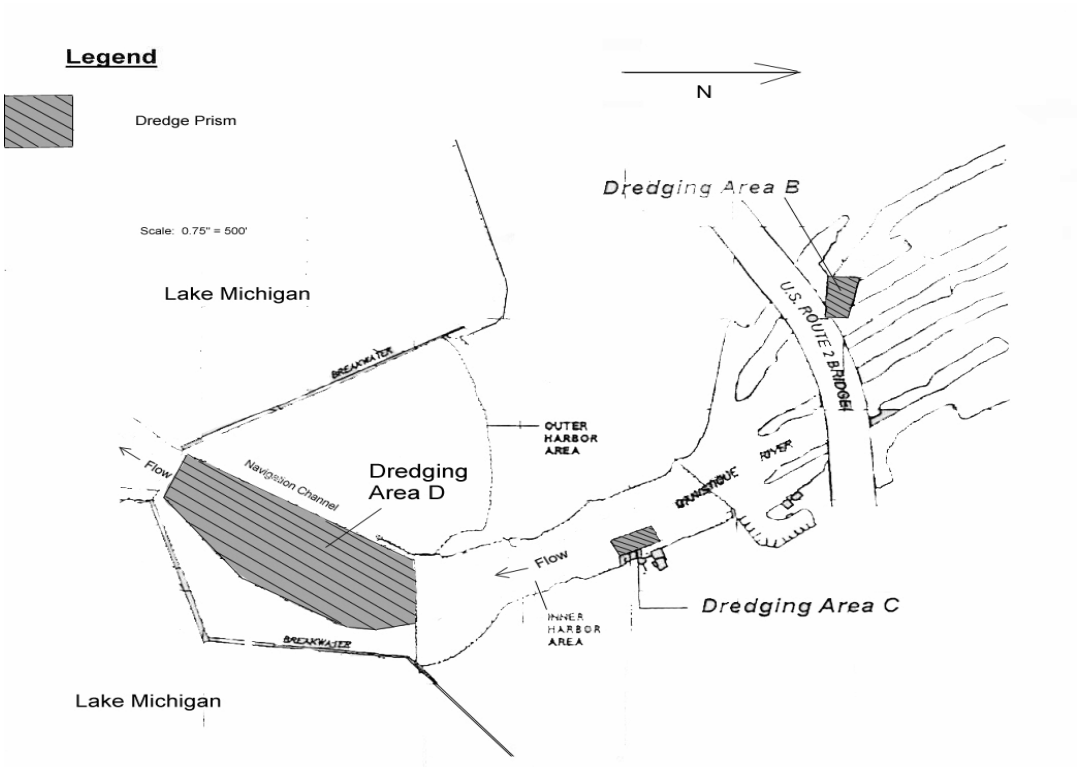
NOTE: Following several opportunities for EPA Region 5 to review the draft version of the Sediment Technology Memo and individual case studies, EPA requested the following statement be added to the Manistique discussion: "U.S. EPA Region 5 Superfund Emergency Response Branch has not reviewed nor approved information in this report. Preliminary production estimates indicate that a total of 178,708 cubic yards of contaminated sediments, containing 27,444 pounds of PCBs have been removed from the site. Once the final QA/QC evaluations have been completed, results will be included in the Administrative Record, and considered in any pending cleanup determination for the Lower Fox River and Green Bay Site."

Figure 1 Remedial Dredge Plan - Manistique River and Harbor



Source: Blasland, B. L., Inc., 1999. Field Study, tech. report

1 Statement of the Problem

- Dredged 1993-1995
- Metals
- 100,200 cubic yards
- $142 per cubic yard

The Marathon Battery Superfund site was contaminated with metals, primarily cadmium and nickel, from wastewater discharges of manufacturing nickel-cadmium batteries with maximum detected concentrations of 171,000 ppm and 156,000 ppm, respectively. Established target sediment cleanup standards for human and ecological protection were revised over time to focus on a depth removal of one foot with no final concentration level objective. Remedial methods consisted of dredging, dewatering and fixation on site, followed by transportation to an off-site sanitary landfill. The lead agency for the project was U.S. Environmental Protection Agency (EPA) Region 2.

2 Site Description

The Marathon Battery Superfund site is located on the Hudson River near the city of Cold Springs, New York (Figure 1). The site includes a former nickel-cadmium battery plant (in operation from 1952 to 1979), the city of Cold Springs pier, and a series of backwater areas known as Foundry Cove and Constitution Marsh. Foundry Cove consists of East and West Foundry Coves. East Foundry Cove consists of approximately 20 hectares, of which 5 hectares is marsh and 15 hectares tidal flat and cove. Constitution Marsh is connected to Foundry Cove by a channel system with a 117-hectare Audubon Society sanctuary to the south. The residential and business district of Cold Springs is located to the north.

Marathon Battery
Source: EPA

Water depths in the vicinity of the Cold Springs pier range from 0 to about 18 feet. The water circulation between Foundry Cove and the Hudson River is influenced by a tide of 3 to 4.5 feet, exposing a large portion of the East Foundry Cove at low tide. Shallow water depths in the Cove facilitate aquatic plant growth in 30 percent of the cove bottom. Loose unconsolidated sediments of silty clay 1 foot or less in thickness overlay a hard impermeable clay-like material. Shallow groundwater flows toward Foundry Cove and the Hudson River.

3 Site Investigation

Prior to 1965, the battery plant's wastewater system discharged directly into the Hudson River at the Cold Springs pier through the municipal sewer system. During periods of overflow or system shutdown, the

wastewater was discharged directly into East Foundry Cove. A new sewage treatment plant designed in 1965 could not handle the battery plant's industrial discharge, therefore, plant operators began channeling the wastewater into East Foundry Cove. In 1966, the state of New York ordered Marathon Battery to cease discharge and clean up the contamination. Parts of the cove were dredged between September 1972 and July 1973. After completion, the dewatered dredge spoils were deposited in a clay-lined underground vault on the plant property and then sealed with asphalt and fenced. Post-dredging monitoring continued to detect elevated levels of cadmium and nickel concentrations in the Cove's sediments, flora, and fauna.

In October 1981, EPA listed the Marathon Battery Company site on the National Priorities List (NPL). EPA and the State of New York signed a cooperative agreement to undertake a remedial investigation and feasibility study (RI/FS) for the site. The site is composed of three study areas which consist of Area I, Area II, and Area III. Each area was designated under separate Record of Decisions (RODs) established in 1986, 1988, and 1989, respectively. Area II consisted of the former battery facility and did not involve dredging; Areas I and III did include dredging components.

Area I, designated in the 1986 ROD, encompassed the East Foundry Cove Marsh and Constitution Marsh. Area III, designated in the 1989 ROD, included dredge sediments from East Foundry Cove and the Cold Springs pier area. Each ROD proposed a long-term remedy of dredging the contaminated sediments, chemically binding them, removing them from site for disposal, restoring the marsh, and long-term monitoring along with public participation. The major contaminants of concern were metals (cadmium and nickel). The maximum concentration detected in site sediments were 171,000 ppm cadmium and 156,000 ppm nickel (EPA, 1986). The extent of contamination was 340 acres of backwater marshes and sheltered cove, 200 acres of open cove, and a small cove in the Lower Hudson River (near Cold Springs pier).

4 Target Goals and Project Objectives

The primary cleanup target goal for Area I focused on dredging of sediments greater than 100 ppm cadmium (EPA, 1986). Area III focused on a 95 percent mass removal of cadmium with a target goal of 10 ppm (EPA, 1989). To achieve this target, the necessary removal depth was determined to be 1 foot. A risk-based approach was used to define the target criteria. A "no action" criteria was established for other metals since it was assumed that any remedial action would mitigate these metals as well. The long-term remedial action objective was the restoration of marsh vegetation. The stated objective was to alleviate the environmental and potential human health effects stemming from excessive levels of heavy metals contamination, and to prevent further migration of these highly contaminated sediments to Foundry Cove, the Hudson River, and Constitution Marsh.

5 Project Design

A phased evaluation process was used to determine feasible remedial technologies due to the complex environmental, technical, regulatory, and health issues associated with this site. Based upon consideration of the requirements of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), EPA, and NYSDEC (New York State Department of Environmental Conservation) a remedial alternative was selected. The remedial action plan included dredging of the contaminated sediments as specified in the target objectives. It was estimated that 30,000 cubic yards of sediment would be dredged from Area I and 56,000 cubic yards of sediment dredged from Area III. Dredged sediments would then be thickened and treated by chemical fixation on site. Chemical fixation technologies were verified using bench-scale testing (EPA, 1989). Treated sediments would then be transported for off-site disposal. Area I included restoration of the original contours by installing a bentomat layer with the placement of a 1-foot-thick layer of cover soil. After reconstruction, a restoration project would then be implemented to include replanting of various wetland and upland plant species. Both Area I and Area III were then subject to continued long-term monitoring of contaminant concentrations (EPA, 1994; EPA, 1995; EPA, 1999).

The selected remedy complied with all action and location-specific ARARs (applicable or relevant and appropriate requirements). Specifically, ARARs included the Clean Water Act Section 401, federal and New York State water quality criteria and mixing zone requirements under the National Pollutant Discharge Elimination System (NPDES) permit program, National Historic Preservation Act (NHPA), and Resource Conservation and Recovery Act (RCRA) facility location requirements, and New York State non-hazardous soil waste requirements. In addition, appropriate actions were taken to comply with the following environmental statutes and executive orders: Endangered Species Act, NHPA, Coastal Zone Management Act, Executive Order 11990 (Wetlands Protection), and Executive Order 11988 (Floodplain Management).

6 Remedial Actions

6.1 Dredging

Schedule and Duration. The remedial actions began in August 1993 and were completed in April 1995 for a duration of 21 months, including restoration activities. Detailed duration of dredging activities was not available for review.

Equipment. Remedial methods applied were hydraulic and mechanical dredging for coves and ponds, and dry excavation for marshes. Due to rocks, a custom-built horizontal auger dredge was used during dredging along with a barge-mounted clamshell to complete the cove in the Lower Hudson River (GE/AEM/BBL, 1999). Silt curtains were utilized to contain resuspended sediments and minimize short-term environmental

impacts. Remediation of the East Foundry Cove Marsh was accomplished via specialized marsh excavation vehicles with extra-wide tires and low-pressure tracked excavators. Water-filled containment structures were used to hydraulically isolate the marsh during remediation. These were replaced in sections by earthen berms due to failure of the hydraulic containment structures.

Total Volume Removed and Production Rates. The total volume of sediment removed was 100,200 cubic yards. The distribution of sediment dredged from Area I and Area III were: East Foundry Cove Marsh, 23,000 cubic yards; East Foundry Cove, 53,200 cubic yards; East Foundry Pond, 14,400 cubic yards; and Cold Springs pier, 9,600 cubic yards (GE/AEM/BBL, 1999).

Site-Specific Difficulties. Replaced hydraulic water-filled containment structures with earthen berms after failures.

6.2 Dewatering and Water Treatment Operations

Decant water from the on-site gravity settling basin was pumped to sand trickling filters, then treated with a polymer in a return settling basin. Treated water was tested to make sure it met EPA and New York State water quality standards before being discharged into the East Foundry Cove.

6.3 Storage and Disposal

Dredged sediments were allowed to settle out on site in settling basins and then chemically fixated in a pug mill using Maectite (GE/AEM/BBL, 1999). After curing and TCLP testing, the fixated material was transported in 1,979 railcars to City Management Landfill in Michigan and to Chemical Waste Management's hazardous waste landfill in Model City, New York.

7 Environmental Monitoring Program

In May 1984, NYSDEC initiated the Area I RI/FS covered by the cooperative agreement in May 1984. The RI/FS for Area III was prepared by EPA. Surface and subsurface soils, sediments, and surface water were sampled during the RI. Additionally, fish were sampled and bioassays were performed using contaminated sediment. All media were found to be contaminated to various degrees. Cadmium contaminants were of greater concern than nickel and cobalt because cadmium is more toxic and concentrations were generally of the same magnitude between metals of concern. East Foundry Cove Marsh was contaminated to the greatest extent. Monitoring provided insights to the extent of contamination, the effects of contaminants on receptors, and the result of remedial dredging actions. Refer to Table 1 for comparison of baseline, post, and long-term monitoring results.

7.1 Baseline

Baseline results are presented from the RODs for Area I (1986) and Area III (1989).

Physical. Data not available for review.

Chemical. The Area I RI determined the highest levels of contamination occurred in the East Foundry Cove Marsh sediments as high as 171,000 ppm cadmium, with a mean of 27,799 ppm. Contamination in the surrounding channels to Constitution Marsh decreased by four orders of magnitude as distances increased. Distribution of cadmium in the remainder of East Foundry Cove appeared to be dictated by flooding tidal patterns, ebbing tidal patterns, the 1972–1973 dredging effort, and the presence of aquatic vegetation. Background cadmium concentrations in the Hudson River Estuary was shown to have a mean concentration of 10 ppm.

The RI found that cadmium contamination in Area III ranged from 0.28 ppm to 2,700 ppm with a mean of 179.25 ppm cadmium for all depths in the East Foundry Cove. In the Hudson River at the Cold Spring pier, cadmium contamination ranged from 1.2 ppm to 1,030 ppm with a mean of 12.6 ppm cadmium for all depths. Only six samples showed levels above 20 ppm. The major portion of contamination was found in the upper layer of sediment (0 to 10 cm). West Foundry Cove had a cadmium contamination range of 1.1 ppm to 569 ppm with a mean of 43.9 ppm cadmium for all depths. Contamination in West Foundry Cove appeared to be evenly dispersed vertically and acted as a depositional area.

Biological. Cadmium contamination present in the biota in the Foundry Cove area was a clear indication of the environmental threat posed at the site. Baseline monitoring showed the majority of trophic groups sampled had elevated tissue burdens of cadmium (EPA, 1986). Most biological sampling was centered around Area I.

At Area I, in the East Foundry Cove Marsh, the wetland vegetation showed a mean cadmium concentration in the roots of 500 ppb. Vegetation serves an important role in the trophic pathways of the marsh ecosystem. Benthic algae sampled in the area measured a mean cadmium concentration of 506 ppb. Cadmium concentrations in Foundry Cove phytoplankton measured a mean of 245 ppt and zooplankton measured a mean of 342 ppt. A widespread problem at the site showed cadmium contamination of the macroinvertebrates (blue crab) at a mean concentration of 19.4 ppt. Cadmium concentrations in the liver of the *Morone americana* (white perch) were measured as high as 47 ppt. However, due to the mobility of fish it could not be concluded that contamination was the result of exposure to Foundry Cove. A bioaccumulation study was conducted and revealed that significant body tissue uptake of cadmium occurs even under a limited duration of exposure.

Fish samples were collected at four locations in Area III. All fish analyzed measured cadmium concentrations below detection limit results; however, interference from matrix effects prohibited the laboratory from attaining a detection limit lower than 1.0 ppm.

7.2 Implementation During Dredging

Implementation Monitoring was not conducted at the Marathon Battery Site.

7.3 Post

Post-monitoring results are presented for the completion of the remedial action in the spring of 1995 (Advanced Geoservices, 1997a; Advanced Geoservices, 1997b).

Physical. Data not available for review.

Chemical. Post-monitoring results for Area I in the East Foundry Cove Marsh had a mean residual sediment concentration of 11.8 ppm, a 99.6% decrease from average pre-dredge considerations (Table 1). Monitoring samples in the East Foundry Cove Marsh were collected within the cover soil placed as part of the Marsh restoration.

The monitoring results for Area III also measured a decrease in sediment cadmium concentrations. Post-project monitoring in the East Foundry Cove had cadmium concentrations that ranged from 0.74 ppm to 81.2 ppm, with a mean value of 10.9 ppm. The Cold Springs pier area had cadmium concentrations ranging from 2.5 ppm to 35.7 ppm, with a mean value of 15.0 ppm. Results in the East Foundry Pond had cadmium concentrations ranging from 1.0 ppm to 37.1 ppm, with a mean value of 8.4 ppm.

Biological. Biological monitoring was scheduled to take place in the summer of 1996 to be included in the long-term monitoring results.

7.4 Long Term

The long-term monitoring results refer to sampling conducted after all dredging actions were completed in order to assess the success of remediating the Marathon Battery site. Results presented are from the June 1996 sampling event 1 year following dredging and are included in the sampling event report issued June 1997 (Advanced Geoservices, 1997a).

Long-term monitoring results were inconsistent with post-remediation concentrations and variations may be attributed to the method of sample collection. Post-remediation sampling utilized a hand auger to retrieve a representative 6-inch sample of the bottom sediments. The sampling dredge did not penetrate the full 6 inches within the firm bottom and thus retrieved a disproportionate amount of surface material. An alternative sediment sampling procedure using a hand auger was issued in

the February 21, 1996 Supplemental Long-term Monitoring Plan. This procedure was and will continue to be used to collect subsequent samples.

Physical. Data not available for review.

Chemical. Area I long-term monitoring in the East Foundry Cove Marsh was conducted by sampling within the cover soil placed as part of the marsh restoration. Sediment cadmium concentrations measured a range of non-detect to 0.475 ppm with a mean value of 0.203 ppm. This indicated an increase from post-monitoring. The source of the increase was not believed to be leaching of the underlying marsh soils, but rather a result of cyclic flooding of the marsh during high tide deposits from East Foundry Cove. Long-term monitoring sediment cadmium results for Area III were generally consistent with post-monitoring cadmium concentrations.

Biological. Biological sampling was conducted during the late summer and fall of 1996. Vegetation samples collected from the East Foundry Cove Marsh had a mean cadmium concentration of 0.08 ppm. Benthic invertebrate samples consisted of a mixture of oligochaete worms and chironomid midge larvae. The cadmium concentration of the algae sample collected from East Foundry Cove was 0.78 ppm. Long-term sampling also included sampling for whole body swallows and marsh wrens. Cadmium concentrations for whole body swallows measured a range of 0.1 ppm to 0.42 ppm with a mean of 0.24 ppm. Sampling of whole body marsh wrens measured a range of 0.13 ppm to 0.31 ppm with a mean of 0.2 ppm cadmium.

The ROD for the Marathon Battery Remediation Site required the performance of long-term monitoring for a period of 30 years after completion of the remedial action. Future sampling results will become available as sampling event reports and annual reports are prepared. Re-vegetation of the East Foundry Cove Marsh will also be monitored on a regular basis with replanting and/or other techniques used for sparsely vegetated areas.

Table 1 Summary of Monitoring Results

Monitoring	Testing Parameters - Max/Mean Cadmium Concentration (ppm)				
	Baseline 1989	Post 1995	Long Term 1996	Percent Decrease 1989–1996	Long Term 1997
Area I					
Sediment	171,000 (Avg = 27,799)	0.38 to 90 (Avg = 11.8)	NC	99.9% (Avg = 99.6%)	
Cover soil	NC	ND	ND to 0.485 (Avg = 0.203)	52.9%	
Benthic Algae	0.51	NC	0.78		
Zooplankton	342,000	NC	NC		
Phytoplankton	245,000	NC	NC		
Macroinvertebrates	19,400	NC	NC		
Plant	0.50	NC	0.08	84%	
Birds (whole body)					
Swallow	NC	NC	0.24		
Marsh Wren	NC	NC	0.20		
Area III					
Sediment	2,700 (Avg = 179.3)	81.2 (Avg = 10.9)	3.2 to 50.6	98% (Avg = 92%)	0.39 to 104 (Avg = 20)
Fish	<1.0	NC	NC		
Background (sediment)	10 ppm	10 ppm	10 ppm		

Note:
NC represents no data collected.
ND represents non-detect.

8 Performance Evaluation

8.1 Meet Target Objectives

Dredging of cadmium contaminated sediments at the Marathon Battery site has succeeded in meeting performance-based target remediation goals. Cadmium concentrations in Area I sediments were remediated below the 100 ppm target criteria with an average reduction of 99.9 percent: however, concentrations were higher than background. Area III remediation actions also meet the target objective of 95 percent cadmium removal with an average reduction of 94 percent. However, the average post-sediment concentration was 10.9 ppm cadmium, slightly above the 10 ppm action level. Post-dredge as well as long-term monitoring confirm attainment of the target remediation goals.

Long-term monitoring for marsh restoration is inconclusive at this time. Re-vegetation has been slowed due to inclement weather and predation.

8.2 Design Components

Extensive pre-design consulting and planning was implemented prior to dredging actions. This included site history and conditions, bench-scale tests, monitoring, risk assessment, and modeling. Unforeseen conditions

at the site did pose difficulties when dredging. Tidal conditions slowed dredging when limited water depths occasionally grounded the hydraulic dredge used in the confined inshore areas. Areas with coarse sand, gravel, and rock in deeper areas of the Hudson River reduced the effectiveness of the hydraulic dredge and required clamshell dredging. Clogging of screens by organic materials in the initial dewatering operations caused a redesign in the process.

8.3 Lessons Learned

Understanding initial site conditions will aid in developing a dredge design and may reduce difficulties encountered such as tidal cycles and sediment profile. It is important to establish a baseline monitoring program that will enable future monitoring to be consistent for comparison. This will aid in determining the success of the remediation action. Overall, contaminated sediment can be successfully removed using environmental dredging technologies.

9 Costs

Dredging at the Marathon Battery site was estimated to cost between $9 and $11 million for the East Foundry Cove and Pond and for the cove at Cold Spring Pier ($110 to $142 per cubic yard).

10 Project Contact

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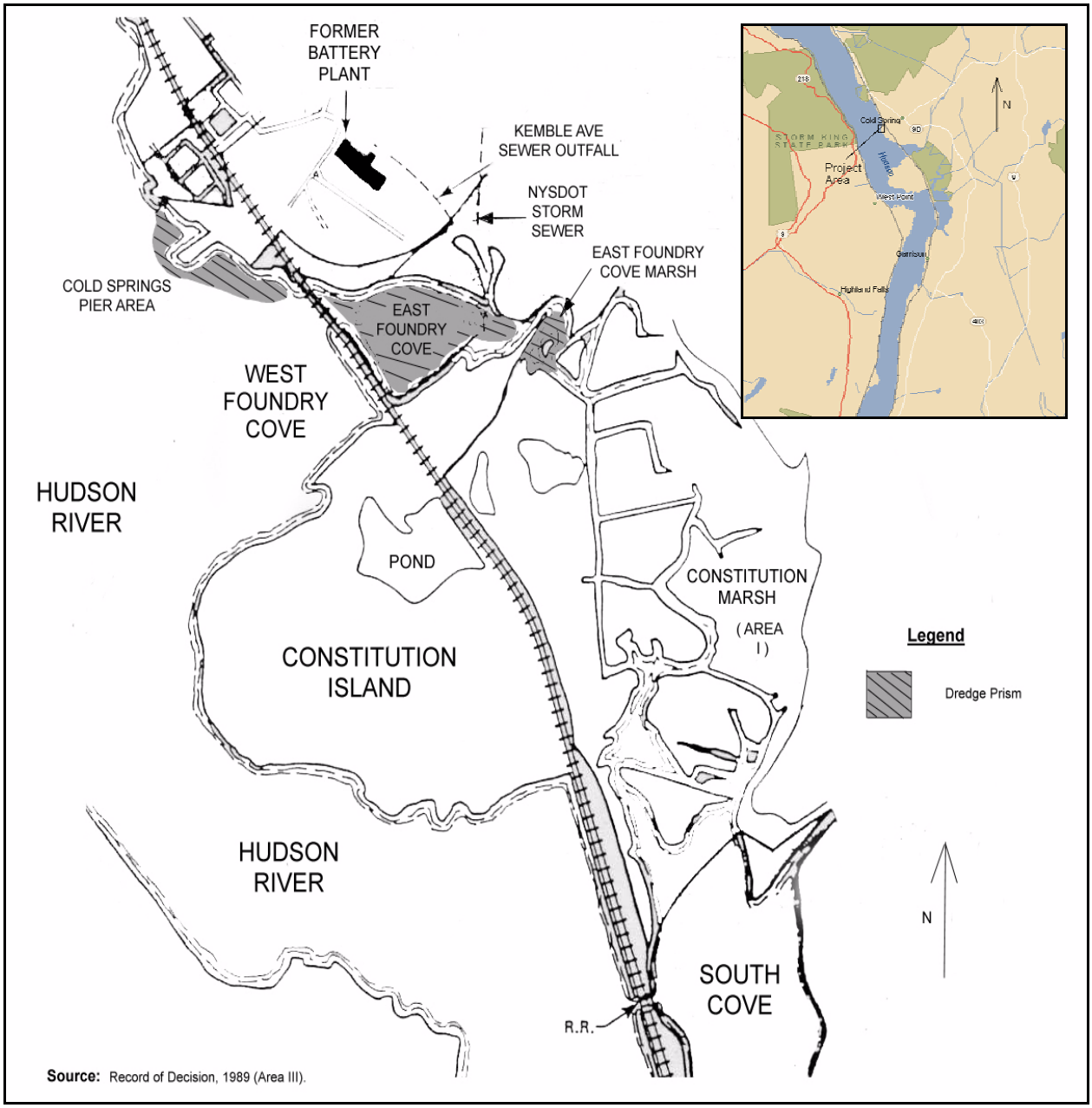
Figure 1 Remedial Dredge Plan - Marathon Battery



1 Statement of the Problem

- Dredged 1983-1987
- Mercury
- 1,025,000 cubic yards
- $40 per cubic yard

Mercury contamination in Minamata Bay and the Agano River was the result of discharges from the manufacture of acetaldehyde by the Chisso Corporation between 1932 and 1968 (History of Minamata Disease, 1998). Discharges of mercury to Minamata bay were estimated to be in excess of 70 to 150 tons. Ingestion of mercury-contaminated fish caused Minamata disease; a poisoning disease of the central nervous system. The first Minamata disease patient was reported initially as suffering from nervous symptoms of an unknown cause in 1956. It took 12 years to reach the official conclusion that mercury was the cause of the disease. While the reported effects varied from source to source, Minamata disease resulted in permanent health effects in several thousand people and the death of over 100 people (Kudo et. al, 1998). Typical symptoms included sensory and auditory disturbances, ataxia, dysarthria, constriction of the visual field, and tremor.

2 Site Description

Minamata Bay is a small marine inlet located on the southwestern coast of Japan on Kyushu Island (Figure 1). The coast is sparsely populated, with steep hills and dense vegetation. Although historically an isolated fishing village, the protected harbor supported the development of a valuable commercial fishing industry. The only inflow of fresh water to the Bay is a creek with an average flow rate of 130 gallons per second, primarily fed by the Chisso Corporation. The harbor is up to 50 feet in depth and is protected by Koiji-Shima Island. Up to 20 percent of the Bay water can be exchanged twice a day by the tide with the outlying Yatsushiro Sea (Kudo and Miyahara, 1987).

3 Site Investigation

The Chisso Corporation began production of acetaldehyde in 1932 using mercury as a catalyst. Wastewater was discharged directly to Minamata Bay. The presence of mercury in fish tissue had been documented in Minamata Bay since 1961. The Chisso Corporation installed a closed circulatory wastewater system in 1965 and discontinued production of acetaldehyde in May 1968. Mercury was officially recognized as the constituent responsible for Minamata disease in a report released by the Japanese government in September 1968. The report cited the Chisso Corporation Minamata factory as the source of mercury contamination in Minamata Bay.

Aerial of Minamata Bay
Source: www.pitt.edu.lecture

Early investigations of mercury concentrations in sediment, shellfish, and human tissue were performed in 1959 and 1960. Sediment concentrations were as high as 2010 mg/kg (wet weight). Marine life displayed high concentrations of mercury ranging from 11.4 to 39.0 mg/kg in *Hormomya nutabilis* (a littoral mussel), 5.61 mg/kg in oysters, 35.7 mg/kg

in crabs, and 14.9 mg/kg in *Scidena schlegelii* (Harada, 1995). Tissues of human patients who died from Minamata disease measured mercury concentrations ranging from 22.0 to 70.5 ppm in livers, 2.6 mg/kg to 24.8 mg/kg in brains, and 21.2 to 140.0 mg/kg in kidneys. Analysis of hair samples obtained from patients ranged from 2.46 mg/kg to 705 mg/kg.

Surface sediment samples were collected in 1975 to define the vertical and horizontal extent of contamination. Contamination in excess of 25 mg/kg was present in approximately 490 acres of Minamata Bay at sediment depths up to 6.6 feet. Concentrations were greatest at the creek which served as the Chisso Corporation discharge location and deceased with distance from the discharge point. Maximum concentrations in the vicinity of the discharge location were in excess of 600 mg/kg.

Additional investigations have been conducted to measure changes in mercury concentrations in the Yatsushiro Sea, which lies directly outside of Minamata Bay (Kudo and Miyahara, 1984; Kudo et. al, 1998). Mercury was transported by natural processes to the Yatsushiro Sea. Surficial sediment sampling (up to 4 cm) has been conducted at 24 stations annually since 1975. Mercury concentrations generally increased between 1975 and 1984. After 1984, decreases in mercury concentration were measured in the Yatsushiro Sea and were likely attributed to the initiation of dredging in Minamata Bay in June 1983. Mercury concentrations in Yatsushiro Sea surface sediments ranged between 0.027 mg/kg and 15.9 mg/kg (Kudo et. al, 1998).

4 Target Goals and Project Objectives

The goal of the Minamata Bay Dredging and Reclaiming Project, sponsored by the national and prefectural governments and Chisso Corporation, was to rapidly and safely dispose of the mercury contaminated sediment. The target concentration for mercury in fish tissue was established at 0.4 mg/kg in 1973 based on human health risk assessments using normal consumption of seafood. The sediment cleanup criterion was established in 1973 by the Provisional Standard for Removal of Mercury Contaminated Bottom Sediment at a concentration of 25 mg/kg. Criteria considered in the development of this standard included protection of marine life, mercury content in seafood, mercury accumulation in food chains, leaching of mercury from bottom sediments, and diffusion and mixing of mercury in water (Ishikawa and Ikegaki, 1980).

5 Project Design

Pre-planning and Bid Documents. The Kumamoto prefectural government commissioned Kumamoto University to perform a study of viable treatment methods for bottom sediment of Minamata Bay. A committee of scholars, and officials from the Ministry of Transport, the Environment Agency, the Fisheries Agency, the Kumamoto prefectural government, and other government agencies was formed in 1974 to develop the remediation plan (Ishikawa and Ikegaki, 1980).

Summary of Remedial Action Plan. October 1977 marked the commencement of remediation in Minamata Bay with the installation of 12,000-foot fish containment net surrounding the Bay. A 720-foot break in the net was provided to allow access of passenger and cargo ships to Minamata Port. Acoustic devices were set on the sea bottom to prevent passage of fish through the opening. A temporary cofferdam was installed at the north end of Koijishima Island to create quiescent conditions thereby minimizing transport of contaminants outside of the remediation area.

The remediation project consisted of a combination of reclamation and dredging. Areas in the vicinity of the discharge location with mercury concentrations in excess of 100 ppm were reclaimed through the construction of two containment cells. Contaminated sediments in the remaining harbor areas with mercury concentrations in excess of 25 ppm were dredged.

The containment cells were formed through the assembly of multiple cylindrical cells with steel piles. The cells were placed with a vibratory hammer and then filled with sand. The cells stood side-by-side and were linked together with arc-shaped combined piles to form a watertight containment wall. A total of 950,000 cubic yards of mercury contaminated sediment were isolated through creation of the containment cells. An additional 1,025,000 cubic yards were removed from the Bay by dredging and placed in the containment cells. Dredging continued until 1987. The reclamation area created 143 acres of land and received its final cover in 1990.

Limitations and Permits. Due to limited capacity for sediment disposal, the dredge depth was minimized through real-time monitoring of dredge depth and three dimensional computer programs displaying actual and target bottom topography. However, the intended design depth for overdredge material was not available from documents reviewed.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. Dredging was conducted between June 1983 and December 1987. Confirmation samples were collected following dredging and the results provided to the Supervisory Committee. The Supervisory Committee officially confirmed that all sediment with mercury exceeding the maximum limit had been removed in February 1988.

Equipment. Four ships, each fitted with a dredge, were dispatched to the work area. Hydraulic dredging was conducted using suction heads without cutters. Dredged sediment was transported by an individual pipeline from each vessel to the reclamation area.

Total Volume Removed and Production Rates. A total of 1,025,000 cubic yards of mercury contaminated sediment were dredged from an area of 373 acres.

Site-specific Difficulties. No site-specific difficulties for the dredging project were noted in the review. However, the occurrence of a 200-year rainfall event which occurred in 1982 resulted in 11.4 inches of rainfall in three hours and the deposit of nearly one million tons of clean sediment in Minamata Bay and the Yatsushiro Sea (Kudo et. al, 1998).

6.2 Dewatering and Water Treatment Operations

Dewatering, Treatment and Disposal. The sediment slurry was allowed to settle under quiescent conditions in the containment cell. A treatment plant was operated 24 hours a day to treat overlying water. The treatment system consisted of polymer coagulation/sedimentation and filtration.

Water Quality Monitoring of Discharge. Water discharged from the water treatment plant was analyzed for turbidity and total mercury. After developing a correlation between turbidity and mercury concentration, turbidity was continuously monitored before final discharge as a quick screening tool. The Japanese Standard Effluent Concentration used as the mercury discharge limit was 0.005 mg/L. Treated water which did not meet this standard was returned to the containment cell. Following treatment, water which met criteria was discharged to Minamata Bay.

6.3 Storage and Disposal

Dredged sediment was piped into a newly constructed nearshore containment cell located in the project area. Physical stabilization and soil capping were utilized to isolate contaminated sediment in the reclamation area. Following gravity settling and dewatering, reclaimed sediment had a high proportion of fine particles and contained large quantities of interstitial water. The soft sediment was stabilized with application of a 2.6-foot thick layer of volcanic ash earth to produce suitable physical conditions for soil capping (Hosokawa, 1993). Following stabilization, the sediment was capped with clean soil and leveled. The cap was completed in March 1990, three years after initial placement. The thickness of the final cap was not specified.

7 Environmental Monitoring Program

7.1 Baseline

Physical. Bathymetry and physical characteristics of the sediment were documented prior to remediation. Bathymetry information was utilized to prepare three-dimensional programs to aid in achieving the desired dredge depth.

Chemical. Baseline distribution of mercury in the bottom sediment and water were measured to assist the project planning effort in 1975. Sediment mercury concentrations collected on a 200 meter grid system were used to define the horizontal and vertical extent of the dredging project. Maximum pre-dredge mercury concentrations exceeded 600 mg/kg in surface sediments.

Biological. Monitoring of mercury concentrations in resident fish tissue collected from Minamata Bay area began in 1961. Fish tissue concentrations generally decreased in time from 1961 to 1974 from over 16.5 mg/kg to less than 1.0 mg/kg (Environmental Health Department, 1997). However, mercury levels in fish rose to their maximum between 1978 and 1981 (Zarull, et. al, 1999) during placement of the net. The data from this period were excluded from the Environmental Health Department data presentation (1997) and were therefore not available for review.

Land Reclaimed from Minamata Bay
Source: www.fsinet.or.jp/~soshisha/10tisiki/10_3_e.htm

7.2 Implementation During Dredging

Physical. Continuous monitoring was conducted during dredging for turbidity measurement and bottom configuration detection. Monitoring devices mounted beside the mouth of the dredged included a continuous-type turbidometer, a submerged television camera, and four echo sounders. With the help of a microcomputer, an operator monitored the dredge cut and bottom sediment topography before and after dredging, suction head position, swing speed and swing direction, and dredged volume of sediment and solid concentration. Real-time adjustments to the dredging depth were made by comparing the assigned dredging program to the actual dredge depth on the monitoring screen.

Chemical. Water quality was monitored for total mercury, pH, chemical oxygen demand (COD), dissolved oxygen, cyanide, and lead at four locations just inside of the fish containment net. Total mercury was measured three times a day, pH, COD, and dissolved oxygen were measured once a day, and cyanide and lead were measured once a week. Mercury concentrations remained below criteria at the monitoring locations during dredging (Hosokawa, 1993).

Biological. Biological monitoring consisted of mercury measurements in resident fish tissue collected inside and outside of the fish containment nets, and in cultivated fish deployed inside the nets. Resident fish were collected from three stations outside of the containment nets four times a year and one station inside the containment nets once a month. Cultivated fish were collected every 10 days and consisted of 10 individuals each of porgy and croaker. Mercury concentrations in fish within the project area continued to exceed the 0.4 mg/kg criteria until 1994, over six years after the completion of dredging. The numerical data from this period were excluded from the Environmental Health Department data presentation (1997) and were therefore not available for

review. Fish collected outside of the project area did not exceed the 0.4 mg/kg criteria (Hosokawa, 1993).

7.3 Post

Physical. As discussed in the implementation during dredging section, bottom topography was monitored from the mouth of the dredge during and immediately following dredging. Dredge depth ranged from approximately 3.3 to 6.6 feet in the inner bay to 0.0 to 0.4 feet in the off-shore areas.

Chemical. Post-dredge surficial sediment samples were collected over a grid system established at 200-meter intervals over the project area. Samples were collected at each of the grid-line intersections. The mean mercury concentration was of the four grid points surrounding each location was calculated and compared to the mercury criteria (25 mg/kg). Sampling locations were co-located with baseline sampling locations and the method of data averaging was established prior to sampling. Mean concentrations were calculated at 59 locations and ranged from 0.91 mg/kg to 8.99 mg/kg. The overall mean post-dredge mercury concentration was 4.60 mg/kg. This data were reported in February 1988. Table 1 shows a summary of pre- and post-dredge sediment mercury concentrations.

Biological. Although the data were not available for review, fish tissue mercury concentrations were in excess of the 0.4 mg/kg criteria in samples collected following dredging.

7.4 Long-term

Physical. No long-term physical monitoring was noted in the review.

Chemical. No long-term physical monitoring was noted in the review.

Biological. In the three-year period from 1994 to 1997, mercury concentrations remained below the 0.4 mg/kg criteria in fish and shellfish. Although data were not available for the period prior to 1994, mercury concentrations were above the 0.4 mg/kg criteria demonstrating that a significant lag time was necessary after dredging to achieve the target mercury body burdens. After 1997, monitoring of fish and shellfish continued at a frequency of twice a year for at least three additional years.

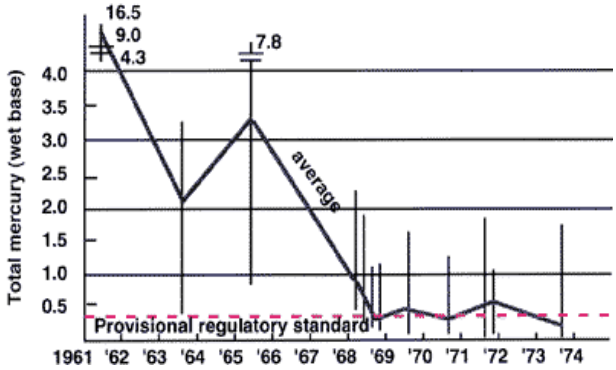
Table 1 Pre- and Post-Dredge Sampling Results

Sampling Events	Mercury Concentrations (in mg/kg)				
	Pre-dredge (1975)	Implementation During Dredging (1983-1987)	Post-dredge (1988)	Long-term (1994-1997)	Percent Decrease (1993-1995)
Surface Sediment Minimum Maximum Average	25 mg/kg > 600 mg/kg NE	NA	0.91 mg/kg 8.99 mg/kg 4.60 mg/kg	NA	96.4 % > 98.5 % NE
Surface Water	NA	Below Criteria (<0.0005 mg/kg)	NA	NA	NE
Biological Tissue					
Fish	<1.0 to >16.5 mg/kg	> 0.4 mg/kg in project area <0.4 mg/kg outside project area	> 0.4 mg/kg	< 0.4 mg/kg	NE
Shellfish	Mussel 11.4 to 39.0 mg/kg Oyster 5.61 mg/kg Crab 35.7 mg/kg *Scidena schlegelii* 14.9 mg/kg		> 0.4 mg/kg	< 0.4 mg/kg	NE
Human	Liver 22.0 to 70.5 ppm 2.6 Brain 2.6 to 24.8 mg/kg Kidney 21.2 to 140.0 mg/kg Hair 2.46 mg/kg to 705 mg/kg	NA	NA	NA	NE

NE - The average could not be evaluated due to lack of detailed data.
NA - Not analyzed

8 Performance Evaluation

8.1 Meet Target Objectives



Minamata Bay Fish Levels
Source: www.pitt.edu.

Short-term Target Goals. The target surface sediment mercury concentration of 25 mg/kg was met at each of the 59 sampling locations. The average surficial sediment concentration was 4.6 mg/kg and the maximum concentration was 8.99 mg/kg.

Long-term Remedial Objectives. Mercury concentrations in fish declined below the 0.4 mg/kg target level in 1994. Dividing nets were removed and fishing restrictions were lifted in 1997.

8.2 Design Components

The remediation design was completed by a committee of scholars, and officials from the Ministry of Transport, the Environment Agency, the Fisheries Agency, the Kumamoto prefectural government, and other government agencies. The large scale remedial action benefitted greatly from pre-planning and extensive investigative efforts. Extensive baseline sampling and bathymetry measurements were used to produce three dimensional computer models of the proposed dredge prism.

8.3 Lessons Learned

The Chisso Corporation and the Kumamoto prefectural government have received extensive criticism due to the extreme health effects caused by Minamata disease and the length of time required to document its cause.

As stated in the design components section above, the horizontal and vertical extent of contamination and site conditions were well documented prior to mobilization. Adequate characterization and good communication during implementation were components of the successful project. Echo sounders attached at the mouth of the dredge were used to generate real-time displays of the dredging progress ensuring complete removal of target depths.

Contaminated sediment was determined to be the primary exposure pathway of observed mercury concentrations in fish and human tissue. Source control of sediment was a viable pathway to risk reduction and long-term protection of human health and the environment.

9 Costs

The total cost of the dredging project was approximately $40 million to $42 million U.S. dollars (Zarull, et. al, 1999) or approximately $40 per cubic yard. The total project cost including reclamation and the creation of a modern harbor was estimated at $500 million (Kudo et. al, 1998).

10 Project Contact

No project contact was available.

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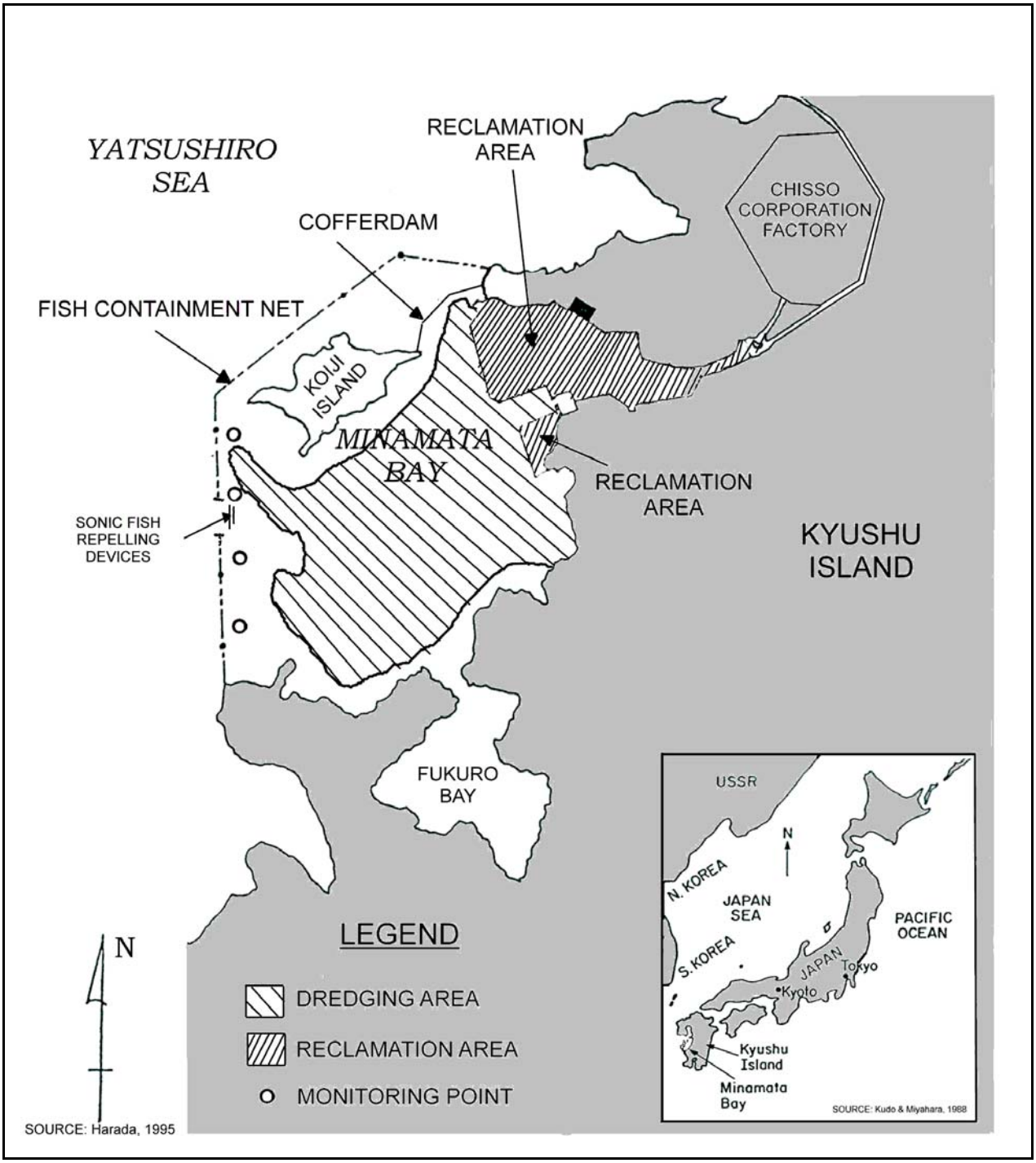
Figure 1 Remedial Dredge Plan



1 Statement of the Problem

- Dredged 1994–1995
- PCBs
- 14,000 cubic yards
- $1,430 per cubic yard

Polychlorinated biphenyl (PCB) contamination was present in New Bedford Harbor sediments at concentrations over 100,000 parts per million (ppm). A hotspot remedial dredging action was conducted in 1994/1995 to remove sediments containing over 4,000 ppm PCBs to reduce a source of migrating contamination, remove a significant mass of PCB contamination, and protect public health and marine life by preventing contact. A pre-design field test (PDFT) was conducted in August 2000 to demonstrate and record performance data for use in developing a full-scale remediation plan. Further remedial activities are planned for remaining contamination and are presently in the design stage. The lead agency for this project was U.S. Environmental Protection Agency (EPA) Region 1.

2 Site Description

The New Bedford Harbor Superfund Site is located in Bristol County, Massachusetts. The site extends from the Acushnet River estuary south through New Bedford Harbor and into Buzzards Bay. The entire Superfund site includes four areas: mouth of Acushnet River including the hotspots, upper New Bedford Harbor, lower New Bedford Harbor, and approximately 17,000 acres of Buzzards Bay. This area of Buzzards Bay is closed to lobster fishing because of PCB contamination. This case study addresses the removal of six hotspots of contamination limited to the Acushnet River and upper New Bedford Harbor and the PDFT in a 100- by 550-foot area in the upper New Bedford Harbor. The collective area encompassed by the hotspots was approximately 5 acres with water depths ranging from 1 to 6 feet. The remediation area is within a shallow tidally-influenced estuary. Sediments consisted of fine sandy silt with some clay.

View of New Bedford Harbor
Source: City of New Bedford Harbor Development Commission

3 Site Investigation

The primary sources of contamination were two electronic component manufacturers, which used PCBs in the production of capacitors. Evidence of PCB contamination in sediments and seafood was first discovered through EPA region-wide sampling programs conducted during the mid-1970s. The site was placed on the Superfund National Priority List (NPL) in September 1983. The Record of Decision (ROD) for

hotspot dredging was issued in April 1990 with oversight by EPA Region 1 (EPA, 1990). The ROD for the upper and lower harbor, including the remaining contamination in the hotspots (<4,000 ppm) was issued on September 25, 1998.

PCBs are the principle contaminant of concern, although high concentrations of cadmium, chromium, copper, and lead were also present. PCB contamination was found at levels as high as 100,000 ppm in some areas. Contamination was principally found in the top 2.0 feet of sediment, but extended to depths of 3.9 feet in several areas.

The entire Superfund site includes four areas: mouth of the river and the upper harbor (OU-1) and the lower New Bedford Harbor extending out to Buzzards Bay (OU-2). The ROD for this second operable unit was issued on September 25, 1998 and is currently in the design stage (EPA, 1998). The entire project study area and their respective selected remedies were summarized in the 1998 ROD (listed from upstream to downstream):

Area of Concern	Size	Cleanup Level
Acushnet River	16.5 acres	10 ppm PCBs
Upper Harbor	187 acres	10 ppm PCBs
Lower Harbor	750 acres	50 ppm PCBs
Buzzards Bay	17,000 acres	1 to 25 ppm PCBs intertidal areas
Total	**17,953.5 acres**	

The highest PCB concentrations were detected in the upper harbor sediments and were considered to be a continued source of contamination to the lower segments of the harbor and bay. The hotspot dredging project occurred mostly in the upper harbor in the shallow tidal estuarine area where the Acushnet River merges with the harbor.

4 Target Goals and Project Objectives

The principle objective of the hotspot removal project in the upper harbor and adjacent sections of the Acushnet River was to remove sediments contaminated with PCBs in excess of 4,000 ppm for source control. The 4,000 ppm criteria was derived from an optimum point by removing the greatest percentage of PCB mass for the least volume of sediment. The hotspot excavation was estimated to contain 45 percent of the total mass of PCBs for the entire site. A second objective for the remediation was to avoid the need for additional remediation in the lower harbor as a result of the dredging program by minimizing contaminant transport. This was evaluated through environmental monitoring.

The goal of the PDFT was to evaluate new technology, including the use of a water recirculation system, with regard to site-specific cleanup levels and to compare these values with previous estimates. Performance data was demonstrated and recorded that included dredge production,

accuracy, slurry solids concentration, and air and water quality impacts. Estimates of PCB removal efficiency and dredge production would be used in developing a full-scale remediation plan. Additional objectives were to evaluate the effectiveness of applying contaminant dispersants and flocculents within the CDF to reduce PCB losses to air, to evaluate mechanical dewatering methods, and to evaluate the use of granular activated carbon (BAC) to treat wastewater.

5 Project Design

Pre-planning and Bid Documents. The EPA employed the U.S. Army Corps of Engineers to perform an engineering feasibility study (EFS) of dredging and disposal alternatives (EPA, 1987) which included field data collection, literature reviews, bench-scale studies (Allen & Fowler, 1989), and analytical and numerical modeling (Francinques *et al.*, 1988). Five alternatives were evaluated prior to selection of dredging and on-site incineration (Allen & Ikalainen). A confined disposal facility (CDF) was used in place of on-site incineration due to public opposition. The EFS was conducted from August 1985 to September 1988 and consisted of several tasks: 1) preparation of maps of water depth and mudline elevations, 2) sediment characterization of contamination extent and physical properties, 3) physical characterization of soils and groundwater elevations, 4) lab and field tests predicting sediment/contamination released by dredging, relationship of flow and suspension/settling, estuarine and hydrodynamic and transport model for sediment, 5) testing of dewatering/treatment parameters including settling, solidification/stabilization, flocculation/clarification, necessity of effluent water treatment, and 6) a study of the most effective dredges. A pilot dredging study was conducted to evaluate three recommended dredges and dredging practices (Otis & Andreliunas, 1987). The pilot study also included chemical, physical, and biological monitoring (Otis & Averett, Holmes, 1987).

Prior to the hotspot removal project, a pilot study removed two sediment cells containing 300 cubic yards (cy) each for implementability assessments. The hotspot removal was awarded as a fixed price contract that also included water treatment and incineration.

Summary of Remedial Action Plan. Dredging operations were designed for hydraulic dredging using the Ellicott 370 12-inch cutterhead dredge within silt curtains. No other sediment removal alternatives were used in the hotspot operable unit. Sediment was to be dewatered and incinerated, however, due to public opposition, sediment was stored in a CDF. Sediment was transported from the dredge to the CDF through a floating pipeline. Process water from dewatering operations was treated in an on-site wastewater treatment plant and discharged to the Achshnet River.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. The remedial dredging action took place from April 26, 1994 to September 5, 1995. Work was scheduled for five days a week, although dredging was only conducted on a total of 261 of the available days. Due to shallow water conditions at the site, dredging activities took place only during high tides at water depths of 1 to 6 feet. Dredge operation was limited to 4 to 6 hours per day due to tides and limited capacity of the wastewater treatment plant. Work was discontinued from December 1994 through March 1995, because of ice formation in the Acushnet River.

Equipment. Hydraulic dredging of sediments was performed using an Ellicott 370 12-inch cutterhead dredge. High suction rates and slow auger rotation were used to control dispersion of sediments after exceeding air monitoring criteria during the first three days of dredging. Silt curtains were initially used during dredging for containment of sediment dispersed by dredging. Agitation of silt curtains by reversing tidal currents resulted in the disturbance of sediment and subsequent release of PCB oil. Use of silt curtains was therefore discontinued.

Total Volume Removed and Production Rates. A total of 14,000 cubic yards of sediments were removed from an area of approximately five acres at a production rate of approximately 13 cubic yards per hour. The solids content of dredged material was approximately 5 percent (ThermoRetec, 2000). A likely reason for the low solids content was that the dredge was used to vacuum oil released during dredging from the water surface. Removal to target contamination levels was confirmed with post-dredge sampling. A total of 15 final composite samples were analyzed over the 5-acre area for PCBs. Results ranged from 67 to 2,068 ppm and a median value of 707 ppm. One of six hotspot areas (Area B) was not dredged due to its proximity to submerged high-voltage power lines.

Site-specific Difficulties. The presence of submerged high-voltage power lines prohibited dredging in one of the six hotspot areas. Use of silt curtains was discontinued because the weights contacted the surface bottom during the lower part of the tidal cycle (4 ft tidal range) and released PCB oils). Dredging difficulties included the tides, shallow water depths, and high PCB concentrations in sediments.

6.2 Dewatering and Water Treatment Operations

Dewatering, Treatment and Disposal. Dredged sediments were transported up to one mile distant via a floating pipeline to a CDF located along the New Bedford shoreline for storage and water treatment. Dewatering and water treatment consisted of an equalization tank, alum flocculation tanks, a secondary clarifier, automatic sand backwash filter, ultra fine polishing filters, activation by hydrogen peroxide and PCB destruction by ultraviolet light (application of an innovative technology). Treated water was discharged to the Acushnet River.

Water Quality Monitoring of Discharge. Effluent was analyzed for PCBs, cadmium, chromium, copper, and lead. Discharge requirements were developed during the design phase and were defined in a permit based on degradation of the Acushnet River and quantitation limits. The PCB monthly discharge level of 0.6 ppb was consistently met. Requirements for metals were consistently met with the exception of copper which was exceeded in May 1994 (11.4 ppb) and lead in December 1994 (8.9 ppb) and January 1995 (4.9 ppb).

6.3 Storage and Disposal

The April 1990 ROD called for on-site incineration of contaminated sediment. EPA terminated the incineration component of the project due to vehement and congressionally-supported public opposition. Contaminated sediments were temporarily stored in an interim shoreline CDF approximately one mile from the dredge area for five years. The hydraulically dredged sediments were pumped directly into the CDF via a floating pipeline. EPA issued a proposed plan in August 1998 to dewater and dispose of sediments in an off-site landfill.

7 Pre-Design Field Test Actions

7.1 Dredging

Schedule and Duration. Trial dredging took place over 4 days (August 10 through 13, 2000) during which the dredge system underwent modifications to prepare for test dredging, which was performed over the course of 5 days (August 14 through 18, 2000).

Equipment. A hybrid environmental mechanical/hydraulic excavator dredge was used to enable accurate dredging of the contaminated sediment, to minimize the amount of water added during the slurry pumping process by recycling water decanted from the slurry effluent, and to minimize the potential for adverse environmental impacts. A horizontal profiling grab bucket (HPG) is able to mechanically excavate thin layers of material with a high degree of accuracy causing minimal spill and turbidity. A crane monitoring system (CMS) with an onboard electronic sensor system and slurry processing unit (SPU) that delivers high percent solids concentrations by introducing controlled amounts of recycled water from the CDF to mechanically dredged material were both part of the innovative techniques utilized for the PDFT.

Total Volume Removed and Production Rates. Dredging was performed to obtain representative production rates over a range of conditions, including varying depths, bank height, and chemical and physical conditions. The representative average production rate for the excavator was 80 cubic yards per hour (cy/hr) in areas with bank height ranging between 1.7 and 2.0 ft. It is estimated that a production rate of 95 cy/hr could be achieved on a full-scale project in deeper areas of the upper harbor if the system is optimized. In shallower areas, where working of the tides would increase the number of barge movements and reduce the overall dredging efficiency, the dredge production would be anticipated to be similar to the use of a smaller dredge (35 to 50 cy/hr).

The solids content of dredged material ranged from 13.3 to 16.3 percent solids by weight. These concentrations were achieved in dredge areas having *in-situ* sediments with average solids concentrations of 32 to 43 percent solids by weight (40 to 50 percent solids by volume).

Dredging accuracy of the test dredge equipment demonstrated that a mechanical bucket, operated from an excavator with rigid connections and a state-of-the-art monitoring and positioning system, could achieve a plus or minus (±) 4-inch vertical dredging accuracy based on comparison of the PDFT post-dredge survey with the target depths. An accuracy evaluation showed that 95 percent of the test area was dredged to within 6 inches of the target depth and 90 percent of the test area was dredged to within 4 inches. The average sediment PCB concentration (upper 1 foot) was reduced from 857 to 29 ppm over the dredged area. The PCB mass remaining after dredging appeared to reside entirely in a thin surface veneer and was attributed to recontamination of the dredged area rather than incomplete removal.

Site-specific Difficulties. SPU production was found to limit dredge production, due primarily to problems with debris clogging. Attempts were made during the PDFT to remedy clogging problems by adding water jets in the suction line, welding baffle walls in the hopper, and other operational measures.

7.2 Dewatering and Water Treatment Operations

Dewatering, Treatment, and Disposal. A pilot-scale wastewater treatment system was used to treat the wastewater generated during the PDFT. Over 1 million gallons of wastewater was treated with unit processes that included chemical addition and settling, ultra-fine sand filtration (0.45-micrometer nominal), granular activated carbon absorption, ultraviolet/oxidation, and sludge dewatering with a plate-and-frame filter press. Contaminants contained in the wastewater are strongly associated with the suspended particles. The seawater with which the dredged sediment was combined to create the slurry contains colloidal particles that cannot be removed by flocculation, clarification, and filtration alone. The concentration of PCBs and copper associated with the colloidal particles is sufficient that wastewater could exceed the discharge limits unless tertiary treatment in the form of activated carbon is performed.

Water Quality Monitoring of Discharge. Effluent was analyzed for PCBs, cadmium, chromium, copper, and lead. Activated carbon was successful in reducing the concentration of PCBs to below the discharge limit of 0.065 micrograms per liter (μg/L) per Aroclor and the concentration of total and dissolved metals, most notably copper.

8 Environmental Monitoring Program

Baseline, progress, post-dredging, and long-term monitoring for physical, chemical, and biological parameters were included in remediation activities. The full-scale baseline monitoring was conducted in 1993. Additional full-scale monitoring events have taken place in 1995 following the hotspot remedial action and in 1999.

The long-term monitoring program has been proposed for 30 years with full-scale sampling events every 3 to 5 years or before and after major remedial activities. Mussel bioaccumulation will be conducted twice a year. A wetland assessment will be conducted every 10 years.

8.1 Baseline

Baseline sampling was performed in 1993 prior to dredging (EPA, 1996). Sampling stations were established just downstream of dredging activities, approximately 1 mile downstream (NBH-2) and approximately 2.5 miles downstream (NBH-4) as shown on Figure 1. This figure shows the CDFs for the entire operable unit that is currently in design, it does not show the hotspot CDF. A reference station was established and designated NBH-5. Sampling stations NBH-2, NBH-4, and NBH-5 were used throughout the bioaccumulation studies to obtain correlating data. Sediment analysis was conducted on grab samples of the top 2 centimeters (cm).

Physical. Physical analysis was conducted on sediments for grain size, total organic carbon (TOC), and acid volatile sulfide (AVS). Site bathymetry was determined using cross-sectional multi-point sampling arrays.

Chemical. Surface sediment samples (2 cm) tested for PCBs in the upper New Bedford Harbor averaged 94 ppm at 24 sampling locations. A maximum concentration of 431 ppm was detected in the upper harbor.

Biological. Bioaccumulation of PCBs from the water column was tested in *Mytilis edulis* and *Fundulus heteroclitus*. Baseline bioaccumulation concentrations in *Mytilis edulis* ranged from 613 to 15,012 nanograms per gram (ng/g). Results are shown in the post-monitoring section. Benthic infaunal invertebrates in sediments (7 cm) were tested for species richness, EMAP index of benthic community condition, and community structure. The average number of species per station was 20 ± species while the outer harbor measured 72 ± 21 species. Sediment toxicity tests were conducted on *Ampelisca abdita* with an average of 55 percent survival in the upper harbor.

8.2 Implementation During Dredging

Progress monitoring was conducted during dredging from April 1994 to September 1995 for the pilot project (EPA, 1997) and during dredging activities in August 2000 (Foster Wheeler, 2001).

Physical. In the hotspot remedial dredging action, as part of the dredging contract, bathymetric measurements were taken to confirm sediment removal to design depths. Dredge cuts were 0.5 ft per pass with a follow-up clean-up pass.

Chemical – Hotspot Remedial Action. Total suspended solids (TSS) and PCB concentrations were monitored in the water column during dredging activities to determine if remedial actions had a significant effect on net downstream transport of PCBs. Samples were intensively collected from five horizontal locations and multiple depths during flooding and ebbing tidal cycles (EPA, 1997). The criteria for maximum cumulative transport was the level of PCBs over background concentrations that would increase the lower harbor sediment PCB concentration by more than 1 ppm. The corresponding total PCB mass was calculated to be 240 kg over the entire dredging period (240 kg/ 260 days). The total mass of PCB transported was 57 kg which was 24 percent of the net sediment transport allowed.

A total 4,041 PCB air monitoring samples were collected during dredging and CDF placement activities and compared to three different action levels (notification, operational, and stop work). A total of 10 samples exceeded the stop work action level of 1,000 nanograms per cubic meter (ng/m^3). Only one of these samples was located within the dredging area (of 2,469 samples taken), the other nine being sampled at the CDF. A total of 49 samples exceeded the action level of 500 ng/m^3 (18 of 2,469 dredge area). A total of 1,063 exceeded the notification action level of 50 ng/m^3 (661 of 2,469 in dredge area). Effluent water quality met discharge requirements on all occasions for all parameters, except for copper exceedances on 3 separate days.

Chemical – Pre-Dredge Field Test. TSS and PCB concentrations were monitored in the water column during dredging activities to determine if remedial actions had a significant effect on net downstream transport of PCBs. Samples were intensively collected from four horizontal locations and multiple depths during flooding and ebbing tidal cycles. (Foster Wheeler, 2001). Field-measured turbidity and PCBs showed some spikes in the vicinity of the dredge, but generally returned to background levels within 500 ft down current of the dredge.

PCB air monitoring samples were collected from nine different potential sources of PCB emissions in a flux changer, and ambient air sampling around the CDF and harbor were collected. Calculations based on surface area inside the silt curtains were approximately 100 milligrams per day (mg/day). Emission rates calculated from raw sediment and from sediment with a thin water cover at the CDF ranged from 666 to 4,090 ng/m^2-min with an average of approximately 2,500 ng/m^2-min. Based on headspace readings from the grizzly and hopper on the dredge, a hopper volume of 72 cubic meters (m^3) and an air exchange rate of one hopper volume every 15 minutes, the emission rate would be approximately 20 μg/min or 0.03 gram of PCBs per 24-hour day (Foster Wheeler, 2001). Emission flux measurements from the mudflat areas ranged from 63 to

600 ng/m^2-min, less than those measured from sediments and sediment-water mixtures at the CDF. The use of surfactants, Dawn and Biosolve, to control the sheen at the CDF does not appear to be effective for controlling PCB emissions.

Biological. PCB bioaccumulation testing in the water column was conducted during dredging using caged mussels, *Mytilis edulis*. Mussels were deployed in mesh bags one-meter above the bottom at three sites for a period of 28 days (NBH-2, NBH-4, and NBH-5). Stations NBH-2 and NBH-4 are located approximately 1 and 2.5 miles downstream, respectively (Figure 1). Caged mussels were also used for baseline and post-remediation monitoring. The available results are shown in the monitoring data table. At stations NBH-2 and NBH-5 (reference site) no increase in PCB bioaccumulation was observed. A significant increase was observed during dredging at station NBH-4. Stations NBH-2 and NBH-4 are located approximately 1 and 2.5 miles downstream, respectively (see Figure 1).

Acute toxicity determinations of the water column were conducted using *Arbacia punctulata*, *Mysidopsis bahia*, and *Champia parvula*. Toxicity criteria for mortality was established to be greater than 50 percent of background for the remedial activities. In 86 *Arbacia punctulatasperm* cell tests, acute toxicity was consistently less than 10 percent than background conditions (NBH-5). In seven acute toxicity tests of *Mysidopsis bahia* 100 percent mortality was observed at one time point at station NBH-2 in the December 12, 1994 sample. Samples at stations closer to dredging operations did not show toxicity on this date. In 85 *C. parvula* sampling points, 50 percent mortality was exceeded in one instance on September 7, 1994 at the reference site (NBH-5). Dredging operation stations did not exceed criteria on this date. Sub-lethal effects attributable to the dredging were measured in *C. parvula* reproduction in two of 72 valid tests. EPA concluded that no acute toxicity effects measured during dredging were attributable to dredging operations (EPA, 1997).

8.3 Post

Following hotspot dredging, physical, chemical, and biological testing were conducted following the same protocols described in the baseline monitoring.

Physical. Data not available for review.

Chemical. Confirmation monitoring in the hotspot was done by collecting 9 to 25 surface sediment (0-2 cm) samples in each dredge unit (approximately 0.25 acre). The samples from each dredge unit were composited into one sample for analysis. If the composite sample concentration was >4000 ppm PCB, then the unit was re-dredged.

Post-dredge verification sampling of sediments in the hotspot areas for PCBs confirmed sediments in excess of 4,000 ppm PCB had been removed. A total of 15 composite samples were collected in 1995 from

the 5 acres of hotspot areas. PCB results ranged from 67 to 2,068 ppm with a median value of 707 ppm.

The October 1995, sampling showed localized increases in surface PCB concentrations in the upper harbor after completion of dredging. In the lower harbor, 27 percent of the surface sediments of stations showed an increase, while 67 percent decreased. The outer harbor concentrations remained virtually unchanged (Bergen, et al., 1998). Post-dredging bathymetry was determined using cross-sectional multi-point sampling arrays.

Biological. PCB bioaccumulation results of a composite, post-operational 1995–1997 study of *Mytilis edulis* in the water column are shown in Table 1. As in the progress monitoring, no increase in PCB concentration was observed at stations NBH-2 and NBH-5, while a significant increase was observed at station NBH-4. However, it is unlikely that this increase was attributable to the hotspot remediation, otherwise, higher concentrations would be expected at NBH-2, located closer to the remediation area (EPA, 1997).

8.4 Long Term

Since the 1995 post-remedial sampling, one set of monitoring data has been collected. This sampling took place in 1999, although data are not presently available. Long-term monitoring followed the sampling protocols established in the 1993 baseline sampling.

For New Bedford Harbor, the primary goal of long-term monitoring is to "assess the effectiveness of remediation by quantifying spatial and temporal biological and chemical changes in different environmental compartments." The primary measurement endpoints are water quality standards (biomonitoring) and FDA standards for PCB levels in seafood (EPA, 1996). As of 1997, four rounds of long-term caged mussel bioaccumulation studies have been conducted (twice per year). No statistically significant increase has been observed for NBH-2 and NBH-5. An increase was observed at station NBH-4 but is unlikely attributable to hotspot remediation since no increase was observed at NBH-2.

Table 1 Summary of Monitoring Results

Testing Parameter		Average PCB Concentration			
		Baseline [1] 1987–1993	Progress [2] April 1994–Sept. 1995	Post [3] 1995–1997	Long Term 1999
Bathymetry Station		Yes	Yes	Design depth achieved	—
Surface Sediment (ppm)		Avg = 94 (N = 24)	—	67 to 2,068 (N = 15)	—
Subsurface Sediment (ppm)		100,000 = max	—	—	—
Water Quality Monitoring		Yes	Net transport of PCB mass below allowable criteria	—	—
Air Monitoring		None	(N = 4,041) minimal exceedances (<1%)	—	—
Water Column Acute Toxicity (ng/g dry)	NBH-2 [4]	None	Minimal exceedances compared to reference	—	—
	NBH-4 [5]				
	NBH-5 [6]				
Caged Mussel Water Column Bioaccumulation (ng/g dry)	NBH-2 [4]	15,012 ±4368	15,052 ±4719	14,639 ±3715	NA
	NBH-4 [5]	3,814 ±892	4,250 ±890	6,315 ±711	NA
	NBH-5 [6]	613 ±187	403 ±73	371 ±204	NA
Sediment Toxicity		Avg. = 55% survival	None	—	NA
Benthic Community		Avg = 20 ±7 species per station	—	—	NA

Notes:

[1] Average of nine sampling events between July 1987 and December 1993.
[2] Average of 14 sampling events between May 1994 and September 1995.
[3] Average of four sampling events between October 1995 and May 1997.
[4] Station located 1 mile downstream.
[5] Station located 2.5 miles downstream.
[6] Reference station.
Results are dry-weight corrected.
NA - Not available for review.
Data generated from EPA, October 1997 Report

9 Performance Evaluation

9.1 Meet Target Objectives

Hotspot Removal. The principal objective of the 1995 hotspot removal was to remove all sediments with PCB concentrations in excess of 4,000 ppm. Post-verification sampling included 15 samples from composites of regularly spaced 2 cm surface samples collected as each dredge unit was

completed (5 acres). Results verified that the target removal goal to 4,000 ppm PCBs was met. Post-remedial PCB concentrations ranged from 67 to 2,068 ppm with a median value of 707 ppm. This source removal effort supported the second objective to minimize potential future downstream transport of PCBs to the lower harbor from physical disturbances (i.e., scour, storm events) as predicted from USACE studies in the late 1980s.

During implementation, the goal was to minimize increased PCB transport from dredging activities (above baseline bedload values). Air quality results during dredging had minimal exceedances. Downstream surface sediment concentrations in the outer harbor remained unchanged (some localized increases and decreases observed in lower harbor, closer to the dredge area). Total PCB mass transport downstream during dredged measured 57 kg, which equaled 24 percent of the net transport allowed.

EPA considered the hotspot removal project successful because of the quantity of PCB mass removed and the minimal amount of PCB transport and biological impact during and after dredging (EPA, 1997). Minimal environmental effect on New Bedford Harbor and Buzzards Bay from the dredging operation was based on:

- Acceptable water quality monitoring results,
- Acceptable air monitoring data results,
- Mussel bioaccumulation studies were not statistically significant during dredging,
- Minimal net transport of PCBs, well below the necessary level calculated to be protective of the lower harbor,
- No acute toxicity effects attributable to dredging, and
- Post-dredge mussel bioaccumulation studies were not statistically different close to the dredge area (did increase further downstream however, discussed below).

Specific criteria were not stated in the long-term monitoring plan for the long-term objectives toward protection of human health and the environment. Measurement criteria to be used for long-term monitoring include bioaccumulation studies, sediment toxicity, and benthic community assessments. As of 1997, four rounds of caged mussel bioaccumulation studies have been completed with significant increase in neither the NBH-2 nor NBH-5 sample. An increase was observed at the NBH-4 station located 2.5 miles further downstream, however this increase was not statistically significant from pre-dredge conditions. A comparison of pre- and post-concentrations measured in the reference sample NBH-5 observed a 60 percent decrease in levels indicating a large temporal variability in sample collection and measurement efforts. Possible explanations for this variability include: potential scour and exposure from PCB sediments in non-dredged areas, variable sedimentation rates in the harbor, variable uptake rates, and storm events. Specific criteria were not stated for long-term objectives toward protection of human health and the environment.

Pre-Design Field Test. In the PDFT, a state-of-the-art hybrid mechanical/hydraulic dredging system demonstrated dredge performance values exceeding those that have previously been achieved at the New Bedford Harbor site in the areas of dredge production, accuracy, and slurry solids concentrations. Both the sediment removal data and PCB data acquired indicate that the dredging technology used for the PDFT is very efficient and has a high probability of achieving sediment PCB cleanup goals established for upper New Bedford Harbor. Furthermore, given the data set collected during this study, the question of residual contamination due to sloughing or migration should be able to be addressed logistically by modifying certain dredging procedures during a full-scale remediation. For full-scale remediation activities, dredging production in water deeper than 4 ft and between 2 and 4 ft are estimated by be 95 and 35 cy/hr, respectively. Vertical dredging accuracy to the design depths is recommended to be estimated at ±4 ft and horizontal accuracy is 1.5 ft. Average solids concentration of the dredge slurry is 10 to 20 percent solids by weight.

Water column monitoring revealed only a very limited impact on the water column from the actual dredging in terms of both PCBs and suspended solids. The detected elevations of these parameters were within the range of fluctuations found in the harbor with changing environmental conditions. This limited impact was attributed to the bucket design and the method of operation. Results of the wastewater treatment pilot study showed that granular activated carbon, when used with clarification and filtration, can remove PCB concentrations to below the site-specific discharge limit of 0.065 mg/L per Aroclor.

9.2 Design Components

Although this was a small hotspot removal project relative to planned additional dredging presently being designed, extensive pre-design consulting and planning was implemented prior to dredging activities. Design components included:

- Field data collection,
- Literature reviews,
- Bench-scale studies,
- Analytical and numerical modeling, and
- A pilot dredging study.

9.3 Lessons Learned

Although the target goal of 4,000 ppm PCBs was met (concluding a successful dredging project), this level is unlikely protective of human health and the environment based on other risk-based cleanup levels reviewed; however, the project was never intended to be a protective remedy. The intent was a cost-effective five acre mass removal of highly contaminated sediments (dredging $124 per cubic yard). Approximately 955 acres of contaminated sediment (55 percent of mass) still remain. The hotspot remediation was an interim action to prevent mass transport of PCBs further downstream and to prevent an expensive cleanup of widely distributed low-level PCB-impact sediments. Additional long-term

monitoring is needed to confirm the reduction of these sediments as a continued source of PCBs. Monitoring results so far indicate no significant change observed in water column bioaccumulation results.

Incineration was initially chosen as the disposal alternative, although congressionally-supported public opposition reversed this decision. This illustrates the need to consider the public's input early in the project design.

The site conditions caused problems with the effectiveness of silt curtains due to disturbance of sediment and release of oil. It is important to consider the nature of contaminant and site-specific factors such as tides and wind. Because PCBs were found in oil form, release of PCBs to the air occurred when oil rose to the surface.

10 Costs

The total project cost, including dredging, CDF construction, and the wastewater treatment plant was $20.1 million ($1,430 per cubic yard). The total dredging cost was $1.74 million ($124 per cubic yard).

11 Project Contact

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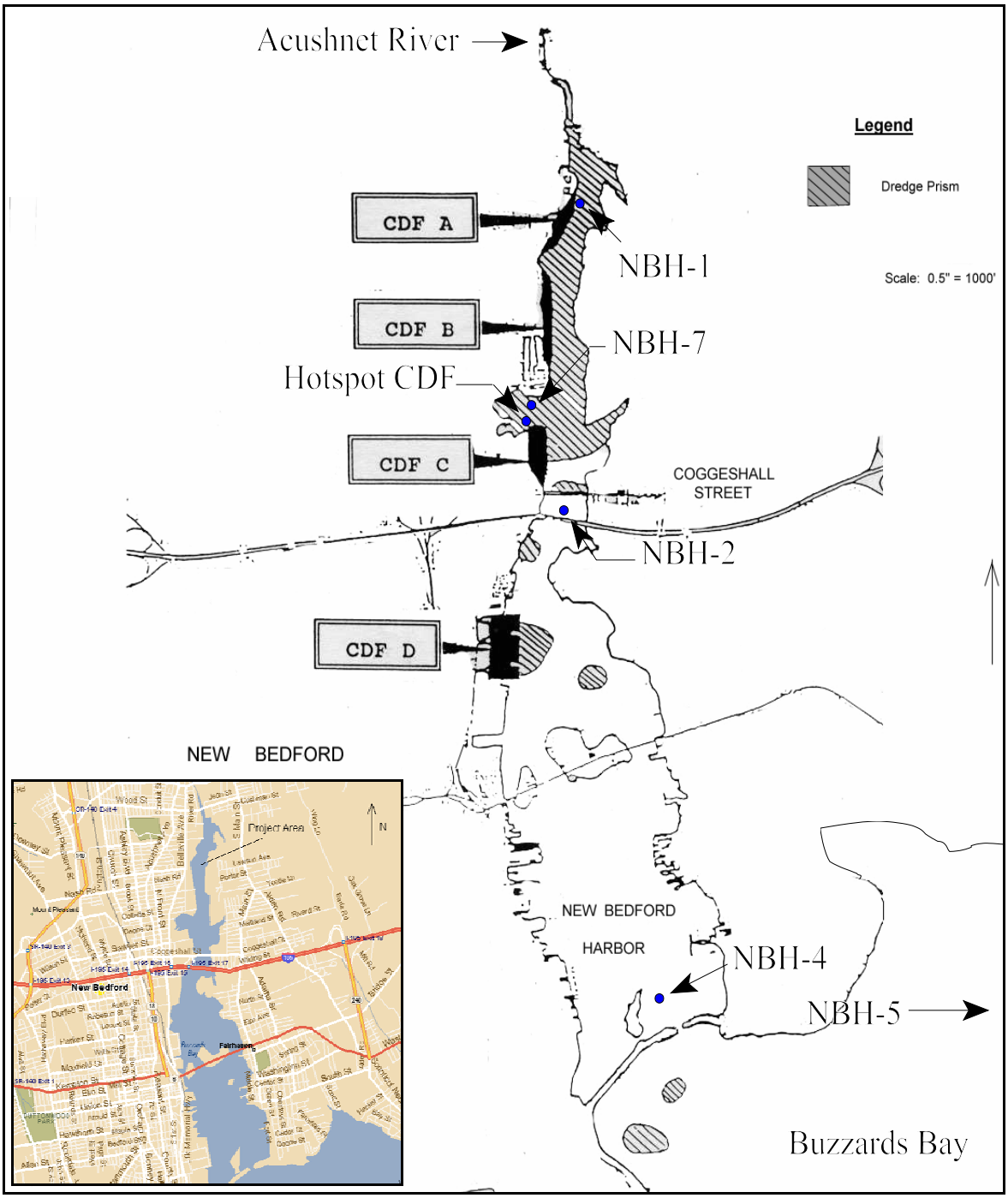
Figure 1 Remedial Dredge Plan - New Bedford Harbor



1 Statement of the Problem

- Dredged 1994
- Pencil Pitch
- 35,000 cubic yards
- $6.20 per cubic yard

Surface sediments were contaminated with pencil pitch (similar to coal tar) from offloading barge activities at the Port of Portland's Terminal 4, Slip 3, Berth 411 facility. Approximately 35,000 cubic yards of pencil pitch-contaminated sediments were mechanically dredged from in-water and underpier areas to achieve a 0.5 percent concentration (by weight). Remediation of spilled pencil pitch of Slip 3 at Terminal 4 was completed in December 1994 through January 1995, in accord with the Consent Decree ordered by the U.S. Environmental Protection Agency (EPA) and state of Oregon. The lead agency for the project was EPA Region 10 under the Clean Water Act.

2 Site Description

The Port of Portland operates Terminal 4, which is located along the Willamette River in Portland, Oregon, approximately 5.2 miles upstream from the confluence with the Columbia River. Terminal 4 is a multi-use, deep-draft cargo facility with 13 berths. Berth 411 has historically been a dry bulk facility used for offloading pencil pitch (coal tar), a cinder-like material used in the manufacture of diverse items including aluminum, electrodes and clay pigeons. Transported as finger-sized pellets, pencil pitch has been imported through the facility since the 1970s.

Aerial of Willamette River and Terminal 4
Source: Port of Portland

Adjacent to the Willamette River, Slip 3 at Terminal 4 is not directly subjected to the currents of the river. The slip experiences sedimentation of fine-grained materials as a result of the slower circulation in the slip relative to the river. The water depths in the slip vary from -45 feet Columbia River Datum (CRD) at the entrance of the slip to -36 feet CRD at the head of the slip.

3 Site Investigation

Initial sampling to determine the extent of pencil pitch in Terminal 4 sediments was conducted in December 1988 consisting of grab and sediment core samples. Those samples were analyzed for physical and chemical characteristics. In early 1989, chronic and acute bioassays were performed using crushed pellets from a new pencil pitch shipment. Depth of pencil pitch contamination was in the upper 10 to 15 cm within Slip 3 near Berth 411 with no acute toxicity detected. Since Terminal 4 was not CERCLA site, a record of decision was not applicable. The site was

remediated under Consent Order RE: USA versus Port of Portland, No. CV 93-267 RE (D.OR) Terminal 4 Consent Decree.

Contaminants of Concern. The major contaminants of concern were primarily polynuclear aromatic hydrocarbons (PAHs) and some trace metals (lead, copper and zinc) with a maximum detected concentration of 33 percent total PAHs (330,000 ppm TPAHs). PAHs were listed as toxic pollutants under Section 307 of Clean Water Act (CWA) and 40 CFR 401.15.

4 Target Goals and Project Objectives

The project was performed under consent decree to remediate spills of pelletized pencil pitch (coal tar) at the Port of Portland's Terminal 4, Slip 3, based on chemical concentration. No acute toxicity was found related to the spilled pellets although the consent decree stated that PAHs may cause adverse health effects under certain circumstances. The consent decree specified that pencil pitch levels were to be remediated to 0.5 percent (by weight) as defined through infrared scanning spectroscopy (IR scanning). Consent Decree, page 6, stated:

> "For purposes of this Consent Decree, removal and disposal shall be considered to be complete when pencil pitch levels are at or below one-half of one percent dry weight of the sediments remaining in the slip as determined by sampling and testing."

The site was to be remediated within four years of the Consent Order. The Consent Decree specified either an upland or aquatic confined disposal area. Even though the consent decree did not specify remediation levels for trace metals and PAHs, the dredging plan addressed the remediation of the entire sediment matrix.

5 Project Design

The Port of Portland developed a dredge plan called Dredging, Transportation and Disposal Plan that described the proposed remediation effort for permitting purposes as well as for construction purposes. It formed the scope of work for the contractor's work and integrated the controls of the Consent Decree. The objective of the operation was to remove contaminated sediments by mechanical dredge, load them into bottom-dump scows, and dispose of them at a confined disposal area. Removal of the pencil pitch was specifically designated by the Consent Decree; capping was not an option.

The dredging contract was awarded to M. Cutter, who was given flexibility to modify operations to meet the project goals. However, since dredging operations were successful as proposed, modifications to the plan were not necessary. Insufficient information was available to know whether the contract was competitively bid or awarded based on low-bid or qualifications-based.

The Port, with EPA's assistance and consult selected a confined in-water disposal area at Hardtack Island, part of the Ross Island Lagoon mining and disposal operation operated by Ross Island Sand & Gravel. The disposal area is located approximately 9 miles upriver from Terminal 4 (EPA, 1993).

Operational Constraints. The remediation plan required dredging of riprapped banks located under the docks of Terminal 4. Sediments overlaying the riprap were inaccessible with a bucket dredge. These sediments were "swept" with a hand-operated airlift pump into the middle of the slip and then dredged as usual.

Permits/Restrictions. Project permit conditions stipulated the use of a closed bucket mechanical dredging system. An exception was made for materials along the riprap under the dock face that were inaccessible to a mechanical dredge. The Consent Decree and permit also contained requirements for water quality monitoring to meet State Section 401 requirements and the placement of a silt curtain across the entrance to Slip 3. Remedial dredging was carried out under federal Nationwide Permit 38 and State Removal/Fill Permit #RF8820.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. The contractor mobilized to the site on December 17 and 18, 1994 and dredged from December 19 to January 7, 1995, taking only Christmas Day off (19 days). Dredging activities operated for two consecutive eight-hour shifts and then took one eight-hour shift for maintenance.

Equipment. An enclosed, or "shrouded" bucket was selected by the contractor for the clamshell dredge. The clamshell bucket placed dredged material from open-water areas into bottom-dump barges. A silt curtain was placed across the entrance to Slip 3. Nearshore sediments overlaying the riprap were inaccessible with a bucket dredge so these sediments were "swept" with a hand-operated airlift pump into the middle of the slip and then dredged as usual.

Total Volume Removed and Production Rates. Approximately 35,000 cubic yards of sediment was removed by a clamshell bucket and loaded into bottom-dump barges.

6.2 Dewatering and Water Treatment Operations

Mechanically-dredged material was transported in bottom-dump barges to an aquatic confined disposal area. Water treatment was not an issue, and water quality monitoring was not needed.

6.3 Storage and Disposal

The Port of Portland selected a confined aquatic site as its disposal area. The selection of an aquatic confined site was consistent with the

Environmental Protection Agency's preference for confined in-water disposal. Short-term or interim storage of the material was not necessary. The material was carried in dump scows approximately 9 miles upriver to the aquatic disposal area at Hardtack Island operated by Ross Island Sand & Gravel. The Dredging Plan stipulated that the dredged sediment from Slip 3 would be covered with 1 foot of clean cap material within one month of placement (ACOE, 1994).

The CDF operated in conjunction with a sand and gravel mining operation by private party with long-term submerged lands lease with the State of Oregon. The disposed material, both clean and contaminated was used to replace materials harvested from the island site by Ross Island Sand & Gravel.

7 Environmental Monitoring Program

The environmental monitoring program included bathymetry, sediment chemistry and bioaccumulation tests, water column monitoring and toxicity tests (State of Oregon, 1995; Hartman Associates, 1995).

7.1 Baseline

Initial baseline data collection and characterization occurred in December 1988 when the Port of Portland carried out synoptic studies of the horizontal and vertical distribution of pencil pitch at Slip 3.

Physical. Hydrographic surveys of all Port terminals were conducted on a regular basis by the Port of Portland to determine dredging needs. Slip 3 was surveyed during routine reconnaissance surveys near the time of the original pencil pitch distribution studies in late 1988. However, bathymetric surveys were not referenced in original characterization studies. Sediment grain size was also measured from the samples taken in December 1988.

Chemical. Chemical characterization had two primary purposes:

- Quantify the amount of pencil pitch in the sediment; and
- Quantify the presence/absence of PAHs, trace metals, pesticides and PCBs.

Preliminary laboratory testing was conducted to determine whether and how pencil pitch was distinguishable from the sediments themselves. Results of the laboratory studies indicated that pencil pitch had very low solubility in water, and the concentration of pencil pitch could be detected and roughly estimated in sediment by extraction with freon and IR scanning.

The horizontal extent of pencil pitch in the sediments was determined by collecting 28 surface samples to a depth of 10 cm and determining the physical and chemical properties (grain size, organics). The presence or absence of pencil pitch was established by estimating its concentration by

volume (g/cc) using IR scanning. Samples were additionally analyzed for PAHs, trace metals, pesticides and PCBs. Sediment core samples were also taken at six stations to estimate vertical distribution of contamination.

The IR scan of Terminal 4 sediment samples measured concentrations of pencil pitch ranging from a high of 33 percent to less than 1 percent a short distance away. Results indicated the pencil pitch residue was confined to the upper 10 to 15 cm of surface sediments. Results of PAH testing demonstrated PAHs outside the area known for pencil pitch concentration. Their connection to coal tar contamination was inconclusive so a correlation between pencil pitch and PAHs could not be determined.

Background water quality sampling was performed on December 17 and 18, 1994. Data included ambient water quality profiles for field positions and laboratory analysis of total suspended solids (TSS), and turbidity.

Biological. Water column toxicity tests, sediment toxicity tests and bioaccumulation studies were conducted in 1988 to determine acute and chronic toxicity to aquatic organisms (invertebrates and fish). Tests were designed under "worst-case" conditions. The water toxicity tests included elutriate tests to examine the flux or bioavailability of PAHs between pencil pitch and the water column. The potential for bioaccumulation was evaluated by determining body burden after 20-day exposure. Creating the "worst-case" scenario with pencil pitch for bioassays was problematic; grinding the pellets changed the pencil pitch's physical form so that *in-situ* conditions could not be replicated and correlations made with confidence.

Chronic and acute toxicity testing resulted in the following:

1. The elutriate was not acutely lethal to the freshwater cladoceran *Daphnia magna*. However, sublethal toxicity was evident in the 100 percent elutriate, but not at 30 percent.

2. Pencil pitch in powdered form was toxic to the freshwater amphipod *Hyalella azteca* at all levels (0.4, 4, and 40 percent by weight).

3. Limited bioaccumulation of five PAH compounds occurred in coho salmon exposed to 4 percent pencil pitch powder in sediment. The tests were terminated after 12 days due to high mortality.

7.2 Implementation During Dredging

Physical. Hydrographic surveys were conducted for purposes of dredging contractor payment.

Chemical. The State Water Quality Permit required initial characterization of the ambient conditions of the construction, disposal, control and reference sites prior to startup. Previous monitoring near the site demonstrated high variability in turbidity and TSS since the site is along an active navigation channel and downstream of shipyard operations. Sampling location requirements included:

- One reference site (upriver and out of project influence),
- Stations in the construction site within the silt curtain, and
- A control site outside the silt curtain.

The Port's final sampling locations included an upstream reference point, a downstream control point, a point in the mixing zone of the dredging area, and disposal site point. Real-time data were reported from three depth locations in the water column: surface at approximately 2 to 3 feet below the water surface; the mid-depth; and the bottom, approximately 3 to 6 feet off the river's bottom. Daily reporting of water quality during both dredging and disposal was required by the water quality permit. TSS samples were collected only when the mean turbidity value was greater than 10 NTU above the mean background value. Water quality requirements included:

- *Turbidity (Jackson Turbidity Units, JTU):* No more than a 10 percent cumulative increase in natural stream turbidities as measured relative to a control point.

- *Dissolved Oxygen:* Maintained above 8.0 mg/L outside the silt curtain.

- *Pencil Pitch:* Monitored in the water column to ensure that the resuspension of particulate pencil pitch was not entering the waterway. Pencil pitch measurement was specified as *in-situ* colorimetric analysis, as an alternative to IR scanning. Since IR scanning required two weeks of laboratory time, the method was not responsive to ongoing construction operations.

Measurements indicated that natural variability in river conditions for turbidity was highly variable (10 to 55 NTU) at the Terminal 4 sampling stations and that natural events such as propeller wash and storm events raised turbidity levels more than dredging. Dissolved oxygen remained stable to the background measurement except during storm events when it dropped.

Water quality samples were also analyzed for pencil pitch at all locations with results reported within 24 hours using *in-situ* colorimetric analyses. With a reporting limit of 0.001 percent, and a method detection limit of 0.00025 percent, no pencil pitch was detected.

Sediment samples were collected during dredging to confirm contractor progress and provide information on sediment chemistry. Sediment

samples were analyzed for pencil pitch, trace metals, PAHs, and grain size. Sampling dates were December 27, 1994, and January 5, 1995. Analytical results from some areas exceeded the target cleanup goals and required redredging. Redredging and resampling was conducted before equipment was demobilized.

Biological. No biological testing was conducted during dredging.

7.3 Post

Physical. Post-dredging surveys were conducted and additional dredging was performed based on those survey results.

Chemical. Over 30 post-dredge sediment samples were collected on January 7 and 26, 1995 after redredging of areas and resampling. The chemical analyses by IR scanning indicated that the pencil pitch levels had been reduced to below the specified 0.5 percent (by weight) in all of the dredged areas. Additionally, the concentrations of trace metals and PAHs showed a substantial reduction in concentrations relative to the pre-dredge levels.

Biological. None required or performed.

7.4 Long Term

No long-term monitoring of the dredging site appears to have been required. A monitoring program for the disposal area was instigated in 1999 due to other concerns in the Willamette River and at the disposal area.

Table 1 Summary of Monitoring Results

Testing Parameter		Concentration			
		Baseline 1988/1994	**During 1994/1995**	**Post 1995**	**Long Term**
Bathymetry		Yes	Yes	Yes	
Surface Sediment (0 to 10 cm)		(N = 28) 1 to 33% pencil pitch	Some exceedances; redredged	(N = 30) <0.5% pencil pitch, PAHs, and metals decreased	None required
Water Column Toxicity Tests	*Daphnia magna*	Not lethal, but sub-lethal >30%	None	None	None required
	Hyalella azteca	Lethal at all test levels	None	None	None required
Surface Water Quality		TSS/turbidity	10 to 55 NTU pencil pitch = no exceedances DO stable	—	None required
Sediment Bioaccumulation		Limited bioaccumulation (inconclusive)	None	—	—

8 Performance Evaluation

The project was considered a success since the terms of the consent order were fulfilled. Chemical analyses of sediment samples indicated that the concentrations of pencil pitch remaining in the sediments after dredging was below the cleanup target goal of 0.5 percent limit (by weight) in all areas of the dredge prism. Even though the consent order did not specify a reduction level for PAHs, post-project sampling showed that concentrations of trace metals and PAHs in the sediments were substantially reduced. Water chemistry samples collected during dredging also indicated no measurable release of pencil pitch from the dredging operations.

9 Costs

The pencil pitch remediation effort cost approximately $212,000 to dredge 35,000 cubic yards ($6.20 per cubic yard). This cost did not include disposal or capping efforts (Haynes, 2000).

10 Project Contact

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11 References

ACOE, 1994. Portland District, U.S. Department of the Army Nationwide Permit 38 Pre-Discharge Notification, Application No. 94-549.

EPA, 1993. Civil Minutes of Consent Decree CV 93-267 RE: USA versus Port of Portland. United States District Court, District of Oregon. Date of Proceeding May 7, 1993.

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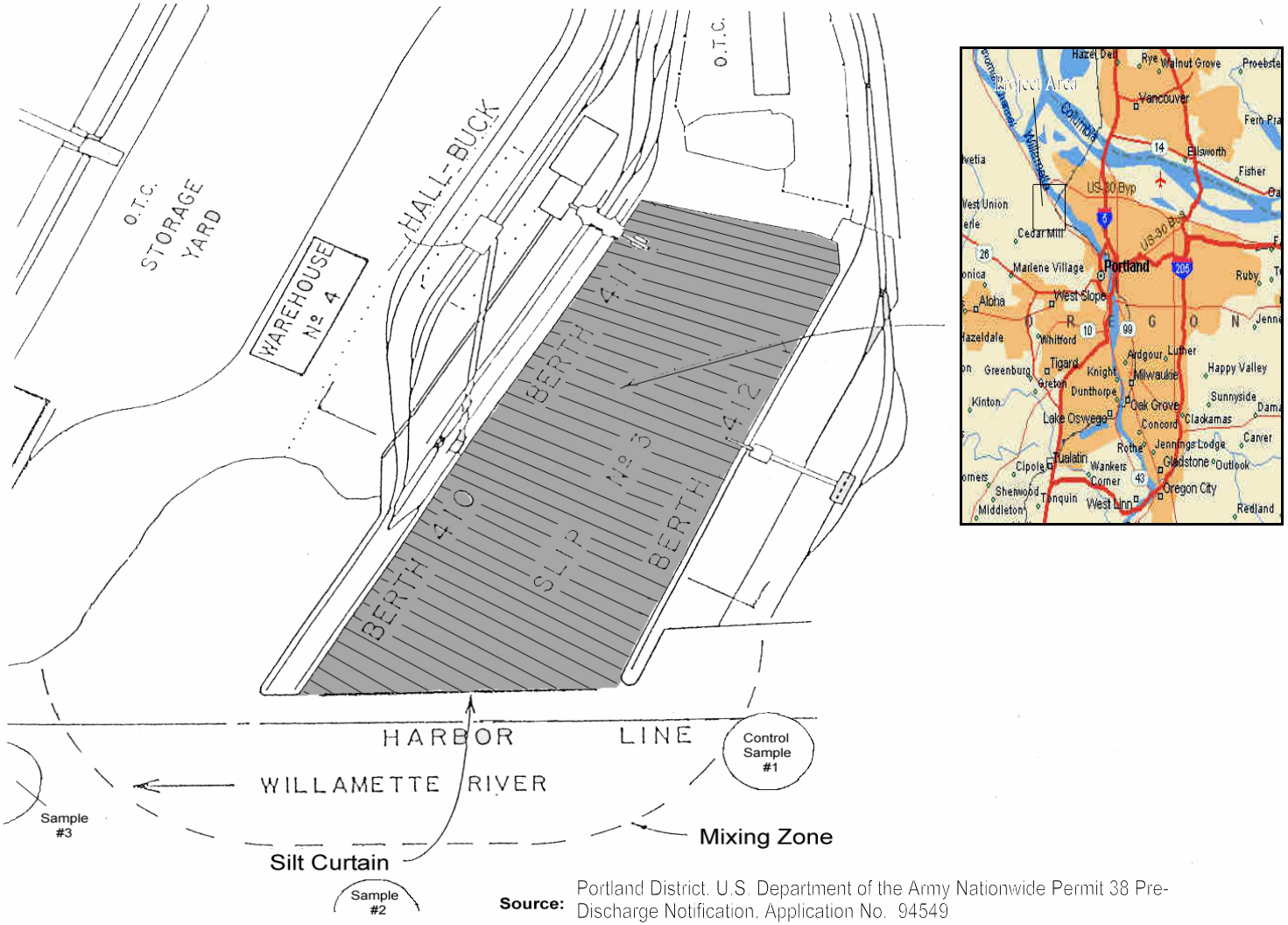
Haynes, Walt, 2000. Personal communication with Project Engineer at Port of Portland, Portland, Oregon. January 5.

State of Oregon, 1995. Material Removal/Fill Permit No. 8820 for the Port of Portland. Oregon Division of State Lands. August 29.

Figure 1 Remedial Dredge Plan - Port of Portland T4 Pencil Pitch



Source: Portland District. U.S. Department of the Army Nationwide Permit 38 Pre-Discharge Notification. Application No. 94549

PORT OF VANCOUVER COPPER SPILL - VANCOUVER, WASHINGTON

1 Statement of the Problem

- Dredged 1990
- Copper
- 1,900 cubic yards
- $526 per cubic yard

Approximately 1,900 cubic yards of sediment were contaminated with copper concentrate exceeding state standards from bulk loading activities along Berth 7 at the Port of Vancouver. The maximum detected concentration in surface sediments was approximately 68,000 ppm copper. The state required removal of sediment from in-water and under dock areas to less than 1,300 ppm copper concentration in surface sediments. Sediments were hydraulically dredged to a depth of 1.5 feet in July and August 1990 with baseline, progress, and post-monitoring performed for chemical exceedances. The lead agency for this project was the Washington State Department of Ecology (Ecology).

2 Site Description

The Port of Vancouver's Berth 7 (bulk loading facility) is located on the Columbia River at River Mile Post 104.5 near Vancouver, Washington. With a 40-foot-deep navigation channel, the Columbia River represents a major shipping corridor used by deep-draft vessels and barges. The currents in the Columbia River vary throughout the year, but an average current is on the order of a few feet per second. Also, the currents differ across the project site, being slower in the shallower water than the main channel.

Aerial Port of Vancouver
Source: EPA

The site sediments were contaminated with copper concentrate from material spilling from ship loading conveyors prior to 1987. The water depths affected by high levels of copper concentrate range from -5 feet Columbia River Datum (CRD) to deeper than -40 feet CRD. The river sediments at the project site consist primarily of poorly graded medium to fine sands with about 10 percent of fines (silt and clay fraction). Since the copper concentrate was fine grained, the percent of fines served as an indicator to the amount of concentrate present. The sediments with the highest copper concentrations had approximately 25 percent fines. Based on Ecology data and U.S. Army Corps of Engineers (ACOE) database information, the average background copper concentration in Columbia River sediments was approximately 24 to 25 ppm copper.

3 Site Investigation

Since 1982, the Port of Vancouver has operated an ore concentrate transfer facility at its dockfront site, using conveyors to transfer copper concentrate into deep-draft ships for export. Prior to 1987, a section of the ship loading conveyor system lacked protection against spillage loss into the Columbia River. Sediment sampling conducted in 1988 indicated that copper concentrations in the sediments below the loading

dock exceeded 68,000 ppm, classifying the sediments as dangerous waste under Ecology regulations. The initial field sampling and laboratory analyses were conducted in 1988 with additional data collected in 1989. Sediment samples were collected and analyzed to determine the copper concentrations, acute bioassay toxicity, and benthic macroinvertebrate abundance. Pursuant to the Model Toxics Control Act (MTCA), Ecology issued a Remedial Action Order (No. DE-90-5189) to the Port of Vancouver for contaminated sediments. Ecology set the cleanup criteria at 1,300 ppm copper since testing indicated that this concentration did not exceed the lower limit of toxic effects for copper concentrate.

Contaminants of Concern. The contaminant of interest was copper concentrate. The highest copper concentrations were centered below the dock at Berth 7, as shown on Figure 1, with lower concentrations surrounding the dock area. Based on sediment sampling, the extent of copper contamination appeared to extend from the surface down to a depth of 18 inches. The maximum copper concentrations at the project site were around 70,000 ppm, located in a central deposit underneath the upstream dock face.

4 Target Goals and Project Objectives

Ecology established a cleanup level of 1,300 ppm (mg/kg) for copper concentration. The remedial objective was 100 percent removal of contaminated sediment exceeding 1,300 ppm copper surrounding Berth 7. Defined by previous sampling investigations, the target depth for dredging was 2 feet (with 6 inches of overdredge included). This target depth was assumed to meet the required 100 percent mass removal objective.

Although the chemical cleanup criteria was established by Ecology, the port interpreted the target objective as the overall average sediment concentration had to be below 1,300 ppm copper, while Ecology intended every sediment sample to be below 1,300 ppm copper (each grid sample).

5 Project Design

The remedy planned to dredge approximately 1,900 cubic yards of material to a target removal depth of 1.5 feet. Due to the high copper concentrations, the sediments underneath the bulk loading dock at Berth 7 and adjacent areas along the upstream dock face (Figure 1) were designated a dangerous waste under Revised Code of Washington (RCW) 173.303 Washington State regulations. Termed Area A, the Dangerous Waste Zone contained approximately 310 cubic yards of material (Port of Vancouver, 1990). Area B comprised the remainder of the dredge prism (1,600 cubic yards) with the sediments containing copper concentrations in excess of 1,300 ppm (but well below Area A concentrations), but still requiring remediation. The dredge prism was subdivided into a grid with cells measuring 40 feet by 40 feet to assist project management. Dredging was the only activity considered feasible for the site. While natural recovery would have decreased the high levels of copper concentrate due to sediment transport, the amount of time required was unacceptable to the agencies. Given the site's proximity to

a navigation channel, capping was not a preferred alternative. Dredging was not required to maintain navigational depths. Dredged material was pumped to upland disposal sites located on the Port of Vancouver's property for permanent storage or treatment depending upon chemical concentration (Ogden Beeman, 1989 and 1991).

Operational Constraints. No information available.

Permits/Restrictions. Permits for this project included the USACE Section 10/404 and Washington Department of Fisheries Hydraulic Project Approval.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. The primary dredging work occurred from July 17 through August 16, 1990. Dredging was permitted to occur 24 hours a day.

Equipment. A small cutterhead pipeline dredge performed the initial dredging for the entire prism, dredging the Dangerous Waste Zone (Area A) first and then completing Area B. For the area underneath the dock, diver-operated redredging was necessary since the pipeline dredge was unable to reduce the copper concentrations below the threshold level in some locations.

Total Volume Removed and Production Rates. Information not available.

Site-Specific Difficulties. Sediments beneath the loading dock proved difficult to access with dredging equipment due to the limited horizontal and vertical clearances. The loading dock consisted of a concrete pier supported by 35 to 40 steel piles with a row of 8 to 10 steel fender piles along the face of the dock. The pilings underneath the dock were closely spaced with a vertical clearance less than 20 feet. In addition, steep, unstable gravel slopes under the dock made successful remediation difficult. The contractor changed methods to better access underpier areas, with limited success (see monitoring section).

One other factor involved the heavier weight of the copper concentrate relative to the river sands. Follow-up sampling indicated that during dredging, a fraction of the heavier copper particles were not entrained by the hydraulic dredge, but rather resuspended and redeposited on the bottom as confirmed by verification sampling.

6.2 Dewatering and Water Treatment Operations

Two dewatering/disposal sites were used, depending upon the characterization of the dredged material. The dredged material containing dangerous wastes from Area A was discharged to Disposal Site I, a lined, diked sedimentation pond on the Port's property, to allow the solids to settle out of suspension. Dredged material from Area B was deposited in

an upland disposal site on Port property termed Disposal Site II. The disposal site was located on a paved lot equipped with surface drains that connected to the Port's stormwater treatment facility. Settling basins were used to treat the large volumes of return flow created by hydraulic dredging with the discharge water returned to the river per authorization from Ecology.

If the return water from either disposal site contained copper concentrations that exceeded the Ambient Water Quality Standards chemical criteria, then the return water was treated in the Port's stormwater treatment facility and discharged to the City of Vancouver's Westside Treatment Plant. No problems occurred with surface water since all water samples collected were non-detect for copper.

6.3 Storage and Disposal

Disposal of the dredged material depended upon the concentration of copper in the sediments. For the dredged sediments with high levels of copper (from Area A), the materials were piped to Disposal Site I, a temporary dangerous waste disposal site located on Port of Vancouver property. The port planned to recycle the dredged solids through the ore process system to recover the copper concentrate. For the sediments with significantly lower copper concentrations (from Area B), recovery of the ore was not cost effective and the materials were piped to Disposal Site II, an upland site located on port property (Port of Vancouver, 1990).

7 Environmental Monitoring Program

The monitoring program included bathymetry surveys, water column sampling and sediment sampling for compliance with chemical criteria. Baseline toxicity testing and benthic abundance studies were also conducted (Table 1) (Century West, 1989 and 1990).

7.1 Baseline

Physical. A pre-dredge survey was performed within two weeks of the start of dredging and served as the contract basis for the work.

Chemical. The initial field sampling and laboratory analyses were conducted in 1988 by Century West Engineering with additional data collected in 1989. Sediment samples were collected by surface grabs and core samples and analyzed to determine the copper concentrations present.

Biological. Based on the results of acute static bioassay tests and benthic macroinvertebrate studies, Ecology designated a portion of the dredged materials, contained in Area A, to be Dangerous Waste.

7.2 Implementation During Dredging

Physical. No surveying was performed during the dredging operation.

Chemical. As a condition of the permits, water quality sampling was performed three times during the first week of dredging to monitor turbidity and dissolved copper concentrations. For the initial dredging in the Dangerous Waste Zone (Area A), samples were collected on the first day of dredging, July 17, 1990, and also later on July 19, 1990. For Area B, one round of samples was gathered on the first day of dredging, July 27, 1990. Samples were gathered downcurrent of the dredging at both the midpoint of the dilution zone (225 feet from the dredge) and at the dilution zone boundary (450 feet from the dredge). Within the water column, samples were collected near the surface, mid-depth, and 3 to 5 feet above the river bottom.

Ecology established an upper concentration limit of 12 ppb of copper at the edge of the dilution zone (450 feet downcurrent from the dredge). Based on the results of the sampling analyses, no detectable concentrations of dissolved copper occurred at the midpoint or downstream boundary of the dilution zone.

One sediment sample was collected from each of the 35 grid cells (Figure 2) in the dredge prism and analyzed to determine the level of copper concentrate that remained in the bottom sediments. The sediment samples were gathered from Area A on August 3, 1990 following the completion of the dredging of the Dangerous Waste Zone with the samples for Area B gathered on August 16, 1990.

Sampling results indicated that cells 4, 10, 11, 17, 18 and 25 contained copper concentrate levels that exceeded the 1,300 ppm threshold (six out of 35 cells). Using a diver-articulated dredge, cells 4, 11, and 10 were redredged, in that order, with the cutterhead hydraulic dredge used in cells 17, 18 and 25. Cells 10 and 11 were redredged again with the cutterhead due to a ridge of gravels and cobbles raising concerns about diver safety.

Biological. No biological testing was performed during dredging.

7.3 Post

Physical. Post-dredge surveys were conducted within three working days following the completion of dredging.

Chemical. The redredging effort during August 1990 for the remaining hotspots also proved unsuccessful at removing enough copper concentrate to drop the level below 1,300 ppm of copper for three grids (Table 2). Post-dredge sediment sampling revealed that three cells in the dredge prism grid (numbers 10, 11 and 25) still had copper concentrations in excess of 1,300 ppm. Cells 10 and 11 were located underneath the dock on a slope that varied from 1V:4H to about 1V:2H. In cells 10 and 11, the sediments consisted of a shallow (1 foot) layer of sandy sediment mixed with gravel, underlain by a layer of cobbles and rock. Cell 25 was located in the channel of the Columbia River with water depths of -40 feet to -44 feet CRD and sandy bottom sediments. The combination of water depth and river currents at Cell 25 proved problematic for the

dredge given the weight of the heavier copper particles relative to the sandy bottom.

Overall, the average copper concentration after dredging was 622 ppm for all of the grid cells (both Areas A and B), which was lower than the perceived agency objective of 1,300 ppm for copper. However, according to Ecology, the cleanup criteria required that each grid sample be below 1,300 ppm copper.

Biological. No biological testing was performed after dredging.

7.4 Long-Term

Additional sediment sampling was performed in April 1991 to determine the current copper concentrations at the time. While sampling showed that residual copper concentrations had diminished, the sediment sampling also revealed that four cells contained copper concentrations in excess of 1,300 ppm, specifically cells 10, 11, 25 and 26, as shown in Figure 3.

Table 1 Summary of Monitoring Results

Testing Parameter	Copper Concentration (ppm)			
	Baseline 1988–1990	During Dredging July/August 1990	Post-Dredging August 1990 (3 days after)	Long Term April 1991
Bathymetry	Yes	None	Yes	
Surface Sediment Grabs	ND to 68,000	None	(N = 35) ND to >1,300 (Avg = 622)	ND to >1,300
Sediment Cores	NA	None	None	
Water Column	None	No exceedances	None	
Sediment Toxicity Tests	NA	None	None	
Benthic Macroinvertebrate Community	NA	None	None	

Notes:

NA - Data not available for review.
ND - Non-detect.
None - Not tested.

Table 2 Summary of Post-Dredge Copper Concentrations

Grid Cell Number (35 total)	Sediment Copper Concentration (ppm)	
	August 1990 (days after redredging)	April 1991
10	4,790	2,020
11	4,610	2,030
25	3,430	5,240/4,280 (duplicate)
26	906	1,570
All Other Cells	<1,300	<1,300

Cell 26 was located downstream and adjacent to cell 25 with natural downstream sediment transport credited for the increase in the copper concentrate level.

Given the location of cells 10 and 11 underneath the dock, limited options existed to allow dredge equipment access to the area, with diver-controlled apparatus being the most viable alternative. However, the unstable nature of the slope, combined with the presence of gravels, cobbles and rocks posed a serious threat to diver safety. In cells 25 and 26, the river's velocity and water depths hampered the ability of the dredge to reclaim the copper concentrate.

8 Performance Evaluation

Dredging successfully reduced the overall average copper concentration to well below the agency objective of 1,300 ppm from the area around the Berth 7 bulk loading facility at the Port of Vancouver. However, isolated spots with concentrations of copper concentrate exceeding 1,300 ppm remained underneath the dock and in the river channel, despite repeated dredging attempts.

For discrete samples, the dredge prism was divided into 35 discrete cells within the dredge footprint (grid) and surface sediment samples were collected from each cell after dredging. Out of 35 samples, only three samples exceeded the compliance criteria of 1,300 ppm copper after repeated dredging attempts (88 percent success). Dredging was difficult in these three areas (two underpier, one open channel) because of unstable cobbles and gravel ridges under the piers and strong currents in the open channel.

Overall, the dredging did not fulfill the agency objective of remediating the entire prism to copper concentrations below 1,300 ppm. The difficulties encountered in dredging were primarily related to two factors:

1. The gravels and cobbles under the dock were covered by a foot of sand and were not detected during sampling due to the difficulty in obtaining sediment cores in sands. The

threat to diver safety introduced by the ridge of gravels and cobbles eliminated using diver-operated equipment while the restricted access hampered the operation of mechanical equipment.

2. The difficulty experienced by the dredge in removing the copper concentrate due to its heavier weight was not anticipated.

9 Costs

Project costs for dredging and disposal were approximately $1 million ($526 per cubic yard) for 1,900 cubic yards of contaminated sediment.

10 Project Contact

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11 References

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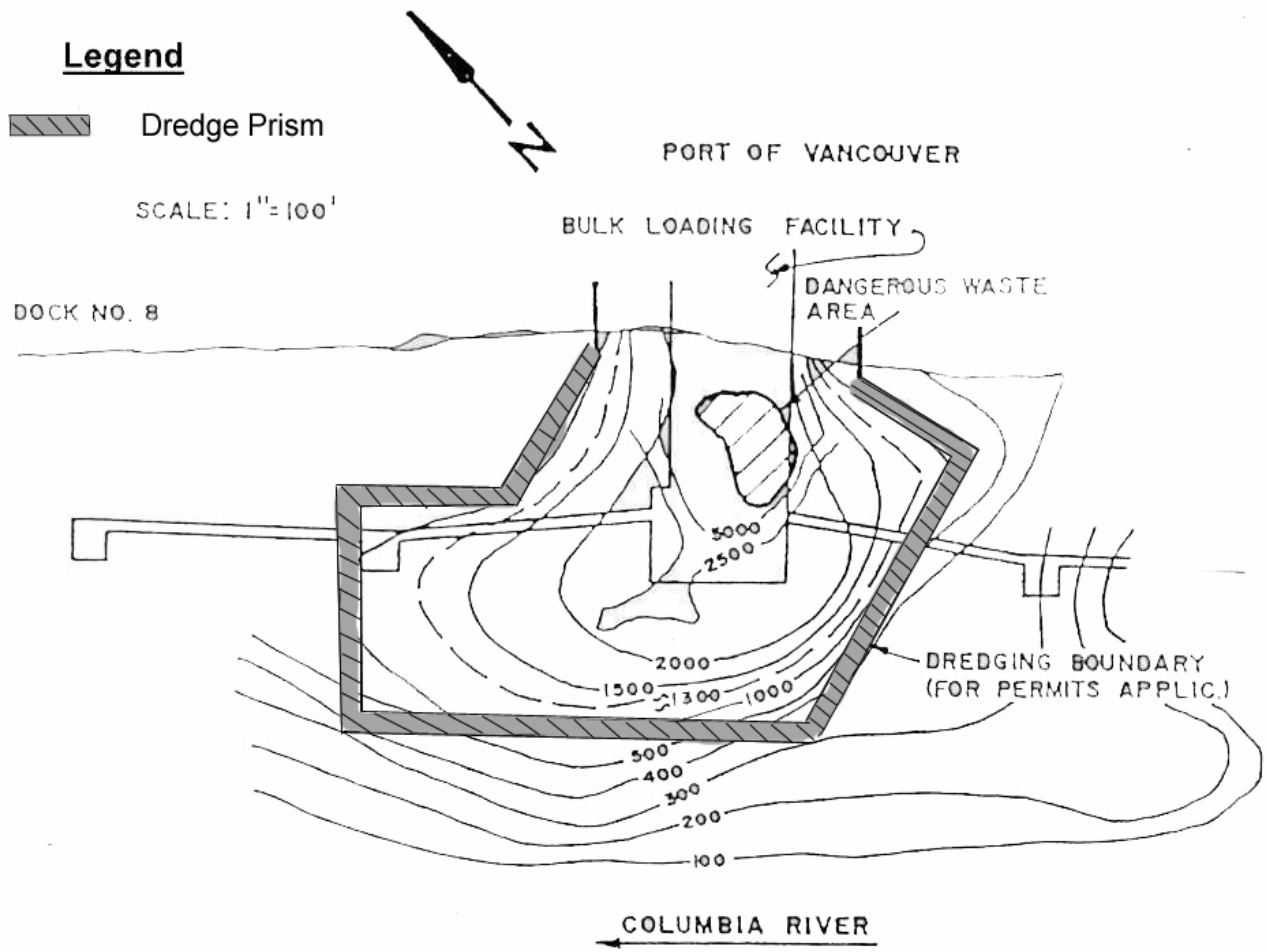
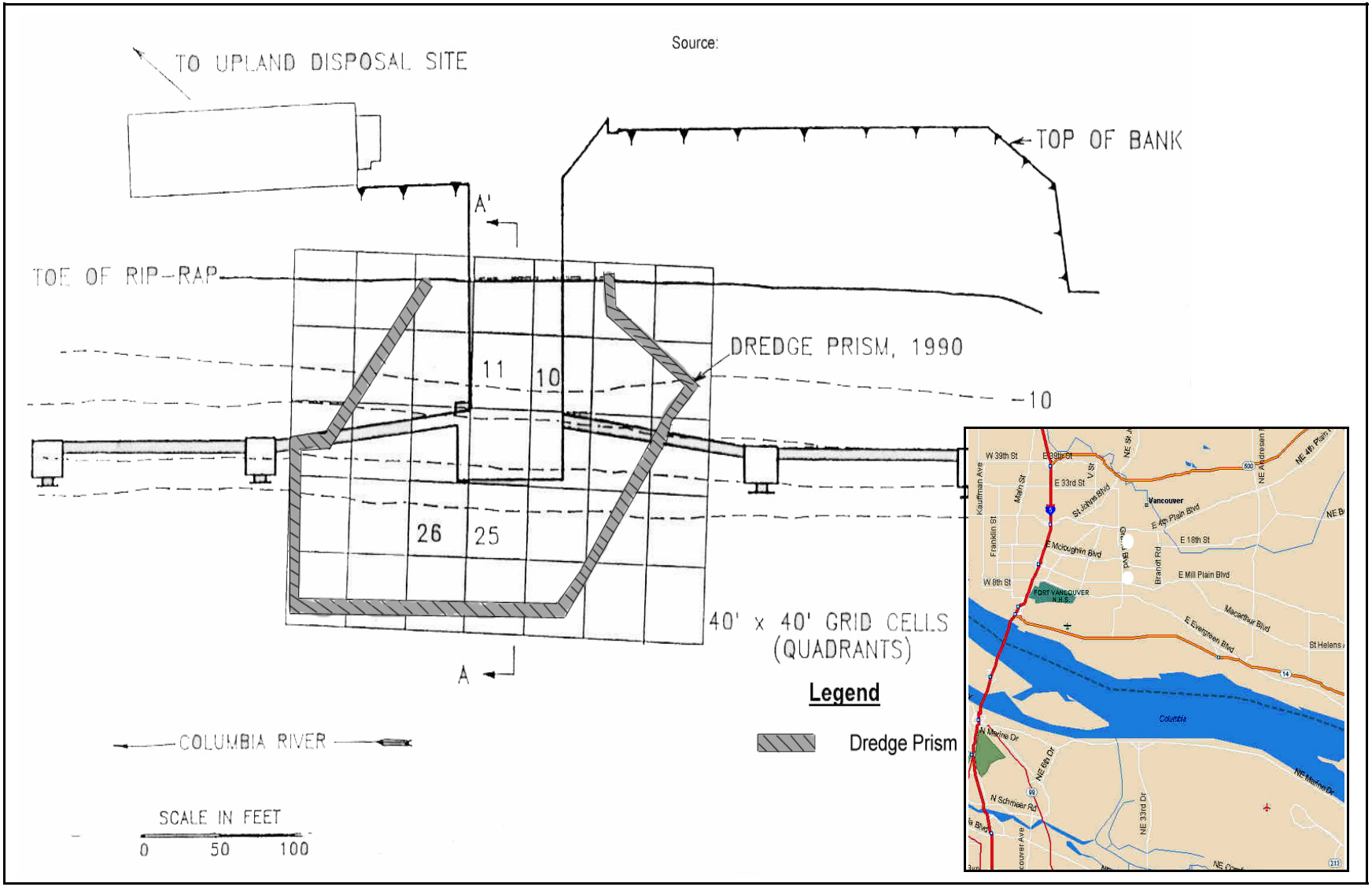
Figure 1 Remedial Dredge Plan - Port of Vancouver Copper Spill



Source: Century West Engineering

Figure 2 Remedial Dredge Grid Plan - Port of Vancouver Copper Spill



PUGET SOUND NAVAL SHIPYARD PIER D - BREMERTON, WASHINGTON

1 Statement of the Problem

- Dredged 1994-1995
- PCBs, PAHs, metals
- 53,400 cubic yards
- Costs not available

The primary purpose of the dredging project was to deepen the berths along Pier D to accommodate larger Navy vessels at the Puget Sound Naval Shipyard. However, the sediments in the vicinity of the pier were contaminated with a variety of metals and chemicals from shipyard operations since the late 1800s. Dredging provided the necessary navigational improvements with contaminated sediments within the dredging prism removed and relocated to an upland disposal site. Pier D is contained within Operable Unit B, which is currently being evaluated under CERCLA for additional remediation. The lead agency for this project was U.S. Environmental Protection Agency (EPA) Region 10 with the assistance from the Washington State Department of Ecology (Ecology).

2 Site Description

The Puget Sound Naval Shipyard is located on the northern shoreline of Sinclair Inlet in Bremerton, Washington (Figure 1). Established in 1891 as a naval station, Puget Sound Naval Shipyard built new ships during World War I, primarily repaired battle damage to ships during World War II, and modernized carriers after World War II. Currently, the shipyard repairs submarines and is a nuclear-capable repair facility. The largest and most diverse shipyard on the West Coast, the Puget Sound Naval Shipyard has the capability to alter, repair, construct, deactivate, overhaul and drydock the Navy's ships in addition to serving as the home port for nuclear cruisers and fast combat support ships (U.S. Army Corps of Engineers [ACOE]). Over time, the shipyard operations have resulted in the contamination of sediments with metals, polychlorinated biphenyls (PCBs), polynuclear aromatic hydrocarbons (PAHs), and other chemicals.

View of Puget Sound Naval Shipyard Pier D
Source: EPA

Sinclair Inlet is a slender estuary that connects to the main part of Puget Sound through Rich Passage. With a maximum depth of 65 feet, Sinclair Inlet is 3.4 miles long and has a maximum width of 1.4 miles. The wind-generated waves in Sinclair Inlet range from 0.5 to 2.5 feet in height with weak tidal currents producing maximum water velocities of 0.2 to 0.3 knots. Typically, the water movement is slow enough to allow fine-grained sediments to settle out of suspension and deposit within the inlet. As Washington State Shoreline of Statewide Significance, Sinclair Inlet is classified as a Class A water body, indicating that it is considered fishable and swimmable. Substrate consists of a 2- to 4-foot-thick layer of soft, black silt and fine sand (mud)

overlying a more dense, gray silty sand. Proposed dredge depth ranged between 4 and 13 feet below mudline with an average depth of 9.3 feet (ProTech, 1994).

3 Site Investigation

Under the Model Toxics Control Act (MTCA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the Navy is conducting a Remedial Investigation/Feasibility Study (RI/FS) on Operable Unit B, which includes the sediments at Pier D. Due to past fill practices, the site is classified as a hazardous waste site under the MTCA. Ecology's Toxic Cleanup Program and the EPA Region 10 Federal Facilities Superfund Section were the regulatory agencies during the design of the RI/FS. A CERCLA ROD for Operable Unit B has not been issued at this time. Other RODs for the Puget Sound Naval Shipyard Complex include EPA/541/R-97/046 for Operable Unit 1 and EPA/541/R-97/047 for Operable Unit 4. The Final Supplemental Environmental Impact Statement (FSEIS) for the Pier D dredging was prepared with coordination of the EPA Region 10, the ACOE Seattle District, Ecology, the City of Bremerton, Washington and the Suquamish Tribe (August 1994).

Contaminants of Concern. Sediment samples tested according to 1994 Puget Sound Dredged Disposal Analysis (PSDDA) criteria revealed elevated concentrations of metals, PAHs, PCBs, bis(2-ethylhexyl)phthalate, and DDT. The depth and extent of contamination at the Puget Sound Naval Shipyard extend beyond the dredging prism at Pier D. The contaminated area, termed Operable Unit B, encompasses a portion of the industrial core at the Puget Sound Naval Shipyard and the offshore sediments. It also contains the Pier D dredging footprint.

4 Target Goals and Project Objectives

The project goals were to maintain and expand navigational water depths. The scope of dredging was to enlarge the mooring basins on each side of Pier D to accommodate the Navy's largest vessels. The goal was to provide safe navigation depths and mooring for ACOE-type transport ships on the east and west sides of Pier D and for an aircraft carrier on the west side of Pier D. Water depths around Pier D were to be increased from -42 feet mean low-low water (MLLW) to -44.4 feet MLLW at the ACOE-6 berthing and to -49.4 feet MLLW at the deep-draft berth.

5 Project Design

The FSEIS anticipated dredging a total of 105,000 cubic yards of material, which included 1-foot of over-depth dredging. The materials to be dredged were mainly fine-grained silts and sands with more than 70 percent fine material. The sediments were similar to other sediments dredged from quiescent Puget Sound bays and harbors.

The dredging prism was divided into Dredged Material Management Units (DMMUs), following PSDDA guidelines, as shown in Figure 3.

The DMMUs were broken down into surface (a layer of the top 4 feet) and subsurface (a layer of material below 4 feet). The dredging footprint contained 63,100 cubic yards in the surface DMMUs and 42,000 cubic yards in the subsurface DMMUs. Based on chemical and biological tests, the PSDDA agencies (the ACOE EPA, Ecology, and Washington State Department of Natural Resources) designated each DMMU as either suitable or unsuitable for open-water disposal.

Of the 17 surface DMMUs, only six were suitable for in-water disposal: S1, S10, S11, S13, S15 and S17, with the rest of the surface DMMUs designated for upland disposal. Of the five subsurface DMMUs, three (C1, C3 and C4) were suitable for in-water disposal with C2 and C5 sent to upland disposal.

The FSEIS expected 51,700 cubic yards of material to be clean and approved for in-water disposal at the PSDDA Elliott Bay site near Seattle. Since the FSEIS considered the remaining 53,400 cubic yards as contaminated, the material was unsuitable for open-water disposal and designated for confined upland disposal. Where possible, the dredging of contaminated materials occurred first in an attempt to prevent contamination of clean material.

Operational Constraints. None specified.

Permits/Restrictions. Permits for this project included: the ACOE Section 10/404 and Washington Department of Fisheries Hydraulic Project Approval for dredging, an Environmental Impact Study for the EPA, and a Water Quality Certification from Ecology (Seattle District; Ecology, 1994).

Restrictions on dredging operations included limiting dredging to daylight hours and halting in-water disposal during periods of Treaty Indian fishing at the disposal site. In addition, booms were to be placed around the dredging area to contain oil or other floating material due to the dredging.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. Dredging operations began on the east side of Pier D from October to mid-December, 1994. The west side of Pier D was dredged from late December 1994 through mid-March 1995. The dredging schedule proposed a five-day work week with a single work shift per day. RCI Environmental, Inc. performed the dredging operations.

Equipment. For both the upland and open-water disposal methods, dredging was performed using a 6.5-cubic-yard flat rehandler clamshell bucket mounted on a derrick barge. A dump scow and tug were used to deposit the clean dredge spoils at the in-water Elliott Bay site while flat-deck barges transported the contaminated materials from the dredge to the upland holding area.

Total Volume Removed and Production Rates. The predicted production rates were 1,200 cubic yards per shift for contaminated materials and 2,000 cubic yards per day for clean materials (U.S. Navy, 1994).

Site-specific Difficulties. None specified.

6.2 Dewatering and Water Treatment Operations

Partial dewatering of the contaminated dredge materials occurred during a series of steps. Initially, water at the surface of the loaded barge was decanted back into Sinclair Inlet, provided water quality requirements were met. In addition, 21,000-gallon storage tanks were proposed to provide additional settling of suspended sediments prior to discharging the runoff from the transfer site into Sinclair Inlet. Surface water that collected in the back of the trucks en-route to the landfill was decanted into the landfill's leachate collection and treatment system.

Additionally, if the dredged material did not meet the landfill's final disposal requirements for water content, additional dewatering was proposed by processing the spoils through a pug mill mixer and adding pozzolan-portland cement. During the hydration of the portland cement, water is removed, and the final product is a mixture of sediment and concrete.

6.3 Storage and Disposal

After dredging, the contaminated materials were transported by flat scow to the upland holding area. At the holding area, a clamshell bucket moved the dredged material from the barge to the paved transfer site. Rubber-tired loaders managed the dredged material stockpile and loaded the trucks for transport to the landfill.

After the contaminated sediments were removed, adjacent clean sediments were dredged and placed on a dump scow for transport to the in-water PSDDA 415-acre disposal site located in Elliott Bay Seattle, WA. A bottom-dump barge was used to transport the clean material to the Elliott Bay disposal site, and the barge was inside the 600-foot radius dump target zone, the hull of the barge was opened, and the clean material released into the water.

Contaminated material unsuitable for open-water disposal was (53,400 cubic yards) designated for confined upland disposal. The contaminated dredged material was offloaded to trucks at an onshore staging area and disposed at an approved upland sediment disposal area. Ten miles south of the site on State Highway 304, the Olympic View (Kitsap County) Sanitary Landfill was the designated disposal site with transportation of the material accomplished by using trucks with trailers. If the local landfill was eliminated as an option, railcar containers were proposed for distant upland disposal at sites including commercial landfills at Roosevelt, Washington and Arlington, Oregon, about 280 miles from Puget Sound Naval Shipyard.

7 Environmental Monitoring Program

7.1 Baseline

Physical. Prior to dredging, the dredging prism was surveyed to establish volumes of material to be removed.

Chemical. Following PSDDA guidelines, chemical analyses were performed on the sediment core samples taken from each DMMU in 1993. Chemicals detected at levels above the 1994 PSDDA screening levels included the following for various DMMUs: antimony (Sb), cadmium (Cd), copper (Cu), lead (Pb), mercury (Hg), zinc (Zn), DDT, PCB, fluoranthene, hexachlorobutdiene (HCB), indeno(1,2,3,cd)pyrene (IP), pyrene (P), total HPAH (TP), and bis(2-ethylhexyl)phthalate (BP). Not all of the contaminants were present in each of the DMMUs slated for upland disposal. In addition, the shipyard is still operating and serves as a possible ongoing source of contamination.

The first round of sediment sampling occurred in 1991 with the samples delineated using the 1992 PSDDA suitability criteria. In response to the amount of time that had elapsed during the planning stage, additional sediment samples were gathered in 1993 to reflect the current bottom conditions and submitted in January 1994. The PSDDA suitability criteria were updated in April 1994 and used to characterize the second round of sediment samples for the shipyard.

Biological. Due to concerns about timing and exceeding bioassay holding times, the Navy chose to perform bioassay tests concurrently with the chemical analyses. Tests performed for the 22 DMMUs included amphipod, sediment larval, Neanthes biomass, saline microtox, and bioaccumulation testing. Mortality and growth results had 50 percent failure of PSDDA screening criteria.

Based on the results of the chemical and biological testing, only six of the 17 surface DMMUs were suitable for in-water disposal, with the rest of the surface DMMUs designated for upland disposal.

7.2 Implementation During Dredging

Physical. A daily project log was maintained during the dredging that included the dredging location, volumes and disposal in addition to noting any incidences of state water quality standards being exceeded.

Chemical. Daily water quality testing of the discharge from the transfer site was performed during the first week of operations to measure turbidity, dissolved oxygen and pH.

Biological. No biological testing was performed during dredging.

7.3 Post

Physical. Following the completion of each DMMU, a final record survey of the DMMU was conducted to ensure that the specifications for the proposed footprint were achieved.

Chemical. Post-dredging samples were collected to determine the environmental effects of dredging as a condition of the Ecology Water Quality Certification. In accordance with the Puget Sound Estuary Program protocols, Beak Consultants, Inc. collected sediment samples at 10 stations, five on each side of the pier, located along the center of the dredging prism at 200-foot intervals. Beak Consultants sampled the east side of the pier on December 17, 1994 and the west side on March 7, 1995, gathering the samples within one week after completion of dredging. Surface sediment samples were collected from the top 2 centimeters and analyzed for the Washington State Sediment Management Standards (SMS) suite of chemicals and the PSDDA chemicals of concern. The SMS chemical analysis related the concentrations to two chemical criteria: the lower Sediment Quality Standards (SQS), the chemical concentration that allows for minor adverse biological effects, and the more stringent Cleanup Screening Level (CSL) (Beak, 1995).

Of the 10 stations, six stations had metal concentrations above the CSL, and one station exceeded the SQS. Of the 10 stations, three stations had PCB concentrations above the CSL and six stations exceeded the SQS.

In general, the concentrations of chemicals in the surface sediments were similar between the pre- and post-dredging sampling with some metal concentrations measured at slightly lower concentrations after dredging. Since the sediment samples represented only the top 2 centimeters of sediment, it would appear that resuspension during dredging or natural sediment transport mechanisms were responsible for covering the dredging prism with material from the surrounding operable unit still requiring sediment remediation.

Biological. Using SMS requirements, the Navy could elect to perform bioassay testing concurrently with the chemical analyses.

7.4 Long Term

Long-term sampling and monitoring requirements were included in the permits, recognizing the possibility that they could be superceded by the decisions included in the CERCLA ROD for Operable Unit B.

One year after the initial sampling, the same 10 locations would be resampled with testing performed on the top 2 centimeters of each sample. The results of the chemical analyses would determine if a need existed for additional sampling or testing. The sampling would occur on an annual basis, unless superceded by Ecology approving a sampling and testing plan under CERCLA and/or MTCA. The need for biological sampling, such as bioassays or benthic abundance, depended upon the results of the chemical analyses of the sediment samples.

Table 1 Summary of Monitoring Results

Testing Parameter	PCB Concentration in mg/kg (ppm)			
	Baseline 1993	Progress 1994	Post 1994/1995	Long Term
Bathymetry	Yes	Unknown	Achieved design depth	
Sediment Samples	4.9 PCBs	NC	(N = 10) 0 to 2 cm depth max = 104 mg/kg overall, similar to baseline conditions Avg = 32 mg/kg	
Sediment Toxicity	50% failure of PSDDA criteria; exceedances of screening criteria	NC	NC	
Bioaccumulation Potential	AF = 1.9 Significant uptake of Aroclor 1254 in clams compared to reference [1]	NC	NC	
Water Quality	NC	Turbidity D.O. pH	NC	

Note:

[1] Concentration below FDA guideline of 2.0 mg/kg for PCBs, but designated as high risk from reference.

NA - Not available for review.

NC - Not collected.

8 Performance Evaluation

The dredging successfully enlarged the mooring basins on both sides of Pier D, enabling the shipyard to accommodate larger Navy vessels. The removal of contaminated sediments was a byproduct of the deepening with additional remediation necessary to address contamination still remaining in Operable Unit B.

9 Costs

Not available for review.

10 Project Contact

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11 References

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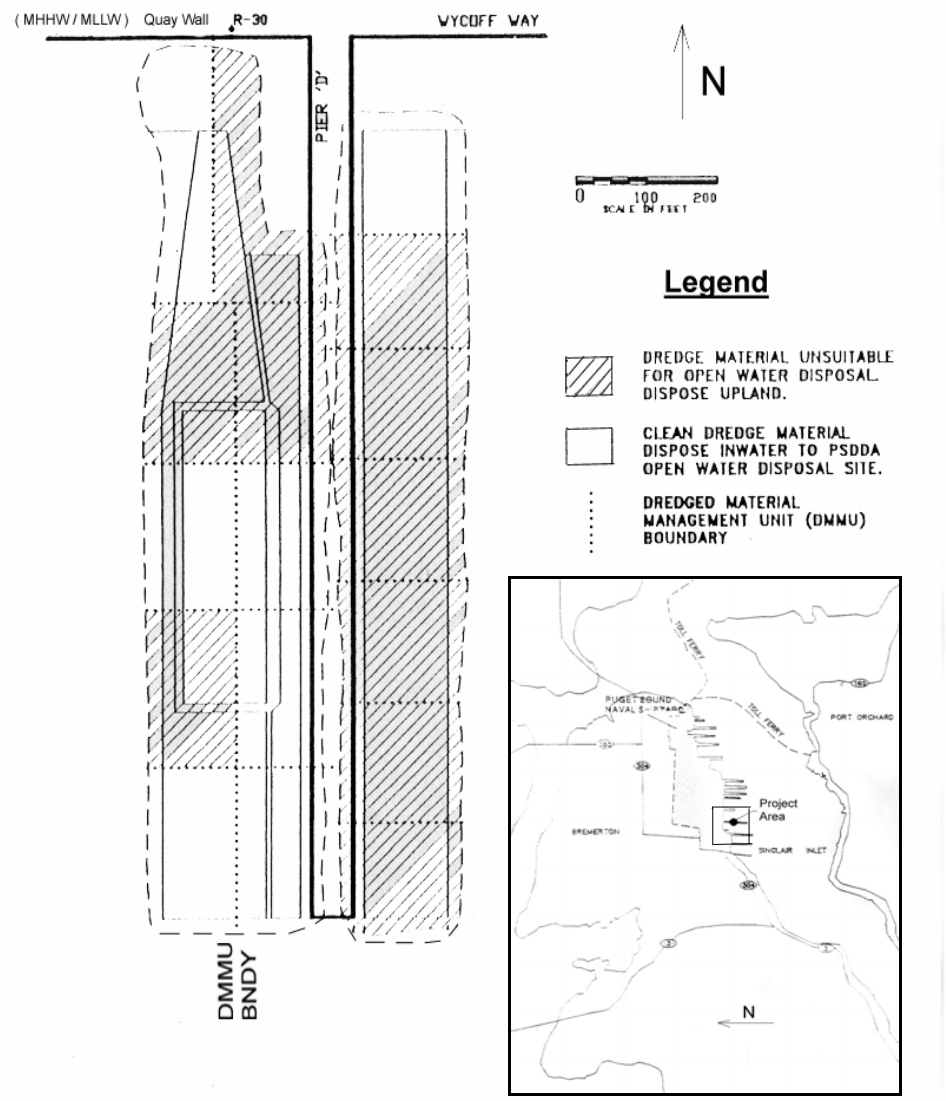
Ecology, 1994. Water Quality Certification for Corps Public Notice #OYB-2-012791-R at Puget Sound Naval Shipyard. Washington Department of Ecology Order No. 94ER-022. September 14.

ProTech, 1994. Sampling and Analysis Plan for Sediment Characterization at Pier D, U.S. Navy Puget Sound Shipyard, Bremerton, Washington. September 20.

Seattle District, U.S. Department of the Army Permit No. OYB-2-012791 (Section 10/404 permit).

U.S. Navy, 1994. Naval Shipyard Puget Sound Pier D Dredging Final Supplemental Environmental Impact Statement: Puget Sound Naval Shipyard, Bremerton, Washington. August.

Figure 1 Remedial Dredge Plan - Puget Sound Naval Shipyard Pier D



Source: U.S. Navy, Naval Shipyard Puget Sound Pier D Dredging Final Supplemental Enviironmental Impact Statement, August 1994

SHEBOYGAN RIVER AND HARBOR - SHEBOYGAN FALLS, WISCONSIN

1 Statement of the Problem

- Dredged 1989-1991
- PCBs
- 3,800 cubic yards
- $450 per cubic yard

The Sheboygan River and Harbor in Wisconsin were contaminated with polychlorinated biphenyls (PCBs) and metals from historical industrial sources (BBL, 1990). The maximum detected concentration was 4,500 ppm PCBs. The target objectives of the 1989–1991 Alternative Specific Remedial Investigation (ASRI) pilot study (pilot study) were to dredge 10 hotspot areas within the upper river, and to analyze aspects of contaminants and remediation techniques for future cleanup and treatment alternatives. The unofficial cleanup goal was the removal of sediments contaminated with greater than 686 ppm PCBs (BBL, 1995). The lead agency for the project was U.S. Environmental Protection Agency (EPA) Region 5.

2 Site Description

The Sheboygan River and Harbor cleanup site is located in the cities of Sheboygan and Sheboygan Falls, Wisconsin. Flowing from west to east, the Sheboygan River discharges into Sheboygan Harbor, which in turn discharges into Lake Michigan. The site is composed of approximately 13 miles of riverine and harbor sediments, on the western shore of Lake Michigan. For cleanup purposes, the river and harbor were divided into three sections, the Upper River (this study), the Middle River, and the Lower River and Inner/ Outer Harbor areas.

Sheboygan Falls
Source: G. R. Frysinger

The Upper River section is a 3.2-mile stretch, located 7 miles upriver from Sheboygan Harbor and approximately 0.5 miles downstream of the Sheboygan Falls Dam. The riverbed is composed primarily of rocks and cobbles, and sand with scattered pockets of soft sediment. Soft sediment is estimated to comprise 15 percent of the sediment surface area and hard sediment the remainder of the area. The average width is 120 feet and the average water depth is 2 to 4 feet. This section was chosen for the pilot dredging and capping project and is included in the selected remedy of the U.S. EPA Record of Decision released in May 2000.

The Middle River section runs approximately 7 miles upriver from Sheboygan Harbor. It is a rapid flow section of the river, with bottom

composed of rocks, gravel, and sand with intermittent soft sediment deposits estimated at 15 percent of the sediment surface area. The average width is 100 feet and the average depth is 0.5 to 2 feet. This section was not chosen for dredging or capping activities in the pilot study but is included in the selected remedy of the U.S. EPA Record of Decision.

The Lower River and Inner/Outer Harbor section is a 2- to 3-mile stretch from the mouth of the Sheboygan River out into the Harbor. This area has deeper, slower moving water than the other river areas, and has more continuous sedimentation, especially within the Harbor area. Average water depths in the river and Inner Harbor are 6 to 12 feet, deepening to 23 feet in the Outer Harbor area. The Inner and Outer Harbor have been designated as a navigation channel. This section was also not chosen for dredging or capping during the pilot study, but is included in the selected remedy of the U.S. EPA Record of Decision.

3 Site Investigation

Historically, Sheboygan River and Harbor were used for recreational and commercial activities, including boating, fishing, and shipping (BBL, 1995). The Wisconsin Department of Natural Resources (WDNR) also used the area for a salmonid stocking program (BBL, 1995). In 1956, the U.S. Army Corps of Engineers (ACOE) began dredging and monitoring the harbor for a navigational channel. However, the dredging was halted in the 1970s when a series of fish and sediment sampling events identified high concentrations of metals in the harbor. In the 1970s, a dike removal project was implemented at the Tecumseh property due to WDNR's discovery of PCBs in fish in the 1970s. In 1986, Sheboygan River and Harbor was added to the Superfund National Priorities List (NPL) (GE/AEM/BBL, 1986). No ROD has been issued to date, but the lead agency is the U.S. Environmental Protection Agency (EPA).

A remedial investigation/feasibility study (RI/FS) was conducted in 1987–1988 by BBL, on behalf of the only participating PRP, Tecumseh Corp. A baseline investigation revealed that sediment contamination existed in the Upper River, the Lower River and Inner Harbor, and in floodplains off the river. In this study, they identified metals and PCBs as the primary contaminants of concern (BBL, 1990).

Contaminants of Concern. Contaminants of concern included PCBs and metals, with the largest PCB mass located in the Lower River and Harbor; however, the largest concentrations are located in the Upper River. In baseline data, concentrations of PCB contamination ranged from less than 0.065 ppm to 4,500 ppm. Four PRPs were named from multiple sources, with Tecumseh Products Company's die casting facility being the most likely source for the Upper River PCB contamination. In 1988, a site-specific endangerment assessment was performed to evaluate long-term effects of contamination to human health and the environment (BBL, 1990). From this study, three effects were noted:

- Long-term dermal exposure to PCB contaminated sediments,
- Long-term ingestion to certain fish species over FDA limit (2 ppm), and
- Long-term ingestion of waterfowl in concentrations over 4 ppm.

Based on the observed exposures and effects, EPA decreed removal of contaminated sediments in the Upper River for the ASRI pilot study. Following the preliminary dredging and capping in 1989 through 1991 (discussed here), a full feasibility study (FS) was submitted in 1998.

Thirty fish advisories were in effect over the course of the pilot study. Fish under advisory included bass, carp, suckers, catfish, crappie, pike, salmon, trout, and walleye. All resident fish were designated as "do not eat" to the general population.

In May 2000, a Record of Decision was released by the EPA outlining specifications for the remedial actions of the Upper River, Middle River, Lower River, Inner Harbor, floodplain soils, and potential groundwater contamination at the Tecumseh property.

4 Target Goals and Project Objectives

The objectives of the ASRI pilot study were more general with no stated cleanup targets. They included further delineation of contaminated sediments, transport of contaminants (PCBs and metals), investigation of applicable remedial technologies, and removal of hotspot sediments from the Upper River, as requested by EPA. This study also aimed at monitoring in-river construction activity, construction and testing of a pilot confined treatment facility (CTF), conducting biodegradation studies, and conducting bench-scale treatability studies (BBL, 1995).

However, the physical target for removal during the pilot study was mass removal of hotspot sediments containing greater than 686 ppm PCB concentrations. This number was based upon dermal contact risk. The estimated target volume for removal was approximately 2,600 cubic yards of sediment. Objectives of dredging included complying with EPA's request for sediment removal, evaluation of removal technique effectiveness, and evaluation of short- and long-term remedial alternatives. No long-term remedial objectives were specified, but could be implied as reduced dermal contact risk.

The EPA's Record of Decision remedial objective is to achieve a soft sediment PCB-contaminated surface weighted average concentration (SWAC) of 0.5 ppm in each section of the river: the Upper River, Middle River, and Lower River and Inner Harbor. Over time, the entire river will reach an average PCB sediment concentration of 0.5 ppm and fish consumption advisories will be phased out.

The Upper River remedy requires a re-characterization and removing approximately 20,774 cubic yards of PCB-contaminated sediment to achieve a soft sediment surface weighted average concentration (SWAC) of 0.5 ppm. The areas capped in the ASRI/removal action activities will be removed and sediment samples will be taken once every five years after dredging to document natural processes.

The Middle River sediments shall be re-characterized because high flow events may have significantly disturbed and redistributed soft sediment. Sediment will be removed, if necessary, to achieve a soft sediment SWAC of 0.5 ppm in the Middle River. Data from the FS indicate that an estimated 12,500 cubic yards of sediment must be removed. PCB contaminated soft sediment shall be removed if its PCB concentrations exceed 26 ppm.

Despite limited 1997 NOAA data collected from the Lower River indicating PCB concentrations in surface sediment have dropped off significantly from the time sediment was obtained from the RI/FS, high flow events and boating traffic likely changed the profile of these soft sediments from year to year. Therefore, the Lower River sediments shall also be re-characterized to determine if removal of contaminated sediments is warranted. From the RI/FS report, EPA estimates that 127,000 cubic yards of sediment must be removed. The top two feet of the sediment surface shall be removed from areas of the Lower River with contaminated sediment concentrations higher than 26 ppm.

The Record of Decision requires the Inner Harbor to be characterized prior to any dredging, and that a bathymetry analysis be done to identify contaminated areas susceptible to scour. These areas as well as areas of PCB-contaminated sediment exceeding 26 ppm will be removed from the Inner Harbor and backfilled/covered with clean sediment. Annual bathymetric surveys of the Lower River and Inner Harbor will be conducted to assess sediment profile changes and determine if buried PCB-contaminated sediment is being exposed and vulnerable to scour and boat effects. EPA estimates that 53,000 cubic yards of sediment will need to be removed to achieve a SWAC of 0.5 ppm in the Lower River and Inner Harbor surface sediments.

The Record of Decision also requires the removal of floodplain soil containing PCB concentrations greater than 10 ppm and the investigation and mitigation of potential groundwater contamination and possible continuing sources at the Tecumseh plant.

5 Project Design

Hydrodynamic modeling was performed prior to implementing the study to estimate the possible extent and role of natural processes in the burial of sediments within the Inner Harbor. Based upon baseline probing and PCB data from sediment cores in all sections of the project cleanup site, areas targeted for sediment removal included hotspots in the Upper River area. Components of the hotspot removal (pilot study) included dredging of individual 18 hotspots in the Upper River section (Figure 1). Each

hotspot was individually curtained off with a silt curtain barrier, and dredged materials were disposed of in a CTF.

Other components of the study included extent and transport of contaminants, determination of the degree and rate of dechlorination of contaminants in CTFs versus *in-situ* burial of contaminated sediments, and capping/armoring of undredged and dredged sediments. Physical and chemical observations recorded during the pilot study would help design the overall remedial action plan. Observation components included volume and dredge techniques, contaminant transport and removal, and various benchmark treatability studies such as sediment dewatering, sediment/ash leachability, armoring, PCB remedial technologies, sediment settleability, and geotechnical tests on river and harbor sediments.

In-situ capping was also completed as part of the pilot study. As a contingency for exceeding chemical criteria and as a study for technical remediation alternatives, nine discrete sections of the site totaling 1,200 square yards were capped/armored to prevent further contaminant releases and support further degradation of PCB contaminated sediment (BBL, 1995). Four hotspot deposits were capped after exceeding chemical criteria in post-dredge monitoring (after four sweeps by dredge equipment). Five additional deposits were capped as part of a non-dredged technical study. Each pilot cap included: a base layer of 150-mil geotextile fabric, a 1-foot-thick layer of coarse material to settle the fabric, a second layer of geotextile, gabions around the corners for anchoring, and additional coarse material to fill in the voids and gaps (minimum of 1 foot thick).

Limitations and Permits. A winter shutdown, dependent on weather conditions, limited operations and typically lasted from November or December to April each year. Permit requirements are unknown.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. The pilot study and remediation was conducted from November 1989 to November 1991. After dredging has been completed as ordered by the Record of Decision, a 30 year monitoring program will be implemented to monitor sediment and fish tissue concentrations in the Upper River, Middle River, and Lower River to ensure that over time the entire river will reach an average PCB sediment concentration of 0.5 ppm or less, and that over time fish consumption advisories will be phased out.

Bucket Dredge
Source:

Equipment. Dredging equipment used during sediment removal of areas targeted in the pilot study included sealed clamshell buckets and land-based backhoes. Mechanical dredging equipment was deployed for wet excavation from barges or along the shoreline of hotspot areas. Backhoes were used in areas inaccessible to the clamshell bucket. Double-

layer silt curtains, composed of geomembrane lined with a geotextile, were hung from booms and anchored to the river bottom.

Total Volume Removed. The total *in-situ* volume removed in the Upper River during the pilot study and an additional 1991 EPA Removal Action was 3,800 cubic yards (GE/AEM/BBL, 1986). This volume of dredge material exceeded the original estimated volume by an additional 1,200 cubic yards. Some possibilities for this overestimate included sediment "bulking" during removal, excess removal of the buffer zone to obtain an acceptable PCB concentration, or inadequate site assessment.

Site-specific Difficulties. Although the pilot study dredging was completed within the proposed two-year time frame, a few site-specific difficulties reduced productivity at the site. Freezing weather and ice buildup lowered production rates and increased production costs during December of 1989. Shallow water created access difficulties for barge passage. High water and strong currents caused overtopping of silt curtains and reduced their effectiveness. Site access was sometimes limited along shorelines due to private land ownership issues, creating additional barge haul distances and times.

6.2 Dewatering and Water Treatment Operations

Water treatment was required in the CTF, but details were not available for review. Any dredged sediment as ordered by the Record of Decision will be dewatered and stabilized.

6.3 Storage and Disposal

All dredged materials were disposed of in a CTF and storage tanks located on Tecumseh property. Once the capacity of the CTF had been reached (late 1990), sediments were then disposed of in a contained holding tank, a Sediment Management Facility (SMF), also located on Tecumseh property (EPA, 1998). The Record of Decision requires any dredged sediment to be dewatered, stabilized, and disposed of in either a WDNR-approved in-state landfill or out-of-state hazardous waste landfill, depending on PCB concentration.

7 Environmental Monitoring Program

The monitoring program included bathymetry, evaluation of physical conditions, sediment cores, caged and netted fish studies, and water column monitoring during dredging (Table 1).

7.1 Baseline

Physical. Prior to any dredging activities at the Sheboygan site, sediment probing and sediment coring were performed to determine the vertical and horizontal extent of PCBs in the sediment. Sediment probing involved probing river sediments with a rod at regular intervals along the banks and across the mid-section of the river. Soft areas that could be penetrated by the rod were considered soft sediments. These areas were noted on an areal photograph, assigned a reference number, and labeled as to their

length, width, average sediment depth, average water depth, and any other physical observations.

Chemical. Fifty-three sediment cores were collected in 1989 by boat or by wading in the Upper River. Cores were driven until refusal with a steel core driver, using reasonable human force. A vacuum pump was used to increase core retention in the coring device. Cores were then segmented into 6-inch sections for the top foot, and 1-foot sections for the remainder of the core, and then analyzed for PCB concentrations. Using both the probing and the coring results, 46 potential areas of concern were identified in the 3.2-mile stretch of the Upper River. Thirteen areas were above the 686 ppm project target for PCBs and were slated for dredging and capping at EPA's request. Five additional areas were approved for capping only (BBL, 1995).

Sheboygan Harbor
Source: SAIC

Water quality monitoring was conducted prior to dredging to establish baseline conditions.

Biological. Caged fish studies were conducted in 1989, 1990, 1992, and 1994. However, due to laboratory error, there are no acceptable baseline results.

In addition to the caged fish studies, netted fish monitoring was conducted in 1989 on specific species of fish to provide information on human health risks posed by PCB contamination. To determine baseline conditions, 80 salmon, 25 steelhead, nine smallmouth bass, and 25 carp were collected for tissue PCB analysis. Adult fish were caught using electrofishing techniques, in accordance with the WDNR Field Procedures Manual.

7.2 Implementation During Dredging

Physical. No bathymetry data were collected during the progress monitoring period of the pilot study. Surface water quality was monitored as described below.

Chemical. Daily and weekly water column monitoring was conducted during the course of the dredging and capping. Daily water column samples were collected and analyzed for total suspended solids (TSS) and turbidity. A correlation between TSS and turbidity was found during 1989 activity and, as a result, only turbidity was monitored in 1990 and 1991. Water samples were taken within the silt curtain and downstream and upstream of the work areas to assess the effectiveness of the silt curtains. Additionally, weekly water samples were collected outside and downstream of silt curtains to monitor PCB transport during dredging. Results indicated that the silt curtains contained substantial amounts of suspended material. Weekly PCB results showed some transport of PCBs

during activities at the sites. Additionally, higher PCBs were noted in dredge areas than in the capping-only areas.

Biological. Caged fish studies were conducted in 1989 and 1990. During both years, cages containing approximately 250 juvenile fathead minnows were suspended at six locations in the Upper River area. Cages were held in place by anchor and floats. Fish were analyzed at seven-day, 21-day, 42-day, and 56-day intervals. Results indicated that fish caged downstream of the Upper River site had higher PCB values than fish caged upstream above the Tecumseh facility. The results also showed higher PCB values in the 1989 study than in the 1990 study (BBL, 1995).

Additional adult fish monitoring was done in 1990, following the same procedures as the previous year. No significant differences were observed between the Sheboygan River fish.

7.3 Post

Physical. No physical data were collected during the post-monitoring period of the pilot study.

Chemical. Post-dredging water column monitoring was performed within the curtained area, following completion of dredging and capping. Exceedances of PCBs were found within the curtained areas, and were higher in areas of dredging and capping than in areas of capping only (BBL, 1995).

Before the silt curtains were removed, surface sediment samples (0 to 3 inches) were collected from each hotspot and at 30-foot intervals along the length of the curtained area. A minimum of two samples were taken from each hotspot area. Samples were composited and analyzed for PCBs. At the end of the pilot study, only four areas had exceeded the goal of greater than 686 ppm PCBs, and it was agreed by EPA that these areas would be capped along with the five previously determined capping areas. In the other 14 dredged areas, PCB values ranged from 0.3 to 38.7 ppm and cleanup standards were reached after dredging. In post-monitoring, water column data and fish monitoring studies showed a decrease in PCBs at the Upper River area of Sheboygan River and Harbor site.

Biological. Post-dredging caged fish studies were conducted in 1991, 1992, and another was done in 1994 under the Interim Monitoring Program (IMP). The same methodology was followed as in the original study. Post-monitoring results showed a decrease in fish tissue PCB concentrations in subsequent years following dredging and capping (BBL, 1995).

Adult fish monitoring of ambient species was done in 1991, 1992, and 1993 (carp only), following the same procedures as the previous years. The steelhead showed no significant difference compared to control fish. The salmon had lower or equal concentrations of PCBs as the control fish. The bass and carp showed no overall trends (BBL, 1995).

7.4 Long Term

Long-term monitoring of the pilot study results will be rolled into the proposed remediation plan for final cleanup at the entire site. An Interim Monitoring Program (IMP) was set up to monitor post-dredging caged fish PCB values from 1994 through 1996; however, only the 1994 results are available, showing a general decreasing trend of PCB values over time.

Table 1 Summary of Monitoring Results

Testing Parameters	Monitoring Periods (ppm PCBs)						
	Baseline 1989	Progress 1989–1991	Post 1991	Post 1992	Long Term 1994	Long Term 1996	Long Term 1998
Sediment Cores	0.065 to 4,500 (N = 53)	None	0.3 to 38.7 (dredge only) 7.7 to 295 (designated for capping)	None	None	—	ND to 840 (in dredge prism) ND to 0.9 (outside dredge prism)
Caged Fish [1]	None (rejected data)	ND to 270 [3]	ND to 283	ND to 91	ND to 109	4.4 mg/kg (N = 18) [4]	11.5 mg/kg (N = 24) [4]
Netted Adult Fish [2]	NA	NA (no significant differences from control)	NA (no significant differences from control)	0.4 to 200 (no significant differences from control)	1993 carp only; no trends		
Water Column Monitoring (ppb)	None	0 to 0.47 (outside silt curtain)	0.5 to 8.3 (inside silt curtain)	ND	None		

Notes:

1 Juvenile fathead minnows at four duration intervals.
2 Netted fish included: salmon, steelhead, smallmouth bass, and carp by electrofishing.
3 Downstream fish had higher concentrations.
4 Rochester Park white sucker resident fish.

8 Performance Evaluation

8.1 Meet Target Objectives

The only specific cleanup target criteria specified during the pilot study at Sheboygan River and Harbor was the removal of three isolated hotspot areas (greater than 686 ppm) by EPA Administrative Order by Consent for Removal Action. The scope of the project was expanded to include a 15 additional hotspot areas (T = 18), each surrounded by clean sediments. The dredging required between two and four sweeps by the removal equipment to remove all delineated sediment, the end result was the total mass removal of these areas. Although no long-term remedial

action objectives were explicitly stated for this pilot study, the Remedial Action Objective (RAO) can be inferred as: 1) reduced dermal contact risk, and 2) protection of human health by reducing PCB concentrations in fish.

Short-term Target Goals. Based on the target goals of the pilot study, the Sheboygan River dredging project met the chemical criteria and mass removal target goal in 14 of the 18 hotspot areas (80 percent success). The four areas exceeding the target criteria were capped and post-verification sediment sampling collected after dredge and cap activities met chemical criteria (100 percent isolation of chemical contaminants in dredged areas). We did not verify why the four remaining areas could not meet the target criteria after several dredging attempts; however, site access and shallow water depths are the most likely reasons based on site conditions.

This project was successful in reducing PCBs in hotspot areas, resulting in an 80 percent success of 18 hotspot areas. However, we did not verify why four hotspot areas could not meet target criteria after several dredging attempts. This was were possibly attributable to debris and access restrictions.

Long-term remedial action objectives were not explicitly stated, but can be inferred as: 1) reduced dermal contact risk, and 2) protection of human health by reducing PCB bioaccumulation in fish. Based on post-remediation surface sediment concentrations, dermal contact risk has been reduced. The fish tissue data are inconclusive; however, a decreasing trend of PCB concentrations in caged fish is observed in post-dredge samples. More long-term monitoring data are required to clearly define these preliminary trends and evaluate long-term RAOs.

Long-term Remedial Objectives. Based on the post-remediation surface sediment concentrations, dermal contact risk was successfully reduced. The fish tissue data are inconclusive; however, a decreasing trend of PCB concentrations in caged fish is observed in post-dredge samples. No significant differences were observed in resident fish between baseline and post-dredge sampling events. More long-term monitoring data are required to clearly define these preliminary trends and to evaluate long-term RAOs.

According to a 1999 External Source Evaluation (BBL, 1999), it is unlikely that long-term protection of human health and the environmental will be achieved until adequate source control is in place. This study was implemented after elevated PCB fish tissue concentrations were measured in resident white sucker fish collected from Rochester Park in 1996 and 1998. Results of the study (BBL, 1999) stated:

> "A review of chromatograms for the various soil samples (collected from the Tecumseh property) indicate a PCB compositional pattern similar to that of the unweathered pattern observed in the 1998 white suckers. This evidence suggests that

the plant site is acting as the external PCB source to the River, and likely is the cause of the recent increase of PCBs and change in the PCB pattern observed in the resident fish."

"Based on these results, the Tecumseh facility contains sufficient PCB concentrations and plausible migration pathways to have caused the noted increase in the 1998 resident fish PCB tissue concentrations. In addition, the PCB chromatogram pattern found in the facility soils, as well as the nearshore sediments, all are similar to those in the 1998 resident fish in Rochester Park (unweathered pattern). Thus, it may be concluded that the Tecumseh facility is the major external source of PCB to the River."

8.2 Design Components

Several dredging technologies were considered. Design engineers selected mechanical dredging to limit carriage water, avoid pipeline logistics and avoid wastewater expenses. A backhoe was used in shallow selected areas; however, the clamshell equipment proved to be more efficient during dredging than the backhoe. This was due to higher amounts of sediment being disturbed and suspended while using the backhoe. It was also noted that deployment of silt curtains also caused suspension of contaminated sediments.

8.3 Lessons Learned

The pilot study and sediment removal plan were mainly used as an avenue to better assess future dredging techniques and remediation technologies for future site cleanup in Sheboygan River and Harbor. In all, a more thorough understanding of the site was gained. It was found that techniques for estimating contaminated sediment volumes (sediment probing and coring) were efficient; however, they underestimated actual volumes of material removed and were not considered accurate. Methods utilized in dredging were found to be versatile, relatively easy to mobilize, and did not require significant equipment for dewatering and water treatment. The study found that short-term effects on water quality could not be eliminated by use of silt curtains, however, they did assist in controlling movement of contaminants away from the dredge area.

9 Costs

The total cost of the design, construction, remediation, sampling, and monitoring of the Sheboygan River and Harbor pilot study was $7 million ($1,842/cy). The specific dredging cost was approximately $450 per cubic yard. This $450 per cubic yard cost included dredging and installation/removal of silt curtains, but did not include costs of transportation, stabilization, mobilization/demobilization, and disposal of removed materials (GE/AEM/BBL, 1986).

The EPA estimates that the total cost of the remedial action outlined in the Record of Decision is more than $47 million with additional expenses for operational and maintenance costs.

10 Project Contact

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Design Engineer/Contractor: BBL
Contractors: McMullen & Pitz, E&K Services (now Superior Services)

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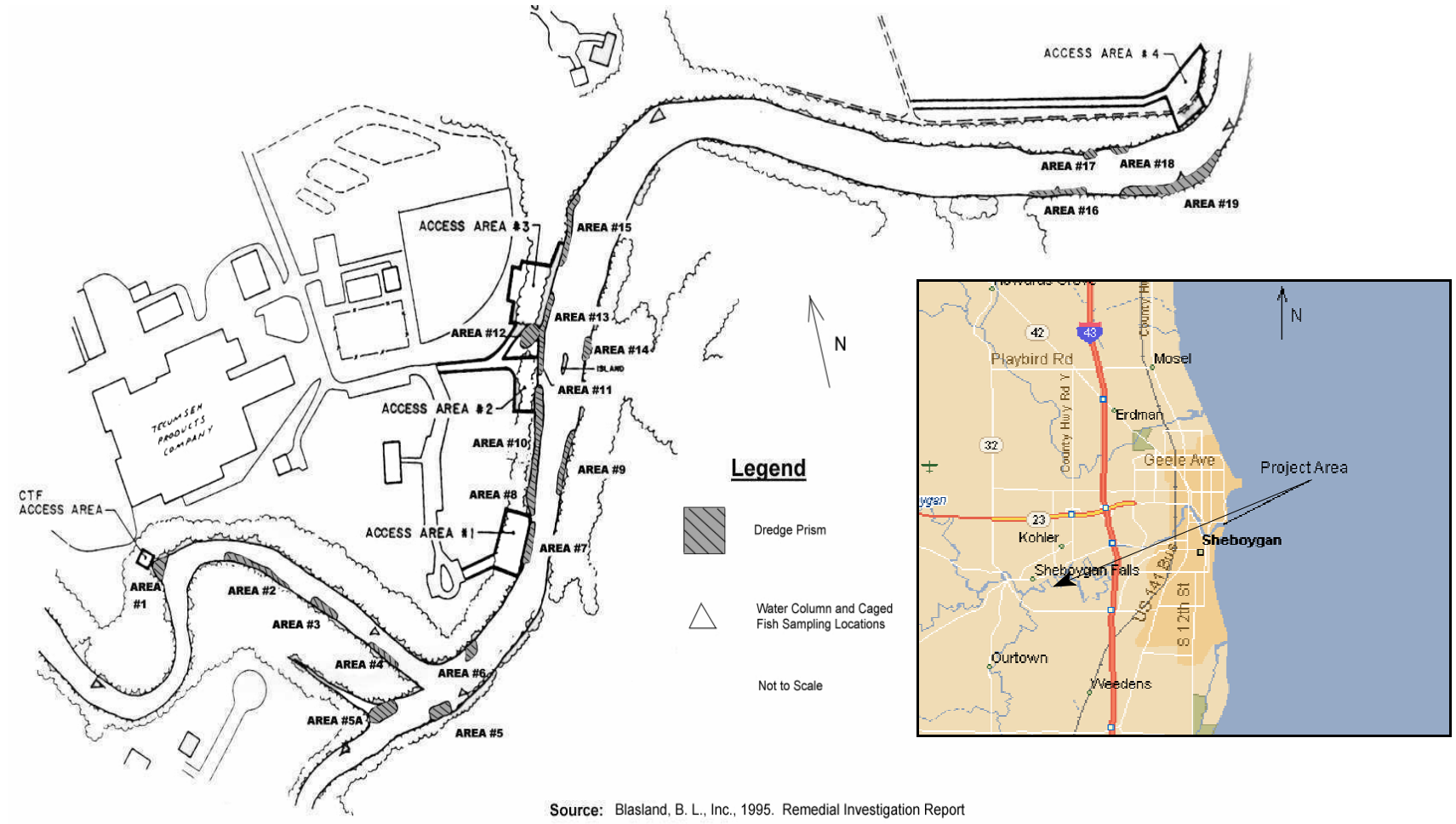
Figure 1 Remedial Dredge Plan - Sheboygan River and Harbor



Source: Blasland, B. L., Inc., 1995. Remedial Investigation Report

SITCUM WATERWAY COMMENCEMENT BAY/NEARSHORE TIDEFLAT - TACOMA, WASHINGTON

1 Statement of the Problem

- Dredged 1993
- Metals and PAHs
- 127,500 cubic yards
- $6.20 per cubic yard

The Sitcum Waterway Superfund Site was contaminated with metals and polynuclear aromatic hydrocarbons (PAHs) from off-loading container and bulk ore activities. The maximum concentrations measured in site samples were 89 ppm PAHs, 2,720 ppm zinc, and 241 ppm arsenic. The selected remedy was 100 percent mass removal of contaminated sediments with additional removal of clean material to maintain navigational depths (plus 2 feet overdredge). Sediment disposal occurred in a nearshore CDF in the adjacent Milwaukee Waterway. The remediation effort was a combined developmental and cleanup project, and dredging was completed in 1994. The lead agency for this project was U.S. Environmental Protection Agency (EPA) Region 10.

2 Site Description

The Sitcum Waterway is one of eight problem areas of the Commencement Bay Nearshore Tideflat (CB/NT) Superfund Site located in Tacoma, Washington (EPA Site ID# WAD980726368). The waterway is 3,000 feet long by 750 feet wide (52 acres) and operates as an active port terminal with adjacent industrial facilities. The waterway is a tidally-influenced, nearshore marine environment with an average water depth of 25 feet. The substrate consists primarily of silty sand and receives continued sediment deposition and shoaling from the nearby Puyallup River (EPA, 1999).

3 Site Investigation

EPA conducted a remedial investigation/feasibility study (RI/FS) of Commencement Bay, including the Sitcum Waterway, between 1984 and 1988. The Record of Decision (ROD) was issued in 1989. The ROD determined that natural recovery would not sufficiently reduce contaminated concentrations in the Sitcum Waterway within 10 years, so active sediment remediation was required. EPA suggested the Port of Tacoma combine the Sitcum Waterway contaminated sediment cleanup project with the navigational requirements and development objectives for expanding port facilities in the Milwaukee Waterway. The ROD set forth specific Sediment Quality Objectives (SQOs) for the Sitcum Waterway which served as performance and compliance criteria for the remediation efforts.

Sitcum Waterway (on the left)

Contaminants of Concern. The major contaminants of concern were metals and PAHs. The highest metal concentrations detected in site samples were 291 mg/kg arsenic, 2,580 mg/kg lead, 2,720 mg/kg zinc and 1.8 mg/kg mercury. The highest total high molecular weight polyaromatic hydrocarbon (HPAH) concentrations were measured in the upper 2 feet at 89,300 μg/kg (Hart Crowser, 1992).

4 Target Goals and Project Objectives

The primary cleanup goal was to dredge all contaminated sediment plus 2 feet of additional overdredge. The two additional feet was the navigational target elevation and ensured that all contaminated material would be removed. However, only 30 percent of the dredged material proved to be contaminated. Remediation success was determined by evaluating post-construction sediment chemical quality. No long-term remedial action objectives were specified, but were implied as maintaining navigational channel depths (Port of Tacoma, 1992).

5 Project Design

Pre-planning and Bid Documents. The remedial design activities included additional environmental, physical, chemical, and biological studies, physical characterizations by diver and video surveys, subsurface sediment sampling to refine the horizontal and vertical extent of contamination, bioassay toxicity tests, benthic infauna abundance enumeration, evaluation of contaminant mobility (elutriate, column leaching, and column settling tests), habitat assessment, and fate and transport modeling.

Aerial of Sitcum Waterway and Milwaukee Fill to the Left of Puyallup River
Source: CECW

Extensive physical and chemical laboratory testing was conducted simulating dredge and fill activities to predict the fate and transport of site chemicals. Computer models (EFQual and Plumes) were used to determine the dilution zone distances and appropriate compliance boundaries (330 feet). A dredging design consultant prepared and issued competitive bid specifications and bid documents. The selected contractor produced a pre-mobilization work plan outlining the dredging, CDF construction, and sediment disposal activities, including a quality control plan. The bid documents allowed contractor flexibility in selecting the most appropriate dredging equipment to be used for the project. Use of barriers such as silt curtains were also left up to the contractor. An independent quality assurance contractor was responsible for conducting environmental monitoring (Manson, 1993a and 1993b; Hart Crowser, 1993).

Water quality during dredging was predicted from modified elutriate tests and computer models (Plumes and EFQual) to determine the dilution requirements and dilution zone distances from the dredging zone and effluent discharge point (Spadaro *et al.*, 1993).

Summary of Remedial Action Plan. In 1992, EPA selected the nearshore fill option as the preferred remedial alternative. The selected remedy dredged and placed about 428,000 cubic yards of Sitcum Waterway sediment behind a berm in the abandoned Milwaukee Waterway via pipeline and diffuser. The Sitcum sediments were capped with clean sediments from the Blair Waterway. After a multi-year settling period, the fill was capped with asphalt and transformed into container storage space. Monitoring wells were constructed around the perimeter of the nearshore fill (and one in the berm) to verify groundwater quality. The remedy also included a 21-acre habitat mitigation area at the mouth of the Milwaukee Waterway using leftover sediment from the Blair Waterway (GE/AEM/BBL, 1999; Gilmor, 1992).

Limitations and Permits. Dredging operations ceased during the fish spawning window from March 25 through June 15.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. Remedial dredging activities operated from October 23, 1993 through September 1994 (excluding fish spawning window from March 25 through June 15, 1994). Operation schedule was six days per week, 24 hours per day, and eight hours per shift.

Equipment. A variety of dredging equipment was used depending upon site conditions, volume, and access. A small 8-inch hydraulic dredge (estimated production of 480 cubic yards per day) was used for underpiers and a large 26-inch cutterhead suction dredge with variable-speed engines (estimated production rate of 15,200 cubic yards per day) was used for the open waterway. The small 8-inch dredge had its ladder and cutterhead removed, and essentially replaced with a double-pipe leading to a 36-foot-wide draghead-type unit at the front of the dredge. Fluidizing jets surrounded the draghead and the draghead and jets were surrounded by a rubber skirt to prevent the jet water from escaping the suction and spreading contaminated sediments.

Two mechanical clamshell dredges (8- and 15-cubic-yard buckets) were also used for the open waterway with a combined production rate of 10,000 cubic yards per day. Other equipment included an 8- and 26-inch pipeline to the CDF, a disposal diffuser barge, boosters to assist with pumping, dump scows, and a small clamshell bucket (5 cubic yards).

Total Volume Removed and Production Rates. A total of 425,000 cubic yards of sediments from the Sitcum Waterway and 2.4 million cubic yards of clean sediments from the Blair Waterway were moved to the abandoned Milwaukee Waterway. The capacity of the

Milwaukee Waterway was very limited. Consequently, the contractor needed to stay within the dredging prism to minimize material volumes. The contractor recognized the limited disposal capacity of the nearshore CDF. Fathometers and GPS were continually used at the site of dredging and dredge depths were verified daily. The fill elevation inside the CDF was monitored hourly.

Site-specific Difficulties. The small underpier dredge was designed to clean the slopes and hard-to-reach areas under the docks. Actual operations encountered extreme debris along the armored slopes, including chunks of concrete, cables, tires and other uneven projections. These materials made it difficult to maintain the dredge's suction face close to the slope and thereby difficult to clean these areas thoroughly.

Another difficulty was attributable to the marked and dynamic tidal fluctuations during a 24-hour dredging day. Although fathometers and GPS were in constant use, the lever man was required to pay constant attention to reading the tide gauges because of the limits on disposal capacity.

6.2 Dewatering and Water Treatment Operations

The solids and water slurry mixture was pumped directly to the bermed CDF in the Milwaukee Waterway. Dredged sediment was dewatered by gravity settling and decanted water was discharged into the bay via an effluent discharge pipe during placement. No water treatment methods were used.

6.3 Storage and Disposal

The dredged sediment, 30 percent of which exceeded the Commencement Bay SQOs, was disposed of in a nearshore, newly-constructed CDF located in the adjacent Milwaukee Waterway. The Milwaukee Waterway was 3,200 feet long by 450 feet wide, ranging from 0- to 40-foot depths. The CDF filled 73 percent of the waterway (24 acres) with dredge material from the Sitcum placed near the bottom and covered with clean material from the Blair Waterway. After a multi-year period of settling, the CDF was capped with asphalt to expand the shipping container port facilities. Groundwater monitoring wells were placed around the perimeter of the CDF and one in the berm for long-term monitoring of water quality.

7 Environmental Monitoring Program

The objective of the Operations, Maintenance, and Monitoring Plan (OMMP) was to determine the effectiveness of contaminated sediment removal (dredging), confirm natural recovery in designated areas, evaluate the success of the remedy, evaluate effectiveness of confinement structure, evaluate the success of habitat enhancement and fisheries mitigation, and confirm the attainment of cleanup objectives. Elements of the monitoring program included bathymetry, sediment chemistry, and surface water column sampling during dredging. Success of the remediation project was determined by post-construction sediment quality.

7.1 Baseline

Physical. Pre-dredge surveys of mudline conditions included underpier side-scan sonar surveys, diver and lead-line spot checks, and bathymetry surveys on 220-foot range lines at 100-foot intervals. Electronic tide gauges and Del Norte DGPS were used for vertical elevation control.

Chemical. Ambient water quality measurements were made before dredging to determine background concentrations and performance standards for dredging. Compliance requirements were set for the point of dredging (330 feet from the activity) and the point of effluent discharge, based on elutriate sampling and modeling. The point of compliance, located downstream of dredging activity, was measured three times per day at three vertical depths. Another sampling location was established at the midpoint between the dredging area and 330 feet downstream as an early indicator of potential exceedances. Parameters included: dissolved oxygen, turbidity, temperature, metals, and PAHs.

Biological. Biological testing included a 1992 *in-situ* 90-day caged mussel study for a NRDA assessment (Port of Tacoma, 1992). The study measured the uptake of contaminants at nine locations in the Sitcum Waterway co-located with the sediment chemistry locations. The results indicated greater than 50 percent mortality in the Penn Cove mussels; however, a NOAA technical response report commented that the study was unusable because of technical design and implementation deficiencies. Other habitat data were not available for review.

7.2 Implementation During Dredging

Physical. Bathymetry surveys were conducted before dredging and at the end of each dredging unit (or every 3 days, whichever came first) to establish the depth and extent of dredging for costing. Conditional surveys also included daily progress surveys to verify appropriate dredge depths. Dredging of specific areas was completed and verified prior to moving to a new dredge area. Survey equipment included sonar sounding devices, electronic tide gauges, tide boards, and GPS.

Chemical. The water column was monitored at the compliance boundary at the edge of the mixing zone (330 feet) and at the water quality midpoint (165 feet). Samples from each station were collected at three discrete depths (upper meter, mid-depth, and bottom 2 meters). Parameters monitored included pH, temperature, turbidity, TSS, dissolved oxygen, and metals. The exceedance criteria for water quality monitoring of dredging activities were:

- Failure of temperature, pH, or DO compliance criteria in 20 percent or more of samples during a single monitoring round; or

- Exceedance of lab-confirmed performance criterion at compliance boundary during two successive monitoring rounds.

Corrective actions were specified in the work plan as "at the discretion of the Port and EPA" if water quality exceeded the criteria. The federal Clean Water Act served as the ARARs for water quality compliance under 1989 EPA Water Quality Acute Criteria Section 304. The water quality monitoring schedule would start as intensive (two per shift) triggered by exceedances, modifications, or startup, then routine (one per day), then limited (one per week) for the duration of dredging. The percentage of water column samples collected at the mixing zone boundary exceeding the compliance criteria were less than 20 percent (recorded in the preliminary reports) and, therefore, were within the performance design criteria. There were reportedly no major violations of the compliance parameters and no adjustments to the dredging plan were made based on compliance measurements.

No air, sediment, or biological tissue monitoring was conducted during sediment dredging activities.

7.3 Post

Physical. Same as progress survey.

Chemical. Success of remediation effort was determined by post-construction sediment chemical quality. Surface (0 to 1 foot) sediment samples were collected at 24 locations and analyzed for PAHs, metals, BEP, PCBs, TS, and TOC. Five discrete samples exceeded the SQOs (one to three analytes each) with enrichment ratios ranging from 1.04 to 2.09. This means that maximum concentrations are one to two times higher than protective thresholds. The 95 percent upper confidence limit (UCL) of the mean sediment concentration for each analyte was less than the SQO with the exception of arsenic at one location (59 mg/kg and ER = 1.03). This area was redredged and supplemental verification samples were below the SQOs. Overall, the post-verification sampling met the compliance criteria in the open-water Phase 1 areas (underpier areas are Phase 2) (Hart Crowser, 1994a and 1994b).

Biological. Habitat was not monitored in the Sitcum Waterway after dredging, however, the newly constructed nearshore habitat constructed along the outer edges of the Milwaukee fill site was monitored for substrate type, benthic abundance, acute toxicity, and caged mussel studies.

7.4 Long Term

Under the long-term OMMP plan, the exposed side slopes and underpier areas were monitored for sediment recontamination at nine locations in 1998. Mercury exceeded the SQOs at four locations and PAHs exceeded the SQOs at one location. These locations had similar sediment quality at the post-construction sediment quality except mercury and five PAHs were not detected in the post-dredging verification survey. Recontamination was likely from continued source input from recent sediment deposition or off-loading activities (Port of Tacoma, 1994).

The open-water areas were characterized during a 1998 PSDDA maintenance dredging evaluation for shoaled areas, and satisfied the OMMP long-term monitoring requirements. The PSDDA prism included 144,000 cubic yards of sediment ranging from 5- to 10-foot thickness. None of the samples exceeded the PSDDA screening levels or the SQOs (Hart Crowser 1998a and 1998b; EPA, 1998).

Table 1 Summary of Monitoring Results

Testing Parameter	Concentrations (ppm)			
	Baseline 1988 RI/FS, 1992	During 1993–1994	Post 1994	Long Term 1995–Present
Bathymetry	Yes	Yes	Not required	—
Surface Water Quality	Yes, to determine baseline (Aug 1993)	No violations	Not required	—
Groundwater	8 Rounds	No Violations	Data collected, not reviewed	—
Sediment Cores	Max PAHs = 89 Arsenic = 291 Zinc = 2,720 Mercury = 1.8	None	(N = 24 0 to 1 foot) All met criteria	1998—Navigational maintenance dredge met chemical disposal criteria

Notes:

Unknown - Results not available.
NA - Data not available for review.

8 Performance Evaluation

The goal of 100 percent mass removal of contaminated sediment to the design elevation was achieved based on physical and chemical monitoring data. The post-verification sediment sample chemical concentrations were below the compliance criteria; therefore, the remedial dredging objectives were met.

9 Costs

The total cost for dredging, fill construction and monitoring, and habitat mitigation was $17.5 million with an average cost of $6.20 per cubic yard. The hydraulic dredging and placement cost of Sitcum sediments from the navigational channel was $1.50 per cubic yard. The mechanical dredging and placement cost of sediment from the underpier and side slope areas was $25 per cubic yard.

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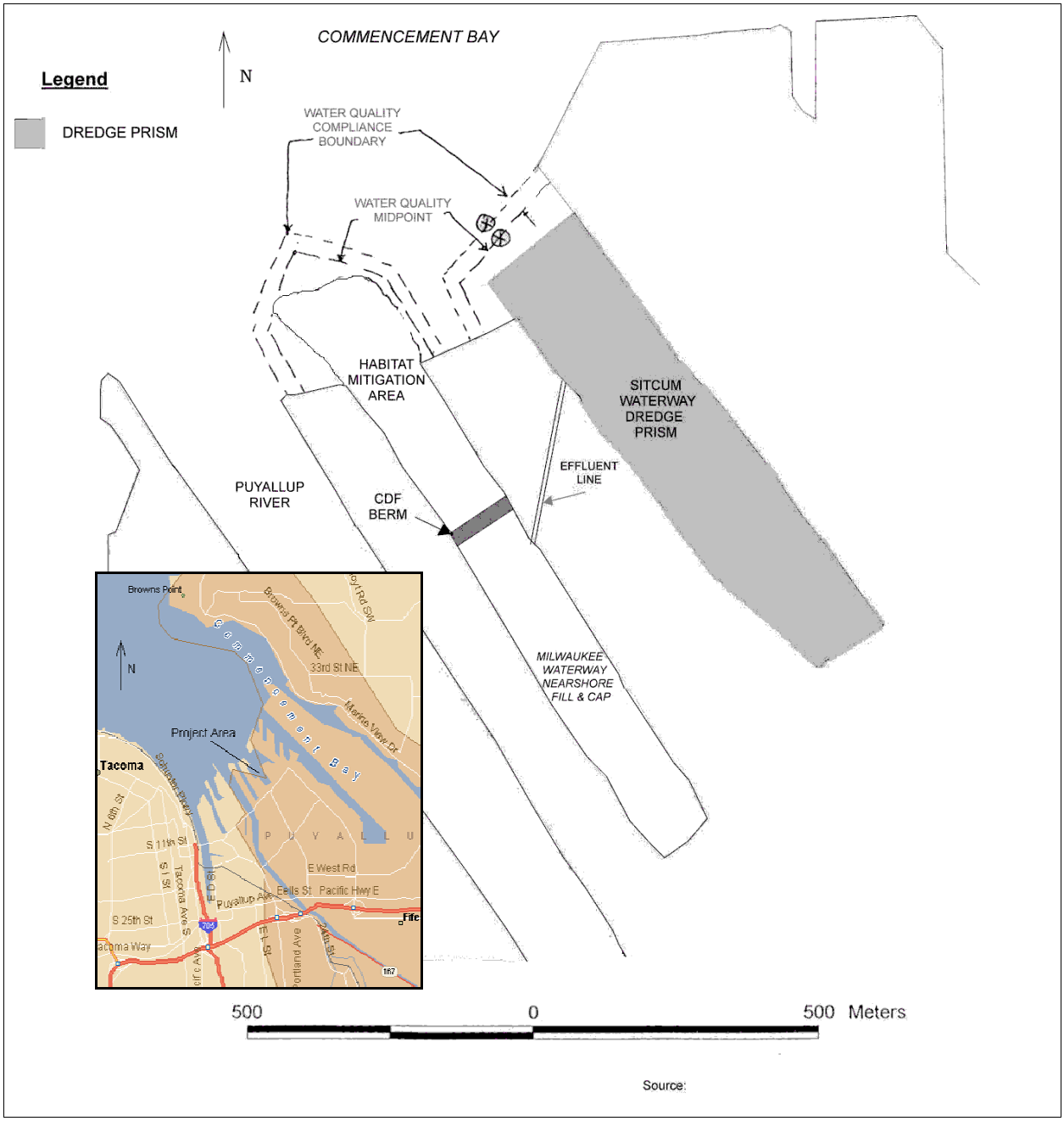
Figure 1 Remedial Dredge Plan - Sitcum Waterway Commencement Bay/Nearshore Tideflat



WAUKEGAN HARBOR/OUTBOARD MARINE - WAUKEGAN, ILLINOIS

1 Statement of the Problem

- Dredged 1991-1992
- PCBs
- 38,300 cubic yards
- $552 per cubic yard

Hydraulic fluid containing polychlorinated biphenyls (PCBs) was used in the die cast works of the Outboard Marine Company (OMC) marine products manufacturing plant from 1961 to 1972. This fluid was discharged to Slip 3 of the harbor and a number of upland areas. An estimated 300,000 pounds of PCBs were released to Waukegan Harbor and 700,00 pounds to the OMC property (EPA, 1999b).

Contamination resulted in beneficial use impairments, including benthos degradation, restrictions on dredging activities, beach closings, and degradation of phytoplankton and zooplankton populations. Remedial action pursuant to an ROD signed in 1984 (EPA, 1984) was halted due to litigation between EPA and OMC. A Consent Decree implementing an OMC cleanup proposal was accepted by EPA in 1989 (EPA, 1989).

Dredging of PCB-contaminated sediment in Waukegan Harbor was completed in 1992. Sediment in Slip 3 with PCB contamination ranging between 500 and 500,000 ppm was dredged and thermally extracted on site. Contaminated sediment ranging from 50 to 500 ppm was dredged from the Upper Harbor and placed in a containment cell formed in Slip 3 (Figure 1). The lead agency for the project was U.S. Environmental Protection Agency (EPA) Region 5.

2 Site Description

The Waukegan Harbor Area of Concern (AOC) is located in Lake County, Illinois, on the west shore of Lake Michigan. The harbor receives drainage from Waukegan River basin and subsequently discharges to Lake Michigan. The present shape of the harbor reflects the industrial activities at the site including filling of the natural inlet and wetlands.

Waukegan Harbor
Source: EPA

Waukegan Harbor is approximately 37 acres in area. The water depth in the upper harbor ranges from 14 to 25 feet (IJC, 1999). Sediments consist of 1- to 7-foot-thick layer of soft organic silt overlying a 4-foot layer of sand and a 50- to 100-foot layer of glacial till. A 20- to 25-foot steel sheetpile wall surrounds the harbor.

3 Site Investigation

A 1972 benthic survey of the Waukegan Old North Harbor found that pollution-tolerant forms of benthic life predominated at each station sampled. Sediment sampling conducted by EPA in May 1976 (six

stations) found sediment PCB concentrations ranged from 1.8 to 36 ppm in the Lower Harbor (five samples), and 216 ppm in the Upper Harbor (one sample). Further investigation was conducted in June 1976 in the Upper Harbor and Slip 3. PCB concentrations ranged from 74 to 301 ppm in the Upper Harbor (four samples) and from 3,900 to 10,300 ppm in Slip 3 (two samples). The 10,300 ppm result was the average of replicate samples with concentrations of 4,200 and 16,400 ppm. Investigations conducted by EPA in 1976 also revealed PCB concentrations in resident fish species were in excess of the U.S. Food and Drug Administration action level of 2.0 ppm. Surface sediment sampling conducted in July 1977 exhibited PCB concentrations from 350 to 3,600 ppm in Slip 3 (three samples), 36 to 460 ppm in the Upper Harbor (five samples), and 0.8 to 26 ppm in the Lower Harbor (eight samples). In 1981, EPA made a formal recommendation against consumption of fish from Waukegan Harbor. The site was proposed for the National Priorities List on October 8, 1981 and was placed on the list on September 18, 1983.

In 1983, EPA approved a $100,000 feasibility study to identify alternatives for remedial action at the site (EPA, 1983). A ROD signed in 1984 proposed on-site containment and off-site disposal of upland contaminated soil and dredged sediment as the preferred alternative. All remedial actions were suspended in 1985 due to litigation between OMC and EPA regarding access to OMC property. In 1986, OMC signed a Consent Decree under which the remedial actions established in the ROD remained unchanged with the exception of the addition of on-site treatment for highly contaminated soil and sediment. The addition of the treatment step was required due to re-authorization of Superfund during litigation. The final Consent Decree and ROD specifying the remedial activities was signed March 31, 1989 (EPA, 1989; EPA, 1999a). Remedial activities were conducted with PRP lead with oversight by EPA Region 5.

4 Target Goals and Project Objectives

Results of a 1981 modeling study conducted by HydroQual, Inc., showed that residual PCB concentrations of 10 to 100 ppm would result in negligible PCB influx to Lake Michigan. EPA established a target sediment cleanup goal of 50 ppm based on the results of this study (Herbich, 1995). EPA calculations showed that removal of sediment to a concentration of 50 ppm would result in removal of 96 percent of the PCB mass in the Upper Harbor. Long-term remedial action objectives for the project were described as protection of human health and the environment.

5 Project Design

Summary of Remedial Action Plan. The remedial action included both on-site containment and on-site treatment of upland contaminated soil and dredged sediment. The remedy included construction of a permanent containment cell through isolation of Slip 3 with a double sheetpile cutoff

wall. A new slip was constructed on the east side of the Upper Harbor to replace Slip 3.

The dredging plan entailed (EPA, 1999a):

- Slip 3 sediment (greater than 500 ppm PCBs) that was highly contaminated was dredged, treated on-site by thermal desorption, and returned to the Slip 3 containment cell (6,300 cubic yards).
- Slip 3 sediment (moderately contaminated 50 to 500 ppm) was left in-place.
- Upper Harbor sediment (50 to 500 ppm) was dredged and placed directly in the containment cell without treatment.
- All sediments less than 50 ppm PCBs were to be left in-place.

It assumed that sediments in the Upper Harbor did not exceed 500 ppm.

Sediment from the Upper Harbor was dredged and placed directly in the Slip 3 containment cell without stabilization. The 6,300 cubic yards of highly contaminated sediment (greater than 500 ppm PCBs) dredged from Slip 3 were treated on site by thermal desorption and returned to the Slip 3 containment cell. A short-term water treatment facility was constructed for treatment of water generated during remedial activities. A smaller permanent water treatment system was constructed for the treatment of water extracted from the containment cells. Water was removed from the containment cells using extraction wells to maintain an inward hydraulic gradient and prevent PCB migration. Upon reaching 90 percent consolidation, the containment cells were capped with a high-density polyethylene liner and a soil cover. Monitoring wells were constructed around the perimeter of the containment cells to verify groundwater quality.

Limitations and Permits. No dredging was permitted in the Upper Harbor during boating season which lasted from April 30 to October 30. Dredging was therefore conducted during the winter season.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. Remedial activities were conducted between 1990 and 1994. Actual dredging took place in late 1991 and early 1992. Slip 3 was dredged during a two-week period in December 1991 and the Upper Harbor was dredged over a period of eight weeks from January 3 to February 25, 1992. On May 17, 1994, after two years and five months of settling, 90 percent consolidation of sediment was achieved in the containment cell and was subsequently capped. Continued treatment of containment cell water was initially proposed until 1999, although

treatment is presently anticipated to continue for an extended period of time.

Waukegan Harbor
Source: Waukegan Harbor Citizens' Advisory Group website
http://nsn.ns/silus.org/wkkhome/iepa

Equipment. Hydraulic dredging removed sediment from both Slip 3 and the Upper Harbor using cutterhead dredges. Slip 3 was dredged using an 8-inch cutterhead and the Upper Harbor was dredged with a 10-inch cutterhead. Bottom anchored silt curtains were installed for containment of dispersed sediment at the lower (southern) boundary of the Upper Harbor and at the entrance to the newly constructed slip.

Total Volume Removed and Production Rates. Approximately 6,300 cubic yards of sediment in excess of 500 ppm PCBs were dredged from Slip 3, treated on site by thermal desorption, and placed in the Slip 3 containment cell. Approximately 32,000 cubic yards of contaminated sediment with PCB concentrations ranging between 50 and 500 ppm were dredged from the Upper Harbor and placed directly in the containment cell (EPA, 1998b).

Site-specific Difficulties. Sediment placed into the Slip 3 containment cell required over two years to reach the target 90 percent consolidation, although dewatering and applications of sand and coagulant were implemented.

6.2 Dewatering and Water Treatment Operations

Dewatering, Treatment and Disposal. A total of 95 million gallons of water associated with dredging were treated by sand filtration in the temporary water treatment system. The water treatment system consisted of four filters with a combined capacity of 1,000 gpm. Water produced by recovery wells installed to promote sediment consolidation and maintain an inward water gradient was treated by the permanent water treatment system. The water treatment system consisted of sand filtration and carbon adsorption. Treated water was discharged to a nearby storm drain which flowed to the Upper Harbor.

Water Quality Monitoring of Discharge. The water discharge limit for treated dredge water was 15 ppb PCBs. Discharge criteria for treated water from the containment cell was 5 ppb PCBs. Water discharge criteria were consistently achieved for dredge water discharge.

6.3 Storage and Disposal

A requirement for treatment of a portion of the contaminated material on site was included in the 1989 Consent Decree and ROD. Although a treatment technology was not specified, a PCB treatment efficiency goal of 97 percent was included. Slip 3 sediment with PCB concentrations

greater than 500 ppm were treated on site using the SoilTech mobile Anaerobic Thermal Processor (ATP) extraction system. Contaminated material from the OMC site with PCB concentrations greater than 10,000 ppm were also treated with the ATP system. The ATP was a thermal desorption treatment which included a feed system, a rotary kiln thermal desorber, a vapor recovery system, a flue gas treatment system, and a tailings handling system. Extracted PCBs were transported to an off-site facility for high-temperature combustion in accordance with the U.S. Toxic Substances Control Act (TSCA). No soils or sediments that exceeded 50 mg/kg PCBs remained on site except those within the containment cells.

The ATP system operated from January 22, 1992 until June 23, 1992 and treated 12,700 tons of PCB-contaminated soil (from upland remediation) and sediment, including the 6,300 cubic yards of sediment dredged from Slip 3. The ATP system met the PCB treatment efficiency goal with an average PCB removal efficiency of 99.98 percent. PCB concentrations in the treated soil ranged from 0.4 to 8.9 ppm. The 99.9999 percent DRE stack emission requirement for PCBs was not met during the proof-of-process period (January 23 until March 5, 1992). The system was shut down from March 5 to May 30 while SoilTech made modifications to the system. All stack gas emission requirements were met for the remainder of operation (EPA, 1995).

The containment cell received 6,300 cubic yards of sediment dredged from Slip 3 and 32,000 cubic yards of dredged sediment from the Upper Harbor. The 6,300 cubic yards of sediment dredged from Slip 3 was treated by thermal desorption prior to placement in the containment cell. Water was removed from the containment cells using extraction wells to maintain an inward hydraulic gradient and prevent PCB migration. On May 17, 1994, after two years and five months of settling, 90 percent consolidation of sediment was achieved. The containment cell was capped with a high-density polyethylene liner and a soil cover. Monitoring wells were constructed around the perimeter of the cell to verify groundwater quality (GE/AEM/BBL, 1998).

7 Environmental Monitoring Program

The monitoring program included bathymetry surveys, waste quality sampling during dredging, sediment sampling, sediment toxicity testing, and fish tissue analyses (IJC, 1999; EPA, 1998a and 1998b; Fox River Group, 1999).

7.1 Baseline

Physical. Physical investigations showed that sediment consisted of one to seven feet of soft organic silt overlying four feet of sand. Glacial till underlies the sand from 50 to over 100 feet thick. PCB contamination was present only in the soft organic silt layer.

Chemical. Prior to remediation, generalized PCB sediment concentrations were stated between 10 to 50 ppm in the Lower Harbor,

50 to 500 ppm in the Upper Harbor, and 500 to 500,000 ppm in Slip 3 (Figure 1), based on the results of sampling investigations conducted by EPA in 1976 and 1977. Actual ranges of PCB concentrations for each area are shown in Table 1.

Biological. Toxicity testing of baseline sediment samples demonstrated significant reduction in survival and growth of *Hyalella azteca* after 29 days exposure to Waukegan Harbor sediments (EPA, 1998a).

Whole carp PCB tissue analysis of samples taken in 1978 (one sample) and 1979 (three samples) had average PCB concentrations of 26.5 and 21.7 ppm, respectively. Carp fillet samples collected in 1983 (three samples) and 1991 (one sample) had PCB concentrations of 9.2 and 19.0 ppm, respectively. A summary of carp tissue analysis is presented in Table 2.

7.2 Implementation During Dredging

Physical. A fathometer depth sounder was used to determine when the design depth of dredging had been reached. Upon reaching this depth, sediment samples were collected to ensure that organic silt had been removed. The criteria for dredging success was when at least 50 percent (by weight) of the material collected was retained by a No. 200 sieve or 4 inches or less depth sample was recovered.

Turbidity criteria was established to be less than 50 NTU outside of the silt curtains. Samples were collected daily at depths of 10 and 20 feet outside of the silt curtain and 500 feet south of the curtain in the Lower Harbor. All turbidity readings were less than 17 NTU and within the criteria limits.

Chemical. No PCB sediment verification samples were collected following dredging. Physical data were used to determine the extent and completion of dredging.

Air monitoring data were collected on personnel and at the perimeter of the remedial activities. The criteria for personnel was below the TLV-PEL of 1 mg/m^3. The highest concentration during sampling was 0.008 mg/m^3 and all samples were non-detect during dredging. The perimeter criteria of 2.31 $\mu g/m^3$ was not exceeded during remedial activities.

Biological. No biological data were available from the period during dredging.

7.3 Post

Physical. No physical data were available from the period immediately following dredging. Physical data collected during dredging were used to determine completeness of excavation.

Chemical. No chemical sediment verification sampling was conducted to document residual PCB concentrations. Physical data collected during dredging were used to determine completeness of excavation.

Biological. No biological data were available from the period immediately following dredging. However, long-term monitoring was initiated after 1993 and included sediment sampling, sediment toxicity testing, and fish tissue analyses.

7.4 Long Term

Long-term monitoring included sediment sampling, sediment toxicity testing, and fish tissue analyses. Sediment samples were collected and analyzed for PCBs from 18 locations in Waukegan Harbor between April 17 and 19, 1996. Results ranged from 3 to 8.9 ppm in eight samples collected in the Upper Harbor (dredged between January 3 to February 25, 1992) with an average concentration of 6.4 ppm. The Lower Harbor concentrations ranged between 0.87 and 6.3 ppm with an average of 4.5 ppm. The average concentration of all samples was 5.4 ppm. No samples were collected from the containment cell (previously Slip 3).

Although not a consideration in the success of remedial dredging, metals and PAHs were also present in sediment samples. Concentrations ranged from 11 to 120 ppm arsenic, 2 to 30 ppm cadmium, 46 to 228 ppm copper, 0.12 to 0.50 mercury, and 12 to 188 ppm lead. The maximum individual PAH concentration was 4.25 ppm phenanthrene.

Table 1 Summary of Sediment Monitoring Results

Location	Sampling Date	Number of Samples	Minimum Concentration (ppm)	Maximum Concentration (ppm)
Slip 3	June 1976 (pre-dredge)	2	3,900	10,300
	July 1977 (pre-dredge)	3	350	3,600
Upper Harbor	June 1976 (pre-dredge)	4	74	301
	July 1977 (pre-dredge)	5	36	460
	April 1996 (post-dredge)	8	3	8.9
Lower Harbor (not within dredged area)	May 1976 (pre-dredge)	6	1.8	216
	July 1977 (pre-dredge)	8	0.8	26
	April 1996 (post-dredge)	10	0.87	6.3

Sediment toxicity was evaluated in 20 samples between April 17 and 19, 1996. Toxicity testing included a 42-day whole-sediment toxicity test of the amphipod *Hyalella azteca* for survival, growth, and reproduction, a 28-day whole-sediment bioaccumulation test of the oligochaete *Lumbriculus variegatus*, and bacteria sediment toxicity tests which measured luminescent light emission.

Survival of amphipods was significantly reduced in six of the 20 samples and growth was significantly reduced in all samples relative to a prepared control. Reproduction toxicity was shown in only two of the amphipod

samples. Bioaccumulation data in oligochaetes were not included in the report due to high detection limits which made the bioaccumulation analysis between sampling locations impossible. Bacterial luminescence testing showed toxicity in one organic sediment extract and approximately 50 percent of the sediment samples. Lethal and sub-lethal toxicity in sediment samples was attributed to metals, PAHs, and PCBs (EPA, 1998a).

A significant decrease in PCB bioaccumulation was demonstrated in post-dredging whole carp and carp fillets although only limited data are available (IJC, 1999). Results of PCB tissue analysis of whole carp and carp fillet are summarized in Table 2.

Table 2 Summary of Whole Carp and Carp Fillet Monitoring Results

Sample Year (number of samples)	Average PCB Concentration in Carp, Whole (mg/kg) [1]	Average PCB Concentration in Carp Fillet (mg/kg) [1]
1978 (1) Pre-dredging	26.5	NA
1979 (3)	21.7	NA
1983 (3)	NA	9.2
1991 (1)	NA	19.0
1992 (0)	NA - Samples not collected during dredging	NA - Samples not collected during dredging
1993 (6) Post-dredging	NA	2.6
1994 (1)	NA	3.45
1995 (1) (3)	1.3	1.9
1996 (3)	NA	4.2
1997 (5)	NA	5.0
1998 (3)	NA	6.8

Note:
NA - No samples analyzed.

8 Performance Evaluation

Physical data collected during dredging were used to verify sediment removal to 50 ppm PCBs. No chemical sediment analysis was conducted until April 1996. While evidence from this sediment sampling investigation seems to demonstrate successful removal of PCBs to a concentration below 50 ppm, biological testing results have shown that toxicity is present. Residual PCBs, and the presence of metals and PAHs are possible explanations for these findings.

8.1 Meet Target Objectives

Physical data, including depth and physical sediment characteristics, were used as verification that excavation was complete to a target PCB concentration of 50 ppm. No chemical sediment analysis was conducted

to verify this claim. Sediment PCB concentrations were measured in April 1996, over four years after the completion of dredging. Results of the 1996 sediment investigation showed that PCB concentrations in the Upper Harbor dredging area ranged between 3 and 8.9 ppm with an average concentration of 6.4 ppm. Maximum concentrations in 1996 represented a 97 percent decrease and 98 percent decrease over pre-project conditions in the Lower and Upper Harbor, respectively. Using the data in Table 2 and comparing the average pre- and post-project fish tissue results, data show that concentrations have decreased 94 percent and 72 percent in whole carp and carp fillets, respectively. EPA lifted a partial ban on the consumption of fish from Waukegan Harbor in 1997 (EPA, 1999c; Fox River Group, 1999).

8.2 Design Components

The project was relatively simple in scope, dealing with the removal of one contaminant of interest by a single PRP. No special design components were noted in the review of the remedial action.

8.3 Lessons Learned

Litigation between EPA and OMC and the resulting delays to the remedial action illustrate the need for cooperation in the development and implementation of cleanup activities. Lack of post-dredging chemical sediment data and the limited number of fish tissue samples make determination of success difficult to determine and somewhat subjective.

9 Costs

The total cost of the entire remedial action was approximately $21 million ($552 per cubic yard).

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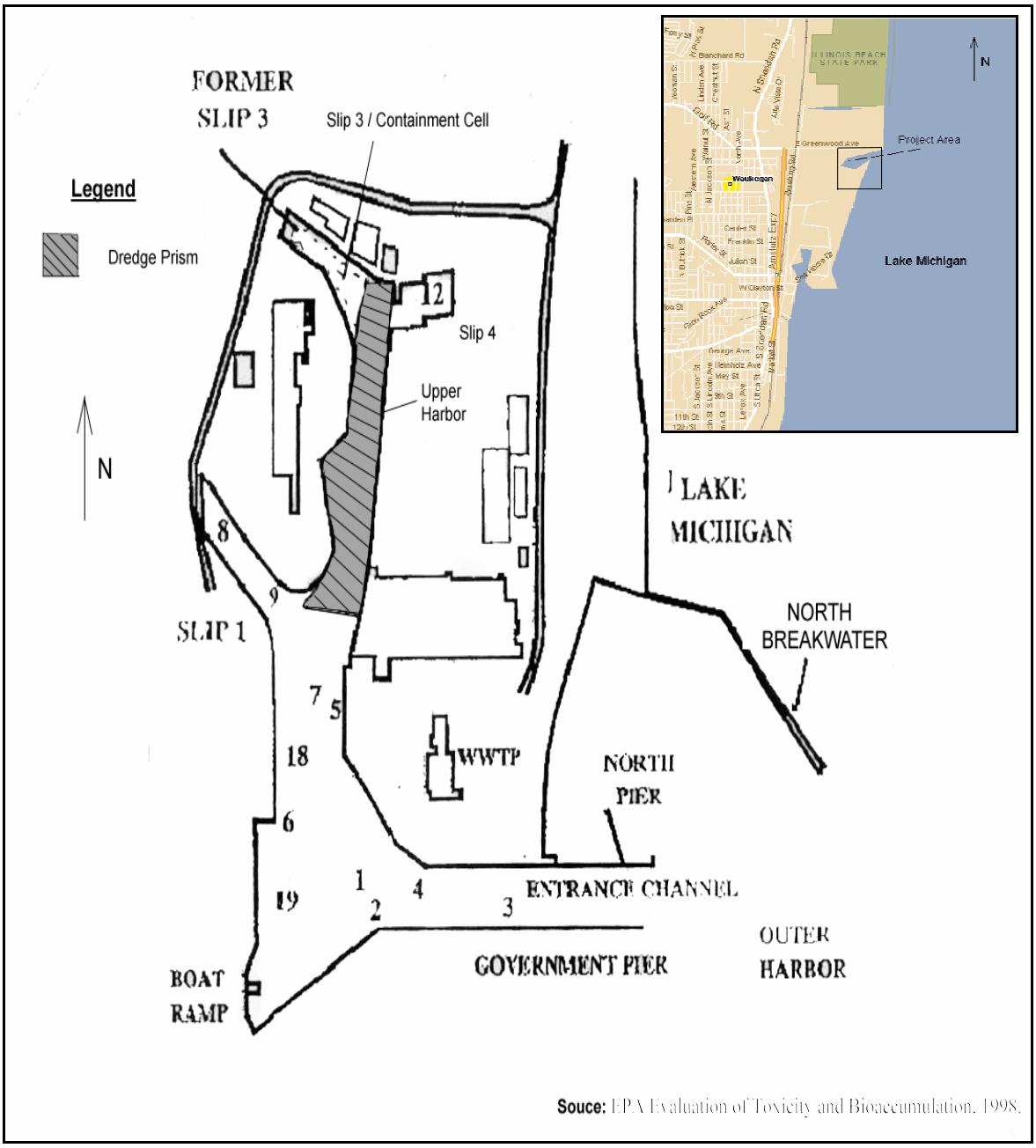
Figure 1 Remedial Dredge Plan - Waukegan Harbor/Outboard Marine



Souce: EPA Evaluation of Toxicity and Bioaccumulation, 1998.

WYCKOFF/WEST EAGLE HARBOR OPERABLE UNIT - BAINBRIDGE ISLAND, WASHINGTON

1 Statement of the Problem

- Dredged 1997
- Mercury and PAHs
- 6,000 cubic yards
- $630 per cubic yard

West Eagle Harbor Superfund site was contaminated with mercury and polynuclear aromatic hydrocarbons (PAHs) from former shipyard and wood treating facilities. Maximum concentrations detected in 1995 surface sediment samples were 32 mg/kg dry-weight mercury and 148 ppm dry-weight total high molecular weight PAHs (HPAHs). The selected remedy was protective of state sediment management standards chemical criteria and included several components: dredging, thick capping, thin capping, and construction of a nearshore confined disposal facility (CDF). Remedial activities were conducted in 1997 and the lead agency for this project was U.S. Environmental Protection Agency (EPA) Region 10.

2 Site Description

The West Eagle Harbor Operable Unit (OU-3) is part of the Wyckoff/Eagle Harbor Superfund Site located on the east side of Bainbridge Island in Central Puget Sound, Washington. The West Harbor OU is one of three operable units within the Superfund site and includes a former shipyard, intertidal and subtidal sediments, and upland sources of contamination. The project area is an intertidal marine embayment of 202 hectares (500 acres) with minimal current, wave action, and sedimentation except for prop wash disturbance from an adjacent ferry terminal. The Eagle Harbor shoreline is mostly residential except for a commercial area around the town center which includes restaurants, shops, a small marina, and public park. Shoreline industry includes a boatyard, ferry terminal and maintenance facility, and former wood treating facility. Site sediments range from gravelly sands to sandy silts with buried timber piles and sandblast grit. Average water depths range from 10 to 20 feet (GE, 1999).

West Eagle Harbor
Source: EPA

3 Site Investigation

The Wyckoff/Eagle Harbor site was proposed for the NPL in 1985, following concerns about hydrocarbon accumulation and potential human health and environmental hazards from initial NOAA and EPA sampling data. A seafood health advisory was posted in 1985 recommending against the harvest and consumption of fish and shellfish in Eagle Harbor. In 1987, EPA initiated an RI/FS which included harbor-wide oceanographic, sediment, shellfish, and fish data studies over a 3-year period. In September 1992, a Record of Decision (ROD) for remedial action was finalized for the West Harbor OU, and amended in December 1995 to include a nearshore CDF alternative. Remedial alternatives for the East Harbor OU (OU-1) and the Wyckoff facility (OU-2) were addressed under separate EPA actions.

Contaminants of Concern. The primary contaminants of concern were mercury from application, use, and removal of bottom paints and antifoulants at the former shipyard during the 1940s and 1950s, and polyaromatic hydrocarbons (PAHs) from the former wood treatment facility. Most of the sediments in the WHOU were characterized by relatively low levels of contaminated sediment over large areas in the upper 3 feet except for a few hotspots. The maximum concentrations measured were 32 mg/kg dry weight mercury and 148,100 μg/kg dry weight total HPAHs in samples collected from the 1995 pre-remedial design sampling effort. The Washington State Sediment Management Standards (SMS) were selected as primary applicable or relevant and appropriate requirements (ARARs) for the project compliance criteria.

4 Target Goals and Project Objectives

As stated in the ROD, "sediments within the top 10 cm must meet the minimum cleanup level (MCUL) chemical criteria within 10 years after active remediation is completed, unless an extension is approved (EPA, 1992 and 1995a and b). In areas where natural recovery is predicted based on accepted mathematical modeling, sediment must meet the MCUL criteria within 10 years of source control." In order to define areas requiring specific types of remediation, the overall cleanup objective developed under the SMS program was supplemented by three EPA chemical criteria objectives: 1) 5 mg/kg dry weight mercury as a means of source control, 2) 1,200 μg/kg dry weight HPAH for intertidal sediments for protection of human health, and 3) 2.1 mg/kg dry weight mercury for protection of biological toxicity. The sediment concentration of 2.1 mg/kg is more than three times the MCUL and is the High Apparent Effects Threshold (HAET) for mercury.

5 Project Design

As stated in the ROD and 1995 ROD amendment, the selected remedy used a combination of alternatives to meet the project objectives (EPA, 1992 and 1995a and b):

- Construct a 1-acre nearshore CDF around nearly half of the targeted sediment (leaving it *in situ),* filling the rest with excavated sediment and increasing the upland ferry terminal capacity by 20 percent;

- Excavate mercury sediment hotspots (greater than 5 mg/kg) and dispose of sediments in nearshore CDF (estimate 13,000 cubic yards);

- Construct a 1-meter cap over surface sediments with greater than 2.1 to less than 5 mg/kg mercury;

- Place a thin-layer cap (6 inches) over surface sediments with greater than 0.59 (MCUL) to less than 2.1 mg/kg mercury; and

- No action for remaining sediments below the MCUL.

Construction of Nearshore Fill CDF
Source: U.S. EPA

Pre-planning and Bid Documents. Extensive physical and chemical laboratory testing was conducted to simulate dredging and filling activities and to predict the fate and transport of site chemicals. A design engineer prepared and issued competitive bid specifications and bid documents. The selected contractor (Wilder Construction) produced a pre-mobilization work plan outlining the dredging, CDF construction, and sediment disposal activities, including a quality control plan. The bid documents allowed contractor flexibility in selecting the most appropriate dredging equipment to be used for the project. Use of barriers such as silt curtains were also left up to the contractor. An independent quality assurance contractor was responsible for conducting environmental monitoring. Unit price and payment changes were considered if any item changed ±25 percent from expected costs. Some subtasks were lump sums. The contractor would be reimbursed for actual production costs for surplus processed material produced by the contractor (Hart Crowser, 1996a and b, 1997a and 1997b).

Summary of Remedial Action Plan. Overall, the remedial action entailed wet excavation of subtidal sediments, dry excavation of intertidal sediments at low tide, stabilizing sediments exceeding TCLP analysis and transporting hazardous wastes to a RCRA landfill, capping, and enhanced natural recovery. The majority of contaminant sediments were placed in a nearshore confined disposal facility via pipelines and barges. Dredging operations were designed with 1 foot of overdredge to ensure removal of target sediments. The CDF was constructed on site with berm walls, and a low-permeability, geomembrane textile liner to help maintain saturated, saline conditions. After a brief settling period, the CDF was capped with clean fill and asphalt. The short-term dredging impacts were somewhat reduced under the CDF alternative since most of the hotspot sediments within the CDF footprint did not require excavation; only the sediments underneath the berm were excavated. Sediments remaining in-place outside of the berm were capped or left for natural recovery. Sediment was dewatered by gravity settling in the CDF lagoon and supernatant water was discharged back to Eagle Harbor (Wilder, 1997).

Limitations and Permits. Permits were not available for review; however, the remedy did call for mitigation of intertidal habitat loss by construction of Shel-Chelb estuary located near southwest corner of Bainbridge Island.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. The remedial action mobilized in April 1997 and was completed in October 1997 (210 days). The number of hours per day and days per week were not specified.

Equipment. Prior to dredging activities, piers, timber piles, railroad spurs, boulders, and other structures identified during previous surveys were removed from the dredging area. Open-water sediment removal was conducted using a roundnose, 5-cubic-yard clamshell bucket. Dredged material from subtidal areas was transported to the CDF via flat-deck barges moored alongside the clamshell bucket. Sediment resuspension was minimized by reducing the rate of retrieval of the full bucket, and placing a silt curtain around the perimeter of the open-water dredging operation. Intertidal sediments were excavated at low tide using a land-based small track excavator, a Bobcat loader, and a 330 track excavator. The 330 excavator transferred material to a Cat 966 loader for transport and temporary upland stockpiling. Open-water capping utilized the same clamshell bucket and underpier capping utilized a centrifugal pump mounted on a flat-deck barge.

Total Volume Removed and Production Rates. A total of 3,650 cubic yards of sediment were removed (1,350 cubic yards by mechanical dredging, 1,650 cubic yards by wet excavation, 650 cubic yards at low tide by dry excavation). A thick cap was placed on 0.5 to 0.7 acres with 7,400 tons of quarry material. A thin cap was placed on 6 acres with 22,600 tons of quarry material to enhance natural recovery. The solids content of dredged material ranged from 2 to 5 percent. The average daily effluent pumping rate was 720,000 gallons.

Site-specific Difficulties. None that impacted the overall success of the project. Tide swings of 12 feet caused sloughing of newly excavated intertidal sediments from underpiers. Contractor backfilled excavated areas with clean gravel to prevent sloughing.

6.2 Dewatering and Water Treatment Operations

Dewatering, Treatment and Disposal. The solids and water slurry water and sediment generated during dredging were gravity dewatered in the CDF lagoon. Supernatant water was discharged directly to Eagle Harbor maintaining specific turbidity and mixing limits. No other method of water treatment was used.

Water Quality Monitoring of Discharge. The gravity settling time was modified to meet water quality discharge criteria as necessary. Water quality was monitored in the CDF lagoon and at the CDF discharge pipe. Parameters included turbidity, temperature, DO, and mercury. CDF supernatant was sampled prior to discharge at 2-foot depth vertical depth intervals down to the maximum depth of proposed drawdown.

6.3 Storage and Disposal

Dredged sediments were disposed of in a nearshore CDF (2,350 cubic yards) following gravity dewatering. The CDF was constructed on 0.9 acre of intertidal land by dredging hotspot sediments located beneath the berm footprint and stockpiling for eventual return to the CDF after completion. Sediments contained within the footprint of the CDF and below the design depth were not disturbed. The CDF was lined with a low-permeability, geomembrane textile fabric to minimize dewatering after closure. Dredged material was filled to 10 feet MLLW elevation. After dewatering and settlement, clean fill was placed up to 15 feet MLLW and topped with an asphalt cap. Settlement plates were installed in the CDF and monitored twice per week for settlement (accuracy 0.01 foot). Remaining sediments were temporarily stockpiled upland and disposed of at an off-site commercial landfill (650 cubic yards).

7 Environmental Monitoring Program

The environmental monitoring program included bathymetry surveys, water column sampling during dredging sediment samples, sediment toxicity tests, and benthic community assessment (Table 1). The ROD stated "physical, chemical, and biological monitoring after cleanup will continue as long as necessary. Assume 30 years for costing purposes." CERCLA requires that EPA review the remedy for signs of contamination for at least five years if contaminants are left in-place (EPA, 1995a and b).

7.1 Baseline

Physical. Underwater geophysical surveys were conducted using bathymetry and video surveys to determine sediment stratigraphy and topography.

Chemical. Ambient water quality samples were collected within two weeks prior to start of dredging activities to determine compliance concentrations. Water samples were collected at five stations approximately 600 feet from water quality monitoring stations on a two-point depth profile (upper 1 meter and bottom 2 meters). Pre-dredge sediment samples were collected in selected areas immediately before dredging to better define the extent of contamination that required removal.

No baseline air monitoring was conducted for sediment remediation activities.

Biological. A benthic community assessment was conducted between August and November 1993 measuring the presence, abundance, and diversity of the macroinvertebrate benthic community. Samples from seven transects were taken at each of two sites (background and downstream of the remedial site). The results showed one impaired community in the downstream transects.

7.2 Implementation During Dredging

Physical. Bathymetry surveys were conducted before dredging and at the end of each dredging unit (or every 3 days whichever came first), to establish the depth and extent of dredging. Survey equipment included sonar sounding devices, electronic tide gauges, tide boards, and GPS. Sounding line station intervals were 20 feet apart and extended 50 feet beyond the project boundary. An independent contractor, de Maximis, verified the dredge's horizontal position and digging depth during remedial activities (de Maximis, 1998).

Chemical. The water column was monitored at five locations downstream of the 200-foot mixing zone radius around the clamshell dredging activities. Each station was sampled at three depths (top, middle, bottom). Parameters monitored included pH, temperature, turbidity, TSS, dissolved oxygen, total lead, and total mercury. In addition, water samples were collected in the middle of the turbidity plume (if observed) not for compliance, but to assess overall performance. The exceedance criteria for water quality monitoring of dredging activities were:

- Failure of temperature, pH, or DO compliance criteria in 20 percent or more of samples during a single monitoring round; or

- Exceedance of lab-confirmed performance criterion at compliance boundary during two successive monitoring rounds.

Per the work plan, if water quality exceeded the criteria, then modifications such as slowing the dredge rate were employed. At the first sign of significant oil sheen or distress/dying fish, then dredging operations would cease. The water quality monitoring schedule would start as intensive (two per shift) for two days or after an exceedance, then routine (one per day) for five days, then limited (one per week) for the duration of dredging. The percentage of water column samples collected at the mixing zone boundary exceeding the compliance criteria were less than 20 percent (recorded in the preliminary reports) and, therefore, were within the performance design criteria.

No sediment sampling was specified. No air monitoring was conducted during sediment dredging activities.

Biological. No biological testing was conducted during dredging.

7.3 Post

Physical. Bathymetric survey was conducted to document the final topography and extent of dredging and capping of the project area using similar methods described in the progress section.

Chemical. Post-verification sediment sampling was conducted immediately after dredging before equipment was demobilized (Pentec,

1997). Surface sediment samples were collected using a van Veen grab sampler at 50-foot grid intervals in the dredge prism and at 50-foot spacing along the perimeter. A detailed contingency plan was in-place to determine exceedances and subsequent actions. A chemical exceedance for sediments was determined by three criteria:

- The areal-weighted average concentration must be less than 5 mg/kg mercury;
- Less than 20 percent of individual samples can exceed 5 mg/kg mercury; and
- No individual sample can exceed 10 mg/kg (ER ratio of 2).

If a sediment exceedance was determined, then two additional verification samples were collected at 5-foot distances from the highest exceedance. If these samples exceeded the criteria, then the area was re-dredged to a uniform depth of 1 foot in a 50-foot-wide grid. The area would be re-sampled for verification of compliance. The post-verification sampling also determined where a thick cap was needed in the dredge area. Compliance criteria for dredge prism DU-2 were met and the maximum mercury concentration detected after DU-2 dredging was 8.7 mg/kg. Collection of water, air, and tissue samples was not specified. Post-verification sampling was based on chemical compliance of sediment. According to Ken Marcy of U.S. EPA, all post-verification sediment sampling met compliance criteria (Paccar, 1996).

Biological. No data available for review.

7.4 Long Term

Long-term monitoring of the cap and of the CDF are proposed; however, only water quality samples from groundwater quality monitoring wells installed in the CDF were available for review (Parsons-Brinckerhoff, 1998). The project was recently completed and, therefore, limited long-term data exist. Based on a conversation with Ken Marcy, the Year 1 OMMP Data Report discussed results of: 1) habitat performance at the Shel-Chelb estuary (mitigation site), 2) groundwater monitoring results inside the CDF, 3) site and stormwater inspections, and 4) eelgrass performance outside of the dredge and cap areas of West Eagle Harbor where it was naturally growing (ThermoRetec, 1999; Herrera, 1998a and b). No sediment sampling was conducted, but it is planned for next year. Results of the eelgrass survey indicated that the eelgrass was not performing well. However, the results were deemed inconclusive since the algae did not die off this winter and may have influenced the decreased rate of growth by limiting the amount of light able to reach the eelgrass. EPA will continue to monitor the results.

Table 1 Summary of Monitoring Results

Testing Parameter	Concentration (ppm dry-weight)			
	Baseline 1995	During 1997	Post	Long Term [1]
Bathymetry	Yes	Yes	Yes, met target depth	Unknown
Water Column	Yes, to establish baseline	Yes	None	Unknown
Surface Sediments	32 mg/kg Hg 148 mg/kg PAHs	NC	All samples met chemical criteria in non-cap areas	Planned
Sediment Toxicity	NA	NC	Unknown	NC
Biological	One impaired community	Monitoring for TSS, TOC, temperature, pH, turbidity and mercury; no significant exceedances	NC	Macroinvertebrate and macroalgae abundance assessment to be collected; eelgrass restoration

Notes:

Long-term defined as 30 years.
NA - Data not available for review.
NC - Not collected.

8 Performance Evaluation

8.1 Meet Target Objectives

Post-verification sediment samples from dredge prism DU-2 met the chemical compliance criteria, and supposedly all the post-verification sediment sampling met the SMS chemical criteria. Based on chemical compliance of confirmation samples, one foot of overdredge designed into the remedy, the mind-set of "environmental dredging" by the contractor, and the immediate verification sampling of each dredging prism prior to demobilization indicate that the dredging effort successfully met the short-term goals. Remedial success of long-term goals (no surface contamination within 10 years of remedial action) have yet to be evaluated.

8.2 Design Components

Several design components including: the mind set of "environmental dredging" by the contractors, adaptive dredging management enabling the contractor to modify onsite equipment operations to try and meet the target objectives, and the design of 1-foot overdredge into the remedy all likely contributed to the success of this remedial project.

8.3 Lessons Learned

Water quality monitoring conducted during dredging and dewatering operations met the performance criteria. Verification sediment sampling met design criteria. Selection of a qualified contractor with environmental experience and good communication skills with the other members of the team proved critical to successful implementation of the project. Public involvement and acceptance were important consider-ations during the design phase. The original ROD specified dredge and offsite disposal of dredge material. However, the community was concerned about the loss of their local shipyard from redevelopment efforts and the ROD was changed, allowing construction of a nearshore fill to accommodate the redevelopment plans and allowing the boatyard to remain.

9 Costs

In the 1995 ROD amendment, the estimated total remedy costs for CDF disposal, dredging and removal, and habitat mitigation was approximately $3.8 million ($630 per cubic yard).

10 Project Contact

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11 References

de Maximis, 1998. Project Completion Report, Eagle Harbor Superfund Site, West Harbor Operable Unit Soil and Sediment Remediation. Prepared by de Maximis, Inc., Hart Crowser, Wilder Construction, and Hartman Consulting Corporation. April 13.

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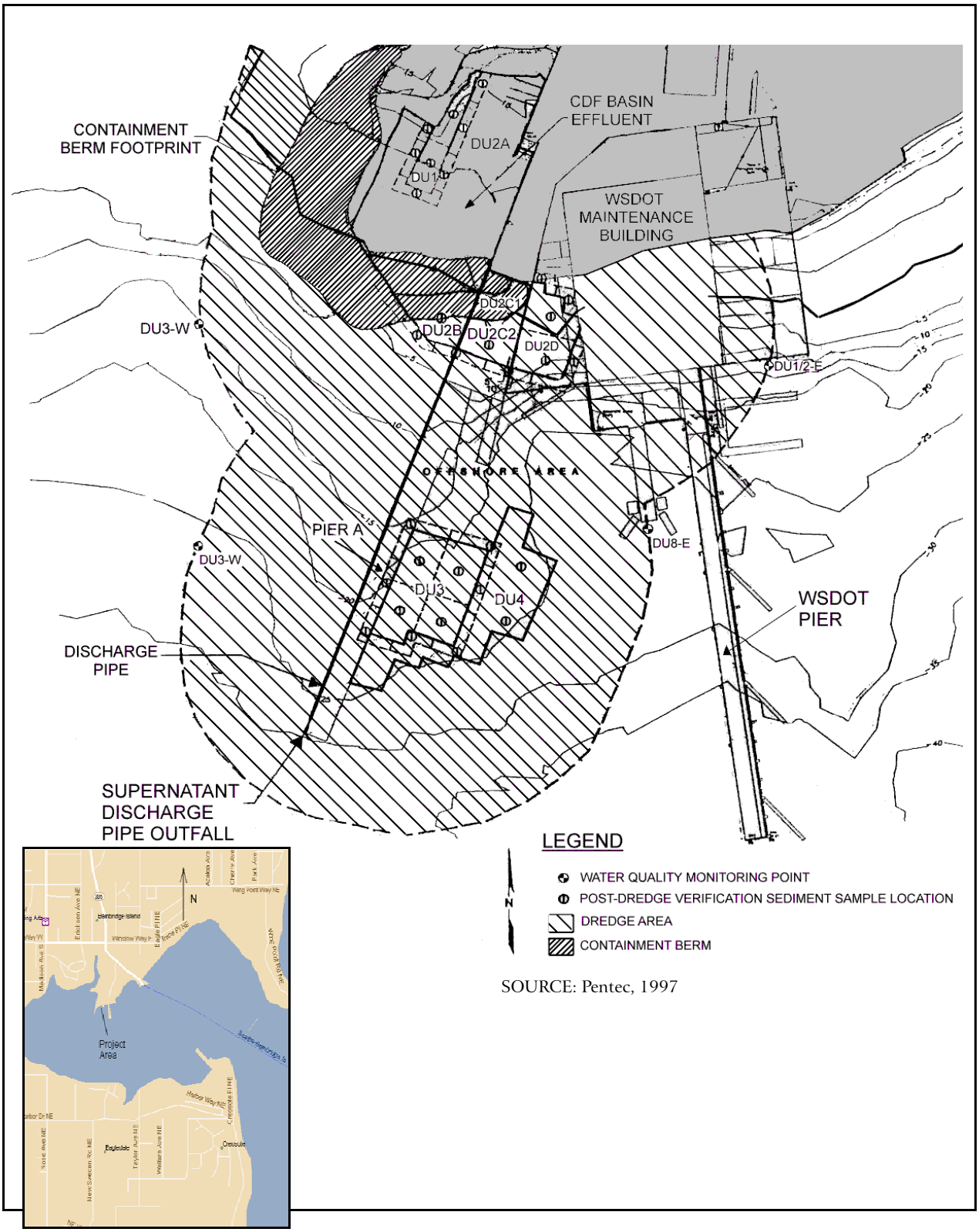
Figure 1 Remedial Dredge Plan - Wyckoff/West Eagle Harbor Operable Unit



SOURCE: Pentec, 1997

Attachment 2

Long-term Monitoring Plan Designs

Contaminated Sediment Remediation Projects – Review of Monitoring Methods

Project Name: Black River Dredging Project

Location: Northwest Ohio, USA

Contaminants of Concern: PAH

Period of Performance: Dredged from 1989 to 1990

Water Body Type: Riverine

Background:
The Black River flows northwesterly through Ohio and into Lake Erie at Lorain Harbor. PAH-contaminated sediments were present primarily from discharges of USX/Kobe Steel (formerly USS Lorain) coking facility. High sediment PAH levels corresponded to a high frequency of liver tumors in resident populations of brown bullheads. Although sediment PAH levels had declined since the USX's coking facility was shut down, elevated levels were still of concern due to fish consumption advisories for PAHs.

Project Goals and Objectives:
The primary cleanup target was the removal of sediment to the underlying shale bedrock in the area of the former USX-Kobe coke plant. The goal of the sediment remediation project was to remove PAH-contaminated sediment in order to reduce risk to brown bullhead, catfish, and other resident aquatic organisms. Monitoring was implemented to measure biological effects through reduction of liver neoplasms in resident brown bullhead populations. Liver neoplasms were measured as the indicator for biological effects because PAHs are rapidly metabolized and excreted by fish.

Remedial Actions:
Sediment remediation occurred as a result of an enforcement action upstream of the federal navigational channel in the vicinity of the coke plant outfall. Dredging of the sediment began in 1989 and was completed in December 1990. A total of 38,000 m^3 of sediment were removed during the operation. Dredging was performed using a closed, watertight clamshell dredge to reduce the loss of sediment to the water column. Dredged sediment was placed in an upland confined disposal facility on the USX-Kobe facility. Following placement, sediment was dewatered and capped (IJC, 1999).

Long-Term Monitoring:
Following completion of dredging in 1990, long-term monitoring of sediment and fish was conducted annually from 1992 through 1994.

Physical: No physical monitoring is known to be included in the long-term monitoring program.

Chemical: Surface sediments were collected using an Ekman dredge sampler. Samples were collected as three-point composites across the river from 14 locations. The distribution included two upstream samples, seven samples from the dredged area, and five downstream samples. Discrete samples were also collected from two locations.

Biological: Biological monitoring consisted of measurements of the frequency of liver neoplasms in brown bullhead (Bauman et. al, 1998). Biological monitoring included fish tissue analysis and liver deformities. Resident adult brown bullheads greater than 250 mm (age 2+) were collected using overnight sets of fyke nets from the Black River and a reference site. Samples were analyzed for serum analysis, necropsy and histopathology of liver neoplasms. Net

locations extended above 0.5 km above and below the coke plant outfall. Sampling stations were randomly selected, and sample sizes per year ranged from 44 to 99 individuals (age 3 or older).

Project Outcome:
As a result of this sediment remediation project, PAH levels in sediment have declined substantially and cancerous liver tumors have now been reduced to less than 1 percent in the resident brown bullhead population. PAH fish consumption advisories for the general population were rescinded in 1997 for all fish species located in the Black River (EPA, 2000).

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References:
Baumann, P. C. and J. C. Harshbarger, 1998. Long-term trends in liver neoplasm epizootics of brown bullhead in the Black River, Ohio. *Environmental Monitoring and Assessment*. Vol. 53, pp. 213-223.

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Project Name: Dokai Bay Dredging Project

Location: Kitakyushu City, Dokai Bay, Japan

Contaminants of Concern: Organic overloading, mercury, cadmium

Water Body Type: Marine

Period of Performance: Discharge regulations since 1970; dredged in 1974 to 1975

Background:
Dokai Bay lies adjacent to Kitakyushu city, one of Japan's major cities with a population of more than one million. Various heavy chemical-industrial plants have been established in this city since the 1900s. Wastewater from factories and untreated sewage effluent have heavily polluted the water and marine bottom environment of the bay. The bay was referred to as the 'dead sea' in the 1960s due to the apparent absence of aquatic organisms.

Project Goals and Objectives:
The project goal was the recovery of the Bay ecosystem. Since 1970, the local government has carried out environmental recovery projects in an attempt to remove pollutants and control nutrient loading.

Remedial Actions:
Stringent regulations have been implemented for discharge of effluent and wastewater. Dredging was performed in 1974 and 1975, removing 350,000 cubic yards of contaminated sediments (Gros, 1999).

Long-Term Monitoring:

Physical: No long-term physical monitoring is known to have occurred.

Chemical: Monitoring of sediment chemistry was conducted in 1990 for acid volatile sulfides, COD, mercury, and cadmium. Surface sediment grab samples (0 to 2 cm) were collected from 13 locations randomly distributed throughout the bay using Ekman and Smith McIntyre grab samplers. Three grab samples were collected per station (two for chemical and one for biological). Surface and bottom water were analyzed for dissolved oxygen. The schedule for additional monitoring was not available for review.

Biological: Biological recovery was monitored by benthic infaunal analysis from collocated sediment grab samples at 13 stations. Benthic animals were sieved through a 1-mm mesh screen and counted, weighed, and identified down to species (Ueda et al., 1994).

Project Outcome:
Since 1989, the authors have assessed the water and benthic conditions of the bay to describe the recovery of the benthic ecosystems, and to monitor the effects of environmental recovery projects on the bottom environment of the bay since 1970. The results of these studies indicate a significant decrease in the levels of heavy metals in the bottom sediments and the recolonization of various benthic organisms, although the innermost areas of the bay remain seriously organically polluted.

Project Contact:
None available

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Project Name: Ford Outfall/River Raisin Dredging Project

Location: Monroe, Michigan

Contaminants of Concern: PCBs

Water Body Type: Riverine

Period of Performance: Dredged in 1997

Background:
The project area is a 2.6-mile section of the lower River Raisin in the southeastern portion of Michigan. PCB-contaminated wastewater generated by cleaning, painting, and plating processes was discharged directly into the River Raisin by the Ford Monroe Stamping Plant from 1949 to 1972. Elevated PCB concentrations were detected in wastewater, sediment and fish surrounding Ford's wastewater discharge pipe. A state fish consumption advisory is in effect for carp and white bass in the Raisin River below the Monroe Dam.

Project Goals and Objectives:
The remedial project goal was to remove contaminated sediment from a hotspot located near the Ford plant's wastewater outfall under a Superfund Emergency Removal Action. The proposed hotspot measured 600 feet by 200 feet containing 28,000 cubic yards of sediment. The target goal was removal of all sediment within the dredge prism down to hardpan and removal of sediment in excess of the 10 ppm PCB cleanup criteria. The long-term remedial action objective was to reduce PCB concentrations in fish and to protect human health (GE/AEM/BBL, 2000).

Remedial Actions:
Approximately 27,000 cubic yards of sediment were removed from the hotspot area from July to September 1997. Sediments were mechanically dredged with a clamshell bucket. Contaminant transport was minimized through the use of silt curtains. Contaminated sediment was stabilized with Portland cement and disposed of in a Toxic Substances Control Act (TSCA) landfill located on site (ACOE, 1998).

Long-Term Monitoring:
Ongoing post-remediation monitoring is being conducted by the Michigan Department of Environmental Quality. Data was available from sampling conducted in the fall of 1988. The schedule or extent of additional sampling events was not available.

Physical: No physical monitoring data was reviewed.

Chemical: Sediment cores were collected from 20 locations in the 1998 sampling event. Samples from two surface intervals (0 to 6 inches and 0 to 18 inches) were analyzed for PCBs (MDEQ, 1998b).

Biological: Biological monitoring for the 1998 sampling event included caged fish bioaccumulation studies and fish tissue analysis for PCBs. Caged fish were placed at one upstream and two downstream locations. Samples of edible portions of 30 resident fish were used for the fish tissue analysis (MDEQ, 1998a).

Project Outcome:
Monitoring has demonstrated significant decreases in sediment and fish tissue PCB concentrations. PCB concentrations in sediment exceed target criteria in some locations. For more detailed information regarding remedial actions, site-specific difficulties, analytical results, and lessons learned, refer to the Sediment Technologies Memorandum located in Appendix B of the Lower Fox River Feasibility Study document.

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References:
ACOE, 1998. Ford Outfall Superfund Site Closeout Report. Prepared by the U.S. Army Corps of Engineers for the U.S. Environmental Protection Agency Region 5 Superfund Division. November 30.

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Project Name: General Motors Foundry Dredging Project

Location: St. Lawrence River, Massena, New York

Contaminants of Concern: PCBs

Water Body Type: Riverine

Period of Performance: Remedial action from 1994 to 2000; dredged in 1995

Background:
The site is located in the St. Lawrence River adjacent to the General Motors Foundry facility in Massena, New York. The General Motors Central Foundry used PCBs in hydraulic fluids for use in aluminum casting processes. Approximately 30,000 cubic yards of PCB-contaminated sludges were produced from 1959 to 1973 resulting in the contamination of sediment in the St. Lawrence River, the Raquette River, and Turtle Cove. At least 11 fish advisories were posted for the St. Lawrence River.

Project Goals and Objectives:
The remediation goal was to remove contaminated sediment to a target concentration of 1 ppm PCBs from a shallow bay shelf adjacent to the General Motors Foundry. The remedy was chosen to protect human health and the environment based on requirements of the Toxic Substances Control Act (TSCA) and human health and ecological risk assessments (GE/AEM/BBL, 2000).

Remedial Actions:
A total of 13,800 cubic yards of contaminated sediments were removed from the St. Lawrence River using an 8-foot horizontal auger head hydraulic dredge. Sheetpile walls were installed around the dredge area to provide containment for disturbed sediment. A cap was installed over a portion of the dredged area due to elevated post-dredge PCB concentrations. Dredged sediment was transported to an equalization basin via pipeline and dewatered (BBL, 1996b). The dewatered sediment was stored until the summer of 1999 when EPA announced the decision to transport it to a licensed disposal facility in Utah.

Long-Term Monitoring:
A long-term monitoring and maintenance plan was developed for the GM Foundry St. Lawrence River site and includes inspection activities and biological monitoring (BBL, 1996a).

Physical: Annual inspection and documentation of the sediment cap condition (underwater video cameras).

Chemical: No long-term chemical monitoring was noted in the review.

Biological: Annual fish tissue sampling of resident juvenile spottail shiners commenced in 1997 for the St. Lawrence River long-term monitoring plan. Spottail shiner fish samples were collected in the general vicinity of GM's main outfall and composited into seven 15-fish composite samples. Samples were photographed, weighed, measured for length, and analyzed for whole body total PCBs, PCB Aroclors, and percent lipids. If spottail shiner samples were not available, then emerald shiner or longnose dace were sampled. Annual fish tissue sampling is expected to continue for 5 years (BBL, 1999).

Project Outcome:
Sediment removal was not successful in achieving the target PCB concentration of 1 ppm. An average PCB concentration of 27 ppm in one portion of the dredged area led to the capping of the location. The remaining areas of the site did not receive a cap, although an average PCB concentration of 3 ppm was measured. Although high variability was present and limited post-monitoring data was available, average PCB concentrations have decreased from pre-dredging measurements. For more detailed information regarding remedial actions, site-specific difficulties, analytical results, and lessons learned, refer to the Sediment Technologies Memorandum located in Appendix B of the Lower Fox River Feasibility Study document.

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References:
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BBL, 1999. St. Lawrence River Monitoring and Maintenance Annual Inspection Report. BBL Environmental Services, Inc., Massena, New York. January.

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Project Name: Grasse River Pilot Dredging Project

Location: Massena, New York

Contaminants of Concern: PCBs

Water Body Type: Riverine

Period of Performance: Dredged in 1995 (Pilot)

Background:
The area of concern is an 8.5-mile stretch of the Grasse River extending upstream from the confluence with the St. Lawrence Seaway. The river bottom consists of glacial till, large boulders, cobbles, and rock overlain with soft sediment. A Non-Time-Critical Removal Action (NTCRA) was proposed by ALCOA as a voluntary cleanup of Grasse River sediment located adjacent to the ALCOA Outfall No. 001. Dredging was conducted in response to a 1993 risk assessment which concluded that the site presented unacceptable risk to human health through ingestion of fish, ingestion and dermal contact with sediment, and dermal contact with surface water.

Project Goals and Objectives:
The project goal was to dredge 3,550 cubic yards of highly contaminated sediment from a hotspot located adjacent to the ALCOA outfall. No target concentration criteria were established for the removal. The pilot study was intended to provide site-specific information towards formulation of a full-scale remedy.

Remedial Actions:
Prior to dredging, boulders and cobbles were removed from the study area and silt curtains were installed. Contaminated sediments were dredged from a hotspot area measuring approximately 100 feet by 500 feet in 1995 using a horizontal auger dredge. Approximately 550 cubic yards of sediment were left in-place due to limited accessibility from the unforeseen presence of boulders and cobbles. Dewatered sediment, boulders, and cobbles were disposed of in an ALCOA on-site secure landfill (OHM, 1995).

Long-Term Monitoring:
Monitoring reviewed in this section was conducted in the 4- to 6-month period following completion of dredging with the exception of benthic community monitoring. Benthic community monitoring was scheduled for 1996, but results were not available for review. Results of additional long-term monitoring were also not reviewed.

Physical: A post-dredge bathymetric survey was conducted to determine final elevations for the project. No known long-term physical data was collected.

Chemical: Post-dredging chemical analysis was conducted on sediment and water column samples after completion of dredging in 1995. Monitoring of sediment and water PCB concentrations is ongoing, although data was not available for review.

Biological: PCB concentrations were analyzed in the tissue of both caged and resident fish immediately after dredging. Caged fish were analyzed from four locations adjacent to the dredging site and immediately outside of the silt curtains. Samples were collected in October and November 1995. Resident fish analyses included samples of brown bullhead, smallmouth bass, and spottail shiners collected immediately after dredging in October 1995 from three locations in the Grasse River. A survey of the benthic community was scheduled for 1996. Additional long-

term monitoring of fish tissue and the benthic community was to be collected; however, the data was not available for review.

Project Outcome:
Baseline pre-NTCRA dredging samples contained PCB concentrations ranging from non-detect to 11,000 mg/kg, while post-removal PCB samples contained concentrations ranging from 1.1 to 260 mg/kg (BBL, 1995). Only approximately 84 percent of the target volume of sediment was removed because of impediments from rocks and boulders. As expected, caged and resident fish tissue data indicated significant increases in PCB concentrations compared to upstream samples during and immediately following dredging. To date, state fish consumption advisories (general and special populations) are in effect for all fish species from PCB levels. The extent of the advisory is from the mouth of the Grasse River to the Massena Power Canal (EPA, 2000).

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References:
BBL, 1995. Non-Time-Critical Removal Action, Documentation Report, Vol. 1, Grasse River Study Area, Massena, New York. Blasland, Bouck & Lee, Inc. December 1995.

EPA, 2000. Listing of Fish and Wildlife Advisories. Prepared by the U.S. Environmental Protection Agency Office of Science and Technology. Website. http://www.epa.gov/ost/fish.

OHM, 1995. Final Implementation Plan for the Grasse River Study Area Non-Time-Critical Removal Action, Massena, New York. OHM Remediation Services Corp., Massena, New York. April 21.

Project Name: Lake Jarnsjön/River Emån Dredging Project

Location: Municipality of Hultsfred, Sweden

Contaminants of Concern: PCBs

Water Body Type: Lacustrine, Riverine

Period of Performance: Dredged from 1993 to 1994

Background:
In 1981, PCB contamination was found at the mouth of the river Emån. The main source of PCB contamination was traced to Lake Jarnsjön, located along the river. The small lake is situated about 10 km downstream of a paper mill that earlier handled the recycling of waste paper containing PCBs. Large quantities of PCBs were discharged from the paper mill and accumulated in Lake Jarnsjön. Studies have shown that the sediments in Lake Jarnsjön were the dominating source of PCBs in the river system. Approximately 1 kg of PCBs reached Lake Jarnsjön from upstream areas, but approximately 7 kg of PCBs left the sediment every year. Based on this yearly discharge, the 400 kg of PCBs in the sediments would cause biological problems for many years in the river system. In 1991, PCB concentrations were significantly higher in both surface water and resident fish downstream of Lake Jarnsjön as compared to upstream samples.

Project Goals and Objectives:
Dredging and monitoring were conducted to protect human health and the environment.

Remedial Actions:
PCB-contaminated sediments were removed using a horizontal auger suction dredge specially designed to minimize leakage. Dredging started in June 1993, ceased during the winter months, and resumed from May through September. Approximately 192,000 cubic yards of sediment were dredged, dewatered and disposed of in a nearby landfill (Ahlen, 1998).

Long-Term Monitoring:
Although no long-term monitoring was specified in the reviewed documents, post-remedial monitoring was conducted from the completion of dredging until 1996.

Physical: Total suspended solids were monitored at two upstream locations; one station at the outlet of the lake, and two stations downstream of the lake at 10-week intervals from the end of dredging until 1996. The results were not obtained for this review.

Chemical: Surface water was monitored weekly for PCBs from May 1995 until 1996. PCB concentrations were also analyzed in surface cores (0 to 0.2 meters) at 54 locations in 1996. Groundwater was analyzed for PCBs through 1997 in the vicinity of the disposal site (Bremle et al., 1998).

Biological: Whole fish analysis of 1-year-old perch was completed in 1996 at four locations located near the water sampling locations. Five female and five male fish were collected at each location and analyzed for PCBs. Caged fish studies of perch and trout were performed to measure physiological responses. Measurements included the liver somatic index (LSI), ethoxyresorufin-O-deethylase (EROD) activity, plasma parameters, and histopathological characteristics (Bremle and Larsson, 1998).

Project Outcome:
Remedial dredging at Lake Jarnsjön removed 99 percent of PCB-contaminated sediment from the site. Post-remedial monitoring has shown declines in PCB concentrations in sediment, lake water, and fish.

Project Contact:
None available

References:
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Hultsfred, 2000. Remediation of PCB-Contaminated Sediments in Lake Jarnsjön, Municipality of Hultsfred, Sweden. Last updated June 19. Website. http://nywww.hultsfred.se/miljo/ironeng.htm.

Project Name: Minamata Bay Dredging Project

Location: Minamata Bay, Japan

Contaminants of Concern: Methylmercury

Water Body Type: Marine

Period of Performance: Remedial action from 1977 to 1990; dredged from 1977 to 1987

Background:
Minamata disease is a poisoning disease of the central nervous system caused by methylmercury. The first Minamata disease patient was reported initially as suffering from nervous symptoms of an unknown cause in 1956. It took 12 years to reach the official conclusion that methylmercury was the cause of the disease (Gros, 1999). Between 1953 and 1972, at least 69 people died of methylmercury poisoning. Methylmercury contamination in Minamata Bay and the Agano River were the result of discharges from the manufacture of acetaldehyde by Chisso Co., Ltd. in Minamata City and Showa Senko Co., Ltd located upstream of the Agano River. Discharges of methylmercury to Minamata Bay were estimated to be in excess of 70 to 150 tons.

Project Goals and Objectives:
The goal of the Minamata Bay Dredging and Reclaiming Project, sponsored by the national and prefectural governments and Chisso Co., Ltd. was to rapidly and safely dispose of the methylmercury-contaminated sediment (Hosokawa, 1993). The sediment cleanup criterion was established in 1973 (Provisional Standard for Removal of Mercury-Contaminated Bottom Sediment) at a concentration of 25 mg/kg. The target concentration for mercury in fish tissue was established at 0.4 mg/kg in 1994 based on human health risk assessments. Monitoring was conducted to measure compliance with the target objectives.

Remedial Actions:
Remedial actions commenced in 1977 and consisted of installing dividing nets to trap contaminated fish, dredging and disposal of contaminated sediment, and environmental monitoring. A total of 1,975,000 cubic yards of contaminated sediment were removed from Minamata Bay through dredging (1,025,000 cubic yards) and the creation of a confined disposal facility (950,000 cubic yards) (Yoshinaga, 1995). Dredging continued until 1987. The confined disposal facility created 58 hectares of land and received its final cover in 1990 (Zarull et al., 1999).

Long-Term Monitoring:

Physical: No long-term physical monitoring was obtained for review.

Chemical: Chemical monitoring was conducted to measure concentrations of mercury in water and surficial sediment.

Biological: Long-term monitoring was conducted on fish and shellfish. In the 3-year period from 1994 to 1997, samples of dace, Japanese barbel, and Crucian carp were collected twice a year and analyzed for mercury. Hair samples were also analyzed to measure human exposure.

Project Outcome:
Mercury concentrations in fish declined below the 0.4 mg/kg target level in 1994. The target sediment concentration was also met, with an average surficial sediment concentration of 5 mg/kg and a maximum

concentration of 8.75 mg/kg. Dividing nets were removed and fishing restrictions were lifted in 1997 (Environmental Health Department, 1997).

Project Contact:
None available

References:

Environmental Health Department, 1997. Our Intensive Efforts to Overcome the Tragic History of Minamata Disease. Government of Japan. Website. http://www.eic.or.jp/eanet/en/topic/minamata/index.html.

Gros, X. E., 1999. Let's Pollute: A Tribute to Japan's Disregard for the Environment. Electronic Green Journal. Issue 11. December. Website. http://egj.lib.uidaho.edu/egi11/gros1.html.

Hosokawa, Y. 1993. Remediation work for mercury contaminated bay – experiences of Minamata Bay project, Japan. *Water Sci. Tech.* Vol. 28, No. 8-9, pp. 339-348.

Yoshinaga, K., 1995. Mercury-contaminated sludge treatment by dredging in Minamata Bay. Dredging, Remediation and Containment of Contaminated Sediments, ASTM STP 1293, K. R. Demars, G. N. Richardson, R. N. Yong, and R. C. Chaney, Eds. ASTM, Philadelphia, pp. 182-191.

Zarull, A. M., J. H. Hartig, and L. Maynard, 1999. Ecological Benefits of Contaminated Sediment Remediation in the Great Lakes Basin. August. Website. http://www.ijc.org/boards/wqb/ecolsed/csae.html.

Project Name: New Bedford Harbor Dredging Project

Location: Bristol County, Massachusetts

Contaminants of Concern: Primarily PCBs; some heavy metals

Water Body Type: Marine/Estuarine

Period of Performance: Dredged from 1994 to 1995 (hotspot removal)

Background:
The 18,000-acre New Bedford site is an urban tidal estuary with sediments that were highly contaminated with polychlorinated biphenyls (PCBs) and heavy metals. Manufacturers in the area used PCBs while producing electric devices from 1940 to the late 1970s. Factories discharged industrial process wastes containing PCBs directly into the harbor and indirectly via the city's sewerage system. As a result, 6 miles of the harbor was contaminated, extending from the upper Acushnet River through the Upper and Lower Harbors, and downstream to Buzzards Bay (Otis, 1994). Levels of PCBs in some fish and lobsters at the site exceeded the Food and Drug Administration's (FDA) limit for PCBs in edible seafood. Bioaccumulation of PCBs within the food chain resulted in closing the area to lobstering and fishing, and recreational activities and harbor development have been limited by the widespread nature of the PCB problem. A final Record of Decision (ROD) was issued in 1998 for remediation of the Upper and Lower Harbors.

Project Goals and Objectives:
The goal of the project was to perform source control remediation by removing contaminated sediments with greater than 4,000 ppm PCBs (mostly in the river). A long-term monitoring program was developed to assess the effectiveness of this remediation through measurements of spatial and temporal biological and chemical change. Monitoring was also conducted to measure compliance with water quality standards and FDA standards for PCBs in seafood.

Remedial Actions:
Contaminated sediments were dredged from hotspot areas located upstream in the upper Acushnet River in 1994 and 1995. A total of 14,000 cubic yards of sediment were removed using a hydraulic cutterhead dredge from an area of approximately 5 acres. The dredged slurry was transported to a holding area through a floating pipeline for dewatering and storage. Although the ROD specified on-site incineration, contaminated sediments were transported to an off-site landfill due to public opposition.

Long-Term Monitoring:
The long-term monitoring program has been proposed with full-scale sampling events every 3 to 5 years, or before and after major remedial actions. Additional remedial actions are anticipated for the Upper and Lower Harbors, and the long-term monitoring will likely serve as post-remediation verification sampling data. In addition, mussel bioaccumulation will be conducted twice a year and a wetland assessment will be conducted every 10 years (EPA, 1996). Since the post-remedial verification sampling event, one round of long-term monitoring samples have been collected. Measurements included in the monitoring program are summarized below.

> *Physical:* Physical measurements in the long-term monitoring program included total organic carbon, grain size, and texture for sediment samples.

Chemical: Grab samples from the top 2 cm of surficial sediments were collected with a Young-modified Van Veen grab sampler. Chemical analyses were conducted for PCBs, PCB congeners, metals, and acid volatile sulfide. Surface water samples for PCBs were not included in the monitoring program due to high cost and the low concentrations present (Bergen, 1998). Results of *Mytilus edulis* (blue mussel) bioaccumulation were used to assess water quality instead (see biological section).

Biological: Biological testing in the long-term monitoring program included sediment toxicity testing, benthic community analysis, and bioaccumulation. Sediment toxicity tests were conducted on surface grab samples of the top 2 cm. Acute sediment toxicity was evaluated as a percentage of control survival of the benthic amphipod, *Ampelisca abdita*. Surface grabs of the top 7 cm were collected for benthic community analyses. Specific endpoints measured included species richness, the EMAP index of benthic community condition, and community structure. Bioaccumulation of PCBs in the water column was evaluated through analysis of *Mytilus edulis* (blue mussel) tissue. Tissue of *Fudulus heteroclitus* (mammichog) were also examined because they feed mainly on material coming from sediment and spend their life cycle in a relatively small area.

Project Outcome:
A qualitative graphical technique was combined with exploratory statistical techniques to examine the spatial and temporal variability in concentrations of PCBs and proportions of the congeners. The combination of the two techniques with PCB congener ratios revealed subtle changes after remediation that were not evident by a more traditional statistical analysis of total PCB concentrations. Although major redistribution of contaminated sediments were confined to the immediate vicinity of remedial activities, there is evidence that low molecular weight PCBs were transported farther (EPA, 1996). For more detailed information regarding remedial actions, site-specific difficulties, analytical results, and lessons learned, refer to the Sediment Technologies Memorandum located in Appendix B of the Lower Fox River Feasibility Study document.

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References:
Bergen, B. J., K. A. Rahn, and W. G. Nelson, 1998. Remediation at a marine superfund site: Surficial sediment PCB congener concentration, composition, and redistribution. *Environ. Sci. Technol.* 32:3496-3501.

EPA, 1996. New Bedford Harbor Long-Term Monitoring Assessment Report: Baseline Sampling. Research Report. U.S. Environmental Protection Agency. Document 600/R-96/097. October.

Otis, M. J., 1994. New Bedford Harbor, Massachusetts dredging/disposal of PCB-contaminated sediments. *Dredging '94: Proceedings of 2nd International Conference on Dredging and Dredged Material Placement, 14-16 November 1994, Orlando, Florida.* E. C. McNair, ed. American Society of Civil Engineers, New York. p. 579-587.

Project Name: Santa Gilla Lagoon Dredging Project

Location: Santa Gilla Lagoon, Southern coast of Sardinia Island, Italy

Contaminants of Concern: Mercury, Lead, Zinc

Water Body Type: Estuarine

Period of Performance: Dredging completed in 1992

Background:
The Santa Gilla lagoon, on the southern coast of the island of Sardinia, received industrial discharge of mercury, lead, and zinc compounds, as well as municipal untreated sewage for several decades from the urban area of Cagliari (about 400,000 inhabitants). An estimated 26 tons of mercury, discharged from a chlor-alkali plant, have been deposited in the lagoon since the mid-1960s, mostly confined to a 2-km^2 area located in front of the industrial area. The lagoon, which covers an area of 15 km^2 of shallow water, represents an important source of fish and shellfish for the island. Pollution sources were brought under control in the mid-1980s, when a costly restoration program (still in progress) was started; however, metals contamination has resulted in the restriction of fishing in the lagoon since 1974.

Project Goals and Objectives:
The purpose of the project was to restore productive use to the area for aquaculture through removal of contaminants. Another objective was to improve the water exchange with the Mediterranean Sea to increase salinity, which was important for the productive reuse of the area for commercial fishing.

Remedial Actions:
The cleanup action included dredging of sediments from polluted areas of the lagoon and isolating the most mercury-contaminated sector through construction of a dyke. Dredged sediment was placed in the dyked area and capped with clean sediment. Dredging was completed in 1992, resulting in the removal of approximately 6,000,000 m^3 of sediment. To increase salinity, a channel 1.5 to 3 meters deep and 300 meters wide was dredged along the central axis of the lagoon, along with a series of smaller parallel channels that branched away from the main canal.

Long-Term Monitoring (post construction to 1 year):
Although implementation of a long-term monitoring program had not occurred at the time of this review, actions recommended in the 1997 publication (Degetto et al., 1997) included:

- Determination of the different chemical forms of mercury, which play a critical role in the partitioning of this element within the biosphere.
- *In-situ* and on-site field experiments for the confined disposal facility (CDF) site, using enclosed area structures, to determine fish and/or crustacean contamination by mercury and other heavy metals present.

Physical: No physical monitoring data was available for review.

Chemical: Mercury concentrations were measured in surficial sediment samples collected from five stations 1 year following dredging.

Biological: No biological monitoring data was available for review.

Project Outcome:
According to Degetto et al, the actual degree of success in restoring this part of the lagoon, which is still connected to the sea, can be completely established only after an ad hoc monitoring program is carried out in the near future.

Project Contact:
None available

Reference:
Degetto, S., M. Schintu, A. Contu, and G. Sbrignadello, 1997. Santa Gilla lagoon (Italy): A mercury sediment pollution case study, Contamination assessment and restoration of the site. *The Science of the Total Environment.* 204:49-56.

Project Name: Shiawassee River Dredging Project

Location: Howell, Michigan

Contaminants of Concern: PCBs

Water Body Type: Riverine

Period of Performance: Dredged in 1982 (pilot); monitored in 1982 and 1983

Background:
Discharge of PCB-contaminated wastewater derived from the manufacture of aluminum cast products resulted in sediment contamination along a 14-mile stretch of the Shiawassee River. The State of Michigan decided that dredging was the best way to remove PCB contamination from the south branch of the Shiawassee River. PCBs in the Shiawassee River presented risk through ingestion of fish and direct contact with river sediments.

Project Goals and Objectives:
Monitoring was used at the Shiawassee River to measure the efficiency of dredging as a means of sediment-bound contaminants and its potential for increasing toxicant concentrations and bioavailability downstream. The remedial objective was to remove contaminated sediments in areas with PCB concentrations in excess of 10 ppm to achieve a PCB concentration of 1 ppm (GE/AEM/BBL, 2000). Conclusions were drawn from monitoring conducted prior to dredging, during dredging, and up to 6 months following dredging.

Remedial Actions:
Pilot dredging of approximately 1 mile of the most contaminated sediment was completed between August and November 1982. The action resulted in the removal of 1,974 cubic yards of river sediment containing an estimated 2,531 pounds of PCBs through hydraulic dredging with a dragline by divers and mechanical removal with a backhoe (EPA, 1998).

Long-Term Monitoring:
To coincide with cleanup operations conducted in 1982, the University of Michigan monitored the impact and results of dredging through studies of PCB uptake by caged fingernail clams and fathead minnows. Monitoring was completed during the 6 months following dredging. Although not considered part of an established monitoring program, additional resident fish tissue analysis was completed by Michigan Department of Natural Resources (MDNR) in 1994 and 1995. A third investigation was completed by Malcolm Pirnie in 1994. This investigation included analysis of PCB aroclor concentrations in 28 river sediment samples, nine wetland sediment samples, resident fish (rock bass, white suckers, pumkinseed, and bluegill), and resident crayfish (Malcolm Pirnie, 1995).

Physical: Physical monitoring of surface water included pH, temperature, dissolved oxygen, specific conductance, and total suspended solids. One control and four study sites were monitored for physical parameters. The study sites were located 0.25 mile, 1.0 mile, 3.3 miles, and 6.8 miles downstream of the contamination source outfall. The dredge area included areas from the outfall to approximately 1.5 miles downstream. Two of the monitoring locations were therefore located within the area of the river where dredging took place.

Chemical: Stream water was collected every 2 to 3 weeks in the spring and summer of 1983 following dredging. Both filtered surface water and suspended solids from surface water samples

were analyzed for PCBs. Water chemistry was analyzed at the same control and study sites used for physical monitoring.

Biological: Caged fish studies of fathead minnows, *Pimephales promelas*, were analyzed for PCBs after exposure periods of 62 days. Samples were collected from the control site and the study sites located 1.0 mile downstream and 6.8 miles downstream. Caged PCB bioaccumulation studies were also conducted on the fingernail clam, *Sphaerium striatinum*. Concentrations of PCBs were evaluated after exposure periods of 14 to 45 days. Caged fingernail clams were analyzed from the same locations as physical and chemical water samples (Rice and White, 1987).

Project Outcome:
Post-dredge monitoring of water, clams, and fish confirmed that significant amounts of PCBs were released from the sediments during dredging. At all locations downstream and in the area of the dredging, there were increases in the biological availability of PCBs for at least 6 months. PCB concentrations in caged fingernail clams and fathead minnows in the dredged zone increased from 64.5 to 87.95 µg/g dry weight and from 13.82 to 18.30 µg/g dry weight, respectively. There was no noticeable change in total PCB concentration in the water.

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References:
EPA, 1998. Shiawassee River, Michigan, Region 5 NPL Fact Sheet. EPA ID# MID980704473. February. Website. http://www.epa.gov/R5Super/npl/michigan/MID980794473.htm

GE/AEM/BBL, 2000. Major Contaminated Sediment Site Database. Last updated February 2000. Website. http://www.hudsonwatch.com.

Malcolm Pirnie, 1995. Development of Sediment Quality Objectives for PCBs for South Branch Shiawassee River, Livingston County, Michigan. Prepared for Michigan Department of Natural Resources. June.

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Project Name: United Heckathorn Dredging Project

Location: Richmond, California

Contaminants of Concern: Pesticides (primarily DDT and dieldrin)

Water Body Type: Marine

Period of Performance: Dredged in 1996 and 1997; monitoring ongoing

Background:
Pesticides, including DDT and dieldrin, were formulated and packaged at the United Heckathorn Site in Richmond Harbor. Contamination was present in sediment, surface water, and biota in 13.5 acres of the Lauritzen Channel and Parr Canal. The Lauritzen Channel and Parr Canal are dead-end channels branching from the Santa Fe Channel, which flows into Richmond Harbor in San Francisco Bay. Fish in the Lauritzen Channel exceeded the Food and Drug Action Levels for DDT and dieldrin (USFWS, 2000).

Project Goals and Objectives:
The goal of the remedy was to provide overall protection of human health and the environment and enable natural recovery of the benthic and water column communities. A target level of 590 ppb DDT was established for removal of sediment to meet a human health risk of 10^{-6}. Project cleanup levels in water were 0.59 ppt for total DDT and 0.14 ppt for dieldrin. A 5-year monitoring program has been implemented to measure achievement of project goals and objectives.

Remedial Actions:
Pesticide-contaminated soft sediment was mechanically dredged down to hard underlying deposits using long-stick excavators between August 1996 and April 1997. A cable arm clamshell was used for soft sediment and a conventional clamshell was used for harder material below. A total of 108,000 cubic yards of sediment were removed, solidified, and disposed in off-site landfills. Dredged areas were backfilled to a depth of 6 to 18 inches with 15,700 cubic yards of sand (GE/AEM/BBL, 2000).

Long-Term Monitoring:
The long-term monitoring program established to evaluate the United Heckathorn project was initiated 6 months after completion of remediation and is scheduled to continue for a period of 5 years. A provision was included to extend the monitoring program if monitoring goals were not achieved (Lincoff & Kohn, 1997).

Physical: No physical monitoring is known to be included in the program.

Chemical: Samples were collected from the water column at various stations and analyzed for DDT and dieldrin. Although not a part of the monitoring program, four samples of the top 10 inches of sediment were collected by EPA in November 1998 based observation of elevated DDT concentrations in a sediment sample collected by the institute of Marine Sciences at the University of California, Santa Cruz in October 1998.

Biological: Biological monitoring included analysis of California mussels (*Mytilus californianus*) and resident mussels for pesticides. California mussels were placed at four stations for a period of 4 months each year. Resident mussels were collected to measure long-term exposure. Tissues were analyzed and lipid normalized. The biological monitoring program was designed to be

comparable with the California State Mussel Watch Program, which monitored mussel pesticide concentrations in the harbor from 1987 to 1993 (Battelle, 1999).

Project Outcome:
Sediment and water column sampling indicate that elevated concentrations of DDT and dieldrin are present at concentrations significantly higher than remediation goals. Biological monitoring, however, has shown dramatic reductions of DDT and dieldrin in resident and transplanted mussels.

Project Contact:
None available

References:
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U.S. FWS, 2000. Notice of Availability, Restoration Plan and Environmental Assessment for Natural Resources Injured by Releases of Pesticides from the United Heckathorn Superfund Site. Department of the Interior, Fish and Wildlife Service. Federal Register, Vol. 65, No. 40. February 29.

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Project Name: Waukegan Harbor Dredging Project

Location: Waukegan, Illinois

Contaminants of Concern: PCBs

Water Body Type: Lacustrine

Period of Performance: Remedial action from 1990 to 1994; dredged from 1991 to 1992

Background:
The Waukegan Harbor Area of Concern (AOC) is located in Lake County, Illinois, on the west shore of Lake Michigan. The harbor receives drainage from Waukegan River basin and subsequently discharges to Lake Michigan. Hydraulic fluid containing PCBs used in die cast works was discharged to Waukegan Harbor from 1961 to 1972. Approximately 300,000 pounds of PCBs were released to the harbor resulting in sediment contamination, benthos degradation, dredging restrictions, beach closings, degradation of phytoplankton and zooplankton populations, and fish advisories.

Project Goals and Objectives:
After a lengthy litigation process, a Consent Decree was entered by the U.S. Justice Department in District Court in 1989. The Consent Decree called for remediation of the contaminated sediments greater than 50 ppm PCBs. EPA calculations showed that removal of sediment to a concentration of 50 ppm would result in removal of 96 percent of the PCB mass in the Upper Harbor. Long-term remedial action objectives were protection of human health and the environment (GE/AEM/BBL, 1998).

Remedial Actions:
Remedial activities were conducted between 1990 and 1994. Hydraulic dredging took place in late 1991 and early 1992 using an 8-inch cutterhead and a 10-inch cutterhead. Dredged sediment was placed in a confined disposal facility (CDF) created from Slip 3 and capped after 2 years and 5 months of settling. Approximately 32,000 cubic yards of PCB-contaminated sediment were removed from the Harbor and an additional 6,300 cubic yards of PCB-contaminated sediment (in excess of 500 mg/kg PCBs) were removed from Slip 3. Sediment removed from Slip 3 was treated and returned to the Slip 3 containment cell. To offset the loss of Slip 3, another slip was constructed and opened to the public in July 1991 (IJC, 1999).

Long-Term Monitoring:
Long-term fish tissue monitoring was conducted by the U.S. EPA from 1978 through 1983 and is now monitored by the Illinois State EPA (1991 through present). A one-time sampling event was conducted in 1996, approximately 4 years after the harbor was dredged. Monitoring parameters in the 1996 event included surface sediment chemistry, sediment toxicity testing, and bioaccumulation studies. No other long-term monitoring programs for biological parameters were known to exist. A 30-year operation and maintenance plan (OMMP) is in place for long-term monitoring of the CDF site.

> *Physical:* A network of groundwater monitoring wells were installed around the CDF and are periodically sampled for PCBs in accordance with the OMMP. No other physical monitoring data was available for review.
>
> *Chemical:* Sediment samples from 18 locations in Waukegan Harbor were collected and analyzed for PCBs in April 1996. Although not contaminants of concern (COCs) for the remedial project, samples were also analyzed for metals and PAHs.

Biological: Sediment toxicity was evaluated in 20 samples collected in April 1996. Toxicity testing included 42-day whole sediment toxicity analysis of the amphipod *Hyalella azteca* for survival, growth, and reproduction, 28-day whole sediment bioaccumulation tests of the oligochaete *Lumbriculus variegatus*, and bacteria sediment toxicity measurements through luminescent light emission (EPA, 1998).

Carp fillet samples were collected and analyzed for PCBs from 1993 to 1998. More recent data was not available for review. Sample sizes ranged between one and six fish.

Project Outcome:
As a result of the dramatic decline in PCBs in fish, some posted Waukegan Harbor fish advisories were removed, although fish advisories still exist for carp and other harbor fish. PCB concentrations in Waukegan Harbor fish are now considered to approximate fish found elsewhere in Lake Michigan.

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References:
EPA, 1998. Evaluation of the Toxicity and Bioaccumulation of Contaminants in Sediments Samples from Waukegan Harbor, Illinois. U.S. Environmental Protection Agency. Website. http://www.epa.gov/glnpo/sediment/waukegan/index.html.

GE/AEM/BBL, 1998. Outboard Marine. Website. http://www.hudsonwatch.com.

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Project Name: Hamilton Harbour *In-Situ* Capping Demonstration Project

Location: Hamilton Harbour, Lake Ontario, Canada

Contaminants of Concern: Metals (Zn, Cu, Pb, Cr, Ni, Cd, As, Hg)

Water Body Type: Lacustrine

Period of Performance: Demonstration *in-situ* capping in 1995; monitoring from 1995 to Present

Background:
Sediments in Hamilton Harbour exceeded the Ontario Ministry of Environmental and Energy (OMEE) sediment quality guidelines at the severe effect level for several metals. The industrial-contaminated sediments were generally confined to the upper 30 cm of very soft clay underlain by very soft silty clay (natural sediment). Environmental impacts included risks to human health through exposure and fish consumption and risks to the environment including adverse impacts to fish and wildlife.

Project Goals and Objectives:
A demonstration project was implemented to assess the feasibility of capping as a remedy for containment of contaminated sediments. A monitoring program was established to assess the long-term mobility of trace elements through the cap material and the physical stability of the cap.

Remedial Actions:
A demonstration *in-situ* capping project was performed on a 100-meter by 100-meter area of contaminated sediments in Hamilton Harbour in 1995 (Zeman and Patterson, 2000). The capping material was clean sand with an average grain size of 0.5 mm. The cap was placed using a custom-designed hopper and a series of 20 130-mm diameter by 12-meter long tremie tubes. Sand was applied in three lifts to achieve a final thickness of approximately 35 cm (Azcue et. al, 1998).

Long-Term Monitoring:

Physical: Bathymetry was completed by acoustic surveys. The cap thickness was measured by divers using handheld probes. Grain size and shear strength were analyzed on cores taken from the cap.

Chemical: Sediment cores were collected and analyzed for metals in sediment and pore water. Cores were collected one to two times per year from 1995 through 1998. Pore water analysis for metals will continue thorough 2000. Results were evaluated to monitor contaminant migration through the cap and the redox state of the metals.

Biological: Biological monitoring was limited because results were not considered useful for evaluation of the project. This was due to the small area of the cap and the presence of contamination surrounding the capping area. A single sampling event was conducted after completion of the cap for biological toxicity (Zeman, 2000). Toxicity was evaluated through bioassays on the chironomid, *Chironomid riparius*, the amphipod, *Hyalella azteca*, the mayfly, *Hexagenia*, and the oligochaete worm, *Tubifex tubifex* (Zeman et. al, 2000).

Project Outcome:
Significant reductions in the flux of site contaminants were observed after capping of the contaminated sediments. Oxygen-sensitive elements such as iron and magnesium were shown to remobilize in anoxic sediments and precipitate in the oxic interface.

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References:

Azcue, J. M., A. J. Zeman, A. Murdoch, F. Rosa, and T. Patterson, 1998. Assessment of sediment and pore water after one year of subaqueous capping of contaminated sediments in Hamilton Harbour, Canada. *Wat. Sci. Tech.* Vol. 37, No. 6-7, pp. 323-329.

Zeman, A. J., 2000. Personal communication between Damon Morris of ThermoRetec and Alex Zeman of the National Water Research Institute regarding Hamilton Harbour capping project. June 22.

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Project Name: New York Mud Dump Capping Project

Location: New York, New York

Contaminants of Concern: Dioxin

Water Body Type: Marine

Period of Performance: Placement of dredged sediment and cap from 1993 to 1994; monitoring from 1992 to Present

Background:
The mud dump site is an open-water sediment disposal site located off the coast of New York. Sediments from the berthing areas at the Port Authority of New York and New Jersey were placed at the dump site and contained trace levels of dioxin. After disposal of contaminated material, a clean sand cap was placed over the material to prevent contaminant migration. Due to concern over the potential effects of dredging and disposal of the material, a comprehensive monitoring and management program was implemented to evaluate long-term effectiveness of capping dioxin-contaminated sediments at the New York Mud Dump Site.

Project Goals and Objectives:
The purpose of long-term monitoring was to document the physical integrity of the cap and the effectiveness of the sand cap for preventing vertical migration of dioxin from the dredged material into the overlying water and benthic community.

Remedial Actions:
Under a permit issued to the Port Authority of New York and New Jersey by the Corps of Engineers, New York District, over 500,000 cubic yards of dioxin-contaminated sediments were disposed of within the New York Mud Dump Site. Sediments were capped with roughly 2,500,000 cubic yards of sand to achieve a cap thickness of 1 meter as required by the disposal permit (McDowell et al., 1994).

Long-Term Monitoring:
Long-term monitoring is being conducted to verify that the cap has effectively isolated the contaminated dredged material from the benthic environment and overlying water column.

Physical: A high-resolution bathymetry survey was conducted on the capped disposal mound and compared to baseline data. Additional physical data collection included REMOTS® sediment profile photography, subbottom profiling to determine cap thickness and assess changes in thickness over time, and geotechnical analysis of cores taken of the cap material and underlying dredged material.

Chemical: Chemical analyses were conducted on surficial sediment samples of the capped mound. Sediment cores were analyzed to obtain chemical data for the capping material sediment and underlying sediment.

Biological: Tissue sampling was conducted for chemical analysis. No further information is available at this time.

Project Outcome:
Engineering of cap construction was considered a success.

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Reference:

McDowell, S., B. May, and D. Pabst, 1994. The dioxin capping project at the NY mud dump site. *Dredging '94: Proceedings of 2nd International Conference on Dredging and Dredged Material Placement, 14-16 November 1994, Orlando, Florida.* E. C. McNair, ed. American Society of Civil Engineers, New York. pp. 1270-1277.

Project Name: Simpson Capping Project

Location: Tacoma, Washington

Contaminants of Concern: Phenolics, PAHs

Water Body Type: Marine/Estuarine

Period of Performance: Remedial action from 1987 to 1988; Capping in 1988

Background:
The Simpson Cap, located near the St. Paul Waterway, was the first aquatic remedial action in the Commencement Bay Nearshore Tideflats Superfund Site located in Tacoma, Washington. Discharge of untreated wastewater from pulp and paper mills, log storage and handling, wood chip handling, and stormwater runoff led to contamination of marine sediments with phenolic compounds and PAHs. Sediment concentrations were above sediment quality guidelines considered protective of environmental health.

Project Goals and Objectives:
The project goal was designed to permanently isolate the chemical contamination found in the marine sediments, and restore intertidal and shallow water habitat. These two objectives were met by capping contaminated marine sediments in-place and by providing habitat features on the surface of the cap to encourage recolonization by benthic infauna and macrophytes (algae) and usage by fish and birds. A 10-year monitoring program was developed to measure achievement of project goals and objectives.

Remedial Actions:
Remediation of the 17-acre area of contaminated sediment occurred in 1987 and 1988. Application of the cap took place in July and August of 1988. Black sand obtained from the nearby Puyallup River was used as the clean capping material because it was physically suitable for isolation of contaminated sediment and would provide a desirable substrate for marine life. The capping material was hydraulically dredged through a pipeline and placed with a downpipe diffuser. The final cap thickness ranged from approximately 2.5 meters to 6.5 meters. Riprap was placed to prevent erosion from wave action in high intertidal areas (Stivers and Sullivan, 1994).

Long-Term Monitoring (10-year):
A 10-year monitoring program was developed to evaluate performance of capping in achieving physical and chemical isolation of contaminated sediments and provision of habitat for benthic infauna.

> *Physical:* Periodic bathymetry surveys were completed to examine the project for large-scale changes in cap structure. Five transects were established to measure elevation changes.
>
> *Chemical:* Through-cap sediment cores were periodically taken from 6 to 12 permanent sampling locations. Cores were collected from a hollow-stem auger drill rig on a barge using the rig to drive shelby tubes. Bulk chemistry samples were collected from depths of 25 to 45 cm and 75 to 95 cm above the cap/underlying sediment interface and 25 to 45 cm below the cap surface.
>
> Surface sediments were sampled for bulk chemistry at six permanent locations. Samples were collected using a Van Veen grab sampler. Additionally, bulk chemistry samples were collected and analyzed at intertidal seeps and naturally occurring methane vents to determine if contaminant transfer was present in these locations.

Biological: Habitat restoration monitoring included benthic infauna and epibenthos sampling at six stations and qualitative macrophyte sampling. Benthic organisms were sieved from the top layer of sediment, enumerated, and taxonomically identified to the lowest taxonomic level possible. Epibenthos were sampled using a suction pump sampler, enumerated, and identified. Qualitative macrophyte monitoring was completed through annual aerial photographs and visual surveys during low tides in late summer.

Project Outcome:
Remediation of contaminated sediment was integrated with natural resource restoration to produce 6 acres of intertidal and 11 acres of subtidal habitat. In general, monitoring results indicate that the cap and new habitat are both functioning as planned. The chemical contaminants in the original sediments appear to be remaining in place, effectively isolated from the biologically important environment of Commencement Bay (Murray et al., 1994).

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References:
Murray, P., D. Carey, and T. J. Fredette, 1994. Chemical flux of pore water through sediment caps. *Dredging '94: Proceedings of 2nd International Conference on Dredging and Dredged Material Placement, 14-16 November 1994, Orlando, Florida.* E. C. McNair, ed. American Society of Civil Engineers, New York. pp. 1008-1015.

Stivers, C. E. and R. Sullivan, 1994. Restoration and capping of contaminated sediments. *Dredging '94: Proceedings of 2nd International Conference on Dredging and Dredged Material Placement, 14-16 November 1994, Orlando, Florida.* E. C. McNair, ed. American Society of Civil Engineers, New York. pp. 1017-1026.

Project Name: Wyckoff/East Eagle Harbor *In-Situ* Capping Project

Location: Bainbridge Island, Washington

Contaminants of Concern: Polyaromatic Hydrocarbons (PAHs)

Water Body Type: Marine

Period of Performance: Capping from 1993 to 1994; monitoring from 1993 to Present

Background:
Eagle Harbor is an embayment of Puget Sound near Seattle, Washington. Chemicals seeping from a former wood treatment plant located in adjacent uplands resulted in PAH sediment contamination. The area was listed as a Superfund site in 1987 by the Environmental Protection Agency (EPA). The site was divided into east and west operable units because sediments were primarily contaminated with mercury in the West Harbor, while PAHs were the primary contaminant in the East Harbor. Elevated PAH Concentrations in surface sediment were above the state management standards for protection of benthic invertebrates. Capping was chosen as the remedial action for PAH contamination in the East Harbor.

Project Goals and Objectives:
The intent of the cap application was to ensure that sediment contamination was within or below the range of minor biological effects and protective of human health. Objectives of the monitoring program were to measure effectiveness of the cap, compare results to contaminant concentrations in off-cap subtidal sediments in East Eagle Harbor, and evaluate source control within the capping area. Specific objectives for each of these categories are outlined below (Nelson et al., 1994).

The monitoring objectives for the cap area were presented as four monitoring objectives:

1. Is the cap material physically stable, remaining in place at the desired thickness?

2. Is the cap effectively isolating the underlying contaminated sediments?

3. Are sediments in the biologically active zone (0 to 10cm) remaining clean relative to the Washington State sediment management standards (SMS)?

4. Is the cap being recolonized by benthic (bottom-dwelling) organisms (i.e., benthic invertebrates and fishes)?

The objectives for source control were presented as three monitoring objectives:

1. Determine whether intertidal seeps of product have been reduced or controlled.
2. Determine whether suspended particulates in the operable unit are contaminated.
3. Determine whether recently deposited sediments in the operable unit are contaminated.

Remedial Actions:
During the fall and winter of 1993-1994, the U.S. Army Corps of Engineers placed approximately 250,000 cubic meters of dredged material over approximately 54 acres of PAH-contaminated sediment in Eagle Harbor. Capping material was obtained from a navigational dredging project approximately 30 miles away. The proposed capping approach divided the capping area into two application areas based on physical characteristics of the bottom sediments. The first area was capped with fine to medium sands,

and the second with predominantly silt. The cap was designed as a 0.9-meter layer of dredged material over the existing bottom (EPA et al., 1994).

Long-Term Monitoring:
The long-term monitoring program is a tiered program focusing on the first 10 years after completion of the remedial action (SAIC, 1996; SAIC, 1998; EPA et al., 1995). The type and frequency of monitoring may be adjusted or monitoring may be discontinued provided project objectives are met.

Physical: Long-term physical motoring of the cap included bathymetry, subbottom profiling, REMOTS® sediment profile photography, and video surveys.

Chemical: Measurements of chemical parameters were made through on-cap cores, surface sediment samples collected at seeps, and sediment collected in sediment traps.

Biological: Biological monitoring included observations using towed underwater video surveys, and REMOTS® sediment profile photography. Benthic infauna measurements were also conducted to assess recolonization of the cap.

Project Outcome:
As of 1997 (year 3 monitoring), the following observations have been made regarding the cap:

- The cap appears to be physically stable, with the exception of some erosion near the Washington State Ferry terminal.
- Creosote contamination may have migrated up into the cap at two locations.
- PAH concentrations in suspended particulate material captured in sediment traps appear to be decreasing.
- Surface sediment concentrations of PAHs have generally increased.
- Biological habitat quality of the cap is improving with time, as suggested by the organism-sediment index (OSI) values derived from the REMOTS® sediment profile photography.

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References:
EPA, USACE, SAIC, 1994. On-Scene Coordinator's Report, Statement of Findings: East Harbor Operable Unit Removal Action, Wyckoff/Eagle Harbor Superfund Site, Bainbridge Island, Washington. Final Report. Prepared by U.S. Environmental Protection Agency, Region 10, and the U.S. Army Corps of Engineers, Seattle District with assistance by Science Applications International Corporation, Bothell Washington.

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Project Name: James River Monitored Natural Recovery (MNR) Project

Location: Hopewell, Virginia

Water Body Type: Estuarine

Period of Performance: No active remediation; monitoring from 1978 to Present

Background:
A pesticide factory located in Hopewell, Virginia discharged kepone, a chlorinated pesticide, to the James River through the municipal sewage system, surface runoff and solid waste dumping. The 81-mile James River estuary extends from 7 miles above the contaminant source to Chesapeake Bay. Pesticide contamination was present in sediments, water column, biota, and small mammals. The estimated volume of contaminated sediment was 221 million cubic yards. Average kepone concentrations in the river channel ranged from 20 to 193 ppb. The maximum concentration (12 ppm) was detected close to the source. The regulatory action was a mitigation feasibility study with oversight by EPA (GE/AEM/BBL, 1998).

Project Goals and Objectives:
The principal goal of the remedial action was to reduce concentrations of kepone in fish and crab and to eliminate all consumption advisories for protection of human health. The action levels established for biota were 0.3 ppm in fish and 0.4 ppm in blue crab. Advisories included a commercial fishing ban and a subsistence fish consumption advisory. A secondary goal of the remedy was to eventually lift a moratorium on maintenance dredging of the main channel.

Remedial Actions:
An investigation of remedial options (stabilization, dredging, and retrievable sorbents) conducted in 1978 indicated a minimum cost of $3 billion for active remediation. The high cost and concern over biological effects of resuspension led to selection of natural recovery remedy though burial by natural sedimentation. A long-term monitoring program was implemented beginning in 1978 (Committee on Contaminated Marine Sediments, 1997).

Long-Term Monitoring:
The monitoring program was based primarily on biological sampling because the remedy was to be protective of human health through bioaccumulation and consumption. No kepone criteria was established for sediment or surface water.

Physical: No long-term physical monitoring is known to exist.

Chemical: Sediment cores and surface water samples were collected and analyzed for kepone concentrations. Monitoring of sediment and surface water was discontinued several years ago (Unger, 2000).

Biological: Tissues of fish, crab, and oyster have been included in long-term monitoring for kepone concentrations. The extent of biological monitoring has changed significantly over time as more data has become available and kepone concentrations have decreased. Crab and oyster sampling was discontinued in 1985. Fish monitoring is still conducted, although the monitoring has declined from intensive to approximately 100 to 150 fish per year. Early in the study, many species of fish were analyzed. Recent fish sampling has been limited to mostly piscivorous fish,

especially striped bass, because historic data has measured the highest biological kepone concentrations in these fish (Unger, 2000).

Project Outcome:
Kepone concentrations were reduced in crab and oyster from 0.8 ppm in 1976 to 0.1 to 0.2 ppm in 1985. The commercial fishing ban was lifted in 1988. A restricted consumption advisory for the general population remains in place for all fish (EPA, 1998).

Project Contact:
None available

References:

Committee on Contaminated Marine Sediments, 1997. *Contaminated Sediments in Ports and Waterways, Cleanup Strategies and Technologies.* National Academy Press. Appendix C.

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Project Name: Sangamo-Weston Monitored Natural Processes (MNP) Project

Location: Pickens, South Carolina

Contaminants of Concern: PCBs

Water Body Type: Riverine/Lacustrine

Period of Performance: No active remediation; monitoring ongoing from 1992 to Present.

Background:
Discharges from Sangamo-Weston, Inc. a capacitor manufacturing plant, resulted in PCB contamination of sediments along a 7-mile portion of Twelvemile Creek and into Hartwell Lake. Typical surface sediment PCB concentrations in Twelvemile Creek ranged from 1 to 3 ppm with slightly higher concentrations in deeper sediment. Maximum concentrations in depositional areas measured as high as 61 ppm. Maximum PCB concentrations in upper Lake Hartwell measured from 5 to 11 ppm. Typical PCB concentrations in the lower lake measured below 1 ppm. Elevated PCB sediment and fish tissue concentrations resulted in posting of fish consumption advisories for all fish species collected in the project area.

Project Goals and Objectives:
The target sediment cleanup level was established at 1 ppm PCBs for the protection of human health based on technical feasibility. Estimates were made through modeling that FDA safe fish consumption levels of 2 ppm PCBs would be reached in largemouth bass after 12 years of MNP (1992 to 2004). A carcinogenic risk-based study determined that a fish concentration of 0.036 ppm resulted in a 10^{-4} risk to anglers through ingestion of fish. However, the risk-based fish cleanup goal was determined to be technically impractical and the FDA level was considered acceptable based on cost versus risk reduction estimates (GE/AEM/BBL, 2000).

Remedial Actions:
The removal, treatment, and disposal of contaminated sediment was rejected as too costly ($500 million) and judged technically infeasible to achieve the 1 ppm cleanup level. Aggressive engineering controls were also rejected as too costly and not providing significant risk reduction.

Natural recovery supplemented by institutional controls (periodic flushing) was selected as the only remedy. A long-term monitoring program commenced in 1995 to fulfill the requirements of the June 1994 Final Record of Decision requiring aquatic biota monitoring and sediment sampling. EPA Region 4 issued a Unilateral Administrative Order on September 25, 1998 requiring the potentially responsible parties to implement a fish consumption advisory and public education program, to perform annual aquatic biota and sediment monitoring to determine PCB levels in fish and other aquatic life, and to periodically flush sediment past three impoundments to facilitate burial of PCB-impacted sediments located downstream.

Long-Term Monitoring:
The long-term monitoring program design included chemical analysis of sediment, surface water, fish tissue and clam tissue. Annual monitoring was conducted in the spring of each year for sediment at 20 locations and fish at six stations beginning in 1995. Sampling will continue for a minimum of 15 years.

Physical: No physical monitoring data was available for review.

Chemical: Sediment chemistry analysis was conducted on surface grabs from the top 6 inches. At sampling locations in the stream, one grab sample was collected. Composites of three grabs were obtained along transects for sampling locations in impounded water. Although surface water was initially tested for PCBs, none were detected and surface water sampling was discontinued.

Biological: Biological tissue sampling for PCBs includes resident game fish, forage fish, and freshwater clams. Fish sampling was conducted from six sampling locations in the impoundment. Three species of fish were collected including one migratory species (stock hybrid bass) and two non-migratory species (bass and channel catfish). Forage fish were collected from locations corresponding to high, medium, and low concentrations of PCBs. Samples of forage fish from each location consisted of composites of 10 fish. PCBs were also measured in 28-day bioaccumulation tests of the native freshwater clam *Corbicula*.

Project Outcome:
Monitoring since 1994 has shown measurable decreases in sediment concentrations of PCBs. Whether the decrease has proven to be statistically significant remains to be determined. Concentrations of PCBs in resident biological tissue have been erratic to date and have not shown noticeable trends. Although attempts have been made to consider lipid content, migration, rainfall, age of the fish, etc. to demonstrate trends, they have not been successful (Zeller, 2000). A no-consumption advisory remains in-place for all species of fish for the general population in Twelvemile Creek and Lake Hartwell (EPA, 1998). Annual monitoring is continuing at the site.

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References:
EPA, 1998. Listing of Fish and Wildlife Advisories. Prepared by the U.S. Environmental Protection Agency Office of Science and Technology. December 31. Website: http://www.epa.gov/ost/fish.

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