Appendix A

Summary of Previous Remedial Action Objectives

Summary of Previous RAOs

Document 1

The first document, *Polychlorinated Biphenyl (PCB) Contaminated Sediment in the Lower Fox River: Modeling Analysis of Selective Sediment Remediation* (WDNR - Bureau of Watershed Management, February 1997), provides the following goals (referred to as endpoints) for the management of impacted sediments:

- Meet existing PCB water quality standards
  - 0.01 ng/L (warm water fisheries)
  - 0.003 ng/L (Great Lakes)
  - 0.12 ng/L (wildlife)

[Note: The concentrations reported above reflect present surface water quality criteria, which are not the same as those originally stated in the referenced document.]

- Reduce mass transport of PCBs from Lower Fox River to Green Bay
- Reduce fish tissue concentrations to levels protective of:
  - Human health
  - Fish-consuming birds and mammals

Document 2

The second document, *Feasibility Study Report for Deposits POG and N on the Fox River* (Graef, Anhalt, Schloemer & Assoc. Inc., April 1997), provides the following RAOs:

- General Lower Fox River and Watershed
  - Reduce the mass and volume of PCB- and mercury-contaminated sediments before the sediments are transported downstream of the De Pere dam or enter Green Bay
  - Reduce or eliminate off-site transport of PCBs and other contaminants from deposits POG and N
  - Eliminate POG and N as continued input/source of contaminants to the system

- Human Health Protection

    - Reduce exposure to humans (via direct ingestion, dermal contact with sediments or from consumption of fish and waterfowl) to mercury and PCBs in sediments transported from deposits N and POG

    - Reduce the exposure of humans to PCBs and mercury bioaccumulated in fish and waterfowl from sediments of deposits N and POG.

- Ecological Protection of Top Receptors (Eagles and Mink)

    - Reduce or eliminate bioavailability of PCBs and mercury present in sediments at POG and N to eliminate biotransfers in the food chain (aquatic and terrestrial) and bioaccumulation in top receptors that cause hazard quotients above 1 and/or acute and chronic toxicity

- Chemical Specific ARARs

    - Reduce exceedances of chemical-specific ARARs/TBCs in water, sediment, fish, and waterfowl in the Lower Fox River resulting from exposure and transport of chemicals originating from Deposits N and POG

Document 3

The third document, *Remedial Investigation/Feasibility Study: Little Lake Butte des Morts Sediment Deposit A* (Blasland, Bouck & Lee, Inc., July 1993), provides the following RAOs:

- Human Health Protection

    - Prevent the ingestion of fish containing PCB concentration in excess of FDA limit (2 ppm)

    - Reduce PCB availability from Deposit A to levels resulting in the reduction of PCB concentrations in fish to levels that are acceptable for ingestion.

- Environmental Protection

    - Reduce bioavailability of Deposit A PCBs to prevent acute or chronic toxicity to aquatic and terrestrial organisms

- Chemical-Specific ARARs
    - Minimize the potential for exceeding Ambient Water Quality Criteria (AWQC) in Little Lake Butte des Morts

Document 4

The fourth document, *Draft Feasibility Study Report for Sheboygan Harbor and River Superfund Site* (Blasland, Bouck & Lee, Inc., April 1998), lists items provided by the EPA to be included as RAOs for the Sheboygan River and Harbor Site. These items were synthesized into four Primary/comprehensive RAOs provided in the FS.

- Provide further protection of human health and the environment from potential adverse effects of PCBs attributable to the Site.
- Mitigate potential PCB sources to the River/Harbor system, and reduce PCB transport within the River system.
- Remove and dispose of Confined Treatment Facility (CTF)/Sediment Management Facility (SMF) sediments.
- Minimize potential human health and environmental risks that may be associated with remedial activities, to the extent practical.

Document 5

The fifth document, *Manistique River and Harbor Engineering Evaluation/Cost Analysis* (Blasland, Bouck & Lee, Inc., April 1994), provides the following RAOs:

- Reduce PCB concentrations in fish and water in the Manistique River and Harbor to levels that would not present an unacceptable human-health or ecological risk and allow elimination of existing fish consumption advisories.
- Maintain the harbor as a navigable waterway for commercial shipping, fishing boats, and recreational watercraft. In general, restore the river and harbor areas for use by deeper draft vessels.
- Minimize the need for future remedial action in the area following completion of a non-time critical action.
- Implement actions which would best contribute to the efficient performance of any future remedial action(s) in the area.
- Achieve compliance consistent with federal and state ARARs for the Site.

- Comply with risk-based objectives defined by TERRA, Inc., as part of the risk assessment.

- Reduce, as much as practicable, the release of PCBs associated with particles and dissolved in the water to Lake Michigan.

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.**

RETEC Project No.: WISCN-14414

December 2002

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

ThermoRetec Corporation would like to thank Odgen-Beeman and Associates and SAIC for their assistance formulating the review parameters and structure of the document. Dr. Mike Palermo and David Bowman of the U.S. Army Corps of Engineers provided key technical reviews of the content and interpretation of the material presented herein. Both Peg Johnson of Odgen-Beeman and Associates and Bill Fitzpatrick of Wisconsin Department of Natural Resources provided helpful technical review of the dredging technologies and their applications. John Lunz of SAIC constructed the review of monitoring methods for numerous dredging, capping, and National Recovery projects (Attachment 2).

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.

Table of Contents

Table of Contents

List of Tables

List of Attachments - Case Studies of Sediment Dredging Projects

List of Attachments - Case Studies of Sediment Dredging Projects

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.

Hydraulic Auger Dredge
Source: EPA

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).

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.

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


Turbidity meter M-2.

Deposit N Water Quality Monitoring
Source: Bill Fitzpatrick, WDNR

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 utilized at Deposit N.

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

Great blue heron on the bank of the Lower Fox River.

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.

7 References

Averett, D., 1997. Data requirements for advancing techniques to predict dredge-induced sediment and contaminant releases—A review. In: (Demars et al., Ed.) Dredging, Remediation, and Containment of Contaminated Sediments. ASTM STP 1293, K. R. Demars, G. N. Richardson, R. N. Yong, and R. C. Chancey, Ed., American Society of Testing and Materials, Philadelphia. p. 128–135.

Averett, D., Daniel, E., Perry, B.D., and Torrey, E.J., 1990. Review of Removal, Containment and Treatment Technologies for Remediation of Containment Sediment in the Great Lakes. U.S. Army Corps of Engineers, Miscellaneous papers, EL-90-25.

BBL, 1999. Analysis of Sediment Management Technologies Effectiveness. Prepared for the Lower Fox River Group. Blasland, Bouck and Lee, Inc., Technical Report, April.

Cleland, J., 2000. Results of Contaminated Sediment Cleanups relevant to the Hudson River. An update to Scenic Hudson's report Advances in Dredging Contaminated Sediment. Prepared for Scenic Hudson. October.

Cura, J., E. Southerland, and K. E. McConnell, 1998. Roundtable discussion: Improving decision making, developing decision-making criteria, monitoring the effectiveness of remediation projects. National Symposium on Contaminated Sediments: Coupling Risk Reductions with Sustainable Management and Reuse, Conference Proceedings 19, Washington, D.C. May 27–29, 1998.

Cushing, B. S., 1999. State of Current Contaminated Sediment Practices, Contaminated Sediment Management Technical Papers. Applied Environmental Management, Inc. Prepared by the Sediment Management Workgroup. Fall.

Demars et al., 1997. Dredging, Remediation, and Containment of Contaminated Sediments. ASTM STP 1293.

DOD, 1994. Remediation Technologies Screening Matrix and Reference Guide, Second Edition. DOD Environmental Technology Transfer Committee. NTIS PB95-104782.

EPA, 1988. Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. EPA/540/G-89/004.

EPA, 1994a. Assessment and Remediation of Contaminated Sediments (ARCS) Program, Final Summary Report. EPA 905-S-94-001.

EPA, 1994b. Assessment and Remediation of Contaminated Sediments (ARCS) Program. Remediation Guidance Document. U.S. Environmental Protection Agency Great Lakes National Program Office. EPA 905-R94-003. October.

EPA, 1997. The National Sediment Quality Survey, Volume 1.

EPA, 1998. EPA's Contaminated Sediment Management Strategy. U.S. Environmental Protection Agency Office of Water. EPA-823-R-98-001. April.

Fairey, R., C. Roberts, M. Jacobi, S. Lamerdin, R. Clark, J. Downing, E. Long, J. Hunt, B. Anderson, J. Newman, R. Tjeerdema, M. Stephenson, and C. Wilson, 1998. Assessment of sediment toxicity and chemical concentrations in the San Diego Bay Region, California, USA. *Environ. Toxicol. Chem.* 17:1570–1581.

Hahnenberg, J., 1999. Presentation on the Lower Fox River and Sediment Site Cleanups. U.S. Environmental Protection Agency Presentation. September 29.

Herbich, J., 1997. Removal of contaminated sediments: equipment and recent field studies. In: (Demars et al., Ed.) Dredging, Remediation, and Containment of Contaminated Sediments. ASTM STP 1293.

Krantzberg, G., J. Hartig, L. Maynard, K. Burch, and C. Ancheta. Deciding When to Intervene: Data Interpretation Tools for Making Sediment Management Decisions Beyond Source Control. Sediment Priority Action Committee Great Lakes Water Quality Board.

Long, E., A. Robertson, D. A. Wolfe, J. Hameedi, and G. M. Sloane, 1996. Estimates of the spatial extent of sediment toxicity in major U.S. estuaries. *Environ. Sci. Technol.* 30:3585–3592.

Lower Fox River Group, 1998. Large-scale Dredging of the Lower Fox River: What Can Be Concluded from Other Environmental Dredging Projects? The Lower Fox River Group. September 11.

Lower Fox River Group, 1999. Effectiveness of Sediment Removal: An Evaluation of EPA Region 5 Claims Regarding Twelve Contaminated Sediment Removal Projects. Green Bay, Wisconsin. September 9.

NRC, 1990. Managing Troubled Waters: The Role of Marine Environmental Monitoring. National Research Council. Washington, DC. Committee on a systems assessment of marine environmental monitoring. PB93232767.

NRC, 1997. Contaminated Sediment in Ports and Waterways: Cleanup Strategies and Technologies. National Research Council. National Academy Press, Washington D.C.

NRC, 1998. Conference Proceedings 19 from the National Symposium on Contaminated Sediments, May 27–29, 1998. National Research Council.

NRC, 2001. A risk-management strategy for PCB-contaminated sediments. Committee on Remediation of PCB-contaminated sediments. National Research Council. Prepared for the National Academy of Sciences and the U.S. EPA. National Academy Press, Washington, DC.

Ortiz, E., R. G. Luthy, and D. A. Dzombak, 1998. Evaluation of Physical/Chemical Mechanisms Controlling PCB Release for Grasse River Sediments: Final Report to Aluminum Company of America. Prepared by the Department of Civil and Environmental Engineering, Carnegie Mellon University. May.

Peterson, G., J. Wolfe, J. Depinto, Limno-Tech Inc., 1999. Decision Tree for Sediment Management. Sediment Management Work Group, 1999. Contaminant Sediment Management Technical Papers. Fall.

Sediment Management Work Group, 1999. Measuring Effectiveness of Remedial Actions Against Remedial Action Objectives at Contaminated Sediment Sites. Sediment Management Work Group. Fall.

Sediment Priority Action Committee, 1997. Overcoming Obstacles to Sediment Remediation in the Great Lakes Basin. White Paper. Great Lakes Water Quality Board, International Joint Commission.

SEDTEC, 1997. Environment Canada's Contaminated Sediment Removal Program. CDRom.

Swartz, R. C., P. F. Kemp, D. W. Schultz, G. R. Ditsworth, and R. J. Ozretich, 1989. Acute toxicity of sediment from Eagle Harbor, Washington, to the infaunal amphipod *Rhepoxynius abronius*. *Environ. Toxicol. Chem.* 8:215–222.

Taylor, A.,1998. Panelist Presentation - Environmental Dredging. National Symposium on Contaminated Sediments Conference Proceedings 19, May 27–28, 1998. National Research Council.

ThermoRetec, 1999. Draft Feasibility Study: Lower Fox River, Wisconsin. Prepared for Wisconsin Department of Natural Resources. February

Thomann, R. V. and J. P. Connelly, 1984. Model of PCB in the Lake Michigan lake trout food chain. *Environ. Sci. Tech.* 18:65–71.

Zarull, Michael, J. H. Hartig, and Lisa Maynard, 1999. Ecological Benefits of Contaminated Sediment Remediation in the Great Lakes Basin. Sediment Priority Action Committee Great Lakes Water Quality Board. August.

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:
Project Location:

Reviewed by:
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
Manistique River, Michigan	Active	248	Schoolcraft Co. downstream from M-94/Old U.S. 2	PCBs (Total)	common carp: NCGP, NCSP, RSP	State	NA
Marathon Battery, New York	Active	3519	Bridge at Catskill South to and including upper bay of New York Harbor	PCBs (Total)	14 species: RGP all fish: NCSP shellfish: NCGP	State	NA
Marathon Battery, New York	Active	3519	Bridge at Catskill South to and including upper bay of New York Harbor	Cadmium	shellfish: RGP, NCGP	State	NA
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 all bottomfish, American eel, flounder, scup, tautog: NCGP, NCSP	State	NA
New Bedford Harbor, Massachusetts	Active	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 Metals	all bottomfish, rockfish, shellfish: NCGP	Local Health Dept.	NA
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) Tetrachloro-ethylene	all bottomfish, shellfish: NCGP	Local Health	NA
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
Waukegan Harbor, Outboard Marine, Illinois	Active	105	977,000 acres	PCBs (Total)	catfish, common carp, lake trout: NCGP brown trout, Chinook salmon, Coho salmon, lake trout: RGP	State	NA
Waukegan Harbor, Outboard Marine, Illinois	Rescinded	105	977,000 acres	PCBs (Total)	brown trout, Chinook salmon: NCGP brown trout, Chinook salmon, Coho salmon, lake trout: NCSP	State	12/31/1996
Wyckoff/West Eagle Harbor, Washington	Active	3339	Bainbridge Island	PAHs Mercury	shellfish, all bottomfish: NCGP	State	NA

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 Volume (cy)	Total Cont. in Prism Mass (kg)	Proposed Volume (cy)	Proposed Mass (kg)	Actual Removal Volume (cy)	Actual Removal Mass (kg)	Remaining in Scoped Area Volume (cy)	Remaining in Scoped Area Mass (kg)	% Reduction Volume	% Reduction Mass	Factors Influencing Outcome
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 (μg/g) in plankton; 170 μg/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

Mark Hansen
Project Manager
U.S. EPA Region 6
1445 Ross Avenue, Suite #1200
Dallas, Texas 75202
(214) 665-7548

11 References

CDM and F. P. Corporation, 1989. Remedial Planning Activities at Selected Uncontrolled Hazardous Substances Disposal Sites in a Zone for EPA Regions 6, 7, & 8, Review of the Bayou Bonfouca Superfund Site Remedial Design. DCN: 7760-002-RT-BBWR. CDM Federal Programs Corporation, Camp Dresser & McKee, Inc., Lenexa, Kansas. June 13.

CH_2M Hill, 1990. Design Investigation Report, Volume I of III: Bayou Bonfouca Source Control Operable Unit, Bayou Bonfouca Site, Slidell, Louisiana. CH_2M Hill. July 16.

EPA. On-site Incineration at the Bayou Bonfouca Superfund Site, Slidell, Louisiana. Website. http://www.epa.gov/swertio1/download/remed/incpdf/bayou.pdf.

EPA, 2000. Listing of Fish and Wildlife Advisories. Prepared by U.S. Environmental Protection Agency Office of Science and Technology. Website. http://www.epa.gov/ost/fish.

EPA, 1987. Record of Decision, Remedial Alternative Selection: Bayou Bonfouca, Slidell, Louisiana. U.S. Environmental Protection Agency.

EPA, 1997. Preliminary Close Out Report: Bayou Bonfouca Superfund Site, Slidell, Louisiana. United States Environmental Protection Agency Region 6 Superfund Division. September.

EPA, 1999. Bayou Bonfouca, Louisiana. U.S. Environmental Protection Agency. Website. http://www.epa.gov/earth1r6/6sf/pdffiles/b-bonfou.pdf.

GE/AEM/BBL, 1999. Bayou Bonfouca, Major Contaminated Sediment Site Database. Website. http://www.hudsonwatch.com.

Klink, K. and J. S. Obert. Remedial Design Approach and Design Investigations at the Bayou Bonfouca Superfund Site. CH_2M Hill, Corvallis, Oregon.

Layton, R. E., 1990. Explanation of Significant Differences, Bayou Bonfouca Superfund Site. U.S. Environmental Protection Agency, Slidell, Louisiana.

Louisiana Department of Environmental Quality, 1996. Letter to Louisiana Department of Health and Hospitals requesting consideration of consumption advisory removal. July 17. Response letter from Office of Public Health, dated July 28, 1997.

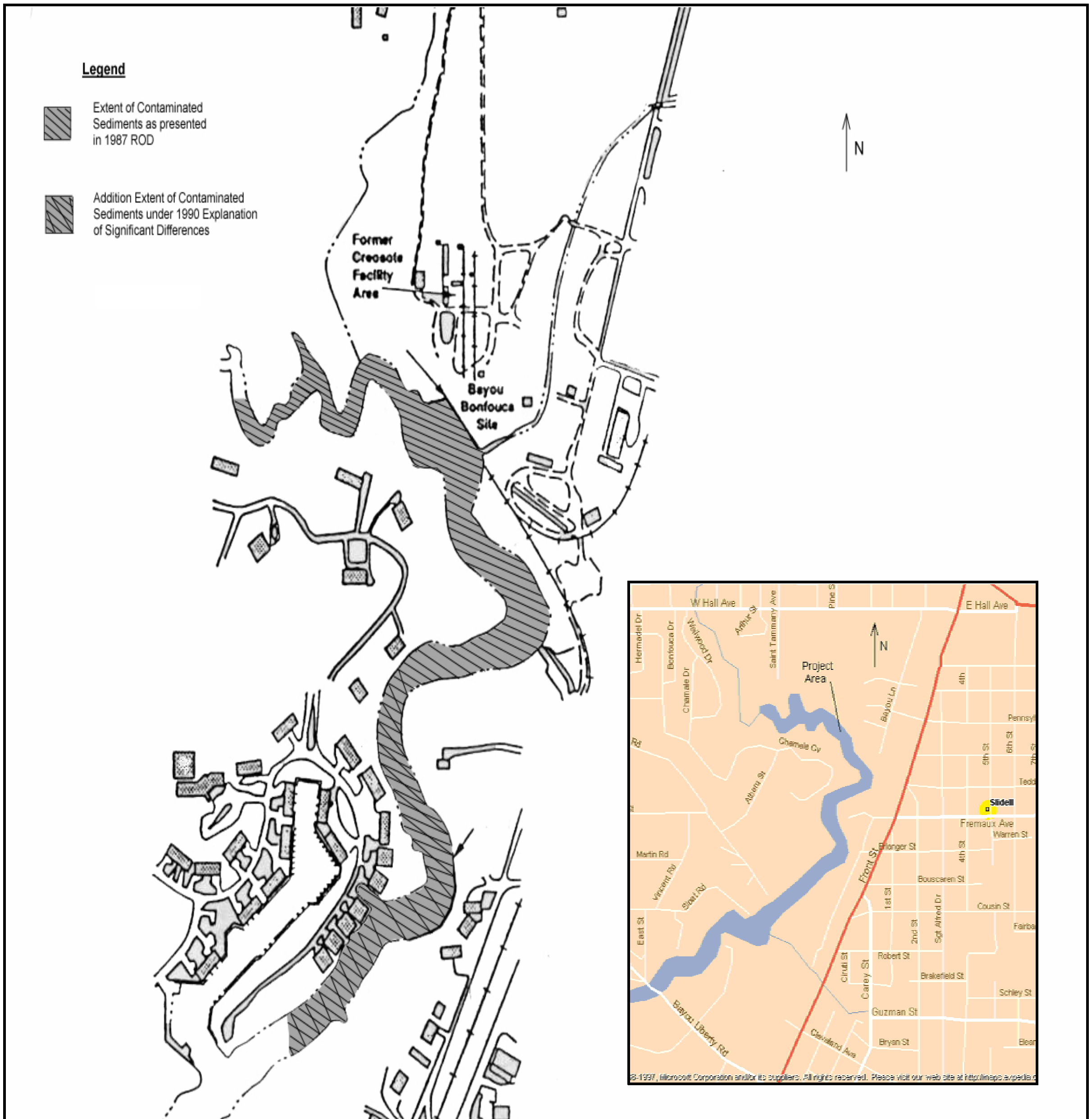
Louisiana Department of Environmental Quality, 1998. Bayou Bonfouca 1997 sediment, water and fish tissue results. Generated as part of stated, ongoing monitoring program. Office of Water Resources. February 4.

Louisiana Office of Public Health, 1994. Public Health Assessment, Bayou Bonfouca. State of Louisiana Office of Public Health, Slidell, Saint Tammany Parish, Louisiana. September 6.

Tetra Tech EM, Inc.. Incineration at the Bayou Bonfouca Superfund Site, Slidell, Louisiana. Website. http://bigisland.ttclients.com/frtr/00000042. html.

Wilson, 2000. Personal communication with Duane Wilson, Louisiana Department of Environmental Quality, regarding Bayou Bonfouca. ThermoRetec, January 12.

Figure 1 Remedial Dredge Plan - Bayou Bonfouca



Source: CH2M Hill Remedial Design Approach and Design Investigations

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)

10 Project Contact

Philip Gehring
U.S. EPA Region 5, Cleveland Office
25089 Center Ridge Road (ME-W)
Westlake, Ohio 44145
Phone: (216) 522-7260
Fax: (216) 522-2295
email: *gehring.philip@epamail.epa.gov*

11 References

Baumann, P. C., 1998. Epizootics of cancer in fish associated with genotoxins in sediment and water. *Mutation Research.* November. 411(3):227–233.

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.* October. 53(1):213–223.

EPA, 1999. United States Environmental Protection Agency Great Lakes Contaminated Sediments Program. Website. http://www.epa.gov/grtlakes/sediments/html.

EPA, 2000. Listing of Fish and Wildlife Advisories. Prepared by the U.S. Environmental Protection Agency Office of Science and Technology. Website. http://www.gov/ost/fish.

Folmar, L. C., J. Harshbarger, P. C. Baumann, G. Gardner, and S. Bonomelli, 1995. Pathological and serum chemistry profiles of brown bullheads (*Ameiurus nebulosus*) from the Black River and Old Woman Creek, Ohio. *Bulletin of Environmental Contamination and Toxicology.* 54(1):50–59.

GE/AEM/BBL, 1998. Major Contaminated Sediment Site Database. Website. http://www.hudsonwatch.com.

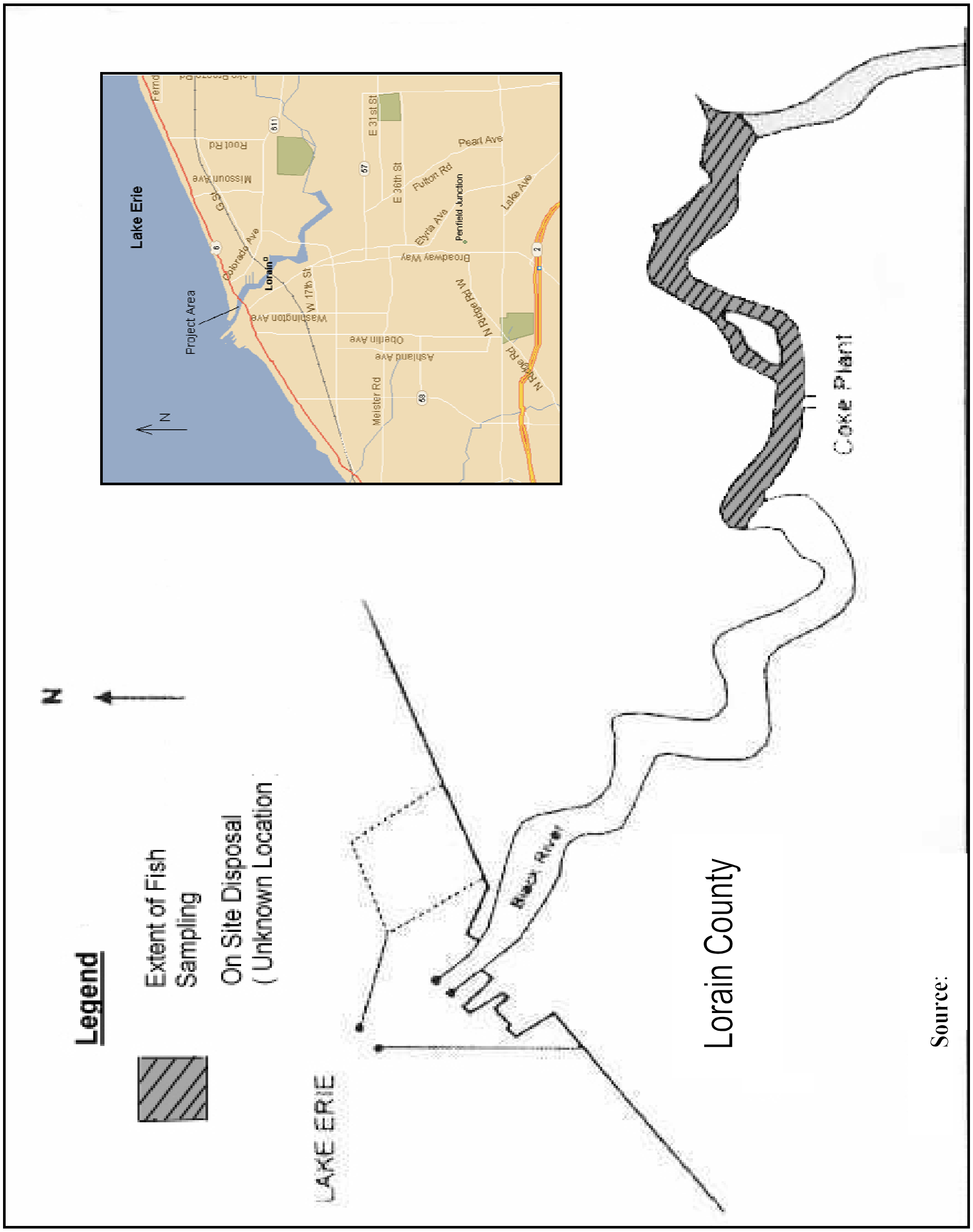
IJC, 1999. International Joint Commission Great Lakes Water Quality Board. Website. http://www.ijc.org/boards/wqb/index.html.

Lesko, L. T., S. B. Smith, and M. A. Blouin, 1996. The effect of contaminated sediments on fecundity of the brown bullhead in three Lake Erie tributaries. *Journal of Great Lakes Research.* 22(4):830–837.

Moloney, M.E., 1993. USS/Kobe Steel Company Black River Sediment Study. U.S. Environmental Protection Agency. May.

Smith, S. B., M. A. Blouin, and M. J. Mac, 1994. Ecological comparisons of Lake Erie tributaries with elevated incidence of fish tumors. *Journal of Great Lakes Research.* 20(4):701–716.

Figure 1 Remedial Dredge Plan - Black River



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

1 Statement of the Problem

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.

10 Project Contact

Murray G. Brooksbank
Contaminated Site Remediation
Environmental Protection Branch - Ontario Region
4905 Dufferin Street
Downsview (Toronto), Ontario M3H 5T4
(416) 739-4940

Gail Krantzberg
(Former) Collingwood Harbour RAP Coordinator
Ontario Ministry of Environment
135 St. Clair Avenue West
Toronto, Ontario M4V 1P5
(416) 314-7973

11 References

Brooksbank, M., 2000. Personal communication with Murray Brooksbank of Environment Canada, regarding Collingwood Harbour operable unit. ThermoRetec, January 17.

C. B. Fairn & Associates, Ltd., 1993. Report on Harbour Dredging Collingwood, Ontario. C. B. Fairn & Associates, Ltd. Collingwood, Ontario. December 21.

Environment Canada, 1998. The Remediation Technologies Program Great Lakes 2000 Cleanup Fund Technical Report. Environment Canada, Environmental Protection Branch, Ontario Region, Ontario. March.

Gamble, T., 1998. Collingwood Harbour Remedial Action Plan, October 1998. Teresa Gamble. Website (Canada Centre for Inland Waters). http://www.cciw.ca/glimr/raps/huron/collingwood/intro.html.

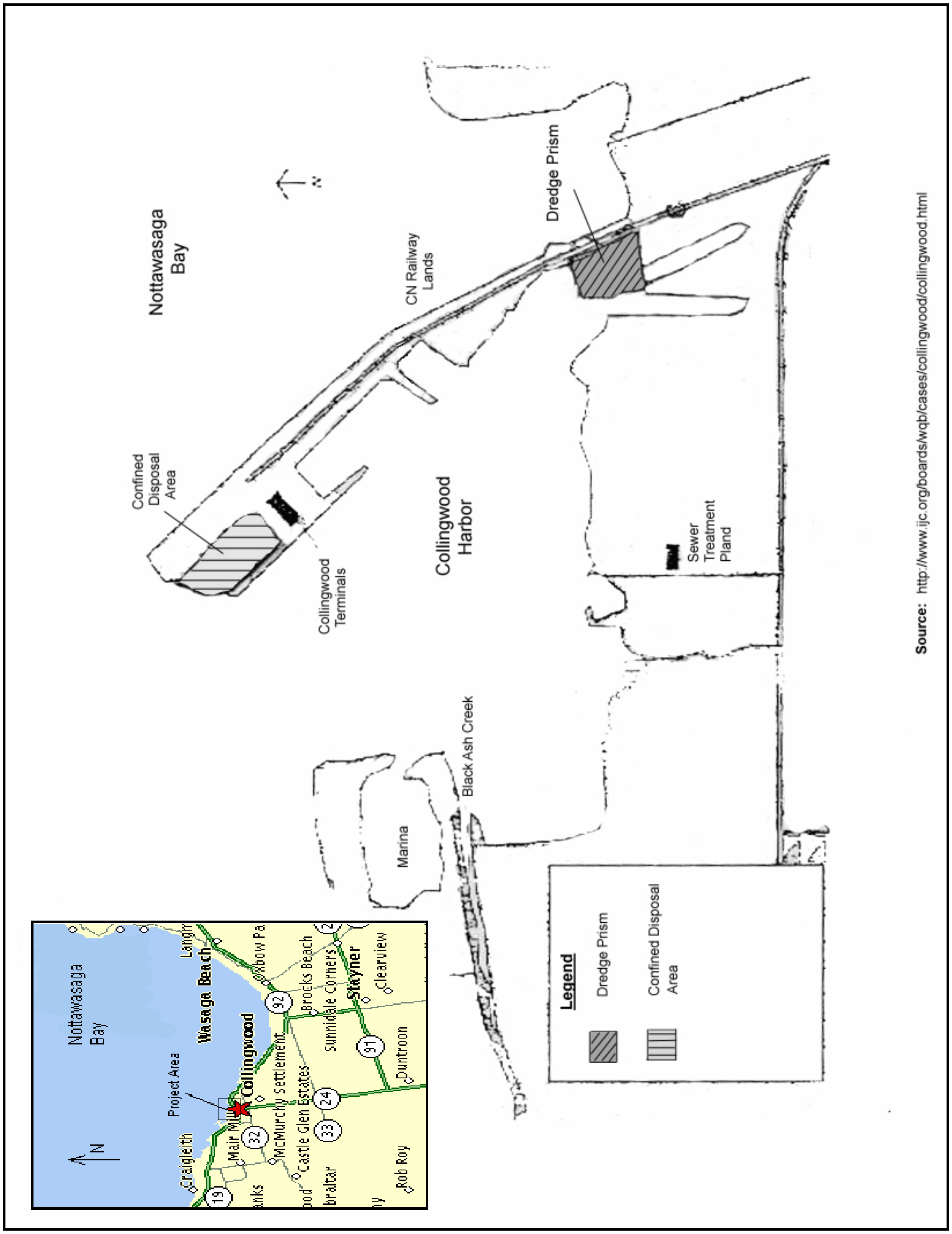
IJC, 1999. Case Study: Collingwood Harbour Sediment Removal Demonstration Project. International Joint Commission. Website. http://www.ijc.org/boards/wqb/cases/collingwood/collingwood. html.

Krantzberg, G. and E. Houghton, 1994. Collingwood Harbour Stage 3 Document ISBN 0-7778-2756-5. Ontario Ministry of Environment and Energy, Toronto, Ontario. June.

OMOE, 1993. Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario. Ontario Ministry of the Environment. August.

SEDTEC, 1993. Collingwood Harbour Dredging Project. Wastewater Technology Centre. CD-ROM, Environment Canada.

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.

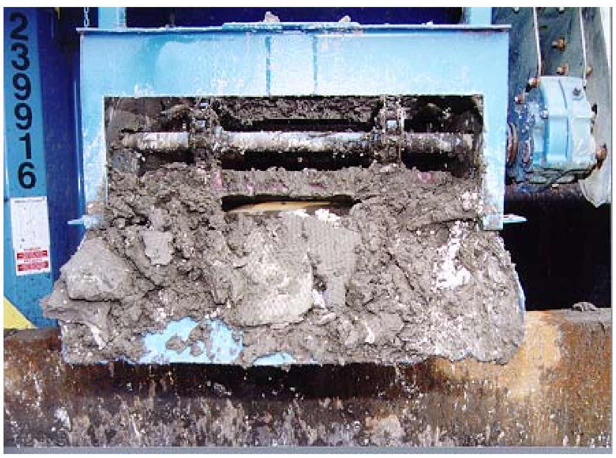
The Ford Outfall Site was identified for a Superfund Emergency Removal Action under the direction of EPA Region V using the Superfund Accelerated Cleanup Model (SACM). A final remedy plan was selected in August 1996. The SACM was intended to provide EPA with greater flexibility to clean up NPL-caliber 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

Roger Jones
Michigan Department of Environmental Quality
P.O. Box 30273
Lansing, Michigan 48909-7773
(517) 373-4704

Michael Collins
U.S. EPA Region 5, Superfund Division
77 West Jackson Boulevard (WC-15J)
Chicago, Illinois 60604
(312) 353-5592
collins.michael@epamail.epa.gov

Lead Agency: U.S. EPA
Design Engineer: Metcalf and Eddy
General Contractor: Sevenson Environmental Services
Dredge Contractor: Luedtke Engineering Company
Oversight: ACOE and MDEQ

11 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 V Superfund Division. November 30.

BBL, 1998. Large-Scale Dredging of the Fox River: What Can be Concluded from Other Environmental Dredging Projects? Prepared for the Fox River Group. December 11.

EPA, 1993. Administrative Order by Consent Between U.S. EPA and the Ford Motor Company.

EPA, 1995. Administrative Order by Consent Between U.S. EPA and the Ford Motor Company: Selected Removal Action Pursuant to the Superfund Accelerated Cleanup Model (SACM).

EPA, 1997. Amended Removal Decision Document for the Ford Outfall Site. April.

EPA, 1998. Realizing Remediation - A Summary of Contaminated Sediment Remediation Activities in the Great Lakes Basin. Great Lakes National Program Office. March. Revised May 28.

EPA, 1999. Completion of Work Order No. V-W-97-C-286. Letter from Mike Collins of U.S. EPA to Ford Motor Company. March 19.

GE/AEM/BBL, 2000. Major Contaminated Sediment Site Database. Website. http://www.hudsonwatch.com.

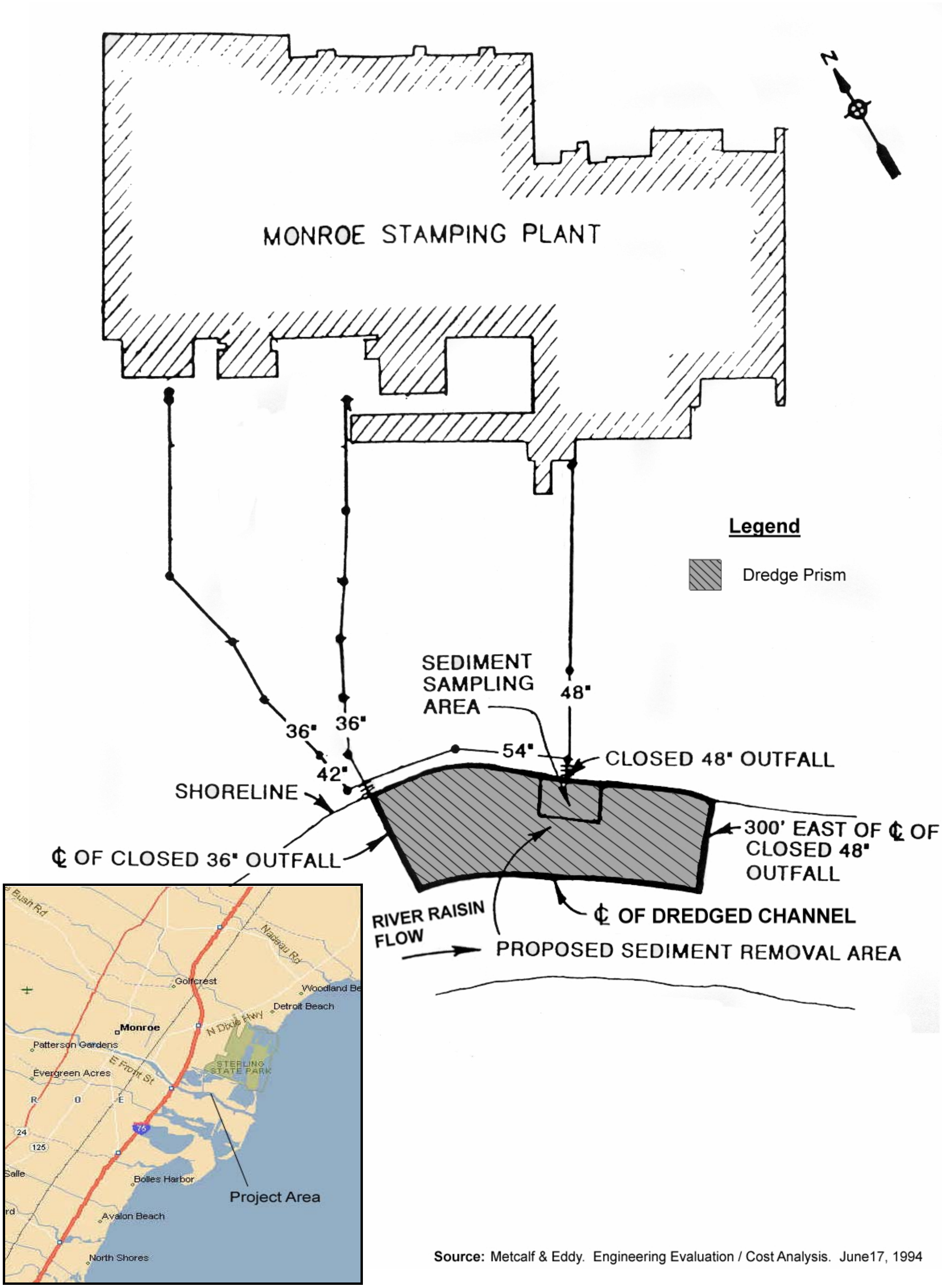
IJC, 1999. Ecological Benefits of Contaminated Sediment Remediation in the Great Lakes Basin. International Joint Commission. August.

MDEQ, 1998. Caged Fish Tissue Concentrations from Three Locations in the River Raison. Unpublished.

MDEQ, 1998. PCB Sediment Investigation: River Raisin Area of Concern, Monroe, Michigan 1995, 1997 and 1998. Michigan Department of Environmental Quality Surface Water Quality Division Staff Report No. MI/DEQ/SWQ-99/108.

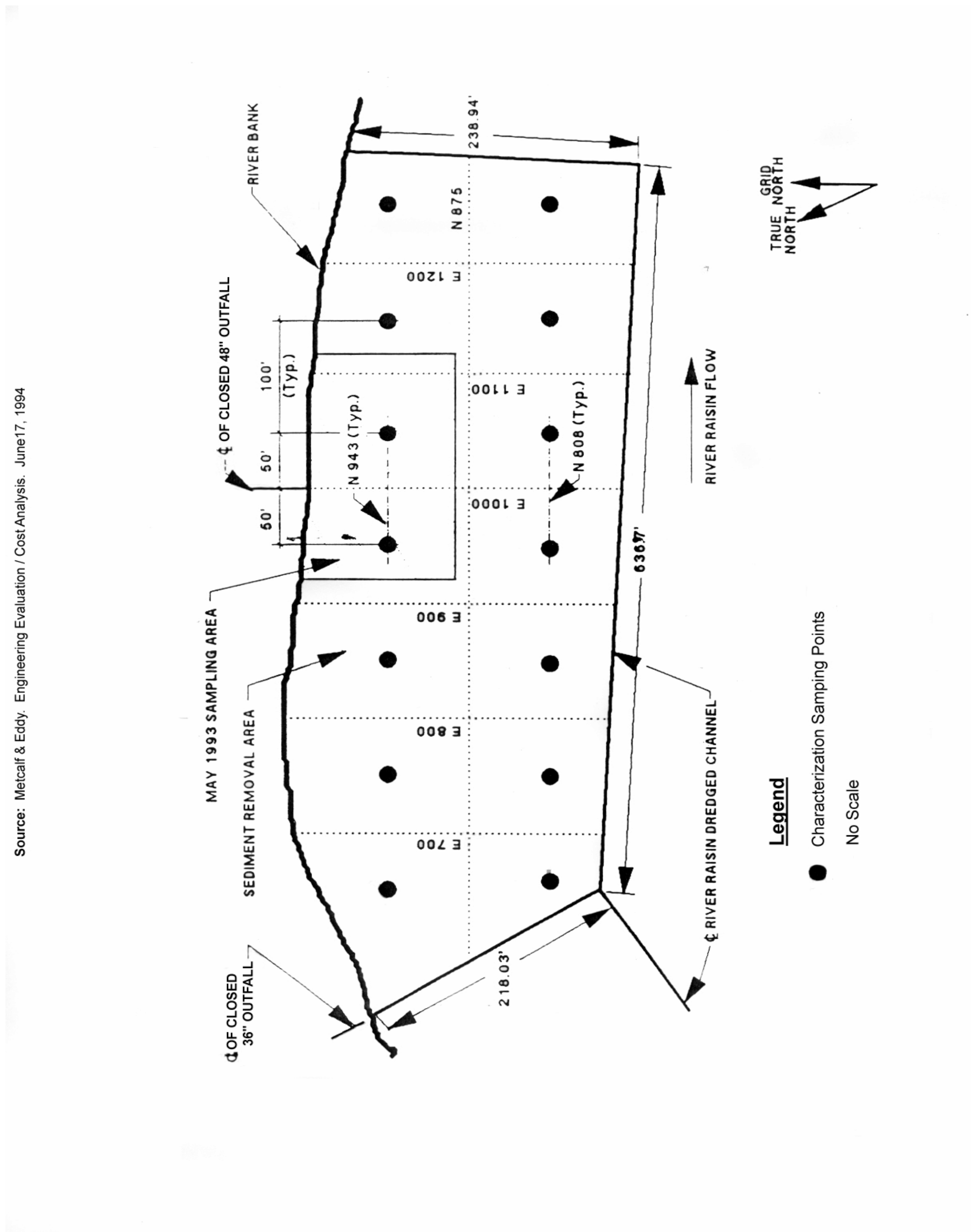
Metcalf and Eddy, 1994. Engineering Evaluation and Cost Analysis: Ford Outfall Site, Monroe, Michigan. (Includes the Streamline Risk Assessment.) Prepared for the Ford Motor Company. June 17.

Figure 1 Ford Outfall Dredge Prism



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

Figure 2 Ford Outfall Dredge Prism/Sampling Locations



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

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

[(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

Bill Fitzpatrick
Remedial Project Manager
Wisconsin Department of Natural Resources
P.O. Box 7921
Madison, Wisconsin 53703
(608) 266-9267
fitzw@dnr.state.wi.us

11 References

Fitzpatrick, 2000. Personal communication between Anne Fitzpatrick of ThermoRetec and Bill Fitzpatrick of Wisconsin Department of Natural Resources, regarding the Deposit N pilot dredging project. ThermoRetec Consulting Corporation. April 14.

Foth and Van Dyke, 1998. Contractor Bid Package (plans and specs)for Sediment Removal - Deposit N Fox River Kimberly, Wisconsin. Prepared for Wisconsin Department of Natural Resources. May.

Foth and Van Dyke, 1999. Interim Project Report: Fox River Deposit N. Prepared for Wisconsin Department of Natural Resources. January.

Foth and Van Dyke, 2000. Summary Report Fox River Deposit N, Final Project Report. Prepared for the Wisconsin Department of Natural Resources. April.

Foth and Van Dyke, 2001. Fox River Deposit N, Appendix to Summary Report. Final Report. Prepared for Wisconsin Department of Natural Resources. April.

FRRAT, 2000. Evaluation of the Effectiveness of Remediation Dredging: The Fox River Deposit N Demonstration Project, November 1998–January 1999. Fox River Remediation Advisory Team, Madison, Wisconsin. June.

GE/AEM/BBL, 2000. Major Contaminated Sediment Site Database. Website. Last updated March 2000. http://www.hudsonwatch.com.

Koester Environmental Services, 1998. Construction Submittals and Contractor Design for Sediment Removal - Deposit N Fox River Kimberly, Wisconsin. September.

Paulson, 2000. Personal communication between ThermoRetec and Bob Paulson of Wisconsin Department of Natural Resources regarding the Deposit N pilot dredging project. ThermoRetec Consulting Corporation. June 20.

SAIC, 1996. Remedial Investigation Report for Contaminated Sediment Deposits on the Fox River (Little Lake Butte des Morts to the De Pere Dam). Prepared for the State of Wisconsin. Prepared by Graef, Anhalt, Schloemer and Associates and SAIC. September 24.

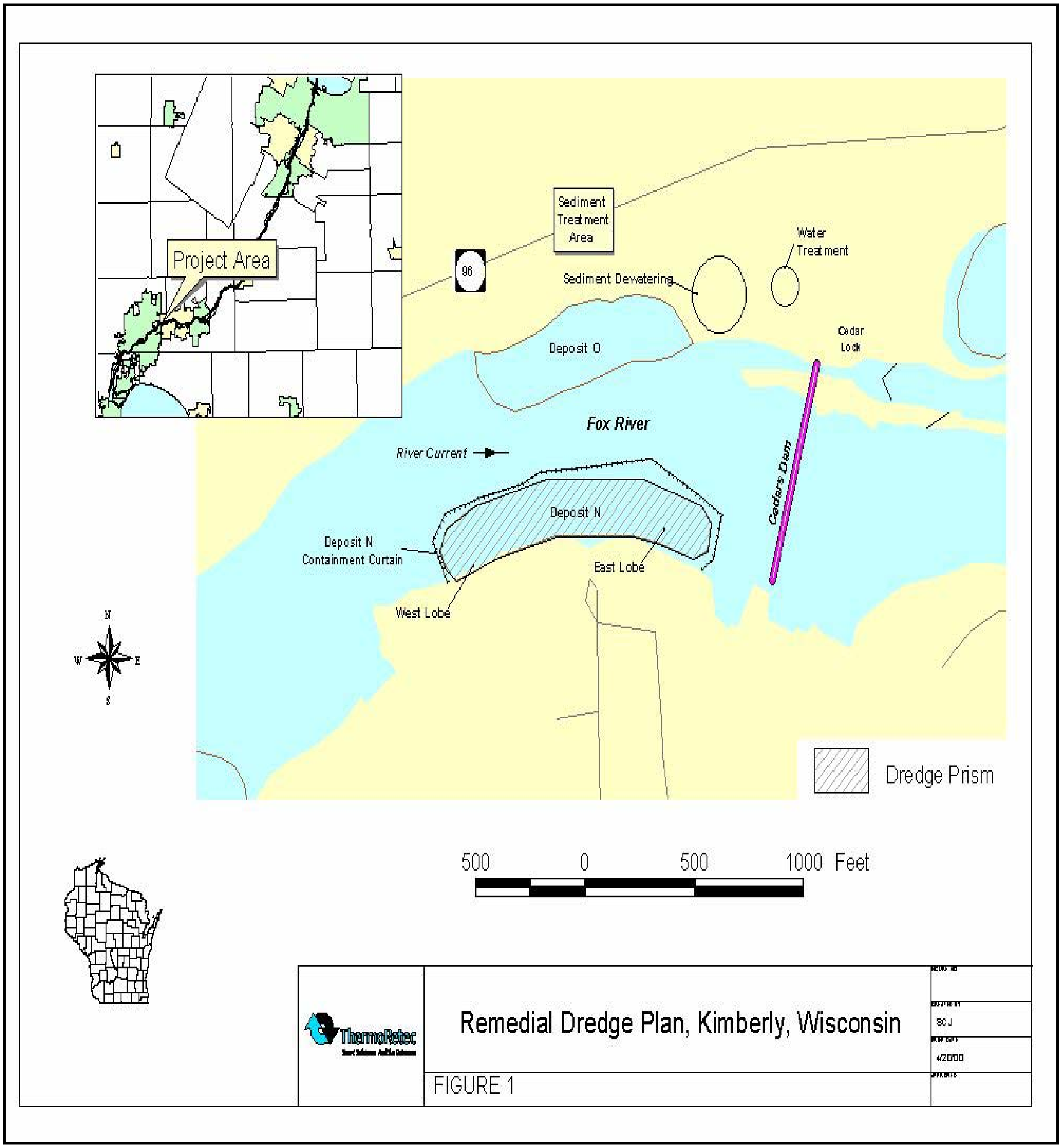
SAIC, 1997. Feasibility Study Report for Deposits POE and N on the Fox River. Final Draft. Prepared for the State of Wisconsin. Prepared by Graef, Anhalt, Schloemer and Associates and SAIC. April.

ThermoRetec, 2000. Draft Remedial Investigation Report: Lower Fox River and Green Bay, Wisconsin. March 26.

Water Resources Institute, 2000. Evaluation of the Effectiveness of Remediation Dredging: The Fox River Deposit N Demonstration Project November 1998 - January 1999. Prepared for the Fox River Remediation Advisory Team. University of Wisconsin - Madison. WRISR 00-01. June, 2000.

WNDR, 1998. Permit to discharge under the Wisconsin Pollutant Discharge Elimination System: Fox River Deposit N Sediment Remediation Project. Chapter NR 200 WAC. Wisconsin Department of Natural Resources. March 5.

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

George Boronow
Lower Fox River Team Supervisor
Wisconsin Department of Natural Resources
Green Bay Worksite
801 E. Walnut St.
Green Bay, Wisconsin 54301
borong@dnr.state.wi.us

11 References

Fort James Corporation, Foth & Van Dyke, and Hart Crowser, Inc., 2001. Final Report 2000 Sediment Management Unit 56/57 Project, Lower Fox River, Green Bay , Wisconsin. Prepared for the US EPA and Wisconsin DNR. January

Four Seasons Environmental, 1999a. Proposal for River Dredging: Sediment Removal Demonstration Project, Sediment Management Unit 56 and 57, Fox River, Green Bay, Wisconsin. Four Seasons Environmental, Port Allen, Louisiana. March 26.

Four Seasons Environmental, 1999b. Proposal for Sediment Dewatering: Sediment Removal Demonstration Project, Sediment Management Unit 56 and 57, Fox River, Green Bay, Wisconsin. Four Seasons Environmental, Port Allen, Louisiana. March 26.

Four Seasons Environmental, 1999c. Proposal for Water Treatment: Sediment Removal Demonstration Project, Sediment Management Unit 56 and 57, Fox River, Green Bay, Wisconsin. Four Seasons Environmental, Port Allen, Louisiana. March 26.

GE/AEM/BBL, 2000. Major Contaminated Sediment Site Database. Website. Last updated March 2000. http://www.hudsonwatch.com.

Montgomery Watson, 1998. Basis of Design Report, Sediment Removal Demonstration Project, Sediment Management Unit 56 and 57, Fox River, Green Bay, Wisconsin. Milwaukee, Wisconsin. May.

Montgomery Watson, 1999a. Request for Bid for Dredging, Sediment Removal Demonstration Project, Sediment Management Unit 56 and 57, Fox River, Green Bay, Wisconsin. Prepared for the Fox River Group and Wisconsin Department of Natural Resources, Milwaukee, Wisconsin. February.

Montgomery Watson, 1999b. Request for Bid for Sediment Dewatering, Sediment Removal Demonstration Project, Sediment Management Unit 56 and 57, Fox River, Green Bay, Wisconsin. Prepared for the Fox River Group and Wisconsin Department of Natural Resources, Milwaukee, Wisconsin. February.

Montgomery Watson, 1999c. Request for Bid for Water Treatment, Sediment Removal Demonstration Project, Sediment Management Unit 56 and 57, Fox River, Green Bay, Wisconsin. Milwaukee, Wisconsin. February.

Montgomery Watson, 2000. Draft Summary Report, Sediment Removal Demonstration Project, Sediment Management Unit 56/57, Fox River, Green Bay, Wisconsin. April.

Paulson, B. 2000. Correspondence/Memorandum: Post Dredging Results for SMU 56/57. February 21.

Stever, J., 2000. Fox River SMU 56/57 preliminary PCB water column data analysis. U.S. Geological Survey. May 8.

ThermoRetec, 1999a. Draft Feasibility Study, Lower Fox River, Wisconsin. February.

ThermoRetec, 1999b. Draft Remedial Investigation, Lower Fox River, Wisconsin. February.

WDNR, 2000a. Statement of Work, Lower Fox River Sediment Management Unit 57/57 Removal Action. Wisconsin Department of Natural Resources and U.S. EPA. Prepared for Fort James Corporation. Website address: http:/www.dnr.state.wi.us/org/water/wm/lowerfox/sediment/56_57sowfinal,html.

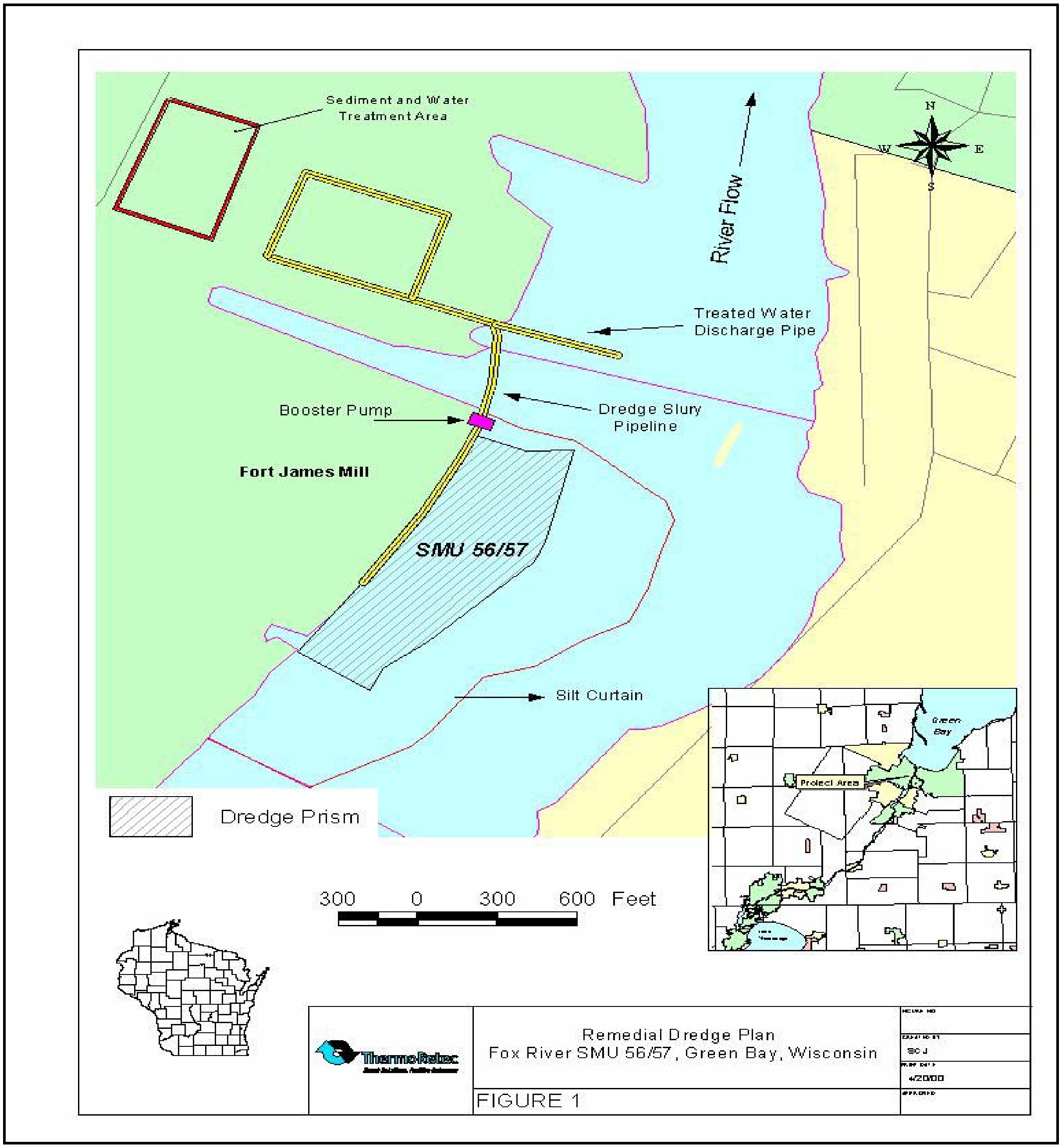
WDNR, 1999. State of Wisconsin Department of Natural Resources Permit to discharge under the WPDES for the Fox River SMU 56/57 Remediation Project, Fox River Group (FRG). WPDES Permit No. WI-0049735-1.

WDNR, 2000b. SMU 56/57 Remediation Project Completed. Project Update. Wisconsin Department of Natural Resources. Website address: www.dnr.state.wi.us/org/water/wm/lowerfox/sediment/56_57update.html.

WDNR, 2000c. Fox River remediation air monitoring Report - ambient PCBs during SMU 56/57 Demonstration Project. August - November, 1999. Bureau of Air Management. October.

USGS, 2000. A mass balance approach for assessing PCB movement during remediation of PCB-contaminated deposit on the Fox River, Wisconsin. SMU 56/57 1999 Dredging Demonstration Project. USGS Water Resources Investigation Report No. 00-4245. December.

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



1 Statement of the Problem

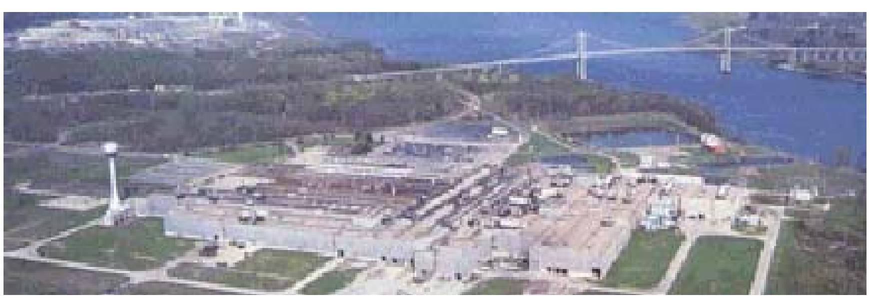
- Dredged in 1995
- PCBs
- 27,000 cubic yards
- $680 per cy total

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.

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.

Dredging in St. Lawrence
Source: K. Martin

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

Anne Kelly
Remedial Project Manager
U.S. EPA Region 2
290 Broadway
New York, New York 10007-1866
(212) 637-4264

Lead Agency: U.S. EPA
Design Engineer: BBL
Contractors: Sevenson Environmental Services

11 References

BBL, 1995. St. Lawrence River Sediment Removal Project Environmental Monitoring Plan, General Motors Powertrain Site. BBL Environmental Services, Inc., Massena, New York. May.

BBL, 1996a. St. Lawrence River Monitoring and Maintenance Plan, General Motors Powertrain. BBL Environmental Services, Inc., Massena, New York. December.

BBL, 1996b. St. Lawrence River Sediment Removal Project Remedial Action Completion Report. BBL Environmental Services, Inc., Massena, New York. June.

BBL, 1999. St. Lawrence River Monitoring and Maintenance Annual Inspection Report. BBL Environmental Services, Inc., Massena, New York. January.

BBL, 2000. St. Lawrence River Monitoring and Maintenance Annual Inspection Report. General Motors Powertrain. Massena, NY. BBL Environmental Services. January.

Crystal, M., 2001. Personal communication between Anne Fitzpatrick of ThermoRetec and Mike Crystal of Sevenson Environmental regarding volume of material removed. July 2.

Cushing, B. S., 1999. State of Current Contaminated Sediment Practices, Contaminated Sediment Management Technical Papers. Applied Environmental Management, Inc., Sediment Management Workgroup. Fall.

EPA, 1990. Decision Summary, General Motors - Central Foundry Division Site. U.S. Environmental Protection Agency, Massena, New York. December.

EPA, 1992. Decision Summary, General Motors - Central Foundry Division Site. U.S. Environmental Protection Agency, Massena, New York. March.

EPA, 1998. Realizing Remediation, A Summary of Contaminated Sediment Remediation Activities in the Great Lakes Basin. Great Lakes National Program Office, U.S. Environmental Protection Agency. March.

EPA, 1999. Record of Decision Amendment, General Motors Corporation, Central Foundry Division. U.S. Environmental Protection Agency, Massena, New York. March.

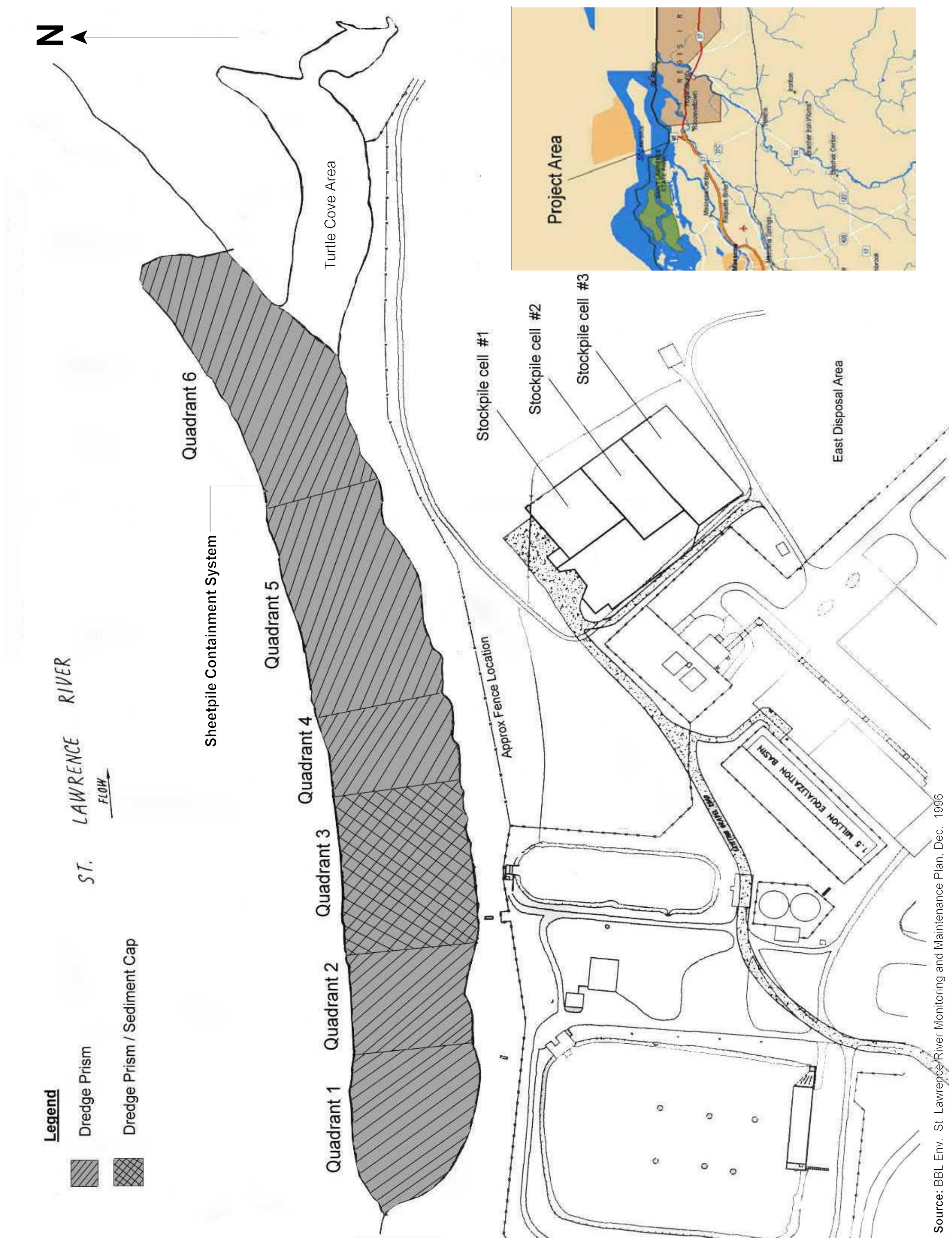
EPA, 2000a. EPA Selects Cleanup Action for Contaminated Soils and Sediments at the General Motors Superfund Site in Massena, New York. U.S. Environmental Protection Agency. Website.

EPA, 2000b. GM to Start Removal of Contaminated Sediments and Soils next Week at Federal Superfund Site in Massena, New York. U.S. Environmental Protection Agency. Website.

Fox River Group, 1999. Effectiveness of Sediment Removal: An Evaluation of EPA Region 5 Claims Regarding Twelve Contaminated Sediment Removal Projects. Green Bay, Wisconsin. September 27.

GE/AEM/BBL, 1999. GM Central Foundry (Massena). Major Contaminated Sediment Site Database. Last updated March 1999. Website. http://www.hudsonwatch.com.

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



Source: BBL Env. St. Lawrence River Monitoring and Maintenance Plan, Dec. 1996

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

1 Statement of the Problem

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

Mary Logan
Project Manager
U.S. EPA Region 2
290 Broadway
New York, New York 10007-1866
(212) 637-4321

11 References

ALCOA, 1999. Draft Analysis of Alternative Report. Excerpted pre and post figures obtained from U.S. EPA Region 2. December 29.

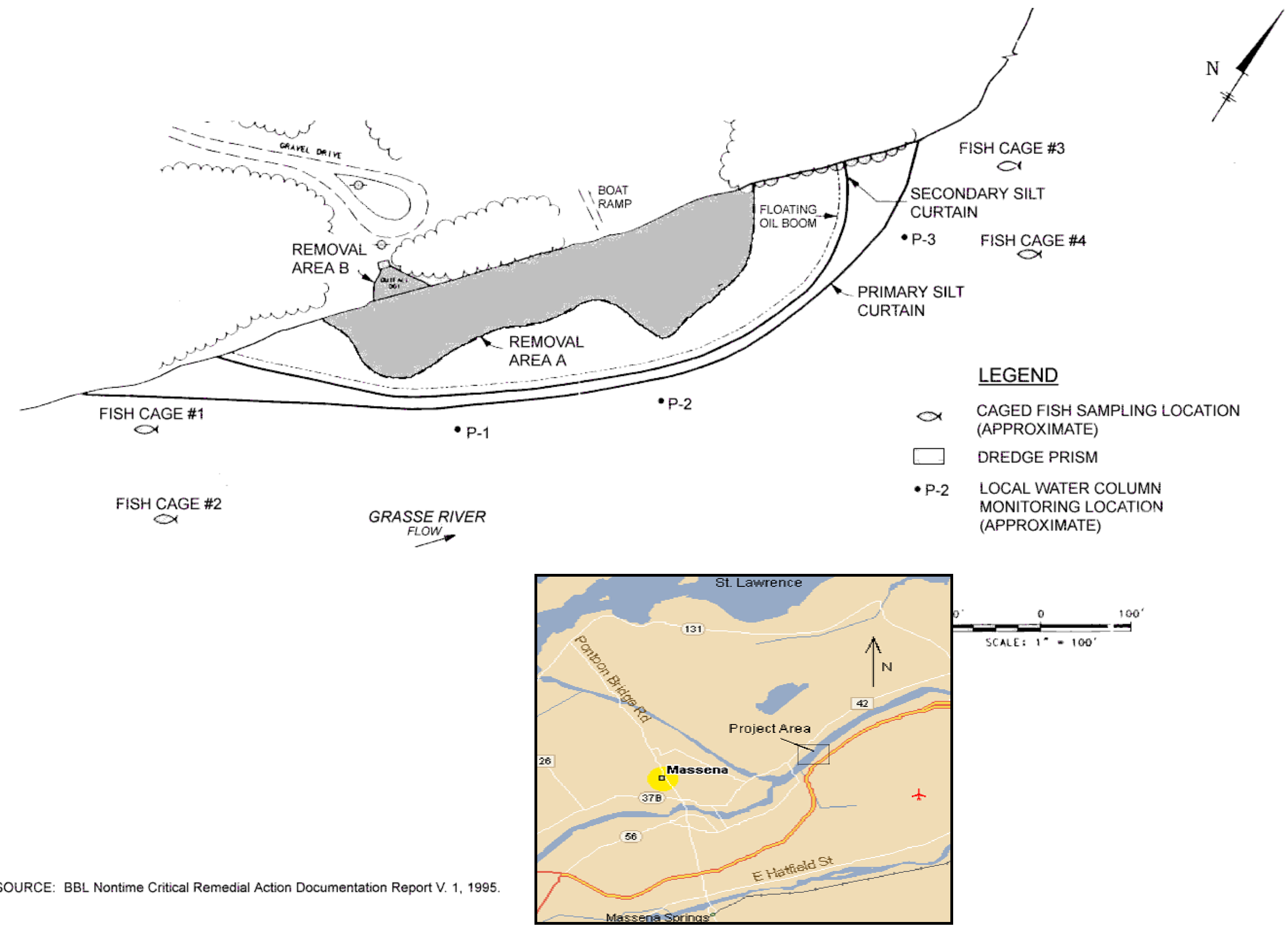
BBL, 1995. Non-Time-Critical Removal Action Documentation Report, Volume 1 (Grasse River Study Area, Massena, New York). Blasland, Bouck & Lee, Inc., Massena, New York. December.

EPA, 2000. Envirofacts Warehouse Facility Information EPA Web Reports. Website. http://www.epa.gov:9966/envirodcd/owa.

GE/AEM/BBL, 1995. Grasse River - Project 1 (Hot Spot). Major Contaminated Sediment Site Database. Website. http://www.hudsonwatch.com.

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.

Figure 1 Remedial Dredge Plan - Grasse River



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

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

1 Statement of the Problem

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.

10 References

Bremle, G., 1997. Polychlorinated biphenyls (PCBs) in a River Ecosystem. Ph.D. Lund University, Lund, Sweden.

Bremle, G. and G. Ewald, 1995. Bioconcentration of polychlorinated biphenyls (PCBs) in chironomid larvae, oligochaete worms and fish from contaminated lake sediments. *Marine Freshwater Res.* 46:267–273.

Bremle, G. and P. Larsson. PCB concentration in fish in a river system after remediation of contaminated sediment. *Manuscript.* 11.

Bremle, G. and P. Larsson, 1998. PCB in Eman River Ecosystem. *Ambio. Aug.* 27(5):384–392.

Bremle, G. and P. Larsson, in press-a. Long-term variations of PCBs in the water of a river in relation to precipitation and internal sources. *Environmental Science Technology*.

Bremle, G. and P. Larsson, in press-b. PCB in air during landfilling of a contaminated lake sediment. *Atmos. Environ.* 14.

Bremle, G., P. Larsson, T. Hammar, A. Helgee and B. Troedsson, in press. PCB in a river system during sediment remediation. *Water, Air, Soil Pollution.* 11.

Bremle, G., L. Okla and P. Larsson, PCB in water and sediment of a lake after remediation of contaminated sediment. *Manuscript.* 13.

Bremle, G., L. Okla and P. Larsson, 1995. Uptake of PCBs in fish in a contaminated river system: Bioconcentration factors measured in the field. *Environmental Science and Technology*. 29(8):2010–2015.

Elander, P. and T. Hammer, 1998. The remediation of Lake Jarnsjön: Project implementation. *Ambio. Aug.* 27(5):398–403.

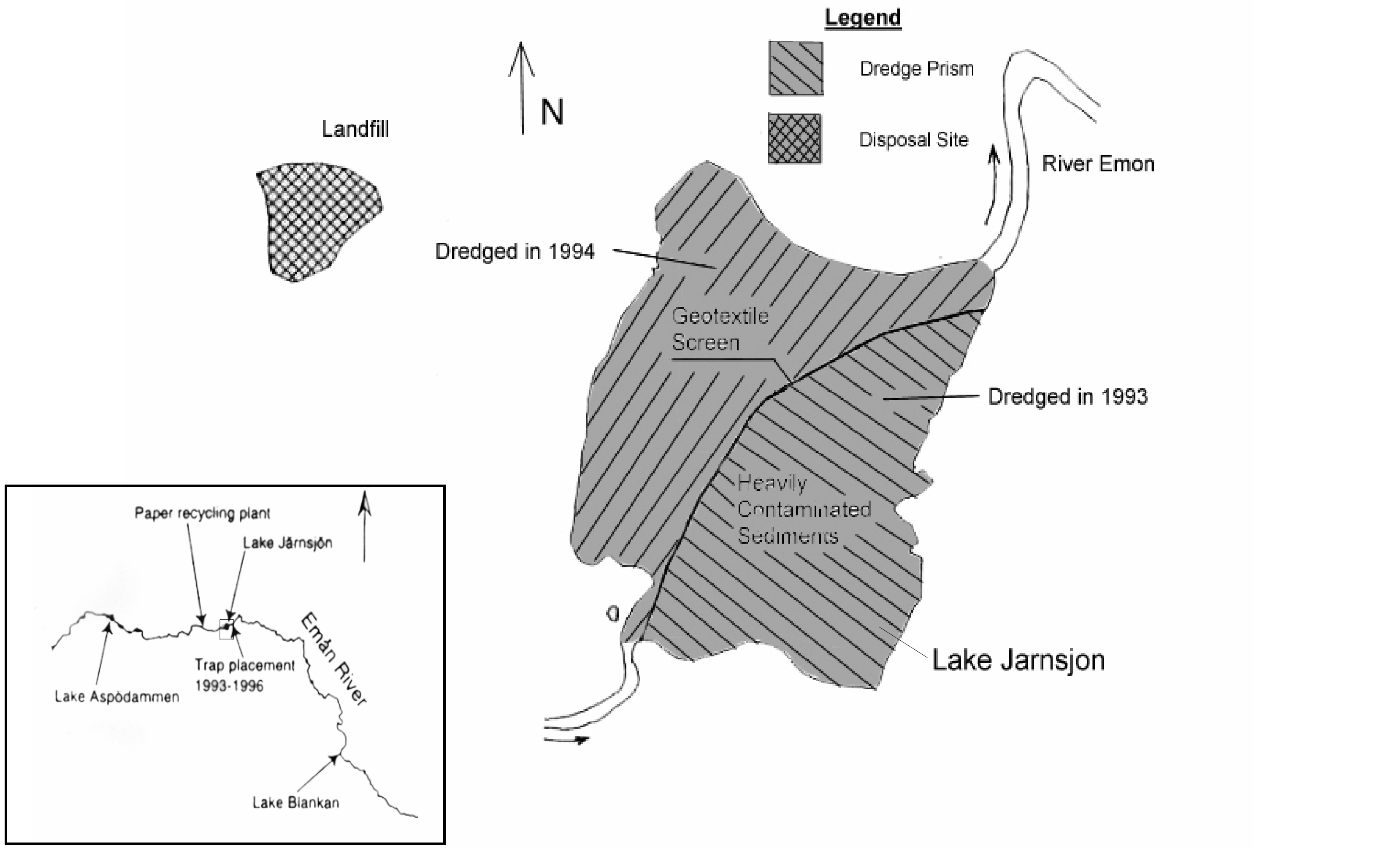
Engwall, M., C. Naf, D. Broman and B. Brunstrom, 1998. Biological and chemical determination of contaminant levels in settling particulate matter and sediments. *Ambio. Aug.* 27(5):403–410.

Forlin, L. and l. Norrgren, 1998. Physiological and morphological studies of feral perch before and after remediation of PCB contaminated lake: Jarnsjön. *Ambio. Aug.* 27(5):418–424.

Fox River Group, 1999. Effectiveness of Sediment Removal: An Evaluation of EPA Region 5 Claims Regarding Twelve Contaminated Sediment Removal Projects. Green Bay, Wisconsin. September 27.

Gullbring, P., T. Hammar, A. Helgee, B. Troedsson, K. Hansson and F. Hansson, 1998. Remediation of PCB-contaminated sediments in Lake Jarnsjön: Investigations, considerations and remedial actions. *Ambio. Aug.* 27(5):374–384.

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

Walter Nied, On-Scene Coordinator
U.S. EPA Region 5 - SE-5J
77 West Jackson Boulevard
Chicago, Illinois 60604-3590
(312) 886-4466

11 References

Blasland, Bouck, and Lee, Inc., 1998. Post-Dredging Sediment Sampling of Manistique Harbor. Syracuse, New York. April.

Blasland, B. L., Inc., 1999. Dredging-Related Sampling of Manistique Harbor - 1998 Field Study. Technical Report. Blasland, Bouck & Lee, Syracuse, New York. March.

EPA, 1995a. Manistique Action Memorandum. U.S. Environmental Protection Agency Region V. October.

EPA, 1995b. Manistique Enforcement Action Memorandum October 6, 1995. October 6.

EPA, 1996a. Manistique Site Update (Update No. 2). Fact Sheet Update. U.S. Environmental Protection Agency, Region V, Chicago, Illinois. July.

EPA, 1996b. Manistique Site Update (Update No. 3). Fact Sheet Update. U.S. Environmental Protection Agency, Region V. Chicago, Illinois. September.

EPA, 1997. Manistique Site Update (Update No. 4). Fact Sheet Update. U.S. Environmental Protection Agency, Region V, Chicago, Illinois. April.

EPA, 1998. Manistique Site Update (Update No. 7). Fact Sheet Update. U.S. Environmental Protection Agency, Region V, Chicago, Illinois. November.

EPA, 1999. Manistique Pollution Report (POLREP 69: 10-18-99 through 10-31-99). POLREP 69. November 2.

Garbaciak, S. D. and D. A. Averett, 1999. A review of three recent sediment remediation projects. *Journal of Dredging Engineering*. 1(1):10.

GE/AEM/BBL, 1993. Manistique River/Harbor. Major Contaminated Sediment Site Database. Website. http://www.hudsonwatch.com.

Hahnenberg, J., 1998. Response Letter to BBL 1998 Report Titled Post-Dredging sediment Sampling of Manistique Harbor. June.

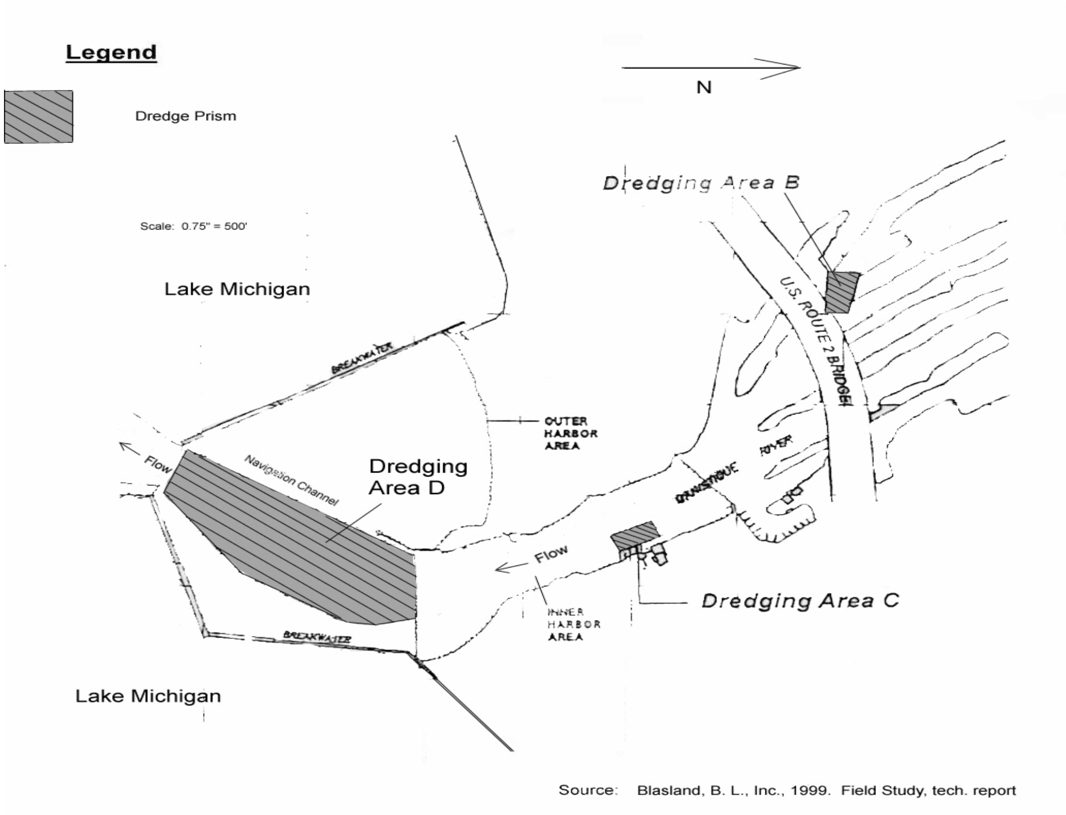
Hahnenberg, J., 2000. Personal communication with Jim Hahnenberg, U.S. Environmental Protection Agency, and J. Zwiebel of ThermoRetec regarding Manistique River and Harbor. January 18.

Interagency Review Team, 1995. Assessment of Remediation Technologies, Manistique River and Harbor Area of Concern. Final Report. U.S. Environmental Protection Agency, National Oceanic and Atmospheric Administration, and U.S. Army Corps of Engineers. April 10.

Lopata, M.L., 1994. Interoffice Memorandum regarding Manistique River and Harbor Field Report on Underwater Inspection of EPA-installed sediment cap.

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



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

Pamela Tames
Project Manager
U.S. EPA Region 2, New York Office
290 Broadway
New York, New York 10007
(212) 637-4255
tames.pam@epa.gov

Lead Agency: U.S. EPA
Design Engineer:
General Contractor: Sevenson Environmental Services

11 References

Advanced Geoservices, 1997a. Annual Report November 1995–December 1996: Long Term Monitoring Program Marathon Remediation Site. Prepared for Gould Electronic Services, Inc. Advanced Geoservices Corp., Chadds Ford, Pennsylvania. June 20.

Advanced Geoservices, 1997b. Sampling Event Report April 1997: Long Term Monitoring Program Marathon Remediation Site. Prepared for Gould Electronic Services, Inc. Advanced Geoservices Corp., Chadds Ford, Pennsylvania. September 19.

EPA, 1986. Record of Decision: Marathon Battery Company Site Area I. U.S. Environmental Protection Agency Region II, New York, New York. September 30.

EPA, 1989. Record of Decision: Marathon Battery Company Site Area III. U.S. Environmental Protection Agency Region II, New York, New York. September 26.

EPA, 1994. Preparation of Bid Documents for Dredging/Excavating Contaminated Sediments, Soils, and Marsh Deposits at the Marathon Battery Superfund Site. Dredging 94 Conference Proceeding of the Second Int'l Conference on Dredging and Dredge Material Placement. Vol. 1 and 2. 1994

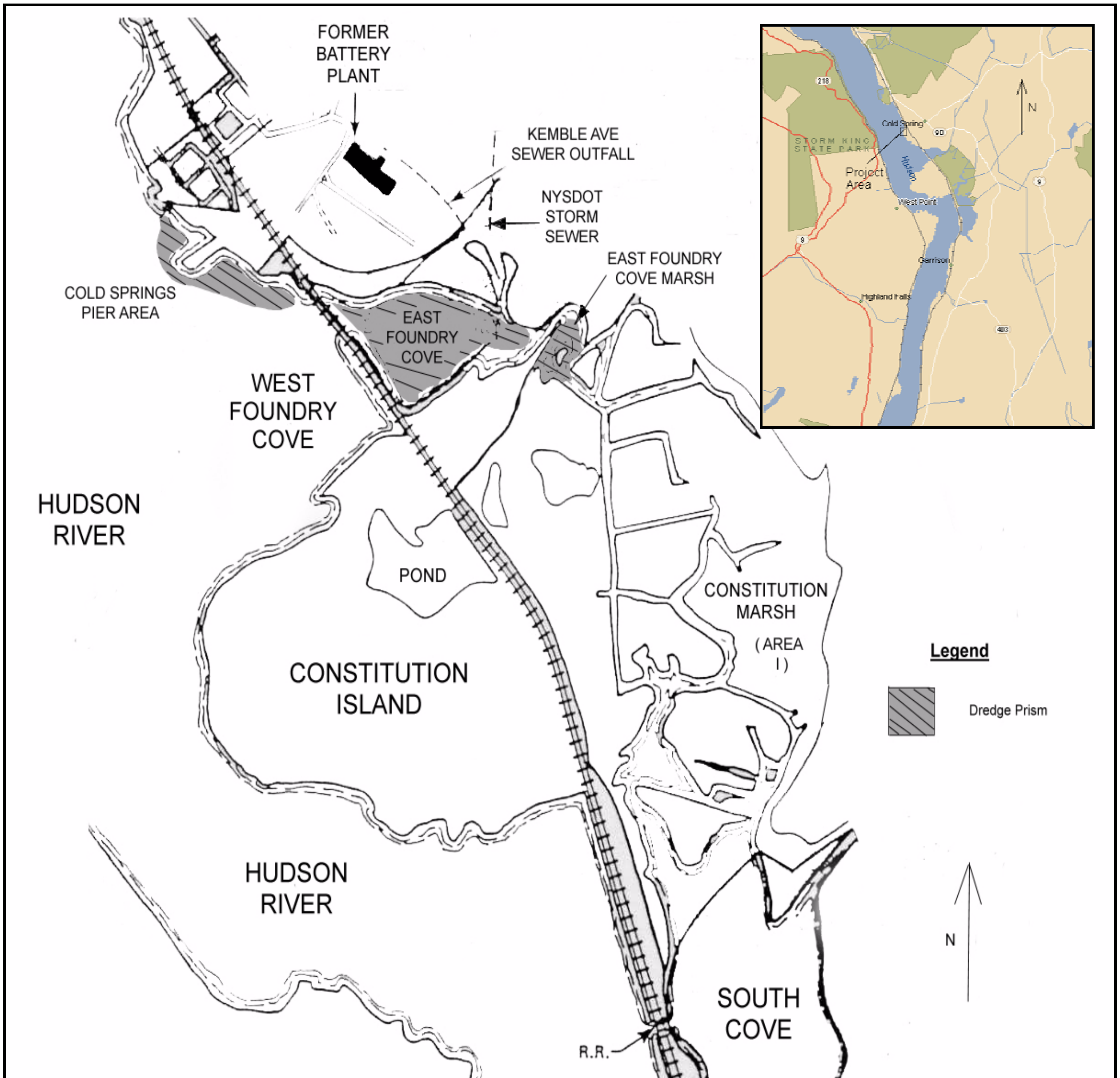
EPA, 1995. Superfund Site Close-out Report. September 28.

EPA, 1999. U.S. Environmental Protection Agency. Website. http://www.epa.gov/oerrpage/superfund/programs/recycle/1-pagers/marathon.htm.

GE/AEM/BBL, 1999. Major Contaminated Sediment Site Database. Website. http://www.hudsonwatch.com.

Sevenson, 1998. Monitoring Report, June 22, 1998: East Foundry Cove March Marathon Battery Project. Sevenson Environmental Services, Niagara Falls, New York. June 22.

Figure 1 Remedial Dredge Plan - Marathon Battery



Source: Record of Decision, 1989 (Area III).

- Dredged 1983-1987
- Mercury
- 1,025,000 cubic yards
- $40 per cubic yard

1 Statement of the Problem

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.

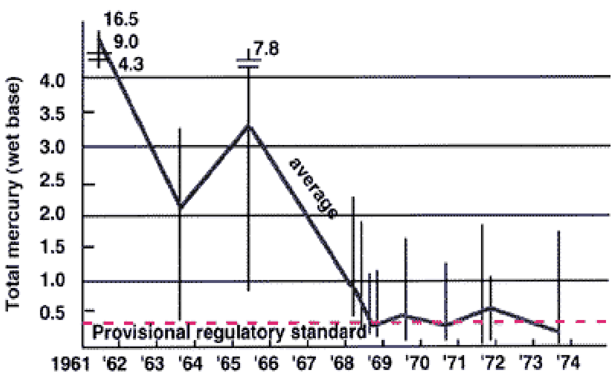
Table 1 Pre- and Post-Dredge Sampling Results

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.

11 References

Environmental Health Department, 1997. Our Intensive Efforts to Overcome the Tragic History of Minamata Disease. Government of Japan. http://www.eic.or.jp/eanet/en/topic/minamata/index.html.

History of Minamata Disease, 1998. Minamata City Home Page. Created August 26th. Webpage. http://island.qqq.or.jp/hp/minamata.city/english/me_3c1f2.htm.

Harada, M. 1995. Minamata Disease: Methylmercury Poisoning in Japan Caused by Environmental Pollution. Critical Reviews in Toxicology, 24 (1): 1-24.

Hosokawa, Y. 1993. Remediation work for mercury contaminated bay-experiences of Minamata Bay project, Japan. Water Sci. Tech. 28: (8,9) 339-348.

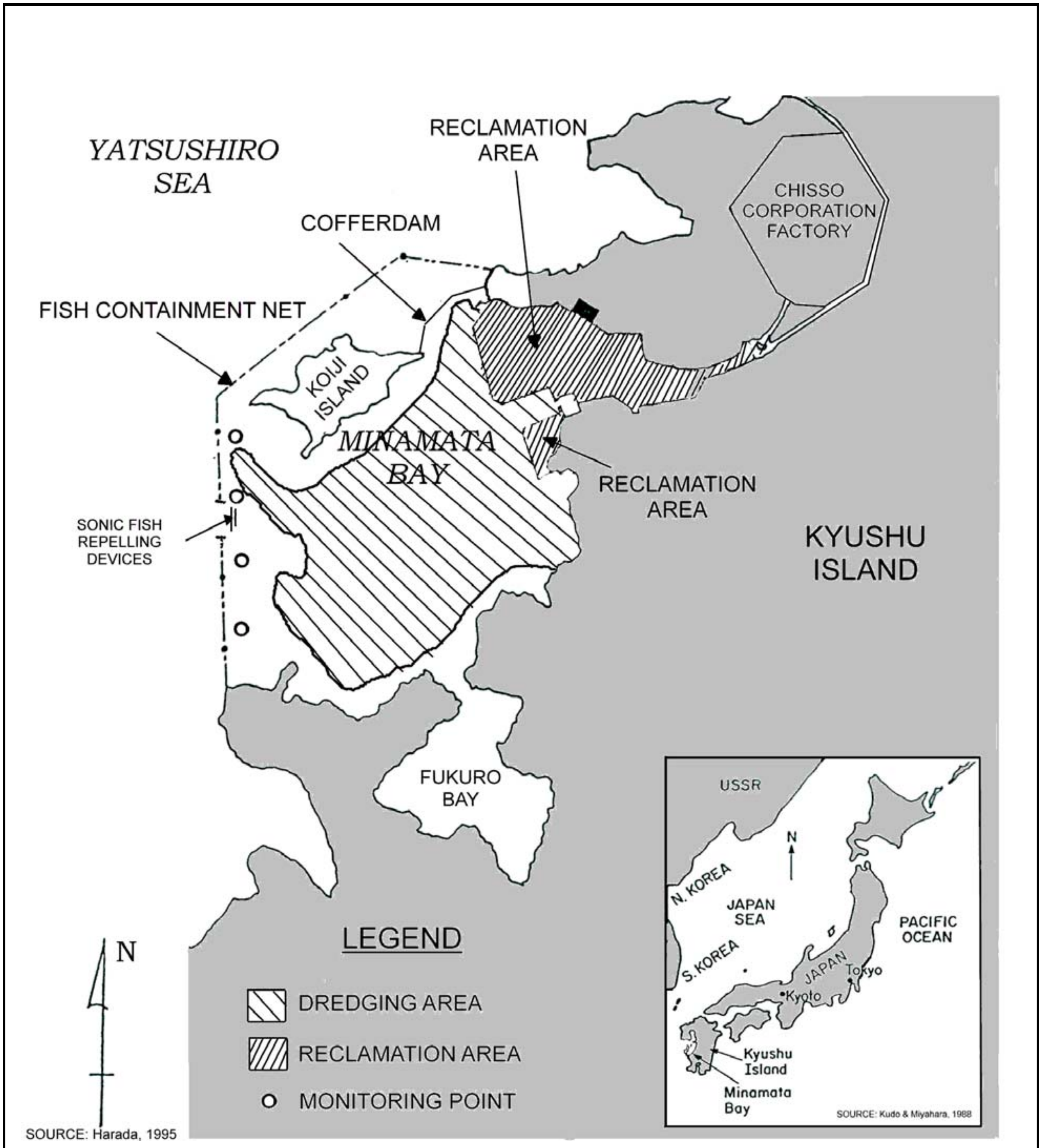
Ishikawa, T. and Y. Ikegaki. 1980. "Control of Mercury Pollution in Japan and the Minamata Bay Cleanup." Journal Water Pollution Control Federation. 52: 1013-1018.

Kudo, A. and S. Miyahara, 1984. Mercury Dispersion from Minamata Bay to the Yatsushiro Sea during 1975-1980. Ecotoxicology and Environmental Safety. 8: 507-510.

Kudo, A., Fujikawa, Y., Miyahara, S., Zheng, J., Takigami, H., Sugahara, M. and T. Muramatsu. 1998. "Lessons From Minamata Mercury Pollution, Japan - After a continuous 22 Years of Observation." Wat. Sci. Tech. 38:187-193.

Zarull, A.M., J.H. Hartig, & L. Maynard, 1999. Ecological Benefits of Contaminated Sediment Remediation in the Great Lakes Basin. August. http:/www.ijc.org/boards/wqb/ecolsed/csae.html.

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

David J. Dickerson
Project Manager, Office of Site Remediation and Restoration
U.S. EPA Region 1
1 Congress Street, Suite #1100 (HBO)
Boston, Massachusetts 02114-2023
(617) 918-1329

12 References

Allen, D. C. and A. S. Fowler, 1989. Overview of the Bench-Scale Treatment Technology Test Program New Bedford Harbor Feasibility Study. U.S. Environmental Protection Agency. August.

Allen, D. C. and A. J. Ikalainen. Selection and evaluation of treatment technologies for the New Bedford Harbor (MA) superfund site. *Wetlands/Waterways and Their Remediation.* 329–334.

Averett, D. E., and N. R. Francinques, Jr. A Case Study: Dredging as a Remedial Action Alternative for New Bedford Harbor, Massachusetts. USACE. *Wetlands/Waterways and Their Remediation.* 338–342

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. Tech.* 32: 3496-3501.

Cullen, A., D. Vorhees and L. Altshul, 1996. Influence of harbor contamination on the level and composition of polychlorinated biphenyls in produce in greater New Bedford, Massachusetts. *Environ. Sci. Technol.* 30(5):1581–1588.

EPA, 1987. New Bedford Harbor Site New Bedford, Massachusetts. Superfund Program Information Sheet. U.S. Environmental Protection Agency, Region 1. April.

EPA, 1990. Record of Decision Summary, New Bedford Harbor/Hot Spot Operable Unit, New Bedford, Massachusetts. U.S. Environmental Protection Agency, Region 1. April.

EPA, 1996. New Bedford Harbor Long-Term Monitoring Assessment Report: Baseline Sampling. U.S. Environmental Protection Agency, New Bedford, Massachusetts. October.

EPA, 1997. Report on the Effects of the Hot Spot Dredging Operations, New Bedford Harbor Superfund Site, New Bedford Massachusetts. U.S. Environmental Protection Agency. October.

EPA, 1998. Declaration for the Record of Decision, New Bedford Superfund Site/Upper and Lower Harbor Operable Unit, New Bedford, Massachusetts. U.S. Environmental Protection Agency, Region 1. September.

Foster Wheeler, 2001. *Final Pre-Design Field Test Dredge Technology Evaluation Report, New Bedford Harbor Superfund Site, New Bedford, Massachusetts.* Prepared for the United States Army Corps of Engineers by Foster Wheeler Environmental Corporation. August.

Francinques, N. R., D. E. Averett and M. J. Otis, 1988. New Bedford Harbor Superfund Project, Acushnet River Estuary Engineering Feasibility Study of Dredging and Dredged Material Disposal Alternatives. Report 1: Study Overview. Draft Report. U.S. Department of the Army, Vicksburg, Mississippi. March.

GE/AEM/BBL, 1995. Major Contaminated Sediment Site Database. New Bedford Harbor - Project 1 (Hot Spots). Website. http://www.hudsonwatch.com.

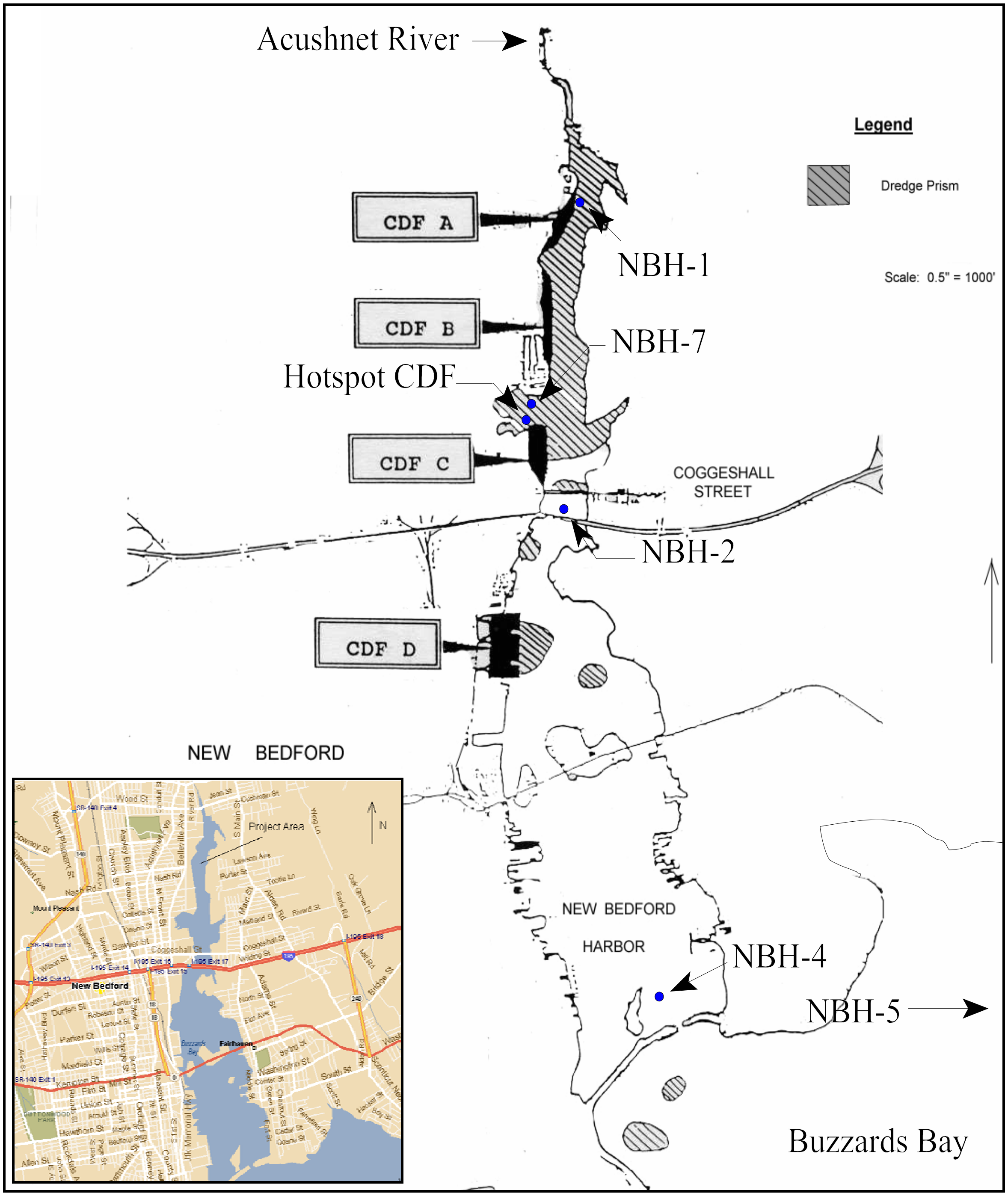
Holmes, T. T., 1987. New Bedford Superfund Project, Upper Acushnet River Estuary Engineering Feasibility Study of Alternatives for Dredging and Dredged Material Disposal. Chemical Analyses of Composite Sediment and Site Water. Interim Draft Report. Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. January.

Otis, M. J. and V. L. Andreliunas, 1987. Pilot Study of Dredging and Dredged Material Disposal Alternatives. Superfund Site, New Bedford Harbor, Massachusetts. U.S. Army Corps of Engineers, Waltham, Massachusetts. November.

Otis, M. J. and D. E. Averett. Pilot study of dredging and dredged material disposal methods, New Bedford, Massachusetts Superfund site. *Wetlands/Waterways and their Remediation.* 347–352.

ThermoRetec, 2000. Personal communication with Dave Dickerson, U.S. Environmental Protection Agency, Region 1 Project Manager, regarding New Bedford Harbor operable unit. January 26.

Figure 1 Remedial Dredge Plan - New Bedford Harbor



PORT OF PORTLAND T4 PENCIL PITCH - PORTLAND, OREGON

- Dredged 1994
- Pencil Pitch
- 35,000 cubic yards
- $6.20 per cubic yard

1 Statement of the Problem

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

Mr. Walt Haynes, P.E.
Port of Portland
P.O. Box 3529
Portland, Oregon 97208
(503) 944-7343

11 References

ACOE, 1994. Portland District, U.S. Department of the Army Nationwide Permit 38 Pre-Discharge Notification, Application No. 94-549.

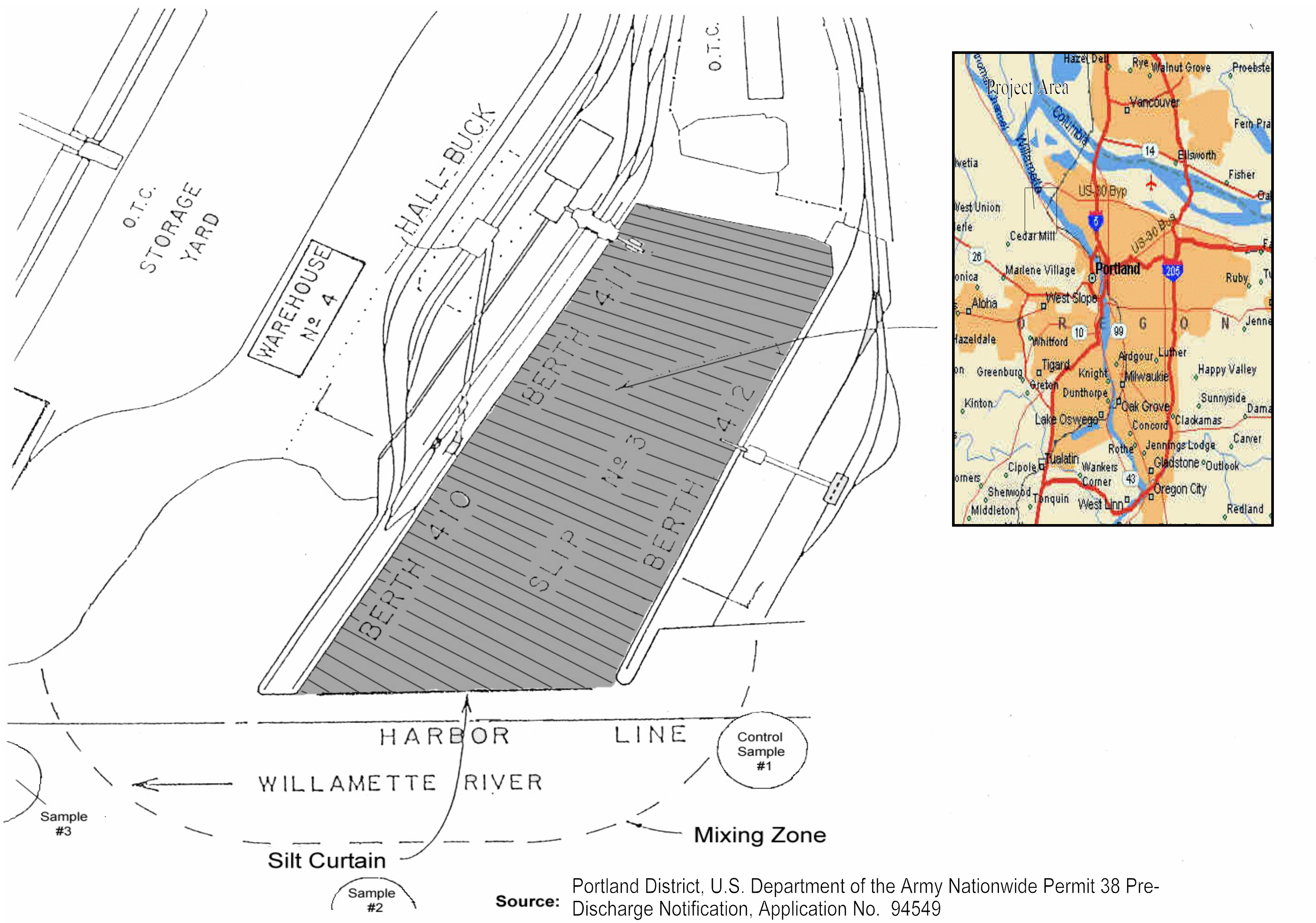
EPA, 1993. Civil Minutes of Consent Decree CV 93-267 RE: USA versus Port of Portland. United States District Court, District of Oregon. Date of Proceeding May 7, 1993.

Hartman Associates Inc., 1995. Water Quality Monitoring During Dredging and Disposal of Sediments from Terminal 4 Slip 3 in Portland Harbor, Final Report. April 28.

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

Walt Morey
Port of Vancouver, USA
P.O. Box 1180
Vancouver, Washington 98666-1180

11 References

Century West Engineering, 1989. Report of Findings Phase II Columbia River Impact Investigation: Copper Concentrate Release. Prepared for Port of Vancouver, Vancouver, Washington. March 17.

Century West Engineering, 1990. Draft Verification Sampling Summary for Bulk Loading Facility, Port of Vancouver. Prepared for Port of Vancouver, Vancouver, Washington. October 11.

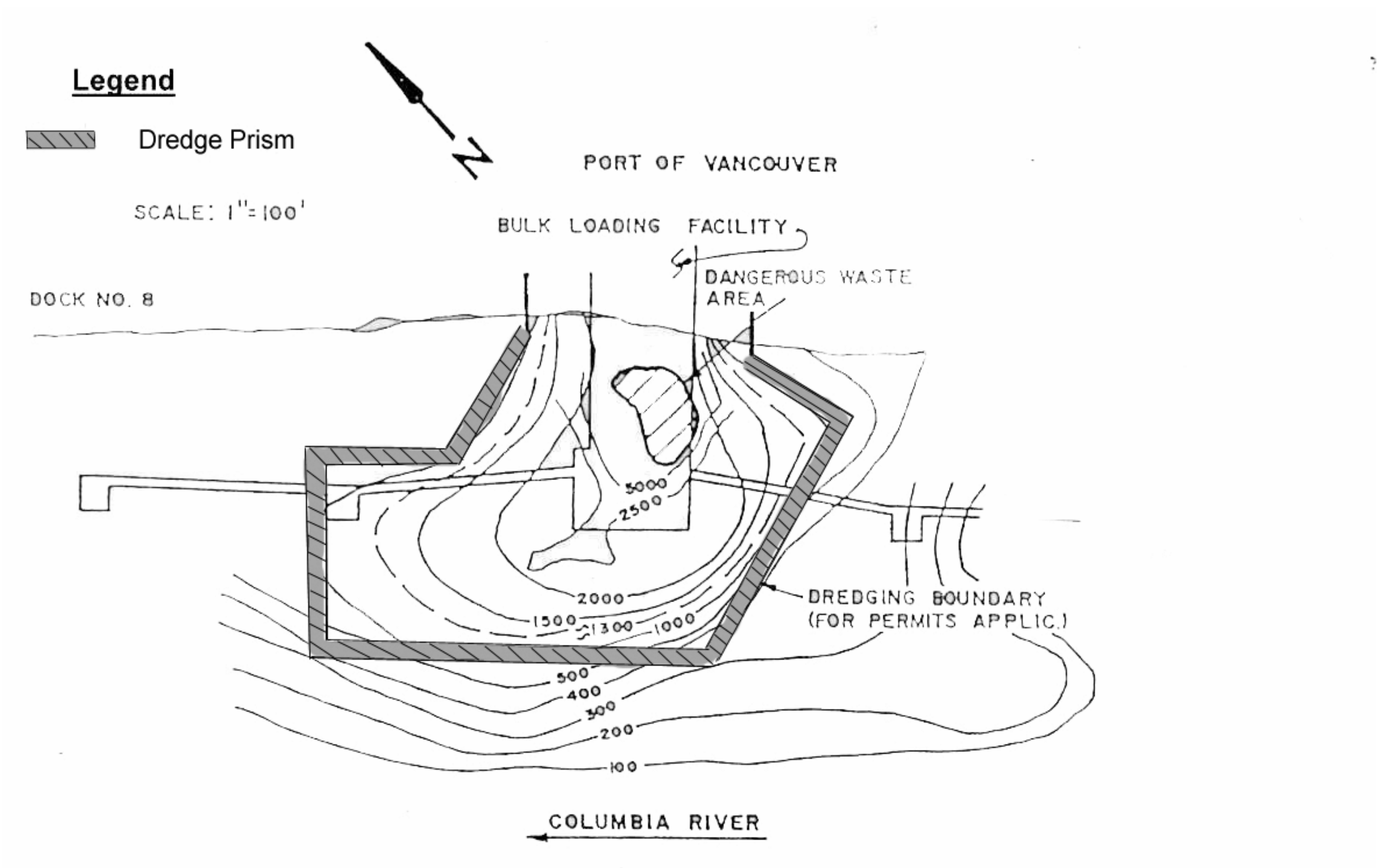
Ogden Beeman & Associates, Inc., 1991. Supplemental Remedial Alternatives Plan Berth 7 Sediment Contamination. Prepared for Port of Vancouver Washington. December 2.

Ogden Beeman & Associates, Inc., 1989. Draft Dredging and Disposal Feasibility Evaluation Port of Vancouver Washington Ore Dock Site. Prepared for Port of Vancouver Washington. December.

Port of Vancouver, USA, 1990. Berth 7, Columbia River Dredging Project, Invitation to Bid. April 24.

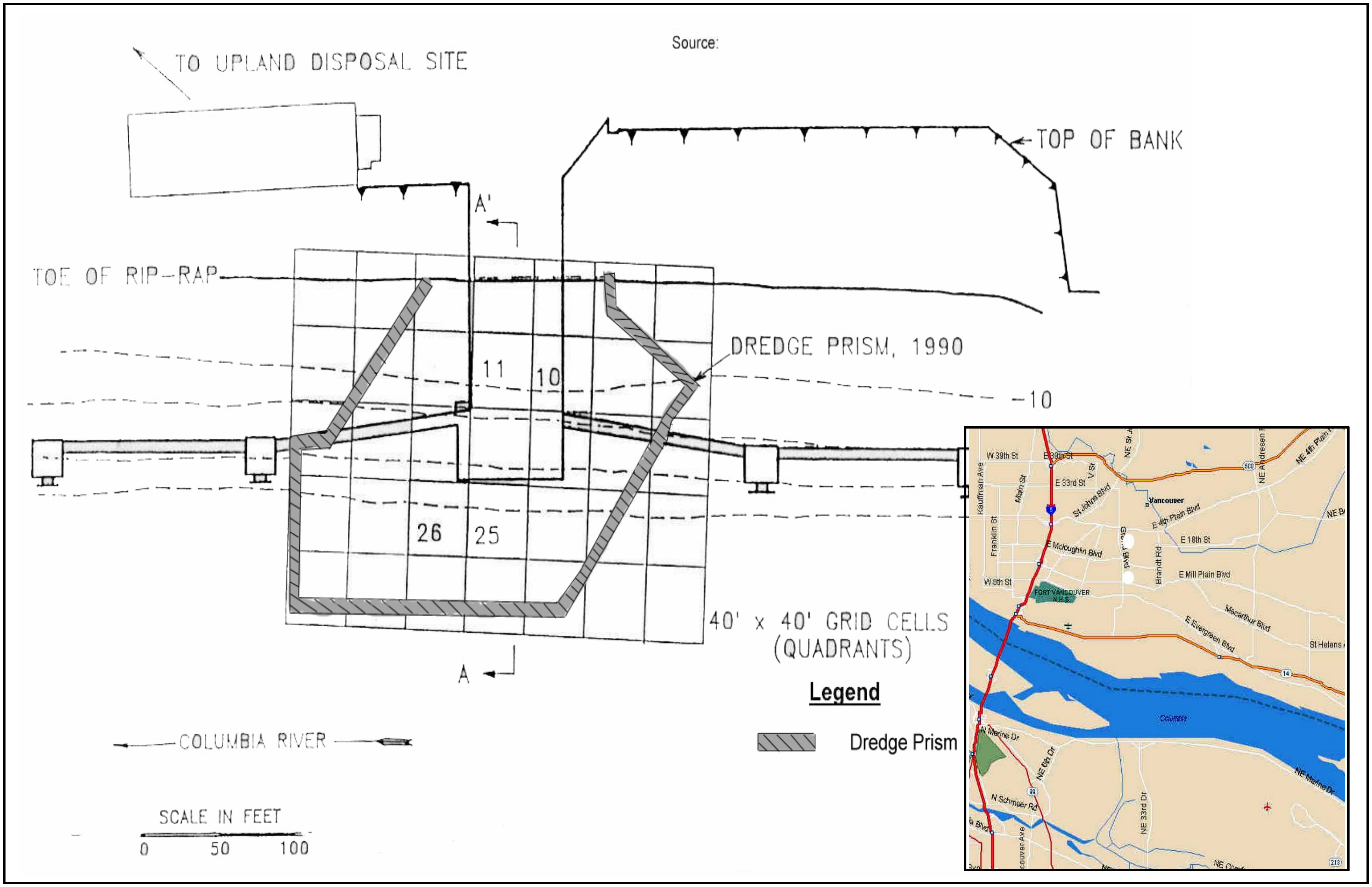
Port of Vancouver, USA, 1990. Environmental Determination of Nonsignificance. April 19.

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

- Dredged 1994-1995
- PCBs, PAHs, metals
- 53,400 cubic yards
- Costs not available

1 Statement of the Problem

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

Peter W. Havens
U.S. Navy
Engineering Field Activity Northwest
3505 Anderson Hill Road
Silverdale, Washington 98383
Telephone: (360) 396-5976

11 References

Beak, 1995. Pier D Long-term Monitoring Final Report: 1995 Sampling and Analysis, U.S. Navy Puget Sound Naval Shipyard, Bremerton, Washington. Prepared for RCI Environmental, Inc. and Department of the Navy. May.

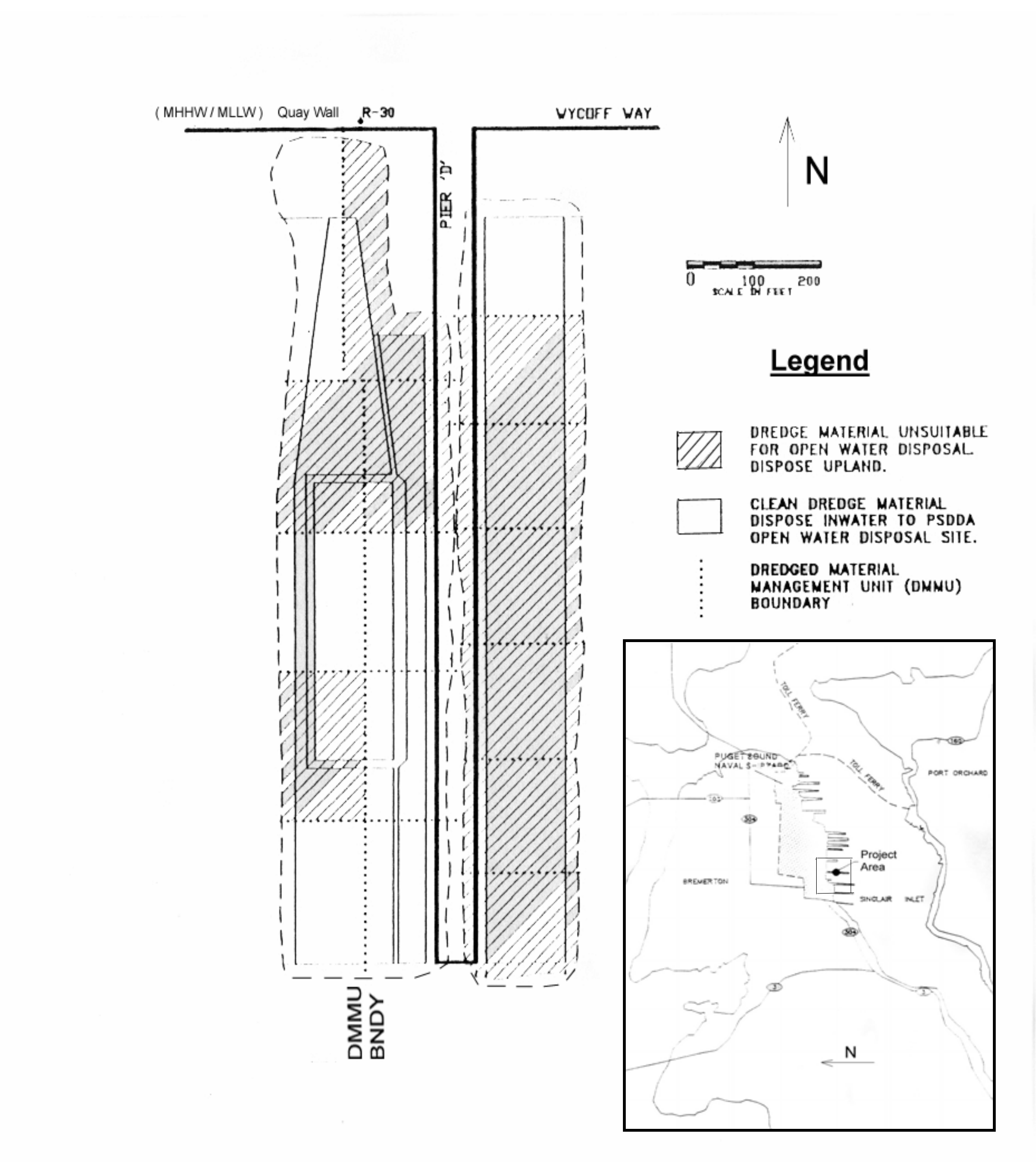
Ecology, 1994. Water Quality Certification for Corps Public Notice #OYB-2-012791-R at Puget Sound Naval Shipyard. Washington Department of Ecology Order No. 94ER-022. September 14.

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

Tom Short
U.S. EPA Region 5, Superfund Division
77 West Jackson Boulevard (S-6J)
Chicago, Illinois 60604
(312) 353-6755

Lead Agency: U.S. Environmental Protection Agency
Design Engineer/Contractor: BBL
Contractors: McMullen & Pitz, E&K Services (now Superior Services)

11 References

Blasland Bouck and Lee, Inc. (BBL), 1999. Technical Memorandum: External Source Assessment. Prepared for Tecumseh Products Company. Sheboygan Falls, Wisconsin. November.

Blasland & Bouck Engineers, P.C. (BBL), 1990. Final Work Plan/QAPP, Alternative Specific Remedial Investigation, Sheboygan River and Harbor (Tecumseh Products Company, Sheboygan Falls, Wisconsin). Blasland & Bouck Engineers, P.C., Syracuse, New York. July.

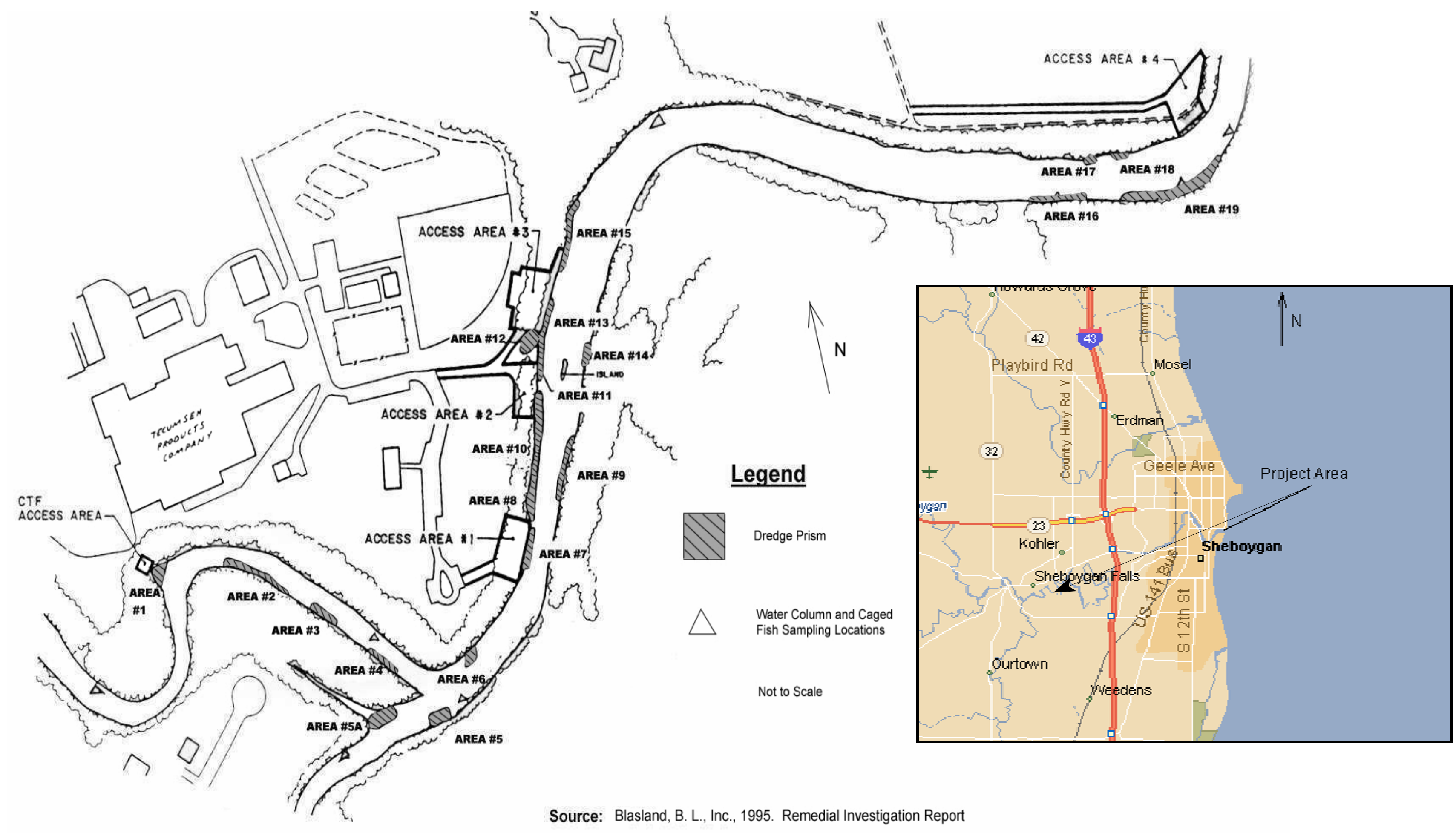
Blasland Bouck and Lee, Inc. (BBL), 1995. Alternative Specific Remedial Investigation Report, Sheboygan River and Harbor, Volume 1 of 4 (Tecumseh Products Company, Sheboygan Falls, Wisconsin). Blasland, Bouck & Lee, Inc., Syracuse, New York. October.

EPA, 1998. Bioremediation of Sediments; from Seminar Series on Bioremediation of Hazardous Waste Sites: Practical Approaches to Implementation. U.S. Environmental Protection Agency, Cincinnati, Ohio.

EPA, 2000. U.S. EPA Superfund Record of Decision, Sheboygan River and Harbor. U.S. Environmental Protection Agency, Sheboygan, Wisconsin.

GE/AEM/BBL, 1986. Sheboygan River/Harbor - Project 1 (Pilot Study). Major Contaminated Sediment Site Database. Website. http://www.hudsonwatch.com.

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

- Dredged 1993
- Metals and PAHs
- 127,500 cubic yards
- $6.20 per cubic yard

1 Statement of the Problem

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.

10 Project Contact

Ken Marcy
U.S. EPA Region 10
Seattle, Washington
(206) 553-2782

Dick Gilmur
Port of Tacoma
Tacoma, Washington
(253) 572-6996

11 References

EPA, 1998. Sitcum Waterway Remediation Project, Milwaukee Habitat Area Monitoring Report. U.S. Environmental Protection Agency. October.

EPA, 1999. Sitcum Waterway Site Summary. U.S. Environmental Protection Agency, Region 10. Website.

GE/AEM/BBL, 1999. Commencement Bay Project 2, Sitcum Waterway. Major Contaminated Sediment Site Database. Website. http://www.hudsonwatch.com.

Gilmur, D., 1992. Personal correspondence from Dick Gilmur, Environmental Program Manager, Port of Tacoma to Lori Cohan, Superfund Site Manager, EPA Region 10, regarding references for CWA 404(b)(1) analysis for the Sitcum Waterway remediation project and the Milwaukee Waterway fill and fisheries mitigation project. July 30.

Hart Crowser, 1992. Data Report: Sitcum Waterway Pre-remedial Design, Phase 1 and Phase 2 Areas, Port of Tacoma, Washington. Prepared for the Port of Tacoma. April 6.

Hart Crowser, 1993. Sitcum Waterway Remediation Project Technical Specifications Construction Quality Assurance Plan. Prepared for the Port of Tacoma. August 6.

Hart Crowser, 1994a. Data Report: Post-construction Sediment Quality Sampling and Analysis Results in Phase 1 Area, Sitcum Waterway Remediation Project. Prepared for the Port of Tacoma, Tacoma, Washington. August 5.

Hart Crowser, 1994b. Data Report: Post-construction Sediment Quality Sampling and Analysis Results, Phase 2 Area Sitcum Waterway Remediation Project, Tacoma, Washington. Prepared for the Port of Tacoma. August 5.

Hart Crowser, 1998a. Sediment Characterization Results, Sitcum Waterway Shoal Area, Commencement Bay. Prepared for the Port of Tacoma, Tacoma, Washington. July 24.

Hart Crowser, 1998b. Sitcum Waterway Area A, Sediment Quality Monitoring Results, Sitcum Waterway Remediation Project. Prepared for the Port of Tacoma, Tacoma, Washington. October 22.

Manson, 1993a. Sitcum Waterway Remediation Project Contractor's Submittal Package, Volume 1: Dredge and Disposal Plan, Schedule, Projected Cash Flow, Quality Control Plan, Environmental Protection Plan. Revision 3. Manson Construction & Engineering Company, Seattle, Washington. September 15.

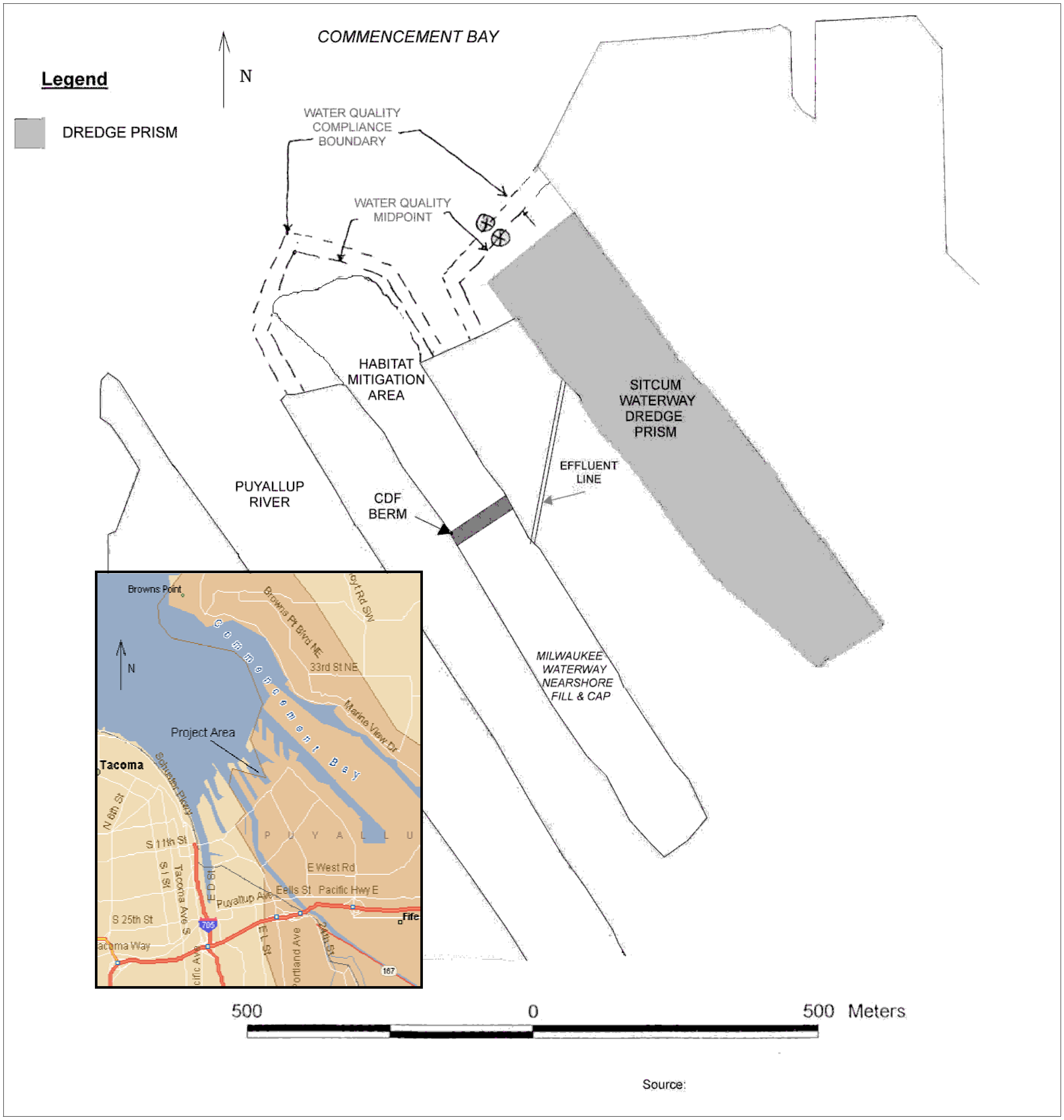
Manson, 1993b. Sitcum Waterway Remediation Project Contractor's Submittal Package, Volume 2: Water Quality Monitoring Plan. Revision 3. Manson Construction & Engineering Company, Seattle, Washington. September 15.

Port of Tacoma, 1992. Appendix 1: Statement of Work for the Remedial Design and Remedial Action for the Sitcum Waterway Problem Area and Other Areas of the Commencement Bay Nearshore and Tideflats Superfund Site. Port of Tacoma, Pierce County, Washington.

Port of Tacoma, 1994. Operations, Maintenance, and Monitoring Plan, Sitcum Waterway Remediation Project. U.S. Environmental Protection Agency, Region 10, Port of Tacoma, Washington. June 3.

Spadaro, P. and D. Templeton *et al.*, 1993. Predicting water quality during dredging and disposal of contaminated sediments from the Sitcum Waterway in Commencement Bay, Washington. *Contaminated Aquatic Sediments.* (28):8–9.

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).

10 Project Contact

Leo Rosales
Project Manager
U.S. EPA Region 5
77 West Jackson Boulevard
Chicago, Illinois 60604-3507
(312) 353-6198

11 References

EPA, 1983. NPL Site Narrative at Listing. U.S. Environmental Protection Agency. Website. http://www.epa.gov/oerrpage/superfund/ sites/npl/nar507.htm.

EPA, 1984. Superfund Decision, Outboard Marine Corporation, Final ROD Report. U.S. Environmental Protection Agency, Region 5, Waukegan, Illinois. May 7.

EPA, 1989. Declaration for the Record of Decision Amendment, Outboard Marine Corporation/Waukegan Harbor, Waukegan, Illinois. U.S. Environmental Protection Agency, Waukegan Illinois. March.

EPA, 1995. Cost and Performance Report, Thermal Desorption at the Outboard Marine Corporation Superfund Site. U.S. Environmental Protection Agency, Waukegan, Illinois. March.

EPA, 1998a. 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.

EPA, 1998b. Realizing Remediation, A Summary of Contaminated Sediment Remediation Activities in the Great Lakes Basin, Great Lakes National Program Office. U.S. Environmental Protection Agency. March.

EPA, 1999a. Record of Decision (ROD) Abstracts, Outboard Marine Corporation. U.S. Environmental Protection Agency. Website. http://www.epa.gov/superfund/sites/rodsites/0500083.htm.

EPA, 1999b. Record of Decision, Remedial Action, Outboard Marine Company/Waukegan Coke Plant Superfund Site. U.S. Environmental Protection Agency, Waukegan, Illinois. September.

EPA, 1999c. Waukegan Harbor Area of Concern. U.S. Environmental Protection Agency. Website. http://www.epa.gov/glnpo/aoc/waukegan.html.

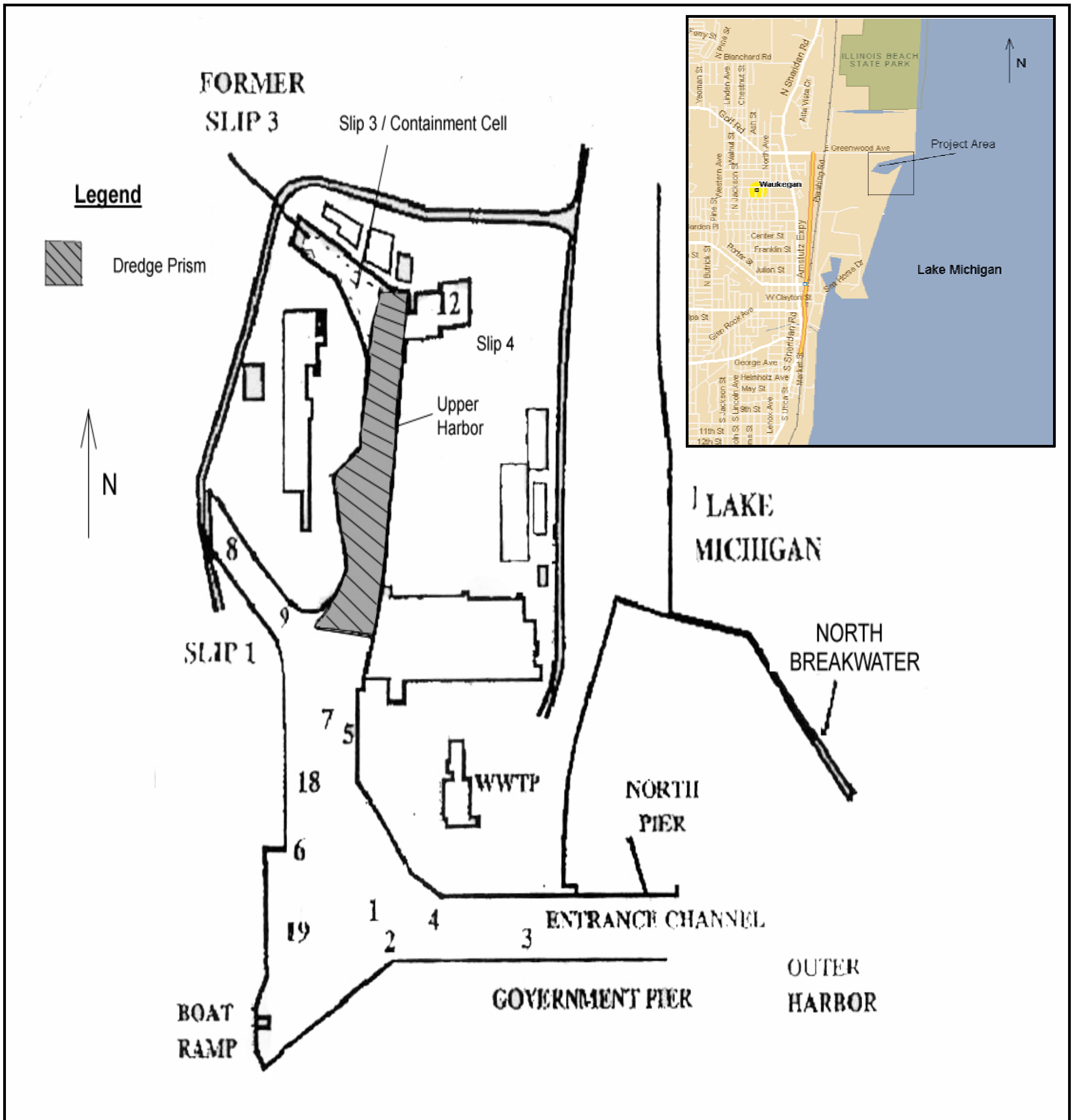
Fox River Group, 1999. Effectiveness of Sediment Removal: An Evaluation of EPA Region 5 Claims Regarding Twelve Contaminated Sediment Removal Projects. Green Bay, Wisconsin. September 27.

GE/AEM/BBL, 1998. Major Contaminated Sediment Site Database. Website. http://www.hudsonwatch.com.

Herbich, J. B., 1995. Removal of contaminated sediments: Equipment and recent field studies. *Dredging, Remediation, and Containment of Contaminated Sediments*. American Society for Testing and Materials (ASTM STP 1293). p. 77–111.

IJC, 1999. Ecological Benefits of Contaminated Sediment Remediation in the Great Lakes Basin, Case Study: PCB Contaminated Sediment Remediation in Waukegan Harbor. International Joint Commission. Website. http://www.ijc.org/boards/wqb/ecolsed/cases.html.

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

- Dredged 1997
- Mercury and PAHs
- 6,000 cubic yards
- $630 per cubic yard

1 Statement of the Problem

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

Ken Marcy
Remedial Project Manager
U.S. Environmental Protection Agency, Region 10
1200 Sixth Avenue, ECL-111
Seattle, Washington 98101
(206) 553-2782

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.

EPA, 1992. West Harbor Operable Unit, Wyckoff, Eagle Harbor Superfund Site Record of Decision. U. S. Environmental Protection Agency, Region 10, Seattle, Washington. September.

EPA, 1995a. West Eagle Harbor Amended Record of Decision. U.S. Environmental Protection Agency, Region 10, Seattle, Washington. December.

EPA, 1995b. West Harbor Operable Unit, Wyckoff, Eagle Harbor Superfund Site: Amended Record of Decision, Decision Summary and Responsiveness Summary. U.S. Environmental Protection Agency, Region 10, Bainbridge Island, Kitsap County, Washington. December.

GE/AEM/BBL, 1999. Wyckoff and Eagle Harbor Project 2, West Harbor. Major Contaminated Sediment Site Database. Website. http://www.hudsonwatch.com.

Hart Crowser, 1996a. Design Submittal, West Harbor Operable Unit, Wyckoff and Eagle Harbor Superfund Site. Hart Crowser, Kitsap County, Washington. May 29.

Hart Crowser, 1996b. Specifications, West Harbor Operable Unit, Wyckoff and Eagle Harbor Superfund Site. Hart Crowser, Kitsap County, Washington. May 29.

Hart Crowser, 1997a. Eagle Harbor Superfund Site Soil and Sediment Remediation Bid Specifications, Volume 1. January.

Hart Crowser, 1997b. Eagle Harbor Superfund Site Soil and Sediment Remediation Bid Specifications, Volume 2: Appendices. January.

Herrera Environmental Consultants, 1998a. Habitat and Substrate Sampling and Analysis Plan, OMMP Annual Report for Year 0 (1997), West Harbor Operable Unit, Wyckoff and Eagle Harbor Superfund Site. Parsons-Brinckerhoff Energy Services, Inc., Kitsap County, Washington. March 24.

Herrera Environmental Consultants, 1998b. Habitat and Substrate Sampling and Analysis Plan, West Harbor Operable Unit, Wyckoff and Eagle Harbor Superfund Site. Herrera Environmental Consultants, Inc., Seattle, Washington. August 26.

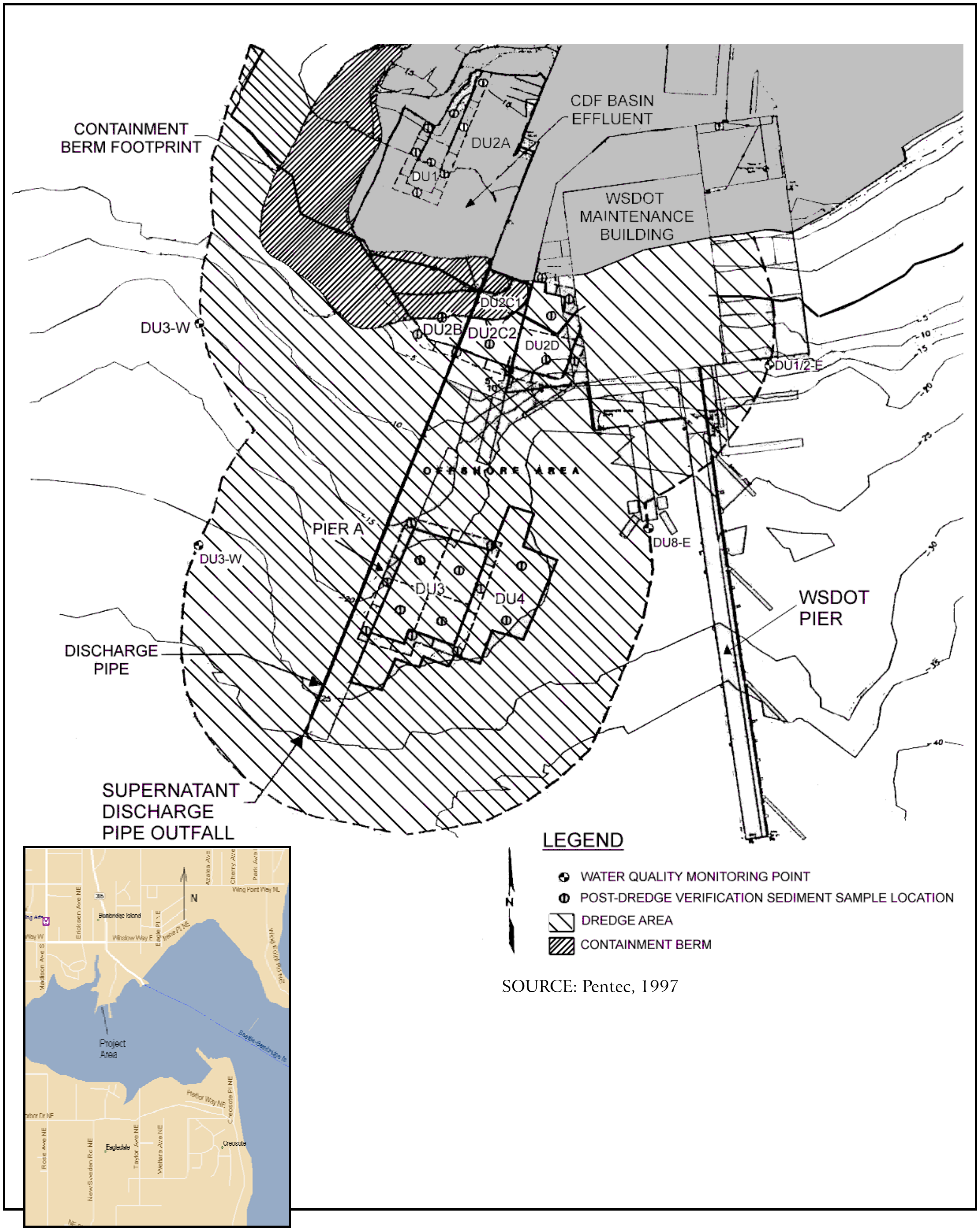
Paccar, 1996. West Harbor Operable Unit Wyckoff and Eagle Harbor Superfund Site Soil and Sediment Remediation. Paccar, Inc.

Pentec, 1997. Post-dredge Sediment Verification and Water Quality Monitoring Final Sampling and Analysis Plan for Wyckoff and Eagle Harbor Superfund Site, West Harbor Operable Unit. Pentec Environmental, Inc., Edmonds, Washington. June 6.

ThermoRetec, 1999. Personal communication with Ken Marcy, U.S. Environmental Protection Agency Project Manager, regarding West Eagle Harbor operable unit. December 28.

Wilder Environmental, 1997. Premobilization Work Plan for Eagle Harbor Superfund Site Soil and Sediment Remediation, Bainbridge Island, Washington, Attachment D: Construction Quality Control Plan. Final Copy. May 1.

Figure 1 Remedial Dredge Plan - Wyckoff/West Eagle Harbor Operable Unit



Attachment 2

Long-term Monitoring Plan Designs

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).

Project Contact:
Mark Moloney or Philip Gehrig
U.S. EPA Region 5, Cleveland Office
25089 Center Ridge Road
Westlake, OH 44145-4170
(440) 250-1709 (Moloney)
(440) 250-1706 (Gehrig)

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.

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.

IJC, 1999. International Joint Commission Great Lakes Water Quality Board. Website. http://www.ijc.org/boards/wqb/cases/studies.html.

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

References:

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.

Ueda, N. et al., 1994. Recovery of the marine bottom environment of a Japanese Bay. *Mar. Poll. Bull.* Vol. 28, No. 11, pp. 676-682.

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.

Project Contact:
Michael Collins
U.S. EPA Region 5, Superfund Division
77 West Jackson Boulevard (WC-15J)
Chicago, Illinois 60604
(312) 353-5592

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.

GE/AEM/BBL, 2000. Major Contaminated Sediment Site Database. Last updated August 1998. Website. http://www.hudsonwatch.com.

MDEQ, 1998a. Caged Fish Tissue Concentrations from Three Locations in the River Raisin. Unpublished.

MDEQ, 1998b. PCB Sediment Investigation: River Raisin Area of Concern, Monroe, Michigan 1995, 1997 and 1998. Michigan Department of Environmental Quality, Surface Water Quality Division Staff Report No. MI/DEQ/SWQ-99/108.

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.

Project Contact:
Anne Kelly
Remedial Project Manager
U.S. EPA Region 2
290 Broadway
New York, New York 10007-1866
(212) 637-4264

References:
BBL, 1996a. St. Lawrence River Monitoring and Maintenance Plan, General Motors Powertrain. BBL Environmental Services, Inc., Massena, New York. December.

BBL, 1996b. St. Lawrence River Sediment Removal Project Remedial Action Completion Report. BBL Environmental Services, Inc., Massena, New York. June.

BBL, 1999. St. Lawrence River Monitoring and Maintenance Annual Inspection Report. BBL Environmental Services, Inc., Massena, New York. January.

GE/AEM/BBL, 2000. Major Contaminated Sediment Site Database. Last updated August 1998. Website. http://www.hudsonwatch.com.

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).

Project Contact:
William Vilkelis
Project Manager
U.S. EPA Region 2
290 Broadway
New York, New York 10007-1866
(212) 637-4274

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:

Ahlen, 1998. Remediation of PCB-contaminated Sediments in Lake Jarnsjön: Investigations, Considerations, and Remedial Actions. Website. http://www.ambio.kva.se/1998/Nr5_98/aug98_1.html.

Bremle, G., and P. Larsson, 1998. PCB concentration in fish in a river system after remediation of contaminated sediment. *Environ. Sci. Technol.* Vol. 32, 3491-3495.

Bremle, G., P. Larsson, T. Hammar, A. Helgee, and B. Troedsson, 1998. PCB in a river system during sediment remediation. *Water, Air and Soil Pollution.* Vol. 107:237-250.

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.

Project Contact:
David J. Dickerson
Project Manager
U.S. EPA Region 1
1 Congress Street, Suite #1100 (HBO)
Boston, Massachusetts 02114-2023
(617) 918-1329

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.

Project Contact:
Tom Williams
U.S. EPA Region 5
(312) 886-6157

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.

Rice, C. P., and D. S. White, 1987. PCB availability assessment of river dredging using caged clams and fish. *Environmental Toxicology and Chemistry.* Vol. 6. pp 259-274.

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:

Battelle, 1999. Biomonitoring: Battelle Assists with Superfund Site Cleanup. Battelle Environmental Updates. Website. http://www.battelle.org/environment/publications/EnvUpdates/Fall99/article5.html.

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.

GE/AEM/BBL, 2000. Major Contaminated Sediment Site Database. Last updated August 1999. Website. http://www.hudsonwatch.com.

Lincoff, A. and N. Kohn, 1997. The United Heckathorn Superfund Site: NPL Listing to Sediment Remediation. Presented at the SETAC 18th Annual Meeting. San Francisco, California. November 16-20.

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.

Project Contact:
Leo Rosales
Project Manager
U.S. EPA Region 5
77 West Jackson Boulevard
Chicago, Illinois 60604-3507
(312) 353-6198

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.

IJC, 1999. Ecological Benefits of Contaminated Sediment Remediation in the Great Lakes Basin, Case Study: PCB Contaminated Sediment Remediation in Waukegan Harbor. International Joint Commission. Website. http://www.ijc.org/boards/wqb/ecolsed/cases.html.

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.

Project Contact:
Alex Zeman
National Water Research Institute
867 Lakeshore Road
Burlington, Ontario L7R 4A6
(905) 336-4882

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.

Zeman, A. J., T. S. Patterson, A. Mudroch, F. Rosa, T. B. Reynoldson, and K. E. Day, 2000. Results of Baseline Geotechnical Chemical and Biological Tests for a Proposed *In-Situ* Sediment Capping Site in Hamilton Harbour. Submitted to the Water Quality Research Journal of Canada for publication. Website. http://www.hsrc.org/capping/zeman1.html.

Zeman, A. J. and T. S. Patterson, 2000. Preliminary Results of Demonstration Capping Project in Hamilton Harbour, Ontario. Submitted to the Water Quality Research Journal of Canada for publication. Website. http://www.hsrc.org/capping/zeman4.html.

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.

Project Contact:
Robert Nyman
U.S. EPA Region 2
Estuary Programs
(212) 637-3809

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).

Project Contact:
David McEntee
Manager of Environmental Services
Simpson Tacoma Draft Company
Tacoma, Washington 98401
(253) 596-0257

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.

Project Contact:
Eric Nelson
U.S. Army Corps of Engineers
Seattle District
P.O. Box 3755
Seattle, Washington 98124
(206) 764-3742

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.

EPA, USACE, SAIC, 1995. Operations, Maintenance, and Monitoring Plan (OMMP-95): East Harbor Operable Unit of the 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.

Nelson, E., A. L. Vanderheiden, and A. D. Schulot, 1994. Eagle Harbor Superfund Project. *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. 1122-1131.

SAIC, 1996. 1995 Environmental Monitoring Report: Wyckoff/Eagle Harbor Superfund Site, East Harbor Operable Unit, Bainbridge Island, Washington. Final Report. Prepared for U.S. Environmental Protection Agency, Region 10, and the U.S. Army Corps of Engineers, Seattle District. Prepared by Science Applications International Corporation, Bothell Washington.

SAIC, 1998. 1997 Environmental Monitoring Report: Long-term Monitoring Program, Wyckoff/Eagle Harbor Superfund Site, East Harbor Operable Unit, Bainbridge Island, Washington. Final Report. Prepared for U.S. Environmental Protection Agency, Region 10, and the U.S. Army Corps of Engineers, Seattle District. Prepared by Science Applications International Corporation, Bothell Washington.

[THIS PAGE LEFT INTENTIONALLY BLANK.]

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.

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.

GE/AEM/BBL, 1998. James River. Major Contaminated Sediment Site Database. Website. http://www.hudsonwatch.com.

Unger, 2000. Personal communication between Damon Morris of ThermoRetec and Michael Unger, Professor at the College of William and Mary regarding James River project. June 22.

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.

Project Contact:
Craig Zeller
Environmental Engineer
EPA Region 4
61 Forsyth Street, S.W.
Atlanta, Georgia 30303-3104
(404) 562-8827

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.

GE/AEM/BBL, 2000. Major Contaminated Sediment Site Database. Last updated August 1998. Website. http://www.hudsonwatch.com.

Zeller, 2000. Personal communication between Damon Morris of ThermoRetec and Craig Zeller of EPA Region 4 regarding the Sangamo-Weston MNP project. June 2.

Appendix C

Long-term Monitoring Plan

Model Long-term Monitoring Plan for the Lower Fox River and Green Bay, Wisconsin

Prepared for:

Wisconsin Dept. of Natural Resources

♦ **The RETEC Group, Inc.**

RETEC Project No.: WISCN-14414

December 2002

Model Long-term Monitoring Plan

Feasibility Study for the Lower Fox River and Green Bay, Wisconsin

Prepared by:

The RETEC Group, Inc.
1011 S.W. Klickitat Way, Suite #207
Seattle, Washington 98134

and

SAIC
18706 North Creek Parkway, Suite #110
Bothell, Washington 98011

RETEC Project No.: WISCN-14414-535

Prepared for:

Wisconsin Department of Natural Resources
100 S. Webster Street
Madison, Wisconsin 53707

December 2002

Table of Contents

Table of Contents

List of Figures

List of Tables

[THIS PAGE LEFT INTENTIONALLY BLANK.]

List of Attachments

[THIS PAGE LEFT INTENTIONALLY BLANK.]

List of Acronyms

μg/kg	micrograms per kilogram
AOC	Area of Concern
ARARs	Applicable or Relevant and Appropriate Requirements
ARCS	Assessment and Remediation of Contaminated Sediments Program
BBL	Blasland, Bouck, and Lee Engineers
bw	body weight
CAD	confined aquatic disposal
CCMA	Center for Coastal Monitoring and Assessment
CDF	confined disposal facility
CENR	Committee on Environmental and Natural Resources
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
cm	centimeter
COC	contaminant of concern
COPC	contaminant of potential concern
DAMOS	Disposal Area Monitoring System
DDD	dichlorodiphenyl-dichloroethane
DDE	dichlorodiphenyl-dichhloroethylene
DDT	dichlorodiphenyl-trichloroethane
DOC	dissolved organic carbon
Ecology	Washington State Department of Ecology
ELIZA	enzyme-linked immunosorbent assay
EMAP	Environmental Monitoring and Assessment Program
EP	Estuary Program - San Francisco
EPA	United States Environmental Protection Agency
EROD	ethoxynesorusin-o-deethylase
FDA	Food and Drug Administration
FRG	Fox River Group
FS	feasibility study
g	grams
GAS	Graef, Anhalt, Schloemer and Associates, Inc.
GBMB	Green Bay Mass Balance Study
GLNP	Great Lakes National Program
GLNPO	Great Lakes National Program Office
Hg	mercury
kg	kilogram
LaMP	Lake-wide Management Program
LFR	Lower Fox River

List of Acronyms

LLBdM	Little Lake Butte des Morts
LTMP	long-term monitoring plan
MDEQ	Michigan Department of Environmental Quality
mg	milligrams
mg/kg	milligrams per kilogram
MNA	monitored natural attenuation
MNR	monitored natural recovery
NCP	National Contingency Plan
NEP	National Estuary Program
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NRDA	National Resource Damage Assessment
NS&T	National Status and Trends
OSWER	Office of Solid Waste and Emergency Response
PCB	polychlorinated biphenyl
PSAMP	Puget Sound Ambient Monitoring Program
QA	quality assurance
RAO	remedial action objective
RCRA	Resource Conservation and Recovery Act
RI/FS	remedial investigation/feasibility study
SAIC	Science Applications International Corporation
SF	San Francisco
SMU	sediment management unit
SWQD	Surface Water Quality Division
TBC	To Be Considered
TOC	total organic carbon
TSS	total suspended solids
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WDNR	Wisconsin Department of Natural Resources
wt	weight
WWC	Woodward-Clyde
YOY	young-of-the-year

1 Introduction

This document presents a model long-term monitoring plan for the Lower Fox River and Green Bay feasibility study (FS). In accordance with the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and the National Contingency Plan (NCP), the Wisconsin Department of Natural Resources is conducting a remedial investigation/feasibility study (RI/FS) for the Lower Fox River and Green Bay to address the current risk to human health and the environment and present feasible remedial alternatives. As part of this FS process, EPA has requested that a proposed long-term monitoring plan be developed. The long-term goal of the remediation project will be to reduce the concentrations of polychlorinated biphenyls (PCBs) and other contaminants in fish and invertebrates, thus reducing ecological and human health risk.

The purpose of this long-term monitoring plan will be to verify reduced risk to ecological receptors in the event that selected remedial strategies and outcomes leave residual PCBs or other site contaminants in surface sediments. Environmental monitoring can be defined as a continuing program of modeling, measurement, analysis, and synthesis that predicts and quantifies environmental conditions or contaminants and incorporates that information effectively into decision-making in environmental management (NRC, 1990). This proposed long-term monitoring plan would be implemented for all remedial alternatives including monitored natural recovery (MNR), however, it does not pre-suppose one remedy over another. It serves as a generic monitoring plan that will require modifications and/or additions depending upon the final remedy selection and design. The final plan would likely be determined and negotiated during the design phase.

The Baseline Risk Assessment (ThermoRetec, 2000b) for the Lower Fox River and Green Bay concluded that PCBs, mercury, and DDE pose the greatest long-term risk to human health and the environment. Therefore, long-term monitoring will focus on monitoring these compounds in several ecological media to assess the long-term effectiveness of the remedial alternatives proposed in the FS. For this project, effectiveness is defined as attainment of the long-term remedial action objectives (RAOs) defined for the Lower Fox River and Green Bay FS. Monitoring parameters described in this document include media, frequency, duration, location, and chemical analyses to verify achievement of project goals.

Long-term monitoring begins after completion of remedial actions or after the decision to implement a MNR strategy. However, adequate baseline data will be collected prior to remediation to ensure establishment of a data set comparable to post-remedy measurements.

1.1 Monitoring Plan Development

The proposed long-term monitoring plan was developed after careful review of regional and national monitoring programs, guidance documents related to management of contaminated sediments, case study projects, and scientifically-based recommendations presented by sediment work-groups, regulatory agencies and resource trustees (Sections 2 and 3). A possible list of monitoring options was developed from these documents, and the final list of monitoring elements selected for the Lower Fox River/Green Bay project were screened through five important management factors developed by the National Research Council (NRC). These factors were defined by the NRC as essential rudiments of a well-defined and implementable monitoring plan (Section 4). The potential monitoring elements retained from the NRC-based screening process were categorized into their intended use for verification of the project remedial action objectives. A detailed description of the monitoring strategy for each element includes the media, sampling location, frequency, sample type, approximate number of samples, and duration developed for each RAO (Section 5).

1.2 Document Organization

This document is organized into five major sections summarized as:

- Section 1 - background, purpose, and scope;
- Section 2 - a review of national, regional, and local monitoring programs;
- Section 3 - a review of applicable guidance documents used on contaminated sediment projects;
- Section 4 - selection of a monitoring plan strategy; and
- Section 5 - the proposed long-term monitoring plan for the Lower Fox River/Green Bay remediation project.

Attachment 1 located at the end of the main text provides additional detail on selected monitoring programs. Attachment 2 presents a draft report of the ongoing Lake Michigan Monitoring Project for the Fox-Wolf River Basin. The Sediment Technologies Memorandum (Appendix B of the FS) also provides useful information on the monitoring programs and lessons learned for site-specific remediation projects that include dredging, capping, and monitored natural recovery alternatives. Attachment 3 presents a cost estimate for the Lower Fox River and Green Bay monitoring program. Labor, equipment, and analytical costs are estimated per sampling event year.

1.3 Background

Background describes historical sources, status of fish and waterfowl consumption advisories, and contaminants of concern (COCs) carried forward for long-term monitoring. The RAOs and exit criteria are also defined in the purpose, goals, and scope subsections.

1.3.1 Historical Sources

An estimated 190,000 kilograms (kg) (418,000 pounds) of PCBs were released into the Fox River and Green Bay between 1954 and the present, mostly during the production of carbonless copy paper by paper mills located along the Lower Fox River (ThermoRetec, 2000a). It is estimated that by 1971 (when use of PCBs in carbonless paper manufacturing ceased), over 98 percent of the PCBs present within the Lower Fox River had been introduced into the system and a portion of these PCBs settled into the river sediments.

The PCB concentrations detected in site sediments along the entire river ranged from 0.34 to 710,000 micrograms per kilogram (μg/kg) with an average sediment concentration of 9,496 μg/kg (median of 1,700 μg/kg) (ThermoRetec, 2000a). Mercury concentrations detected in sediment samples from the river and bay ranged from 0.01 to 9.82 mg/kg with an approximate average sediment concentration of 1.27 mg/kg in the river and 0.22 mg/kg in the bay. Presence of DDT and its metabolites in Green Bay stem from agricultural activities along the shores of Green Bay and its tributaries. DDE concentrations detected in site sediments ranged from 1.9 to 22 mg/kg in the Lower Fox River with an average sediment concentration of 5.54 mg/kg. DDE was not detected in Green Bay sediments, but was detected in several Green Bay fish at adverse risk levels.

1.3.2 Consumption Advisories

Due to the elevated levels of PCBs detected in fish tissue from the Lower Fox River and Green Bay, the Wisconsin Department of Natural Resources (WDNR) issued consumption advisories in 1976 and 1987 for fish and waterfowl, respectively; Michigan issued fish consumption advisories for Green Bay in 1977. General fish consumption advisories are currently in effect for seven species of fish located in the Lower Fox River from Little Lake Butte des Morts (LLBdM) to the De Pere dam, 13 species of fish located from the De Pere dam to the mouth of

Green Bay (WDNR, 2000), and at least 11 species of fish located in Green Bay (MDEQ, 2000) for PCBs (Tables 1-1 and 1-2).

In 1984, Wisconsin initiated its wildlife contaminant monitoring program. Results of the monitoring program indicated that elevated PCB concentrations were present in waterfowl species harvested by sportsmen from Green Bay. Wisconsin then developed procedures for issuing consumption advisories for waterfowl, and issued its first waterfowl consumption advisory for mallard ducks in 1987 (Table 1-3). The advisory has remained in place every year. The advisories are issued each year in the annual hunting guide distributed by the WDNR (Stratus, 1999). WDNR adopted the federal Food and Drug Administration (FDA) threshold level for poultry of 3 milligrams per kilogram (mg/kg) wet weight PCBs on a fat basis.

1.3.3 Contaminants of Concern

Contaminants of potential concern (COPCs) to human and ecological receptors in the Lower Fox River and Green Bay were identified in a Screening Level Risk Assessment for the Lower Fox River (RETEC, 1998) and include: PCBs (total and coplanar congeners), dioxins and furans, DDT and its metabolites (DDE, DDD), dieldrin, and heavy metals (arsenic, lead, and mercury). This COPC list was further delimited in the Baseline Risk Assessment (ThermoRetec, 2000b) to a final list of contaminants of concern (COCs) which include: PCBs (total and coplanar congeners), mercury, and DDE. PCBs, mercury, and DDE are carried forward in the FS and the long-term monitoring plan.

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 (EPA, 1999a). Organochlorine contaminants (i.e., DDE and PCBs) are known to adversely effect the reproductive rates of local bald eagle populations nesting along Green Bay (Dykstra and Miller, 1996). In Green Bay, DDE has been identified as a significant risk factor to local bird populations linking DDE concentration measured in tissue to reproductive success (Custer *et al.*, 1999). Remedial alternatives were developed in the FS to address risks associated with these COCs. In summary, this long-term monitoring plan will include chemical analyses of PCBs, mercury, and DDE in sediments, surface water, and resident bird, fish, and invertebrate populations.

1.4 Purpose and Goals

The purpose of any long-term monitoring plan for a contaminated sediment remediation project should be the protection of human health and the environment.

The purpose of this document is to review relevant sediment monitoring programs, and guidance documents to help formulate a scientifically-based long-term monitoring plan for the Lower Fox River and Green Bay RI/FS process founded on precedent, implementability, appropriateness, and long-term goals. The long-term monitoring program will be designed to verify achievement of, or progress towards, the RAOs for the Lower Fox River and Green Bay. The program will also be consistent with the long-term goals of the Lake Michigan Lake-wide Management Plan (LaMP) (EPA, 2000a).

The goals of the Lower Fox River and Green Bay long-term monitoring plan can be summarized as follows:

- To verify achievement of, or progress towards, the project remedial action objectives (defined below);

- To determine the magnitude of residual risk by collecting fish, bird, and invertebrate tissue data and monitoring the reproductive viability of birds in the project area;

- To determine if suitable mink habitat exists along the shorelines of the Lower Fox River and Green Bay and potentially use this baseline data as a launching point for future mink population surveys.

- To design an effective and technically sound data collection plan that can verify reduced risk and protection of human health and the environment in order to lift fish and waterfowl consumption advisory restrictions over time;

- To formulate clear goals and procedures for the project that will build upon the existing 20-year database and improve sampling consistency and analysis between collection efforts;

- To utilize and continue, to the extent practicable, existing state and federal monitoring programs ongoing in the Lower Fox River and Green Bay; and

- To recognize the long-term goals of the (LaMP).

1.4.1 Project Remedial Action Objectives

For the Lower Fox River and Green Bay contaminated sediment project, five RAOs were defined in the draft FS document (ThermoRetec, 2000c). The primary routes of exposure to human receptors and the measurement endpoints used to verify the condition of ecological receptors for each RAO were defined in the draft Baseline Risk Assessment (ThermoRetec, 2000b). They include:

- **RAO 1 -** Achieve, to the extent practicable, surface water quality criteria throughout the Lower Fox River and Green Bay.

  Primary routes of exposure for surface water to human and ecological receptors are dermal contact with surface water, or incidental ingestion of surface water. Measurement endpoints will be surface water quality.

- **RAO 2 -** Protect humans who consume fish from exposure to COCs that exceed protective levels.

  The primary route of exposure for PCBs and mercury to human receptors identified in the Baseline Risk Assessment (ThermoRetec, 2000b) is direct ingestion of fish or waterfowl. Measurement endpoints will be edible fish and bird tissue.

- **RAO 3 -** Protect ecological receptors from exposure to COCs above protective levels.

  The primary routes of exposure for PCBs, mercury, and DDE to ecological receptors is bioaccumulation and biomagnification from the sediments up through the aquatic food web. Measurement endpoints will include bird, fish and invertebrate tissue, mink habitat, and reproductive viability of local bird populations. Surface sediment samples will also be collected to verify the reduced exposure pathway.

- **RAO 4 -** Reduce transport of PCBs from the Lower Fox River into Green Bay and Lake Michigan.

  The primary mechanism of concern for PCB transport to Green Bay is by storm events or scour effects that significantly increase the sediment bedload and resuspend contaminated sediments that are buried under surficial layers of clean sediment. Measurement endpoints will be surface water and surface sediment quality.

- **RAO 5 -** Minimize the downstream movement of PCBs during implementation of the remedy.

  The primary concern for contaminant releases during active remediation is resuspension of dredged or capped material and downstream transport. This RAO is a short-term objective and is not included in the long-term monitoring plan.

More specifically, the project expectations can be placed on an approximate time line as follows:

- Remediation will be completed within 10 years;
- The sport fish consumption advisories will be lifted within 10 years after remediation (in 20 years); and
- The fish consumption advisories for the general population will be lifted within 30 years after remediation (in 40 years).

1.4.2 Exit Criteria from Monitoring Efforts

The duration of long-term monitoring is expected to last 40 years from the onset of an implemented remediation remedy, including the no action or monitored natural recovery option for the Lower Fox River and Green Bay. Long-term monitoring may be discontinued if decision-making evaluations show that the "exit criteria" for the project have been achieved or that meaningful change has occurred as a result of the remedy. The exit criteria for each remedial action objective can be defined as a numeric or action-related threshold value designed to protect human health and the environment. Attainment of a threshold value must be evaluated before exiting the monitoring program. The exit criteria for this FS are described below.

Proposed exit criteria for the Lower Fox River and Green Bay (RAOs are considered achieved when):

- **RAO 1 -** PCBs measured in surface waters are at or below background levels in Lake Winnebago.
- **RAO 2 -** The fish and waterfowl consumption advisories for the Lower Fox River and Green Bay are removed.
- **RAO 3 -** The levels of PCBs, mercury, and DDE fall below the levels known to effect ecological communities;
    - Whole body PCB, mercury, and DDE levels in resident fish fall below the levels known to effect reproduction;

- Whole body PCB, mercury, and DDE levels in resident fish-eating birds fall below levels known to cause reproductive dysfunction;

- Levels of PCBs and mercury in site sediments fall below levels known to effect benthic communities;

- Bald eagle reproduction along the Lower Fox River and Green Bay consistently achieve levels observed for inland eagle nests in Wisconsin and Michigan; and

- Total PCB and mercury levels in resident eagle eggs fall to levels observed in background samples.

- **RAO 4 -** Mass balance calculations demonstrate the PCB loads exported from the Lower Fox River to Green Bay, or from Green Bay to Lake Michigan, are equal to input sources external to the river/bay system (e.g., atmospheric deposition).

- **RAO 5 -** (Not included as part of the long-term monitoring plan.) This objective will be assessed during development of active remediation work plans.

1.5 Scope

Before developing a long-term monitoring plan for the Lower Fox River and Green Bay RI/FS project, a review of national and regional monitoring programs and guidance documents was needed to determine a scientifically-based approach with precedent in other regulatory programs. The scope of the review included the following:

- **National and Regional Monitoring Programs.** A review of national and regional monitoring programs describing the types of monitoring elements used to determine current site conditions and environmental impacts to valued receptors. Programs selected were some of largest and most comprehensive monitoring programs currently in operation throughout the United States.

- **Site-specific Remediation Projects.** A review of site-specific sediment remediation projects conducted throughout the United States, Canada, Europe, and Asia, describing the types of monitoring conducted at each site. Projects were selected from a variety of different aquatic systems (lake, river, marine, estuary) with a variety of different implemented remedies (dredging, capping, and MNR) with the intent of presenting a cross section of different physical constraints, receptors, and remediation goals. Discussions and findings are presented in Appendix B, Sediment Technologies Memorandum.

- **Wisconsin and Michigan State Monitoring Programs.** A discussion of long-term monitoring programs currently conducted in Wisconsin and Michigan describing the appropriate regional indicators of biological health (e.g., fish tissue concentrations, bird reproduction). The review focused on fish tissue sampling used for updating the consumption advisories.

- **Guidance Documents.** A review of relevant guidance documents pertaining to the remediation, management, and monitoring of contaminated sediments. This review summarized the perspective and level of expectations by regulatory agencies for the protection of human health and the environment. The goals of this review were to increase consistency between monitoring programs and sites, optimize efforts and resources, focus our ability to detect changes in biological health over time, and support the implementation of national monitoring programs.

- **Recommendations Used for Final Selection of a Monitoring Strategy.** The NRC reviewed numerous reports and monitoring programs related to the management of contaminated sediments. They evaluated the major policy and technical limitations of existing monitoring programs. Based on their review, they developed a conceptual model for the design and implementation of monitoring programs and defined the role of monitoring in marine environmental management. Several management factors were developed to ensure an adequately designed monitoring program. These factors were used to select appropriate monitoring elements (i.e., sediment chemistry, fish tissue chemistry, surface water chemistry, benthic abundance) for the Lower Fox River and Green Bay project. Recommendations put forth by other regulatory groups regarding the management of contaminated sediments are also discussed.

Based upon this review of current monitoring programs, guidance documents, and recommendations, a proposed long-term monitoring plan was developed for the Lower Fox River and Green Bay (presented in Section 5). The proposed approach will be used to refine the expectations and implementability of monitoring measurements, to help determine the costs associated with each alternative, and to coordinate efforts early on with local, regional, and state agencies. Early coordination between different interest groups will help integrate data management needs, optimize use of available resources, and establish useful baseline data sets that will be comparable spatially and temporally with post-project sampling events.

As discussed in other sections of the FS, monitoring of a sediment remediation project is grouped into five categories:

1. Pre-action monitoring prior to remediation to establish baseline conditions (sediment, water, tissue);

2. Monitoring during implementation (water, air);

3. Post-verification monitoring to verify completion of a remedy (sediment);

4. Construction monitoring of containment facilities to verify continued source control (sediment, water); and

5. Long-term monitoring to verify effectiveness of the remedy and attainment of the project RAOs (sediment, water, tissue).

This long-term monitoring plan focuses primarily on Category 5, post-remediation sampling events to verify achievement. Construction monitoring is independent of the long-term monitoring plan (LTMP) and will be designed specifically for disposal sites (i.e., CADs, CDFs, or sand caps). Implementation monitoring pertains to water and air quality monitoring during dredging and capping activities and is not included in the LTMP. However, an adequate baseline data set will be necessary to draw comparisons with post-remedy data. Therefore, this proposed LTMP also applies to categories 1, 2, and 3 for development of a comprehensive baseline data set spanning 10 years. Sample media will include a combination of sediment, water, and tissue for all sampling events.

Table 1-1 Wisconsin Fish Consumption Advisories for the Lower Fox River and Green Bay

Water Body/Fish Species	Unlimited	Limit One Meal/Week	Limit One Meal/Month	Limit One Meal/2 Months	Do Not Eat
Fox River from Little Lake Butte des Morts to De Pere Dam					
Carp					all sizes
Northern Pike			all sizes		
Smallmouth Bass			all sizes		
Walleye			all sizes		
White Bass			all sizes		
White Perch			all sizes		
Yellow Perch		all sizes			
Fox River from De Pere Dam to Mouth					
Black Crappie			less than 9"	larger than 9"	
Bluegill			all sizes		
Carp					all sizes
Channel Catfish					all sizes
Northern Pike			less than 25"	larger than 25"	
Rock Bass			all sizes		
Sheepshead			less than 10"	10"–13"	larger than 13"
Smallmouth Bass				all sizes	
Walleye			less than 16"	16"–22"	larger than 22"
White Bass					all sizes
White Perch				all sizes	
White Sucker				all sizes	
Yellow Perch			all sizes		
Green Bay South of Marinette and Its Tributaries (except the Lower Fox River)					
Brown Trout			less than 17"	17"–28"	larger than 28"
Carp					all sizes
Channel Catfish				all sizes	
Chinook Salmon			less than 30"	larger than 30"	
Northern Pike		less than 22"	larger than 22"		
Rainbow Trout			all sizes		
Smallmouth Bass			all sizes		
Splake			less than 16"	16"–20"	larger than 20"
Sturgeon					all sizes
Walleye			less than 17"	17"–26"	larger than 26"
White Bass					all sizes
Whitefish				all sizes	
White Perch				all sizes	
White Sucker			all sizes		
Yellow Perch		all sizes			

Source: State of Wisconsin, 2000.

Table 1-2 Michigan Fish Consumption Advisories for Green Bay

- ▲ Unlimited consumption.
- ● One meal per month
- ◆ Do no eat these fish.
- ▼ One meal per week.
- ■ Six meals per year.

			General Population									Women and Children								
			Length (inches)									Length (inches)								
Water Body	**Species**	**Contaminant(s)**	6–8	8–10	10–12	12–14	14–18	18–22	22–26	26–30	30+	6–8	8–10	10–12	12–14	14–18	18–22	22–26	26–30	30+
Lake Michigan Watershed - All other locations refer to general advice.																				
Green Bay # (South of Cedar River applies to Michigan waters including Menominee and Cedar rivers below first dam. See also **Lake Michigan North of Frankfort**.)	Brown Trout	PCBs			▼	▼	▼	◆	◆	◆	◆			●	●	■	◆	◆	◆	◆
	Burbot	PCBs	▲	▲	▲	▲	▲	▲	▲	▲	▲	▼	▼	▼	▼	▼	▼	▼	●	●
	Carp	PCBs	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
	Channel Catfish	PCBs				▼	▼	▼	▼	▼	▼				■	■	■	■	■	■
	Chinook Salmon	PCBs			▲	▲	▲	▲	▲	▲	▲			●	●	●	●	●	●	●
	Lake Trout	PCBs			▲	▲	▲	▲	▼	▼	▼			●	●	●	●	●	■	■
	Longnose Sucker	PCBs	▼	▼	▼	▼	▼	▼	▼			■	■	■	■	■	■	■		
	Northern Pike	PCBs							▲	▲	▲							●	●	●
	Rainbow Trout	PCBs			▲	▲	▲	▲	▲	▲	▲			●	●	●	●	●	●	●
	Smallmouth Bass	PCBs, Mercury					▲	▼	▼	▼						●	●	●	●	
	Splake	PCBs			▼	▼	▼	◆	◆	◆	◆			●	●	■	◆	◆	◆	◆
	Sturgeon	PCBs									◆									◆
	Walleye	PCBs, Mercury					▲	▼	▼	◆	◆					●	■	■	◆	◆
	White Bass	PCBs	◆	◆	◆	◆	◆	◆				◆	◆	◆	◆	◆	◆			
	Whitefish	PCBs	▲	▲	▲	▲	▲	▲	▲	▲	▲	■	■	■	■	■	■	■	■	■
	White Perch	PCBs	◆	◆	◆	◆						◆	◆	◆	◆					
	White Sucker	PCBs	▲	▲	▲	▲	▲	▲	▲	▲	▲	●	●	●	●	●	●	●	●	●
	Yellow Perch	PCBs	▲	▲	▲	▲	▲	▲				▼	▼	▼	▼	▼	▼			

Table 1-3 Wisconsin Waterfowl Consumption Advisory

Location	Species	Health Advisory Recommendations	Date
Lower Fox River and Lower Green Bay			
Lake Winnebago downstream through Little Lake Butte des Morts (LLBdM) to the city of Kaukauna	Mallard duck	Remove all skin and visible fat before cooking. Discard drippings or stuffings because they may retain fat that contains PCBs.	1987 to present
De Pere dam downstream to the river mouth and includes lower Green Bay south of line from Point au Sable west to the west shore of Green Bay	Mallard duck	Same.	1987 to present

Source: WDNR annual hunting pamphlets. Latest listing year 2000.

[THIS PAGE LEFT INTENTIONALLY BLANK.]

2 Review of National, Regional and State Monitoring Programs

Numerous long-term monitoring programs were reviewed to inventory monitoring elements commonly used in national, regional, and local programs. Two national programs (EMAP, NOAA NS&T) were selected to represent comprehensive national programs focused on assessing the conditions of natural aquatic ecosystems of the United States. Four regional programs (Puget Sound, San Francisco, Great Lakes, and East Coast) were selected to represent progressive and comprehensive regional programs established to understand the human impacts on aquatic resources and to improve the management of these resources. Local and/or state long-term monitoring programs currently in place for the Lower Fox River and Green Bay were also reviewed, consisting primarily of fish tissue sampling for consumption advisory monitoring.

In addition, numerous site-specific contaminated sediment projects were reviewed in the Sediment Technologies Memorandum to document monitoring parameters selected for verification of dredging, capping, and monitored natural recovery remediation alternatives under approval of the Environmental Protection Agency (EPA) and/or state-led agencies (Appendix B of the FS).

The purpose of identifying and reviewing these programs was to point out the recurrence of certain environmental quality measurements in a majority of scientifically based and peer-reviewed programs focused on monitoring the remediation and/or condition of contaminated sediments. Some of the similarities among the national and regional programs in terms of measuring environmental quality are presented in Table 2-1. Table 2-2 summarizes the monitoring elements utilized for site-specific sediment remediation projects. Table 2-3 is a summary of the fish species, including size class and quantity, included in the State of Wisconsin annual fish sampling program for the consumption advisories. Tables 2-4 through 2-7 summarize the distribution and the quantity of existing data collected from the Lower Fox River and Green Bay over time. Detailed descriptions for many of these monitoring programs can be found in Attachment 1 - National and Regional Monitoring Programs and Appendix B of the FS - Sediment Technologies Memorandum.

2.1 National Monitoring Programs

Two of the most comprehensive national monitoring programs include the EMAP and NOAA NS&T programs, which are collecting data on the physical and chemical characteristics of sediments, the bioavailability of contaminants, levels of contaminant residues in the tissues of aquatic organisms, and the health of benthic communities (EPA, 1999a). Each program is briefly described below. Elements of each monitoring program are described in Attachment 1.

2.1.1 EPA Environmental Monitoring and Assessment Program (EMAP)

EMAP is a research program used for developing the tools necessary to monitor and assess the status and trends of national ecological resources. EMAP's goal is to develop the scientific understanding for translating environmental monitoring data from multiple spatial and temporal scales into assessments of ecological condition. These assessments will be used to forecast future risks to the sustainability of our natural resources (EPA, 2000c). EMAP's research supports the National Environmental Monitoring Initiative of the Committee on Environment and Natural Resources (CENR).

The objectives of EMAP are to advance the science of ecological monitoring and ecological risk assessment, guide national monitoring with improved scientific understanding of ecosystem integrity and dynamics, and demonstrate the CENR framework through large regional projects. EMAP will develop and demonstrate indicators to monitor the condition of ecological resources, and investigate multi-tier designs that address the acquisition and analysis of multi-scale data including aggregation across tiers and natural resources.

2.1.2 NOAA National Status and Trends Program (NOAA NS&T)

In 1984, NOAA initiated the NS&T Program to determine the current status of, and to detect changes in, the environmental quality of our Nation's estuarine and coastal waters. The NS&T Program is managed by the Center for Coastal Monitoring and Assessment (CCMA) in NOAA's National Ocean Service. The NS&T: 1) conducts long-term monitoring of contaminants and other environmental conditions at more than 350 sites along United States coasts, 2) studies biotic effects intensively at more than 25 coastal ecosystems, 3) partners with other agencies in a variety of environmental activities, and 4) advises and participates in local, regional, national, and international projects related to coastal monitoring and assessment (NOAA, 2000).

The NS&T Program is comprised of several projects, including: the Benthic Surveillance Project, the Mussel Watch Project, the Quality Assurance Project, Historic Trends, the Sediment Coring Project, the Specimen Banking Project, Sediment Toxicity Surveys, Biomarkers, Environmental Indices, and regional assessment and topical reports.

2.2 Regional Programs

The regional monitoring programs reviewed were intended to provide information regarding a variety of programs extending from the west coast (Puget Sound Ambient Monitoring Program [PSAMP] and San Francisco Bay Estuary Program), to the Great Lakes (Great Lakes National Program Office [GLNPO]), and the East Coast (Disposal Area Monitoring System [DAMOS] disposal site program). Each program is briefly described below. Elements of each monitoring program are described in Attachment 1.

2.2.1 Puget Sound Ambient Monitoring Program (PSAMP)

As part of the PSAMP, the Washington State Department of Ecology has collected sediment samples throughout Puget Sound, Hood Canal, and the Strait of Georgia from 1989 through 1995 (Ecology, 2000). The PSAMP was implemented for the following purposes:

- Provide a record of the condition of Puget Sound sediments.
- Aid in the identification of reference sites/values.
- Provide data for use by researchers concerned with sediment quality.

The following are specific objectives to be addressed by the PSAMP:

- Collect baseline and long-term data on Puget Sound sediments and macro-invertebrate communities in uncontaminated and contaminated areas.

- Identify areas of Puget Sound that are accumulating toxic chemicals.

- Assess the potential sediment toxicity resulting from accumulating toxic chemicals.

- Evaluate the condition of Puget Sound benthic macro-invertebrate communities in relation to the concentration of toxic chemicals in sediments.

- Document both natural and anthropogenic changes to sediment quality.

The current PSAMP program consists of both temporal (long-term) monitoring and spatial monitoring.

2.2.2 San Francisco Bay Estuary Program

The San Francisco Bay Estuary Program is part of the National Estuary Program (NEP) which was established in 1987 by amendments to the Clean Water Act to identify, restore, and protect nationally significant estuaries of the United States (National Estuary Program, 2000). The NEP targets a broad range of issues and engages local communities in the process. The program focuses not just on improving water quality in an estuary, but on maintaining the integrity of the whole system—its chemical, physical, and biological properties, as well as its economic, recreational, and aesthetic values.

To assist in coordinating research and monitoring programs, the San Francisco Estuary Project has fostered the development of a Regional Monitoring Strategy (Monitoring Strategy). The primary purposes of the Monitoring Strategy are to:

- Provide information to assess the effectiveness of management actions that have been taken to improve conditions in the estuary and to protect its resources.

- Evaluate the ecological "health" of the estuary and enhance scientific understanding of the ecosystem.

Implementation of the Monitoring Strategy will strengthen the Estuary Project's continuing effort to promote environmentally sound management of the bay and delta. The Monitoring Strategy will improve the ability to define human-induced stresses on the estuary, help to assess the effectiveness of current estuary management, and monitor the long-term health of the estuary.

2.2.3 EPA Great Lakes National Program Office (GLNPO)

The Great Lakes National Program (GLNP) is part of the EPA. Annual monitoring of the Great Lakes by the GLNP began in 1983 for Lakes Michigan, Huron, and Erie; in 1986 in Lake Ontario; and in 1992 for Lake Superior (EPA, 2000b). GLNPO's Great Lakes Monitoring Program consists of several different elements, including the following:

- Green Bay Mass Balance Study,
- Lake Michigan Mass Balance Project,
- Benthic Invertebrate Monitoring Program,
- Limnology Program, and
- GLNP Indicators Monitoring Program.

Each of these program elements is briefly described below.

The Green Bay Mass Balance (GBMB) Study was conducted in 1989 through 1990 to pilot the technique of mass balance analysis in understanding the sources and effects of toxic pollutants in the Great Lakes food chain. The study was headed by EPA's GLNPO and the Wisconsin Department of Natural Resources. The study focused on four representative chemicals or chemical classes: PCBs, dieldrin, cadmium, and lead (EPA, 2000b).

The Lake Michigan Mass Balance Project began in 1994 and was concluded in 1999. In addition to baseline environmental conditions (air and water temperature, transmissivity, etc.), samples of air, water, sediment and fish tissue have been analyzed for four particular biochemical chemicals of concern: mercury, PCBs, atrazine, and trans-nonachlor. The Lake Michigan Mass Balance study is helping scientists understand where these chemicals are entering the Lake and what happens to them as they move through the ecosystem.

The GLNP has recognized the potential importance of benthic indicator/integrator organisms in the evaluation and management of the Great Lakes, and in 1997 initiated a Benthic Invertebrate Biomonitoring Program to complement its current surveillance sampling. The data is used in conjunction with other physical, chemical, and biological data generated by GLNPO's surveillance program to provide an extensive picture of the condition of the lakes and how benthic invertebrates respond to it.

The GLNP's annual Limnology Program for the Great Lakes began in 1983. The limnology program provides information on key environmental factors that influence the food chain and fish of the Great Lakes. The sampling strategy is to collect water and biota samples at specific water depths from a limited number of locations in each lake twice every year.

The GLNP's Indicators Monitoring Program monitors plants and organisms that are particularly suitable for use as indicators of environmental conditions. The GLNP monitors diatom communities, zooplankton populations, benthic invertebrates, and exotic species in the Indicators Monitoring Program.

All of the GLNPO programs recognize the significance of environmental contamination, and all of them include the collection and chemical analyses of sediments. This indicates the usefulness of sediments as a sentinel of chemical contamination in the environment even when the monitoring objective is not focused on the effectiveness of sediment remediation. Table 2-1 shows some of the similarities among these five national and regional programs in terms of measuring environmental quality.

2.2.4 Disposal Area Monitoring System (DAMOS)

The New England district of the U.S. Army Corps of Engineers (USACE) created the DAMOS program in 1977. The DAMOS program was established to ensure that the disposal of dredged material from numerous industrialized harbors in New England placed in offshore disposal sites had no adverse effect on the environment. After placement of contaminated material, these sites were subsequently capped with clean material. These offshore, open-water disposal sites are located between Long Island Sound and Maine, and are under the jurisdiction of the New England Corps district.

The DAMOS monitoring program was implemented to: 1) ensure the physical integrity and stability of disposal mounds, 2) measure the impacts to bottom organisms around and returning to the disposal mounds, and 3) measure the effectiveness of capping in isolating disposed contaminated sediments (USACE, 1992). Monitoring under the DAMOS program follows a tiered approach, under which techniques in the higher tiers are used only when monitoring results of lower tiers indicate the need for further monitoring.

2.3 State Monitoring Programs—Wisconsin and Michigan

Before finalizing the long-term monitoring plan for the Lower Fox River and Green Bay remediation project, it was important to consider other ongoing state monitoring programs intended to evaluate many of the same valued resources and aquatic receptors under consideration for the Lower Fox River/Green Bay project. Sampling protocols, monitoring methods, species selection, and resource locations have already been determined for many of these programs where extensive databases have already been established. The goal of this review was to consider other programs already in place and how to efficiently adapt the Lower Fox River/Green Bay monitoring plan to complement these pre-existing programs. These programs may have larger goals to consider beyond the scope and spatial extent of the project area, but were helpful for developing the Lower Fox River/Green Bay monitoring plan.

2.3.1 Wisconsin State Fish Monitoring Program

The Wisconsin Department of Natural Resources conducts fish tissue monitoring as part of Wisconsin's Fish Contaminant Monitoring Program. Fish tissue sampling is conducted every 3 to 5 years and collection efforts are focused on the tributaries to Green Bay including the Lower Fox River. The program has two goals: 1) updating the state fish consumption advisories for consumable fish and 2) determining temporal trends in fish indicator species. Spatial differences and temporal trends in consumption are examined by collecting several species of fish from three different river reaches of the Lower Fox River: 1) Little Lake Butte des Morts, 2) Appleton to the De Pere dam, and 3) below the De Pere dam to the mouth. Multiple samples are collected from at least three size classes of fish from each species (Table 2-3). Sampling events are conducted in the spring during spawning seasons.

Fish species used for evaluation of the consumption advisories include: walleye, carp, white bass, yellow perch, catfish, northern pike and two pan fish species (crappie and bluegill). Yellow perch are also collected from the south end of Green Bay. Although Lake perch is an exotic species, it may be added to the game fish collection list since it is desirable by anglers (Amhrein, 2000). These species and sizes represent WDNR's "guideline" of catches, but actual sampling catches may vary from year to year depending upon site conditions. The top fish species caught in the Lower Fox River are generally walleye, white perch, yellow perch, and smallmouth bass. Discrete fish samples are analyzed as skin-on-fillet samples (skin-off-fillet for catfish) and analyzed for total PCBs, percent lipids, DDT for carp, and mercury for walleye. PCB congeners are not typically analyzed as part of this program. Fish length, weight, sex, and presence of external and internal fish tumors are also recorded (Amhrein, 2000).

The second goal of the monitoring program is to observe trends in contaminant concentrations for assessing the status of environmental health. Gizzard shad tissues are used to observe environmental trends. Although gizzard shad are not a desirable fish catch by anglers, they serve as a good indicators of environmental health. Samples are collected in the same manner as the fish consumption advisory sampling events, with the exception that whole body fish tissue samples are analyzed (Amhrein, 2000).

2.3.2 Wisconsin State Bird Monitoring Programs

The Wisconsin Department of Natural Resources conducts waterfowl, double-crested cormorant, and bald eagle monitoring as discussed below.

Waterfowl

The WDNR conducted a game bird sampling event in the mid-1980s to assess PCB and pesticide concentrations in bird tissue ingested by hunters. This sampling event led to the listing of mallard ducks on the waterfowl consumption advisory in 1987. The sampling event was conducted around the state at several locations with multiple samples per location (approximate sample size N = 8). Although a formal monitoring program is not currently in-place and no additional waterfowl sampling has been conducted by WDNR since the late 1980s (additional sampling data have been collected by USFWS in the 1990s), WDNR intends to conduct additional waterfowl tissue sampling events to update the advisory (Peterson, 2000).

Double-crested Cormorants

The WDNR and the U.S. Fish and Wildlife Service (USFWS) periodically conduct bioaccumulation and productivity monitoring studies on resident double-crested cormorant species. Following a ban on the use of DDT in North America in the 1970s, egg tissue residues have decreased by more than 80 percent and the Green Bay population has increased by a factor of 45 in the past 20 years (Stratus, 1999). A summary of the types of monitoring conducted on resident populations in the past 20 years include:

- Whole body tissue (male and female) for total PCB and DDE analysis;
- Incidence of bill and head deformities among nestlings;
- Eggshell thickness;
- Biomarker activity—EROD activity in embryo livers;
- Edema of the head and neck of nestlings, and hemorrhaging;
- Annual productivity and nesting sites;
  - Number of nests
  - Number of hatches per active nest
  - Number of dead embryos
- Foraging areas; and
- Comparison to inland reference sites.

Details regarding sample collection efforts were not specified; however, it appears that several colonies were sampled per year with up to 40 nests and over 100 egg samples per colony for an annual sampling event. Egg samples were analyzed for total PCBs, PCB congeners, and DDE. Based on numerous correlation analyses, the best monitoring indicators of bird health were whole body and egg tissue chemical analysis, reproductive hatching success, and embryonic deformations. The main breeding colonies reside on Cat, Jack, Hat, and Snake Islands in Green Bay, and on Spider Island on the east side of Door peninsula. Breeding times occur between April and September/October before the colonies migrate south.

Recent studies by the USGS and USFWS identified DDE, and not other contaminants of concern, as the significant risk factor effecting reproductive success to double-crested cormorants (Custer *et al.*, 1999). Egg hatching success was positively correlated with shell thickness and negatively correlated with DDE concentration. Results did not support the hypothesized relationship between PCB concentrations in eggs and reproductive success in double-crested cormorants (Custer *et al.*, 1999). In summary, double-crested cormorant populations are recovering in Green Bay, are no longer a threatened species in Wisconsin, and are not good indicators of PCB risk to ecological receptors. However, they are vulnerable to PCB uptake by feeding almost exclusively on forage fish (alewife and smelt) with high lipid contents (Stratus, 1999) and have notably higher PCB concentrations in colonies residing on Cat Island (close to the Lower Fox River) than other colonies. They could serve as resident indicators of changes in PCB exposure and uptake over time.

Bald Eagles

The WDNR has conducted annual monitoring of bald eagles in the Lower Fox River/Green Bay region since 1974 (Dykstra and Miller, 1996). The USFWS also periodically conducts bald eagle monitoring for productivity, and PCB and DDE bioaccumulation in eggs and plasma. In 1997, the State of Wisconsin "threatened species" status was removed since bald eagle populations have significantly increased in the last 10 years; however, the bald eagle is still listed on the USFWS threatened species list. A summary of the types of monitoring conducted on resident bald eagle populations in the past 20 years include:

- Egg tissue for total PCB and DDE analysis (1986 to 1997);
- Blood plasma for total PCB and DDE analysis (1987 to 1995);
- Annual productivity and nesting sites;
  - Number of occupied and unoccupied nests
  - Number of large young produced per active nest
- Prey species and prey remains;
- Food availability and foraging areas; and
- Comparison to inland nesting sites.

In Green Bay, 12 nests were sampled with two to three eggs collected per nest. In the Lower Fox River, only one nest was sampled with one egg analyzed. Chemical analysis focused on PCBs and DDE because: 1) they are the only contaminants that have been found in the Great Lakes bald eagle tissues in high enough concentrations to result in adverse effects, 2) they are the most closely correlated with bald eagle reproductive success, and 3) they are known to result in the types of adverse effects observed in the area assessment of bald eagles

(Stratus, 1999). Reproductive rates have slowly increased since 1987, but rates are still 60 percent lower than inland nesting samples. PCB concentrations in eggs and blood samples from Green Bay were 10 times higher than inland samples (Dykstra and Miller, 1996). The annual productivity rate required to maintain a healthy bald eagle population is a minimum of 1.0 young per active nest.

2.3.3 Michigan State Fish Monitoring for Consumption Advisories

The state of Michigan conducts annual fish tissue monitoring as part of Michigan's Fish Contaminant Monitoring Program. In 1986, a comprehensive program was initiated by the Michigan Department of Environmental Quality-Surface Water Quality Division (MDEQ-SWQD) to assess the degree of chemical contamination in fish from surface waters of the state, and over 12,000 fish tissue samples have been analyzed since 1980. The program has four program goals: 1) to develop and maintain the Michigan Fish Advisory, 2) to regulate sales of commercial catch, 3) to identify spatial differences and temporal trends in the quality of Michigan's surface waters, and 4) to determine whether existing regulatory and remedial programs are effectively reducing chemical contamination in the aquatic environment (MDEQ, 1999). Temporal trends and spatial differences are examined by collecting whole-fish and caged-fish samples in addition to the edible portion samples. The presence of even extremely low concentrations of some bioaccumulative pollutants in surface water can result in concentrations in fish tissue that pose a human and wildlife health risk. Verification of the achievement of, or progress towards, the program goals is evaluated primarily through the collection and analysis of fish tissues.

Components of the fish monitoring program include:

- Edible fish monitoring;
- Whole fish trend monitoring (initiated in 1990); and
- Caged fish chemical bioconcentration studies.

Edible fish monitoring samples are collected every year from inland lakes and rivers, tributary rivers, and Lake Michigan (Day, 2000). In 1998, 1,059 fish were collected from 58 locations and included 21 species of fish; however, none of these 1998 stations were located in the project area. The sampling stations are not on a fixed schedule; samples are collected opportunistically based on fish catches. Collection and analysis focus on key species of concern and fish samples are generally processed as headless, gutless, and skin-off fillets for most fish, with the exception of game fish which are mostly skin-on-fillet. Samples are discrete(no compositing) since MDEQ rarely collects composite samples except for coho and chinook salmon species (Day, 2000).

Whole fish trend monitoring samples are collected every 2 to 5 years from 26 trend locations to assess the spatial and temporal trends in contaminant concentrations. However, only four rounds of data sets have been collected to date, and significant trends have not been detected in most of these data sets, possibly due to sample variability. Only two stations are located with the project area; one station is located near Little Bay de Noc in Green Bay and other is located in the Menominee River tributary to Green Bay.

Caged fish bioconcentration studies are used as a tool to identify sources of bioaccumulative contaminants and identify spatial trends in contaminant concentrations. MDEQ generally places approximately 10 to 30 cages per year (Day, 2000). The caged-fish studies consist of a 28-day test using channel fish (4 to 6 inches long) and are conducted primarily in river watersheds (River Raisin, Saginaw River) and none are located in the project area.

In addition to the Michigan Fish Contaminant Monitoring Program, several agencies in the Great Lakes Basin are monitoring fish contaminant trends. The EPA collects and analyzes whole lake trout or walleye from the open waters of each of the Great Lakes. The Great Lake states work cooperatively with the EPA to collect and analyze coho and chinook salmon from select Great Lake tributaries during the fall spawning migration. The coho and chinook salmon are analyzed as composites of skin-on fillets.

2.3.4 Existing Data for the Lower Fox River and Green Bay

The sediment, water, and tissue data sets used for the Lower Fox River and Green Bay RI/FS project were compiled from over 16 different site characterization studies (Table 2-4). The compiled data set spans over 20 years for certain parameters, and was used to calculate sediment quality thresholds as part of the Baseline Ecological and Human Health Risk Assessment (ThermoRetec, 2000b). The data set includes primarily surface sediment, sediment core, and water quality data.

The purpose of presenting this compilation of existing data for the Lower Fox River and Green Bay is to summarize the types of monitoring parameters already collected in the project area. This data constitutes a remarkable set of baseline data that could be used to detect and determine long-term trends at the site well after post-project remediation. This compilation is not intended to replace a well-developed long-term monitoring plan including a revised set of baseline data that would be directly comparable to long-term data (similar sites, sizes, depths, and types of data), but serves to augment and detect temporal trends.

As summarized in Table 2-5, the types of monitoring elements commonly collected in the Lower Fox River and Green Bay include: surface and subsurface sediment sampling, fish tissue sampling, and mammal sampling with lesser amounts of air, water, and caged fish sampling data. Benthic community abundance and fish tissue deformities/histopathology were not commonly collected.

As described in the Lower Fox River RI/FS Data Management Summary Report (EcoChem, 2000), several of the studies used many different analytical laboratories with different detection limits, different analyte lists, and a wide range of reported percent recoveries and data validation procedures. Thus, it was determined that, in general, the data from the Green Bay Mass Balance Study, along with many other studies listed in this document, should be used as supporting data only. When planning the long-term monitoring plan for the Lower Fox River and Green Bay, consistency between years, laboratories, analytical methods, and detection limits will assist with reliable interpretations of temporal and spatial trends.

Table 2-1 Regional and National Monitoring Programs

Monitoring Program	Environmental Quality Measurement Elements									
	Physical	Chemical		Biological						
	Bathymetry and Sediment	Surface Water Quality	Surface Sediment Quality	Benthic Abundance	Fish Community	Sediment Invertebrate Toxicity	Water Toxicity	Fish and Shellfish Tissue	Invertebrate Tissue	Histological Studies
National Programs										
EMAP	◆		◆	◆	◆			◆	◆	
NOAA NS&T			◆					◆	◆	◆
Regional Programs										
DAMOS	◆		◆	◆		◆		◆	◆	
GLNP		◆	◆	◆	◆			◆	◆	
PSAMP	◆		◆	◆		◆				
SF-Bay Estuary Program	◆	◆	◆	◆		◆	◆	◆	◆	

Table 2-2 State Monitoring Programs—Wisconsin and Michigan

State Monitoring Program	Physical	Chemical			Biological			
	Other	Sediment	Surface Water	Sediment Traps	Benthic Abundance	Toxicity	Concentration Tissue	Histological Studies
Wisconsin State Fish Consumption Monitoring Program							◆	
Wisconsin State Bird Monitoring Program							◆	
Waterfowl							◆	
Double-crested Cormorant							◆	◆
Bald Eagle							◆	
Wisconsin Sensitive Areas Index Monitoring	◆							
Michigan State Fish Consumption Monitor Program							◆	
USACE Navigational Depth Monitoring	◆							

Table 2-3 1998 Wisconsin Fish Contaminant Sample Collection Schedule

Sampling Location	Species	Sampling Guidelines (source: J. Amhrein)			
		Size Class (in inches)	No. of Samples	Sample Form	Parameters
Little Lake Butte des Morts	Walleye	12-15	1	fillet	PCBs
		15-18	4	fillet	PCBs
		18-22	3	fillet	PCBs
		22-24	1	fillet	PCBs/Hg
	Northern Pike	15-18	3	fillet	PCBs
		18-22	3	fillet	PCBs
		22-26	2	fillet	PCBs
	Carp	many	5	fillet	PCBs
	Yellow Perch	many	5	fillet	PCBs
	Smallmouth Bass	10-12	1	fillet	PCBs
		12-15	3	fillet	PCBs
		15-17	2	fillet	PCBs
	White Bass	9-11	2	fillet	PCBs
		11-14	3	fillet	PCBs
		14+	1	fillet	PCBs
	Bluegill	many	5	fillet	PCBs
	Crappie	many	5	fillet	PCBs
	Gizzard Shad	2-25 fish composites	50	whole	PCBs
	Shiner spp.	2-25 fish composites	50	whole	PCBs
Lower Fox River below the De Pere Dam	Walleye	10-12	2	fillet	PCBs
		12-15	3	fillet	PCBs
		15-18	3	fillet	PCBs
		18-22	3	fillet	PCBs
		22-24	2	fillet	PCBs/Hg
	Northern Pike	15-18	2	fillet	PCBs
		18-22	2	fillet	PCBs
		22-26	2	fillet	PCBs
	Smallmouth Bass	10-12	2	fillet	PCBs
		12-15	2	fillet	PCBs
		15-18	2	fillet	PCBs
	White Bass	many	5	fillet	PCBs
	Bluegill	many	5	fillet	PCBs
	Crappie	many	5	fillet	PCBs
	Yellow Perch	many	5	fillet	PCBs
	Carp	many	5	fillet	PCBs
	Gizzard Shad	2-25 fish composites	50	whole	PCBs
	Shiner spp.	2-25 fish composites	50	whole	PCBs
Lower Fox River above the De Pere Dam	Walleye	10-12	2	fillet	PCBs
		12-15	3	fillet	PCBs
		15-18	3	fillet	PCBs
		18-22	3	fillet	PCBs
		22-24	2	fillet	PCBs/Hg
	Northern Pike	15-18	2	fillet	PCBs
		18-22	2	fillet	PCBs
		22-26	2	fillet	PCBs
	Smallmouth Bass	10-12	2	fillet	PCBs
		12-15	2	fillet	PCBs
		15-18	2	fillet	PCBs
	White Bass	many	5	fillet	PCBs
	Bluegill	many	5	fillet	PCBs
	Crappie	many	5	fillet	PCBs
	Yellow Perch	many	5	fillet	PCBs
	Carp	many	5	fillet	PCBs
	Gizzard Shad	2-25 fish composites	50	whole	PCBs
	Shiner spp.	2-25 fish composites	50	whole	PCBs
Green Bay	Gizzard Shad	1 lb young-of-the-year	3	whole	PCBs, Chlor, Dieldrin, DDT
	Yellow Perch	2-5 fish composites	10	fillet	PCBs, Chlor, Dieldrin, DDT

Table 2-4 Compilation of Existing Data for the Lower Fox River and Green Bay RI/FS Project

Study	Years	Location	Monitoring Matrix	OK to Use
WDNR Fox River and Green Bay Mass Balance Studies	1989/1990	river-wide, bay-wide	Over 4,000 sediment and surface water samples	(1)
Deposit A Sampling Collection	1992–1994	Deposit A	Sediment and water samples (BBL, 1993; WWC, 1994)	Yes
Lake Michigan Mass Balance Study	1994–1995	bay-wide	7,000 sediment, water, tissue, and air samples	Yes
1994 GAS/SAIC Sediment Sampling	1994	De Pere to Green Bay	253 sediment samples	Yes
FRG 1996 Sediment and Tissue Sampling	1996, 1998	river-wide, bay-wide	Over 1,000 sediment, water and fish tissue samples	Yes
WDNR Fish Tissue Collection	1996	river-wide	20 fish tissue samples	Yes
WDNR Bird and Mammal Tissue Collection	1984–1996	river-wide	Bird and mink tissue	(1)
USFWS NRDA Fish Tissue Collection	1996	De Pere and Green Bay	376 fish tissue samples	Yes
USFWS NRDA Bird Tissue Collection	1993–1997	De Pere and Green Bay	193 cormorant tissue, 200 tree swallow tissue, 31 eagle samples	(1)
Fish Consumption Advisory Data	1971–1996	river-wide, bay-wide	Over 2,000 fish tissue samples	(1)
Lake Michigan Fish Consumption Advisory Data	1983–1999	Green Bay zones 3 & 4	434 fish tissue samples	(1)
Lake Michigan Tributary Study	1990?	river-wide	88 surface water samples	Yes
USGS National Water Quality Program	1992–1997	only 10% from LFR	441 samples of sediment, water, and tissue	(1)
RETEC RI/FS Data Collection	1998	river-wide	252 sediment and fish tissue samples	Yes
Deposit N Demonstration Project	1997–1999	Deposit N	Sediment, water, 25 caged fish	Yes
SMU 56/57 Demonstration Project	1998–1999	SMU 56/57	Sediment, water, caged fish	Yes

Source: Lower Fox River and Green Bay RI/FS Project Database. Database Management Report (EcoChem, 2000).

Table 2-5 Distribution of Existing Sediment, Water, and Tissue Data in the Lower Fox River and Green Bay over Time

Year	Number of Samples Analyzed for Total PCBs				QA Status		
	Sediment	Tissue (caged)	Tissue (resident)	Water	Validated	Supporting	Blank
1971			14			14	
1975			26			26	
1976			53			53	
1977			62			62	
1978			70			70	
1979			67			67	
1980			69			69	
1981			73			73	
1982			68			68	
1983			51			51	
1984			92			92	
1985			195			195	
1986			97			97	
1987	203		118			321	
1988	161		70			231	
1989	1,354		604	615		2,573	
1990	104		54	197		355	
1991			40			40	
1992	35		233	8	27	249	
1993	70		106	5	67	114	
1994	296		122	54	299	152	21
1995	484		87	40	484	109	18
1996	8		416		255	169	
1997	288		119		370	37	
1998	528	20	375	310	1,233		
1999	43	6	9	20	70	8	
TOTAL	**3,574**	**26**	**3,290**	**1,249**	**2,805**	**5,295**	**39**

8,139 Records

Summary of Data Query		
TOTAL RECORDS	453,394	
Total PCBs (lipid normalized)	80	(not used)
Total Aroclor	215	(not used)
"TOTAL PCBs" Query	9,710	used
YEAR = NONE	31	discarded
	9,679	
Locations outside of project area	1,540	discarded
Total # of samples in query	8,139	

Notes:

1 Resident caged tissue includes fathead minnows only.

2 Refer to the resident tissue worksheet tables for a breakdown of tissue types for the Lower Fox River and Green Bay.

3 The data query was for all samples collected over time for "total PCBs" analysis, and includes the sum of PCB congeners analyses.

4 The data query was limited to the four reaches of Lower Fox River and the four zones of Green Bay.

5 Samples without a year or location designation were eliminated from the data query.

6 The database does not have any air samples for total PCBs analysis.

7 Approximately 100 of the water samples collected in 1998 were from the Deposit N and SMU 56/57 demonstration project studies (during dredging).

Table 2-6 Distribution of Resident Tissue Samples over Time in the Lower Fox River

Year[3]	Fish												Birds					Mammals	Other
	Benthic Fish			Game Fish			Pelagic Fish			Trout			Raptors	Swallow	Upland Game Bird	Waterfowl		Fur Bearer	Insect/ Invertebrate
	No. of Samples	No. of Species	No. of Whole Fish Samples	No. of Samples	No. of Species	No. of Whole Fish Samples	No. of Samples	No. of Species	No. of Whole Fish Samples	No. of Samples	No. of Species	No. of Whole Fish Samples	No. of Samples	No. of Samples	No. of Samples	No. of Samples	No. of Species	No. of Samples	No. of Samples
1971	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1976	6	2	0	11	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1977	24	3	6	12	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0
1978	24	3	9	14	3	8	0	0	0	4	1	0	0	0	0	0	0	0	0
1979	12	3	8	16	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0
1980	36	4	11	25	5	9	1	1	1	0	0	0	0	0	0	0	0	0	0
1981	23	3	14	18	3	8	0	0	0	0	0	0	0	0	0	0	0	0	0
1982	28	3	5	24	6	3	2	1	0	0	0	0	0	0	0	0	0	0	0
1983	8	3	2	10	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	8	2	2	14	7	0	0	0	0	0	0	0	0	0	1	3	1	1	1
1985	15	3	0	35	4	0	0	0	0	0	0	0	1	0	0	12	1	0	0
1986	16	4	2	18	3	2	1	1	1	0	0	0	0	0	0	28	1	0	0
1987	34	5	1	43	7	1	1	1	1	0	0	0	0	0	0	22	1	0	0
1988	7	2	0	6	2	0	0	0	0	0	0	0	0	0	0	6	1	0	0
1989	42	3	24	38	1	26	20	2	20	0	0	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
1991	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	20	2	8	111	9	9	4	1	4	0	0	0	0	0	0	0	0	0	0
1993	15	1	15	0	0	0	0	0	0	0	0	0	0	51	0	0	0	0	1
1994	10	2	5	13	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
1996	109	6	84	185	7	34	13	3	13	0	0	0	0	0	0	0	0	0	0
1997	3	1	3	17	1	0	0	0	0	0	0	0	0	0	0	22	2	0	0
1998	93	4	48	198	7	59	17	3	17	0	0	0	0	0	0	0	0	0	10
1999	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Notes:

[1] No piscivorous birds were collected in the Lower Fox River.
[2] No cormorants were collected in the Lower Fox River.
[3] Samples included in the Lower Fox River and Green Bay RI/FS database.

Table 2-7 Distribution of Resident Tissue Samples over Time in Green Bay

Year[4]	Fish												Birds										Mammals		Other
	Benthic Fish			Game Fish			Pelagic Fish			Trout			Cormorant		Piscivorous Birds		Raptors	Swallow		Waterfowl		Deer	Fur Bearer		
	No. of Samples	No. of Species	No. of Whole Fish Samples	No. of Samples	No. of Species	No. of Whole Fish Samples	No. of Samples	No. of Species	No. of Whole Fish Samples	No. of Samples	No. of Species	No. of Whole Fish Samples	No. of Samples	No. of Species	No. of Samples	No. of Species	No. of Samples	No. of Samples	No. of Species	No. of Samples	No. of Species	No. of Samples	No. of Samples	No. of Samples
1971	0	0	0	0	0	0	0	0	0	14	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1975	7	1	0	18	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1976	15	3	0	20	8	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1977	5	2	0	21	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1978	7	2	1	9	2	2	7	3	1	5	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1979	8	4	8	17	4	9	9	3	9	5	3	5	0	0	0	0	0	0	0	0	0	0	0	0
1980	3	1	0	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1981	15	1	15	13	2	0	0	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1982	5	1	0	4	1	0	0	0	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1983	12	3	2	13	4	0	4	1	2	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	8	3	0	23	6	0	9	4	4	20	4	0	0	0	0	0	0	0	0	4	2	0	0	0
1985	0	0	0	3	2	0	4	3	3	125	5	0	0	0	0	0	0	0	0	0	0	0	0	0
1986	5	1	0	9	3	0	2	1	2	3	2	0	0	0	1	1	0	0	0	13	1	0	0	1
1987	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	16	3	1	0	0
1988	20	2	0	11	2	0	10	1	0	0	0	0	0	0	0	0	0	0	0	10	2	0	0	0
1989	166	1	77	101	2	66	169	3	169	68	3	39	0	0	0	0	0	0	0	0	0	0	0	0
1990	0	0	0	22	3	0	9	2	9	22	2	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	5	1	0	16	2	0	18	3	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	10	1	10	35	3	10	7	2	7	46	5	3	0	0	0	0	0	0	0	0	0	0	0	0
1993	6	2	4	0	0	0	2	1	2	16	2	0	0	0	0	0	0	15	1	0	0	0	0	0
1994	0	0	0	19	2	0	4	1	4	16	3	0	60	1	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	1	1	0	4	1	4	0	0	0	80	1	0	0	0	0	0	0	0	0	0	1
1996	0	0	0	60	3	24	0	0	0	29	4	19	0	0	15	2	0	0	0	5	1	0	0	0
1997	0	0	0	71	2	15	0	0	0	1	1	0	0	0	5	1	0	0	0	0	0	0	0	0
1998	12	2	12	32	4	22	8	2	8	0	0	0	0	0	0	0	0	0	0	2	1	0	0	3
1999	0	0	0	8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Notes:

1 No reptiles were collected in Green Bay.
2 No upland game birds were collected in Green Bay.
3 Date query included all samply body types. The number of whole samples included whole fish and whole fish composites for fish, and whole body for birds.
4 Samples included in the Lower Fox River and Green Bay RI/FS database.

[THIS PAGE LEFT INTENTIONALLY BLANK.]

3 Guidance Documents for the Development of Monitoring Programs

The primary goal of monitoring is to produce information that is useful in making management decisions. The creation of useful information depends on clear monitoring objectives and appropriate technical design. The goals and objectives established for a monitoring plan should be scientifically, technologically, logistically, and financially achievable and comparable to management parameters. To determine appropriate technical design for monitoring programs and to ensure adequate data collection, analysis, and interpretation for management-based decisions, a review of relevant regulatory and agency guidance documents was conducted.

Guidance documents reviewed fell into two categories: 1) research and panel-type discussions that identified general but important elements needed for a successful evaluation of remediation projects, and 2) detailed regional guidance documents that specifically recommend the quantity, types, and frequency of sampling parameters. The guidance documents reviewed included:

- EPA Guidance for Development of Fish Consumption Advisories;
- EPA Guidance for Conducting RI/FS Studies Under CERCLA;
- Great Lakes Protocol for Sport Fish Consumption Advisories;
- EPA ARCS Program Assessment Guidance Document; and
- OSWER Use of Monitored Natural Recovery at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites.

Since a comprehensive guidance document for designing and implementing a long-term monitoring program for contaminated sediments does not exist, these relevant guidance documents could be applied to the Lower Fox River and Green Bay remediation project.

3.1 EPA Guidance for Development of Fish Consumption Advisories

The EPA document titled *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories* (EPA, 1995), provides technical guidance to State and local agencies on methods for sampling and analyzing contaminants in fish and shellfish tissue that will promote consistency between data sets used to determine the need for fish consumption advisories. State agencies routinely conduct chemical contaminant analysis of fish and shellfish tissues as part of their comprehensive water quality monitoring programs. If states conclude that consumption of chemically contaminated fish and shellfish poses an unacceptable risk to human health via consumption, they may issue local fish consumption advisories or bans for specific fish species and water bodies. Although the document does not constitute regulatory requirements for the states, it was formulated to improve data consistency after inconsistencies were identified between 150 publications on seafood contamination. The primary shortcomings included: 1) analysis of nonedible portions of fish, 2) different reporting methods, and 3) lack of crucial information regarding percent lipid, fish size and weight, and contaminant concentrations.

A summary of the recommendations provided in the guidance document are listed below, many of which maybe helpful during the formulation of a long-term monitoring plan for the Lower Fox River and Green Bay RI/FS. The recommendations include:

- Target fish species should include at least one bottom feeder and one predator.

- Target species for Great Lakes waters should include a combination of species from the selected list of: white bass, smallmouth bass, walleye, common carp, white sucker, channel catfish, muskellunge, chinook salmon, lake trout, brown trout, or rainbow trout.

- For the bottom feeder target species, the recommended selection, whenever practical, is common carp, channel catfish, and white sucker, respectively.

- Samples should be collected from harvest areas that have a high probability of contamination.

- Samples should be collected during the legal harvest season when target species are most available to consumers.

- In fresh waters, as a general rule, the most desirable sampling period is from late summer to early fall (August through October). The lipid content of many species (which represent an important reservoir for organic pollutants) is generally highest at this time.

- Collect composite fillet samples for each target fish species (200 g). Individual organisms used in composite samples should be of similar size and collected at the same time. Use skin-on fillets (with belly flap) for scaled species and skin-off fillets for scaleless species. Use edible portions of shellfish. States may use individual fish samples or whole fish and other sample types if necessary to improve exposure estimates of local seafood-consuming populations.

- Samples should include three size classes of the target species. For cost effectiveness, if only one size class of a target species is collected, then the collection effort should focus on larger individuals commonly harvested by the local population.

- Replicate composite samples are recommended.

- For each target species, compare target analyte arithmetic mean concentrations or replicate composite samples with screening values.

- Sampling sites should be located near sites selected for water and sediment sampling for the possibility of correlating contaminant concentrations in different media.

- Each sample location should include: sample site name, water body name, type of water body, coordinates, scientific and common name of species, sampling date and time, sampling gear type used, sampling depth, number of individual organisms used in composite, predominant characteristics of specimens (sex, life stage, total length, body size), description of sample type (fillet, whole fish), total weight, percent lipid, analytical methods, and concentrations (for wet weight in grams).

If resources allow, states may wish to consider documenting external gross morphological conditions in fish from contaminated waters. Severely polluted aquatic habitats have been shown to produce a higher frequency of gross pathological disorders than similar less polluted habitats. Morphological conditions acceptable for use in monitoring programs include: fin erosion, skin ulcers, skeletal anomalies, and neoplasms (i.e., tumors).

3.2 EPA Guidance for Conducting RI/FS Studies Under CERCLA

In the EPA document titled *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA, 1988), monitoring for long-term effectiveness and permanence is discussed when evaluating alternatives and costing (EPA, 1998). The document does not propose regulations, but rather describes how existing statutory and regulatory authorities will be used by EPA to deal with contaminated sediment problems (Zar, 1995). The primary focus of the discussion is to evaluate the risk remaining at the site after response objectives have been met. Although specific elements required for a long-term monitoring plan were not stated, the guidance document included specific components that should be addressed for each alternative:

1. Magnitude of residual risk; and
2. Adequacy and reliability of controls.

The magnitude of residual risk should be analyzed by identifying the remaining sources of risks and how much of the risk is due to untreated residual contamination verses continued source inputs. The adequacy and reliability of controls should be analyzed by identifying the difficulties and uncertainties associated with long-term monitoring and maintenance, the degree of confidence that controls can adequately handle potential problems, and what operation and maintenance functions must be performed.

A summary of the recommendations provided in the guidance document that may be helpful during the formulation of a long-term monitoring plan for the Lower Fox River and Green Bay RI/FS study include:

- Calculate the magnitude of residual risk;

- Carefully consider the integrity of institutional controls and isolation mechanisms, and the amount of sampling that can be applied to each remedy over time without compromising function; and

- Carefully consider the need for source control monitoring.

3.3 Great Lakes Protocol for Fish Consumption Advisories

A Great Lakes Advisory Task Force was convened in the early 1990s to develop uniform protocols for developing Great Lakes fish consumption advisories. The resulting document was titled *Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory* (Anderson *et al.*, 1993) after realizing the need to develop a uniform procedure for sampling, analyzing, and listing of fish species on a state consumption advisory list. The states involved in the drafting committee included state regulators from Wisconsin, Michigan, and Minnesota. Details regarding the fish collection procedures, analyses, and recommended species were not reviewed. However, the 1998 Wisconsin Fish Contaminant Sample Collection Schedule list described in Section 2 represents ongoing fish sampling activities that are in general accordance with the recommendations of the Great Lakes Advisory Task Force.

The task force assumed that the health protection value developed for PCB concentrations in fish would in most instances account for the majority of potential risk from a mixture of chemicals present in fish. For areas where other contaminants are present but not predominant, the health protection value for PCBs would be protective even considering possible additive effects (Anderson *et al.*, 1993). The State of Wisconsin risk-based advisory for the Great Lakes and inland waters sets a "health protection" value for PCBs at 5.0×10^{-5} mg PCB/kg-bw-day. Fish under 0.05 ppm PCB have no consumption restrictions. The FDA's interstate commerce level for the protection of human health is set at 2.0 ppm PCB.

Based on our review of this document, recommendations for development of the Lower Fox River and Green Bay monitoring plan include:

- Use recommended fish species listed in the 1998 Wisconsin fish collection schedule for the protection of human health, and

- Focus our analyses of fish tissue samples on PCBs and mercury for the protection of human health.

3.4 EPA ARCS Program Guidance Document

The EPA document titled *Assessment and Remediation of Contaminated Sediments (ARCS) Program - Assessment Guidance Document* (EPA, 1994) describes types of monitoring elements (sediment chemistry, sediment toxicity, and benthic community structure) commonly used in the Great Lakes regions. The document provides guidance on procedures for assessing the nature and extent of sediment contamination as applied to areas in the Great Lakes region. It was prepared under the Assessment and Remediation of Contaminated Sediments (ARCS) Program, administered by the EPA GLNPO. Although the document does not represent enforcement measures for long-term monitoring requirements, it does provide a foundation of acceptable methods for monitoring and assessing the status and trends of a contaminated sediment site. Monitoring methods used by the ARCS program to determine the nature and extent of sediment contamination in the Great Lakes Areas of Concern (AOC) basically expanded on the sediment quality triad approach and included:

- Sediment chemistry,
- Sediment toxicity,

- Benthic invertebrate community structure, and
- Fish tumors and abnormalities.

General recommendations summarized in the ARCS document that may be applicable to the Lower Fox River and Green Bay RI/FS monitoring program include:

- Use several complimentary methods to assess sediment impacts to biological organisms rather than relying on a single monitoring parameter.

- If conclusions differ between many monitoring parameters, then the differences indicate a need for caution when interpreting the data. Unusual site-specific circumstances may be confounding a clear interpretation of the data.

- If sediment toxicity tests are used, then a minimum of two or three toxicity tests should be used with at least three measured responses (i.e., survival, growth, or reproduction).

- Benthic community structure analysis should be considered in addition to toxicity tests to provide an important compliment to laboratory tests because changes in benthic communities are likely the result of long-term exposures not adequately simulated in the laboratory.

- Surveys of liver lesions in bottom-dwelling fishes have been shown to provide valuable evidence of damage to resident organisms potentially resulting from exposure to contaminated sediments.

Although these recommendations are useful, they focus mostly on the assessment of sediment quality and environmental impacts to the benthic community and not on the risk to human health and fish health. Monitoring efforts will focus on fish, bird, and invertebrate tissue sampling to assess the bioaccumulation of contaminants in biological receptors, as opposed to sediment toxicity tests. Tissue monitoring, along with reproductive viability of birds and mammals, are appropriate methods for verifying achievement of the project RAOs.

3.5 EPA Use of Monitored Natural Attenuation

The EPA's Office of Solid Waste and Emergency Response (OSWER) produced a document titled *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites* (EPA, 1999b) describing the appropriateness of using monitored natural attenuation for the remediation of contaminated soil and groundwater at sites regulated under all OSWER programs. Although this guidance document is not explicitly intended for remediation of contaminated sediments, it will serve as a point of reference for natural attenuation considerations on the Lower Fox River and Green Bay since no other guidance documents currently exist. The purpose of this directive is to clarify EPA's policy regarding the use of monitored natural attenuation (MNA) and to provide technical guidance to the public and the regulated community on how EPA intends to exercise its discretion in implementing its regulations; however it is not a regulation itself.

The term "monitored natural attenuation" refers to the reliance on natural attenuation processes to achieve site-specific remediation objectives within a time frame that is reasonable compared to that offered by other more active remediation methods. These processes work to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater. These *in-situ* processes include: biodegradation, dispersion, dilution, sorption, volatilization, radioactive decay, and chemical or biological stabilization, transformation, or destruction of contaminants.

EPA generally expects that MNA will only be appropriate for sites that have a low potential for contaminant migration and that the use of MNA must be protective of human health and the environment. Performance monitoring for MNA is of even greater importance than other remedies due to the potentially longer remediation time frames, potential for ongoing contaminant migrations, and other uncertainties associated with using MNA. The frequency of monitoring should be adequate to detect, in a timely manner, potential changes in site conditions. At a minimum, the monitoring program should be sufficient to enable determination of the attenuation rate and how that rate is changing with time. The monitoring plan should allow flexibility in the sampling frequency over the life of the remedy to allow for changing conditions. When establishing contingency and/or action plans based on unacceptable monitoring results, care is needed to ensure that sampling variability or seasonal fluctuations do not unnecessarily trigger a contingency. Performance monitoring should continue until remediation objectives have been achieved and verified.

For the Lower Fox River and Green Bay RI/FS project, the term "monitored natural attenuation" will be referred to as "monitored natural recovery" or "MNR." A summary of the recommendations provided in the guidance document that may be helpful during the formulation of a long-term monitoring plan for the Lower Fox River and Green Bay RI/FS study follows:

- Monitored natural recovery should be considered for areas where there is adequate source control.
- MNR alternative should be able to compare upgradient and downgradient sampling results.
- Sampling strategy should allow for flexibility and adaptive management over time.

4 Recommendations and Selection of a Monitoring Plan Strategy

The National Research Council (NRC) reviewed numerous reports and monitoring programs related to the management of contaminated sediments. Based on their review, they developed a conceptual model for the design and implementation of monitoring programs and defined the role of monitoring in marine environmental management (NRC, 1990). Several evaluation parameters were identified to ensure development of an adequately designed monitoring program. These management factors were used as a screening process to select appropriate monitoring elements (i.e., sediment chemistry, fish tissue chemistry, surface water chemistry, benthic abundance) for the Lower Fox River and Green Bay RI/FS project. Recommendations put forth by other regulatory groups regarding the management of contaminated sediments and recommendations based upon our review of monitoring programs (Section 2) are also discussed below.

4.1 National Research Council Contaminated Sediment Monitoring Recommendations

The Marine Board of the National Research Council has examined issues pertaining to the effectiveness of marine environmental monitoring in several studies over the period of a decade. Recognizing the growing need for national guidance on how to improve these monitoring programs, the National Research Council convened the Committee on a Systems Assessment of Marine Environmental Monitoring under the auspices of the Marine Board. The committee was asked to evaluate and make recommendations to improve the usefulness of monitoring information as a component of sound environmental management, and identify needed improvements in monitoring strategies and practices (NRC, 1990).

According to the committee, effective monitoring programs depend on formulating clear goals and objectives, developing an effective technical design, and translating data into information that is relevant and accessible to decision makers and the interested public (Figure 4-1). The recommended parameters of an effective monitoring program are discussed below.

4.1.1 Formulation of Clear Goals and Objectives

The ultimate goal of monitoring is to produce information that is useful in making management decisions. The creation of useful information depends on clear monitoring objectives. In order to develop clear monitoring objectives, the relevant questions and hypotheses to be addressed in the monitoring program must first be clearly identified. These specific questions to be answered by the monitoring program should be designed to meet specific information needs, and the questions should be testable. In addition, the goals and objectives established for a monitoring program should be achievable scientifically, technologically, logistically, and financially.

4.1.2 Effective Technical Design

An appropriate technical design is critical to the success of monitoring programs because it provides the means for ensuring that data collection, analysis, and interpretation address the needs and objectives of management. The goal of a monitoring plan design should be the detection of specific kinds and amounts of changes that are meaningful with respect to the resources at risk. Meaningful change is often confused with significant change. Significant change often refers to change in terms of statistical differences. However, whether changes in the environment are statistically significant has no bearing on the extent to which the changes may be either meaningful or important, for example, in terms of ecological or human consequences. An effective technical program design should also identify and quantify the sources of variability that may obscure or confound responses. The technical program design should also identify which variables to measure, in light of logistical constraints and limitations on scientific knowledge. An important consideration for any monitored variable is that it should be tied directly to the specific questions to be answered and the resources at risk. Changes in the status of the variable must unambiguously reflect changes in the resources at risk. Finally, the technical program design should be capable of being modified as a result of monitoring results.

4.1.3 Translation of Data into Useful and Accessible Information

An effective monitoring program also depends on the translation of data into information that is relevant and accessible to decision makers and the interested public. The monitoring program should provide mechanisms to ensure that knowledge is used to convert data collected into useful information. Effective data management is an essential tool for achieving this task. In addition, clear guidance is required on how data are to be used and what type of decisions are to be made.

Many monitoring programs have proved to be ineffective because they devote too little attention to the above topics. The committee reached the following overall conclusion related to designing and implementing monitoring programs:

> "Failure to commit adequate resources of time, funding, and expertise to up-front program design and to the synthesis, interpretation and reporting of information will result in failure of the entire program" (NRC, 1990).

Without the above commitments, effort and money will be spent collecting data and producing information that may prove to be useless. Figure 4-1 presents a flow chart for designing and implementing a monitoring plan which includes many of the elements discussed above. These recommendations are used later in Section 4 during the monitoring element selection process for application to the Lower Fox River and Green Bay long-term monitoring plan.

4.2 EPA Contaminated Sediment Remediation Strategy Recommendations

One of the key points repeatedly referenced in the EPA document titled *EPA's Contaminated Sediment Remediation Strategy* (EPA, 1998) is the development of standardized protocols for monitoring and interpretation of aquatic systems. EPA believes that they need to develop an agency-wide strategy for coordinating and managing contaminated sediments. The Office of Water intends to use standardized sediment toxicity and bioaccumulation test methods for monitoring of narrative water quality standards and dredged material disposal testing. When appropriate, EPA program offices intend to develop and use sediment quality criteria to assess contaminated sediment sites.

As stated in the document, EPA will consider a range of risk management alternatives including monitored natural recovery. EPA plans to develop criteria for determining when natural recovery is an appropriate remedial alternative using rates of recovery of benthic communities under different environmental conditions and stresses. Factors influencing the recovery rates (i.e., community types, physical factors, types of stresses) will be evaluated. One of the major uncertainties in assessing the effects of sediment-associated contaminants is the ecological significance of bioaccumulated compounds. The EPA Office of Research and Development will continue research on the bioavailability and trophic transfer of contaminants in sediment to shellfish and higher trophic level aquatic species resulting in both lethal and sublethal effects.

In summary, EPA plans to use standard sediment toxicity, bioaccumulation tests, and site-specific field-based methods (i.e., ELIZA immunoassay testing) to identify potential sites for remediation, to assist in determining cleanup goals for contaminated sites, and to monitor the effectiveness of remedial actions. Although EPA did not state specific requirements for long-term monitoring of contaminated sediment remediation projects in the *EPA's Contaminated Sediment Management Strategy* document (EPA, 1998), their research and attention over the upcoming years will likely focus on monitoring of sediment toxicity, benthic community abundance, and bioaccumulation testing as their management strategy is implemented. These elements identified by EPA as important management tools for contaminated sediment projects will help the Fox River and Green Bay remediation project formulate a long-term monitoring plan that will be consistent with EPA's long-term management strategies.

4.3 Monitoring Plan Recommendations Extracted from National, Regional and State Programs

Based on our review of regional, national, and state monitoring programs in Section 2, our recommendations for the Lower Fox River and Green Bay long-term monitoring plan are summarized below:

- Focus on surface water quality and fish tissue sampling to verify protection of human health.

- Conduct surface sediment sampling in areas selected for monitored natural recovery to assess potential recontamination of these areas.

- Long-term biological monitoring to assess environmental health should focus on either: 1) sediment toxicity and benthic community structure; or 2) fish, bird, shellfish, and invertebrate tissue sampling to assess declines in COC concentrations in tissue. This monitoring plan will focus on fish, bird, and invertebrate tissue sampling for PCBs, mercury, and DDE.

- Build upon the existing Fox River and Green Bay database which consists primarily of fish tissue data (20 years), sediment chemistry (15 years), and surface water chemistry (11 years).

- Focus fish tissue sampling on species presented in the project food web model and species of concern for evaluating fish consumption advisories.

- Focus bird tissue sampling on species of interest that have demonstrated sensitivity to contaminant uptake and reduced reproductive success when exposed to contaminants in the food chain (i.e, bald eagles).

- Focus on bird species of concern for evaluating waterfowl consumption advisories (i.e., mallard duck).

- Do not conduct air monitoring as part of the long-term monitoring program. It does not directly relate to the project RAOs, but may be included during remedial design efforts to assess downstream transport of PCBs via volatilization and atmospheric deposition.

- Coordinate data management efforts with other regional monitoring programs to build a comprehensive multi-media database of the project area that is accessible and usable by multiple parties.

4.4 Consistency with the Lake Michigan Lake-wide Management Plan (LaMP)

The Lake Michigan LaMP was created under the auspices of the Great Lakes Water Quality Agreement between the United States and Canada to restore and protect the integrity of the Lake Michigan ecosystem through collaborative, placed-based partnerships. The document was initially created in 1993 by an EPA-directed committee comprised of local and state governments, national trustees, industry, environmental groups, fishers, academia, and native tribes. The plan is considered a working document that will be revised every 2 years based on new findings and public discussion. Lake Michigan has 10 designated AOCs that have contributed toxic contaminants to the Lake Michigan watershed and the degradation of aquatic life. These 10 AOCs, including the Lower Fox River, have been designated as top priority areas where ecosystem management of contaminants and stressors must occur.

Under this program, the Lake Michigan Monitoring Coordination Council was established to provide a forum for coordinating and supporting monitoring activities in the Lake Michigan basin and to develop a shared resource of information, based on accepted standards and protocols, that are usable across agency and jurisdictional boundaries (EPA, 2000a). This council is currently analyzing data collected from an inventory of monitoring programs in the Lake Michigan Basin to determine whether the current monitoring coverage is sufficient to support indicators proposed in the Lake Michigan LaMP. A summary of the proposed indicators are presented in Table 4-1 as they relate to the valued ecological endpoint criteria including: fish community structure and function, fish habitat, and exotic species. The table also lists the metrics to be measured, the parameters for measurement, and the objectives/expectations for each of the valued endpoints.

These endpoints were identified in the Lake Michigan LaMP as important long-term management goals for contaminated sediment projects contributing to the Lake Michigan receiving water body. These goals will help the Fox River and

Green Bay remediation project formulate a long-term monitoring plan that will be consistent with Lake Michigan's long-term management strategies.

4.5 Final Selection of Monitoring Plan Elements

Post-project monitoring plan elements commonly implemented on contaminated sediment management and remediation projects can be summarized into physical, chemical, and biological components including:

- Physical
  - Bathymetry and side-scan sonar surveys
  - Underwater video surveys
  - Sediment characteristics

- Chemical
  - Surface water and groundwater for chemical analyses
  - Suspended and bedded surface sediment for physical and chemical analyses
  - Subsurface sediment cores for chemical analyses
  - Air samples for chemical analysis (usually collected during implementation)

- Biological
  - Benthic biota population and community studies
  - Resident and caged fish tissue for chemical analyses
  - Resident fish observations for physical deformities and histopathology
  - Caged mussels for chemical analyses (usually collected during implementation)
  - Sediment and water column acute and chronic toxicity testing
  - Bird tissue and eggs for chemical analyses
  - Bird observations for physical deformities and sublethal effects
  - Fish tissue for enzymatic indicators
  - Plant assemblage and coverage
  - Plant tissue for chemical analyses

4.5.1 Selection Factors

the possible types of monitoring plan elements listed above, monitoring methods considered most valuable for: 1) documenting contaminant reduction changes in the Lower Fox River and Green Bay, and 2) measuring achievement of the project RAOs will be selected. Final selection of monitoring elements were screened using the five management factors put forth by the sediment systems review committee organized by the Marine Board of the National Research Council. Committee members were selected to ensure a wide range of expertise needed to include a broad spectrum of viewpoints (academic, industry, laboratories, and public agencies). The committee was asked to evaluate and make recommendations to improve the usefulness of monitoring information (NRC, 1990). The five management factors initially described by the National Research Council during their assessment of marine environmental monitoring programs (NRC, 1990) include:

- Simplicity and affordability,
- Comparability against regulatory standards or other significant criteria,
- Implementable and appropriate for the site,
- Social relevance or importance, and
- Ability to be understood by laymen.

In the NRC document titled *Managing Troubled Waters: The Role of Marine Environmental Monitoring*, these factors are loosely defined as fundamentals of a sound program design which are required for successful implementation. Simple refers to a program that is sufficiently flexible to allow for modifications when changes in conditions or new information suggests the need. Affordable refers to a program that has adequate resources not only for the data collection efforts, but allows for detailed analysis and evaluation over the long term. The monitoring program should integrate the regulatory, data, and management needs and responsibilities with the local, state, regional, and federal agencies to optimize use of available resources. Comparability refers to a program where the data gathered can have adequate management, synthesis, interpretation, and analysis. Adequate interpretation generally requires comparison to a regulatory or site-specific standard, reference data, or baseline conditions. The monitoring program should be integrated into the decision-making system, with the decision points and feedback loops clearly established before the data are collected (NRC, 1990).

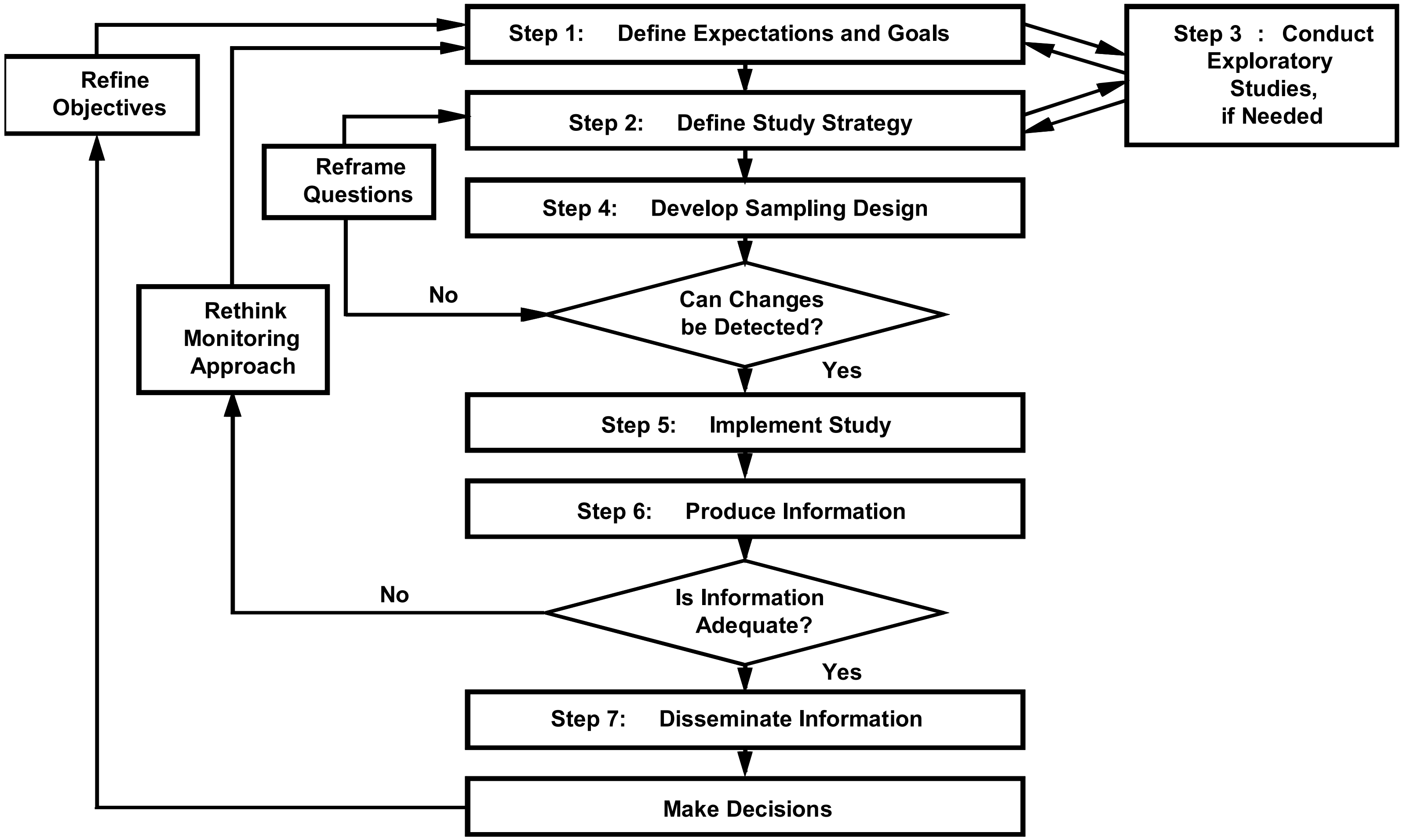
Implementability and appropriateness refers to a program in which the monitoring program can answer the questions being posed, a quality assurance program can be applied, and the data can be interpreted. The goals established should be achievable scientifically, technologically, logistically, and financially (NRC, 1990). Social relevance refers to a program in which the goals and objectives of the monitoring program can be clearly articulated in terms that pose questions that are meaningful to the public. The public generally understands fish tissue concentrations, and perhaps surface water concentrations. Most anglers and local residents want to know: "Can I eat the fish?" "Can I eat the birds?" and "Can I swim in the water?" Ability to be understood by laymen refers to a program where the information is made available to all interested parties in a form that is useful and meaningful to them. These generally include numerical and quantifiable data. Although these management factors are somewhat subjective without well-defined scales of measurement, they provide a useful and relative tool for comparison between different monitoring elements.

The monitoring elements retained after the screening process (compared to our five management factors) are presented in Table 4-2. Elements that met at least 50 percent of the valued factors criteria were retained for further consideration in the Lower Fox River monitoring plan. Surface and subsurface sediment chemistry along with resident fish tissue analyses were among the most commonly implemented measurement endpoints used in the majority of projects reviewed. In addition, these monitoring elements were often measured regardless of the type of remedy selected (removal, isolation, or natural recovery) ensuring their appropriateness to the Lower Fox River and Green Bay project, which will likely have a combination of selected alternatives. The final step in the selection process was to ensure that the retained monitoring elements were diverse in nature and output in order to verify achievement of (or progress towards) the project RAOs. As discussed in the following section, each one of the retained monitoring elements will be used to assess one or more of the project RAOs.

4.5.2 Results

The monitoring elements retained for the long-term monitoring plan (Table 4-2) include: surface water, surface sediment, fish tissue, bird tissue, bird reproductive assessment, and mammal reproductive assessment. Although the monitoring elements for mammals did not satisfy at least three factors (minimum needed for retainment), it was considered a significant data gap and a sensitive receptor identified in the project food web model. A few other monitoring elements, such as groundwater and sediment cores, will be utilized specifically for construction monitoring of engineered CDFs and sediment caps, and are not included in this long-term monitoring plan.

Figure 4-1 Flow Chart for Designing and Implementing a Monitoring Program



Source: *Managing Troubled Waters: The Role of Marine Environmental Monitoring* (NRC, 1990).

Table 4-1 Lake Michigan Lake-wide Management Plan (LaMP) Expectations

Ecological Criteria and Beneficial Use Impairments	Objectives/Expectations	Metrics to be Measured	Criteria for Measurement	Baseline Data	Status
Fish Community Structure and Function	To restore and maintain the biological integrity of the fish community so that production of desirable fish is sustainable and ecologically efficient.				
	Salmonines: Maintain a diverse salmonine community consisting of both wild and planted fish, and capable of sustaining an annual harvest of 6 to 15 million pounds, of which 20% to 25% is lake trout.	Standing stock (biomass) of salmonines.	A predicted standing stock of salmonines ranging from about 21 to 58 million pounds (Lake Michigan Salmonine Stocking Task Group, 1998, CONNECT model).	Based upon historical yields of native lake trout, a range in catch of about 5.7 to 7.3 million pounds annually is considered to be a minimum measure of the lake's capacity to yield salmonines; the theoretical maximum yield has been estimated at about 15.4 million pounds (*Fish Community Objectives for Lake Michigan*, Eshenroder *et al.*, 1995, GLFC).	Current standing stock biomass of salmonines is thought to be about 65 million pounds (Salmonine Stocking Task Group, 1998. CONNECT model).
	Establish self-sustaining lake trout populations.	Percentage of unmarked lake trout in assessment and sport catches.	The percentage of unmarked lake trout in assessment and sport catches is increasing towards 100% (all stocked lake trout are marked).	The percentage of unmarked lake trout in lake-wide assessment catches has ranged from 0% to 8.8% since the mid-1980s without an apparent trend.	No recruitment from natural reproduction is occurring and the lake trout population is comprised entirely of stocked fish.

Table 4-1 Lake Michigan Lake-wide Management Plan (LaMP) Expectations (Continued)

Ecological Criteria and Beneficial Use Impairments	Objectives/Expectations	Metrics to be Measured	Criteria for Measurement	Baseline Data	Status
Fish Community Structure and Function (Continued)	Enhance natural reproduction of coho and chinook salmon, and rainbow and brown trout.	Proportion of unmarked salmon and trout in assessment and sport catches (**a known portion of each species must be marked prior to release**).	Stable or increasing numbers of naturally-produced fish from each species.	Naturally-produced chinook comprised an estimated 32% of the 1990–1993 cohorts in Michigan waters; naturally-produced coho comprised an estimated 9.3% of the 1979 lake-wide sport catch; naturally-produced rainbow trout (steelhead) comprised 6% to 18% of annual smolt production in Michigan streams in the 1980s.	Coho and chinook salmon, rainbow and brown trout are naturally-reproducing in some watersheds tributary to the lake. The Michigan DNR has estimated that from 2.2 to 2.7 million chinook smolts have been produced annually in the 1990s as compared to 0.6 to 0.8 million in the 1970s (Salmonine Stocking Task Group, 1998).
	Planktivores: Maintain a diversity of prey species at population levels matched to primary production and to predator demands; expectations are for a lake-wide planktivore (alewife, smelt and bloater) biomass of 1.2 to 1.7 billion pounds.	Lake-wide biomass estimates of alewife, smelt and bloater.	Alewife, smelt and bloater in varying proportions constitute the bulk of the prey fish biomass; biomass size-spectrum models suggest that a total biomass of planktivores amounting to 1.2 to 1.7 billion pounds is a reasonable range for Lake Michigan (*Fish Community Objectives for Lake Michigan*, Eshenroder *et al.*, 1995, GLFC).	Lake-wide planktivore biomass estimates (portion of population available to bottom trawls) since 1973 have increased from 0.14 to 0.88 billion pounds as the dominant planktivore shifted from alewife to bloater (USGS-BRD); **catches in bottom trawls represent only a portion of prey fish biomass and will therefore always be lower than the actual biomass**.	The 1996 lake-wide planktivore biomass estimate was 0.65 billion pounds from bottom trawls (Note: studies are needed to understand how shifts in species composition affect biomass estimates, and the relationship between trawl catches and total biomass).

Table 4-1 Lake Michigan Lake-wide Management Plan (LaMP) Expectations (Continued)

Ecological Criteria and Beneficial Use Impairments	Objectives/Expectations	Metrics to be Measured	Criteria for Measurement	Baseline Data	Status
Fish Community Structure and Function (Continued)	Inshore Fishes: Maintain self-sustaining stocks of yellow perch, walleye, smallmouth bass, esocids, catfish and panfish; expected annual yields are 2 to 4 million pounds for yellow perch and 0.2 to 0.4 million pounds for walleye.	Indices of relative abundance (CPUE).	CPUEs for yellow perch and walleye capable of sustaining the expected ranges of annual yield have not been calculated and must be derived from lake-wide assessment data.	The Lake Michigan fishery management agencies are in the process of developing a lake-wide assessment plan which will include yellow perch and walleye, as well as other inshore species.	Self-sustaining populations of all these species exist, however, the relative abundance of yellow perch declined an estimated 90% in the southern portion of the lake from 1990 to 1996.
	Benthivores: Maintain self-sustaining stocks of whitefish, sturgeon, suckers and carp; expected annual yield of lake whitefish is 4 to 6 million pounds.	Indices of relative abundance (CPUE).	CPUEs for lake whitefish capable of sustaining the expected range of annual yield have not been calculated and must be derived from lake-wide assessment data.	The Lake Michigan fishery management agencies are in the process of developing a lake-wide assessment plan which will include lake whitefish, as well as other benthivores.	Self-sustaining populations of all these species exist, however, the lake sturgeon and longnose sucker are still listed as protected within the basin.
	Maintain a self-sustaining burbot population compatible with the rehabilitation and self-sustainability of lake trout.	Relative abundance indices (CPUE).	A ratio of relative abundance of lake trout to burbot at about 3.5:1 in the southern portion of the lake and 1:1 in the northern portion.	Historical catches of native lake trout and burbot in small mesh gill nets fished lake-wide for chubs by the vessel *Fulmar* (U.S. Bureau of Fisheries) in 1931–1932 suggest mean ratios of 3.5 lake trout per burbot in southern waters and a 1 to 1 ratio in northern waters.	Current ratios have not been available from annual stock assessments, but will be as the new lake-wide assessment plan is implemented; studies comparing the catchability of these two species are needed to evaluate th reliability of using the proposed ratios.

Table 4-1 Lake Michigan Lake-wide Management Plan (LaMP) Expectations (Continued)

Ecological Criteria and Beneficial Use Impairments	Objectives/Expectations	Metrics to be Measured	Criteria for Measurement	Baseline Data	Status
Fish Community Structure and Function (Continued)	Other Species: Protect and sustain a diverse community of native fishes including species such as cyprinids, gar, bowfin, brook trout, sculpins and others not previously mentioned.	Species richness.	A species is considered to be present in the lake if at least one individual (any life stage) is captured.	By 1970, five species of deepwater ciscoes had been extirpated from the lake as well as the paddlefish (*Fish Community Objectives for Lake Michigan*, Eshenroder *et al.*, 1995, GLFC); lake herring and emerald shiner populations also have never recovered to their historical levels of abundance.	A total of 92 species are known to occur in the lake proper, of which 75 are native and 13 are naturalized (*Fish Community Objectives for Lake Michigan*, Eshenroder *et al.*, 1995, GLFC).
	Sea Lamprey: Suppress the sea lamprey to allow the achievement of other fish community objectives.	Wounding rates on lake trout.	A lake-wide mean wounding rate not greater than 5 per 100 lake trout of all sizes.	The 1984–1996 mean wounding rate was 4 per 100 trout, but has generally been increasing since 1987 (*Sea Lamprey Wounding of Lake Trout in Lake Michigan*, Ebener, 1997, GLFC).	The lake-wide mean wounding rate was 5 per 100 lake trout in 1996.

Table 4-1 Lake Michigan Lake-wide Management Plan (LaMP) Expectations (Continued)

Ecological Criteria and Beneficial Use Impairments	Objectives/Expectations	Metrics to be Measured	Criteria for Measurement	Baseline Data	Status
Fish Habitat	Protect and enhance fish habitat and rehabilitate degraded habitats, including historic riverine spawning and nursery areas fo anadromous species.	Measure key features of the physical (substrate, water depth), chemical (dissolved oxygen, total phosphorus), and biological (vegetation) components of aquatic habitats.	A formal process such as the Classification and Inventory of Great Lakes Aquatic Habitats (CIGLAH) should be considered to classify and inventory habitats in the lake basin.	Inventories have been compiled on the general locations of many important fish spawning habitats in Lake Michigan (*Atlas of the Spawning and Nursery Areas of Great Lakes Fishes*, Vol. IV, Goodyear *et al.*, 1982, USFWS), but specific locations, habitat characteristics (e.g., chemical and biological features), and current status has not been addressed but for a few spawning shoals for lake trout.	The classification, location, and status of important fish habitats in Lake Michigan has not been addressed in a comprehensive fashion.

Table 4-1 Lake Michigan Lake-wide Management Plan (LaMP) Expectations (Continued)

Ecological Criteria and Beneficial Use Impairments	Objectives/Expectations	Metrics to be Measured	Criteria for Measurement	Baseline Data	Status
Exotic Species	Minimize the unintentional introduction of new exotic species and the spread of existing exotics that may negatively impact the structure and function of existing fish communities.	The appearance of new exotic species and the expansion in range (number of locations) of existing exotic species.	An exotic species is considered to be present in the lake or in a specific area if at least one individual of any life stage is captured.	Since the 1800s, some 136 non-indigenous aquatic organisms have become established in the Great Lakes (*Exotic Species in the Great Lakes: A History of Biotic Crises and Anthropogenic Introductions*, Mills *et al.*, 1991, GLFC); most of these have come from Europe (47%), the Atlantic Coast (18%), and Asia (14%), and the rate of introduction has increased as the rate of human activity has increased; more than one-third of the organisms have been introduced in the past 30 years, coincident with the opening of the St. Lawrence Seaway in 1959.	Although various ballast water and aquaculture control measures, and importation and possession bans (bait buckets, pet stores) have been implemented at the state, provincial and federal levels to address potential pathways for the unintentional introduction of exotic species, the appearance of new introductions and range expansion of existing exotics remains a constant threat, and a vigilant watch must be kept throughout Lake Michigan.

Table 4-1 Lake Michigan Lake-wide Management Plan (LaMP) Expectations (Continued)

Chapter 2	Chapter 3		Chapter 4 Lake Michigan LaMP: Current Status of the Ecosystem,	Chapter 5 Lake Michigan Stressor Sources and Loads	Chapter 6	
Lake Michigan LaMP: Vision, Goals and Ecosystem Objectives	**Indicators and Monitoring of the Health of the Lake Michigan Ecosystem**				**Strategic Action Agenda: Next Steps**	
Endpoint Goal	**Monitoring**	**Human Activity**			**Means to an End Goal**	**Recom-mendations**
1. We can all eat any fish.	• Chemical contamination in fish • Site assessments • Eagle reproduction	• Fish advisories • Congressional reports on ‣ Great Water ‣ Mercury ‣ Dioxin				
2. We can all drink the water.	• Raw water quality data • Source water assessments	• Water utility notifications • Source water protection				
3. We can all swim in the water.	• E Coli levels in recreational water	• Beach closing advisories • State 305(b) WQ reports				
4. All habitats are healthy, naturally diverse and sufficient to sustain viable biological communities.	• Fish assessments • Bird counts • Wetlands inventories and assessments • Stream flows • Eco-rich area assessments	• Endangered species list • Wetland mitigation and protection • Zoning • Fish stocking • Fish refuges • USFWS refuges • Ballast water exchange • Dune protection • Eco-rich cluster map				
5. Public access to open space, shoreline and natural areas is abundant and provides enhanced opportunities for human interaction with the Lake Michigan ecosystem, aquatic habitat and biological population.	• Urban density • Coastal parks acreage • Conservation easements	• Open space funding and protection statutes • Coastal zone management				
6. Land use, recreation and economic activities are sustainable and support a healthy ecosystem.	• Contaminants in recreational fish • Sustainable forests • Land conversion	• Superfund cleanups dredging • CRP percent of eligible farm lands • Brownfields to greenfields redevelopment				

Table 4-2 Selection of Monitoring Program Elements Using Five Management Factors

Monitoring Element	Management Factors [4]					Retain
	Simple and Affordable	Comparable to Standards	Appropriate to Site	Socially Important	Clear to Layman	
Surface Water	Yes	Yes	Yes	Yes	Yes	Yes
Groundwater [1]	Yes	Yes	Unknown	No	Yes	Yes [1]
Surface Sediment	Yes	Yes	Yes	No	Yes	Yes
Sediment Cores [2]	Yes	Yes	Yes	No	Yes	Yes [2]
Benthic Abundance	Yes	No	No	No	No	No
Fish Tissue	Yes	Yes	Yes	Yes	Yes	Yes
Fish Deformity	Yes	No	No	No	Yes	No
Toxicity Test	Yes	Yes	Yes	No	No	No
Bird Tissue	No	Yes	Yes	Yes	Yes	Yes
Bird Deformity	No	No	No	No	Yes	No
Bird Reproductive Assessment	Yes	No	Yes	No	Yes	Yes
Mammal Tissue	No	No	Yes	Yes	No	No
Mammal Reproductive Assessment	Yes	No	Yes	No	No	No [3]
Habitat Assessment	Yes	No	Yes	No	No	Yes [3]
Enzyme Test	Yes	No	NA	No	No	No
Plant Assemblage	No	No	No	No	No	No
Plant Tissue	Yes	No	Yes	No	No	No

Notes:

1 Groundwater will be monitored in areas where CDFs are installed.

2 Sediment cores will be advanced in areas where sediment caps are placed.

3 Retained for the long-term monitoring plan for mink because it is a significant data gap and a valued receptor.

4 Management factors derived from NRC 1990 document *Managing Troubled Waters: The Role of Marine Environmental Monitoring*.

[THIS PAGE LEFT INTENTIONALLY BLANK.]

5 Model Long-term Monitoring Plan for the Lower Fox River and Green Bay

This section presents the proposed model long-term monitoring plan for the Lower Fox River and Green Bay RI/FS remediation project. The focus of this document was to design a post-project, long-term monitoring plan based on project expectations, valued endpoints, a review of national and regional monitoring programs, case study precedent, lessons learned, guidance documents, and scientifically-based recommendations. The plan was formulated around achievement of the five RAOs listed in the Lower Fox River and Green Bay feasibility study. A summary of the monitoring plan elements selected for verification of long-term RAOs (RAO-1 through RAO-4) are presented in Table 5-1. RAO-5 is not included in this model plan. Table 5-2 presents a summary of the monitoring elements proposed for long-term monitoring.

In sequential order, this section: 1) summarizes the long-term project RAOs and their associated expectations, 2) discusses the timing and onset of long-term monitoring between different reaches and zones, and 3) presents the monitoring elements (surface water chemistry, sediment chemistry, fish tissue, bird tissue, invertebrate tissue, and reproductive assessments) that will be used to verify achievement of the long-term RAOs. Sampling methods for each monitoring element are described in some detail regarding the frequency, number of samples, location, species selection, and chemical analyses.

5.1 Plan Overview

5.1.1 Defining the Remedial Action Objectives and Expectations

As described in the previous chapters, this long-term monitoring plan is designed to verify achievement of the project RAOs and to monitor the integrity of the physical, chemical, and biological components of the aquatic system. The five RAOs defined for the Lower Fox River and Green Bay project can be translated into expectations and viable measurement endpoints that lay the groundwork for developing a long-term monitoring plan. The project expectations that correlate to the defined RAOs for the Lower Fox River and Green Bay include:

RAO	Expectation	Lower Fox River	Green Bay
Surface Water Quality	Reduction in contaminant concentrations in suspended sediments and surface water	✓	✓
Human Health	Reduction in contaminant concentrations in fish and waterfowl consumed by humans	✓	✓
Health of Environment	Reduction in contaminant concentrations in fish, piscivorous birds, benthos, and mammals	✓	✓
Sediment Transport	Reduction in contaminant loading to Green Bay		✓
Minimize Contaminant Releases	Maintain low contaminant concentrations in surface water during active remediation (short-term)	✓	✓

More specifically, project expectations include the following:

- Remediation will be completed within 10 years;
- Surface water quality will eventually meet background conditions;
- The removal of sport fish consumption advisories will be achieved within 10 years after remediation (in 20 years);
- The removal of all fish consumption advisories within 20 years after remediation (in 40 years);
- The removal of all waterfowl consumption advisories within 20 years after remediation (in 40 years).
- Resident bird populations will achieve sustainable reproductive viability when compared to reference sites;
- Resident fish, bird, and invertebrate populations will achieve safe levels of contaminants in tissue determined by risk-based models and state/federal criteria;
- Annual mass loading of contaminants from the Lower Fox River to Green Bay will not exceed the annual non-point source loading of PCBs and mercury to Green Bay and subsequent loading to Lake Michigan; and

- The plan should be compatible with other regional program objectives, and compliment the long-term goals of the Lake Michigan LaMP. A detailed design of the long-term monitoring program is presented in Table 5-2.

Most of the project RAOs (RAO-1 through RAO-4) address long-term goals that may require 20 to 40 years to achieve. This long-term monitoring plan was designed to address these RAOs. The RAO concerning "minimizing contaminant releases during active remediation" (RAO-5) is a short-term goal to be utilized during active remediation. This long-term monitoring plan does not address this short-term goal. Short-term goals will be used to confirm and verify success of an implemented active remedy, and will be important components of a well-defined remedial action plan for the Lower Fox River and Green Bay project. Short-term monitoring components will be discussed during development of a final remedial action plan and will likely include many elements discussed below.

5.1.2 Initiation of Long-term Monitoring

Long-term monitoring will begin after completion of an active remedy (removal or isolation) or after an area has been designated for monitored natural recovery instead of active remediation. Long-term monitoring is defined as sampling events that begin after post-project completion of a remedy or decision not to remediate. However, sampling data collected during a long-term monitoring program needs to be testable and comparable to pre-remedy conditions. In order to assess the spatial and temporal trends in contaminant concentrations, an adequate baseline data set should be developed. Therefore, the pre-remedy sampling event and the post-project verification sampling event should follow the same technical design as the long-term monitoring plan. Pre-remedy sampling is conducted to verify initial conditions immediately prior to remedy implementation. Post-project verification sampling is conducted to verify achievement of the remedy. While both of these monitoring plans may have a different scope and objectives than a long-term monitoring plan, they will serve as the baseline data set for subsequent long-term monitoring events. They should have, at a minimum, the same monitoring elements proposed in this long-term model. In areas designated for MNR, a pre-remedial baseline sampling event will be conducted for long-term monitoring comparisons. In summary, the baseline data set will be collected prior to initiation of active remediation (or initiation of MNR) and immediately after completion of a remedy for comparison with long-term monitoring elements.

For example, if the Appleton to Little Rapids Reach of the Lower Fox River has 10 years of active remediation planned, then long-term monitoring for that reach will not begin until after final completion of the remedy. If a deposit of contaminated sediment within that reach (identified in the FS) will not be remediated, then long-term monitoring of natural recovery for that deposit may begin at Time 0 while other deposits within the same reach are being remediated. The entire reach will not begin long-term monitoring for another 10 years, after completion of all active remediation within the reach. The extent of sampling within the reach will need to be coordinated within a reasonable effort, scope, and budget to ensure that contaminated deposits remaining in-place are not serving as new sources of recontamination and not contributing to contaminant transport to newly remediated areas.

For a second example, if Green Bay is monitored for natural recovery, then long-term monitoring for these areas begins at Time 0 although the Lower Fox River may undergo active remediation in some areas. The technical design of the river monitoring (during remediation) should be comparable to the bay monitoring over the same time period.

5.1.3 Scales of Measurement

Based on the complexity and duration of the proposed remediation plan for the Lower Fox River and Green Bay, the examples described above reinforce the need for defining different levels of monitoring. For the purposes of this project, three levels of monitoring are defined:

- **"Deposit-wide" Scale -** monitoring around a specific deposit, CAD site, nearshore fill, disposal site, or other physical feature generally confined to within a reach;

- **"Reach-wide" Scale -** holistic monitoring of a reach, generally at the end of a reach to measure transport of contaminants to the next reach, or for fish with home ranges spanning an entire reach; and

- **"River-wide" Scale -** monitoring of the Lower Fox River or Green Bay to compare differences between the river and bay system.

Most of the monitoring elements proposed in this plan are on the reach-wide scale. However, some of these elements may be considered river-wide or bay-wide (i.e., bald eagles or mink habitat) depending upon the final monitoring design. Elements may also be considered on a deposit-wide scale if active remedies are implemented at different times within a reach or if a unique physical feature warrants more detailed attention.

5.1.4 Limitations

The focus of this monitoring plan will be on verification of the valued endpoints and not on continued correlation analysis between physical and chemical components of the Lower Fox River system and observed effects. For example, one valued endpoint is protection of human health via consumption of resident fish in the Lower Fox River, so the monitoring plan will include fish tissue measurements of consumable fish species to verify protection of human health. The plan does not intend to use indicator variables such as sediment chemistry or water chemistry to imply protection of human health. Also, the plan does not intend to further develop a correlation analysis between sediment chemistry and fish tissue concentrations. However, sediments samples will be collected at specified intervals within each reach to assess sediment transport concerns and may be used to verify protection of pathway exposures to resident fish.

5.2 Monitoring Plan Approach

This proposed monitoring plan is designed to verify achievement of (or progress towards) attainment of the long-term project goals summarized as the RAOs. The proposed monitoring plan is organized into measurable physical, chemical, and biological elements that are used to assess the spatial and temporal trends towards these long-term goals. Monitoring plan elements include surface sediment chemistry; surface water chemistry; fish, bird, and invertebrate tissue analyses; and bird and mammal population counts (Tables 5-1 and 5-2). For FS cost estimates, all monitoring elements will be conducted for a period of 40 years, with sampling frequencies of every 5 years. Sampling frequencies and media may change after selection of the final remedy.

These elements are listed as a model framework of sampling methods for long-term monitoring on the Fox River and Green Bay, but are not intended to comprise detailed sampling and analysis design components. Specific management factors such as sample sizes, number of replicates, locations and chemical analysis will be finalized after completion of the RI/FS report and selection of environmental remedies.

Statistical models will be used to determine the appropriate sample sizes based on the desired power of detection (alpha and beta) and the confidence limits surrounding the data results (change of Type I and II errors). However, eight or nine fish samples will be expected per reach/zone. The sampling plan will be designed to minimize the influence of confounding factors and sampling variability as much as possible.

5.2.1 Monitoring for Surface Water Quality

Monitoring elements used to verify long-term achievement of surface water quality will consist of surface water samples collected from fixed locations over time. Collection of surface water samples at sediment remediation sites were used at several site-specific projects including United Heckathorn, Lake Jarnsjön, Minamata Bay, and James River, Virginia.

Surface water sampling will be conducted on a "reach-wide" scale at seven locations: one station in each river reach (4 locations), two stations in Green Bay—zones 2 and 3B (2 locations), and one station in Lake Winnebago. Water samples will be collected near the end of a reach or at fixed locations in a lake over time, to assess the net contribution of contaminated sediments located along each reach to the overlying surface water. The sampling frequency is modeled after the sampling scheme conducted for the Green Bay Mass Balance Study.

For the Green Bay Mass Balance Study, samples were collected intensively at numerous stations over a 1-year period (1989 and again in 1994) to quantify the maximum PCB mass loading during periods of maximum flow events. Since higher mass loading is expected during storm and rainfall events when river flow is highest, the sampling events were structured at monthly intervals during the wet season to predict flow variability and at daily intervals (as needed) during storm events to capture the highest possible PCB loading events. The 1-year sampling events were conducted every 5 years.

The focus of the Lower Fox River/Green Bay monitoring plan will be to assess temporal changes in surface water quality as opposed to horizontal and vertical spatial heterogeneity. Prior to long-term monitoring, pre-remedial and post-remedial baseline sampling will be conducted. Samples will be collected at designated intervals from March through November every 10 years. Several samples will be collected from within each reach/zone at fixed locations over time. Additional samples will be collected during periods of maximum flow events to capture the highest possible PCB-mass loading estimates. Samples will be analyzed for PCB congeners, co-planar PCB congeners, mercury, TSS, DOC and TOC for particulate and dissolved fractions (Table 5-2). Sample concentrations will be compared to project water quality criteria designed to be protective of human health (ingestion and dermal contact).

5.2.2 Monitoring for Protection of Human Health

Monitoring elements used to verify long-term achievement of "reduced potential for chemicals to cause adverse effects to human health" as stated in the Lower Fox River and Green Bay FS will consist of fish tissue sampling from specific reaches over time. Similar methods are described and/or recommended in regional monitoring programs (NOAA NS&T, SF-Bay Estuary and GLNP) and guidance documents, and were used on several Great Lakes projects (Sheboygan River, Waukegan Harbor, Grasse River, Ford Outfall, Collingwood Harbour) and other national and international projects (Bayou Bonfouca, GM Foundry, River Emån, Minamata Bay).

Fish Tissue Sampling

Fish tissue sampling will be conducted on a "reach-wide" scale within each reach of the Lower Fox River (4 regions) and within each zone of Green Bay (4 regions) to assess the uptake of contaminants into fish tissue. The reach-wide scale is appropriate since fish generally have large home ranges, the exact location of fish feeding grounds cannot be determined, and the reaches are separated by dams limiting the fish ranges. The focus will be to assess changes in fish bioaccumulation uptake within each reach over time. The long-term goal of the sampling program will be to support the removal of Wisconsin and Michigan state general fish consumption advisories currently in-place for numerous fish species (EPA, 2000d), assuming fish tissue concentrations show reduced PCB and mercury levels over time.

Resident fish samples will be collected in pre-remedial and post-remedial baseline sampling events, and every 5 years thereafter, after initiation of the long-term monitoring program. These will be concurrent with the surface water sampling years. At the 10-year mark, the sampling plan will be reevaluated based on the data collected. Fish species collected in the Lower Fox River will include resident walleye, carp, and white bass alewife. Discrete whole fish and skin-on-fillet samples will be analyzed for PCB congeners[1], mercury, and lipids. Fish species collected in Green Bay will include walleye, carp, lake trout, white perch, and white bass for the same analyses. The sampling design will include consistent seasonal sampling events, species, sizes, and age classes of fish to the best practicable extent. Three size classes of fish per fish species will be specified.

Bird Tissue Sampling

Bird tissue sampling will be conducted on a "reach-wide" scale within each zone of Green Bay (5 regions including Zone 1) to assess the uptake of contaminants into bird tissue. The reach-wide scale is appropriate since birds generally have large home ranges and the exact location of feeding grounds cannot be determined. The focus will be to assess temporal changes in bird chemical body burdens within each zone. The long-term goal of the sampling program will be to support the removal of the Wisconsin state waterfowl consumption advisory

[1] PCB congeners include the Wisconsin State Laboratory PCB Congener List as well as co-planar dioxin-like PCB congeners.

currently in-place for mallard ducks, if bird tissue concentrations show reduced PCB levels over time.

Resident mallard duck samples and one other sensitive bird species (i.e., coots or mergansers) will be collected in pre-remedial and post-remedial baseline sampling events and every 5 years thereafter, after initiation of the long-term monitoring program and will be concurrent with surface water sampling events. At the 10-year mark, the sampling plan will be reevaluated based on the data collected. Samples will be analyzed for PCB congeners, mercury, and lipids. The sampling design will include consistent seasonal sampling events, species, sizes, and age classes of waterfowl to the best practicable extent. A minimum of one size class per bird species will be specified.

5.2.3 Monitoring for Protection of Environmental Health

Monitoring elements used to verify long-term achievement of environmental health defined as "the reduced potential for chemicals to cause adverse effects to environmental receptors," will consist of resident fish, invertebrate, and bird tissue sampling over time. Monitoring elements will also include reproductive observations such as number of nesting sites, number of eggs, and population counts for bird and mammal populations. Similar fish tissue monitoring methods were used in several national monitoring programs (NOAA NS&T, EMAP and GLNP) and on several Great Lakes projects (Sheboygan River, Waukegan Harbor, Grasse River, Ford Outfall, and Collingwood Harbour). Invertebrate mussel tissue monitoring was used in two regional monitoring programs (San Francisco-EP and EMAP). However, long-term bird tissue monitoring, bird population nor mammal population monitoring have not been documented in any regional, national, or site-specific monitoring programs reviewed.

Frequency of sample collection for all media will include pre-remedial and post-remedial baseline sampling events, and every 2 to 5 years for 10 years thereafter, after initiation of the long-term monitoring plan. At the 10-year mark, the sampling plan will be reevaluated based on the data collected. Sampling events will be concurrent with surface water sampling years. The final selection of sampling media and frequency will be revised after selection of the remedy and project expectations. For the purposes of the FS cost estimate, monitoring elements were sampled every 5 years for 40 years.

Fish Tissue Sampling

Fish tissue sampling will be conducted on a "reach-wide" scale. Samples will be collected for each river reach (4 regions) and each zone of Green Bay (4 regions—zones 2, 3A, 3B, and 4) to assess the bioaccumulation of contaminants in resident fish. The focus will be to assess temporal changes in contaminant uptake over time and spatial variability between reaches and zones. The long-term goal of the sampling program will be to verify if resident fish tissue concentrations are below screening levels determined to be protective of sublethal fish effects such as growth, health, and reproductive potential.

Resident fish samples will be collected in pre-remedial and post-remedial baseline sampling events, and every 5 years thereafter, after initiation of the long-term monitoring program and will be concurrent with the surface water sampling years. Resident fish species collected in the Lower Fox River and Green Bay will include: walleye, carp, perch, emerald shiners, gizzard shad, and alewife. Discrete, adult, whole fish samples will be analyzed for PCB congeners, mercury, DDE and lipids, except shiners and shad will be collected as composites. Young-of-the-year fish samples will also be collected for walleye and gizzard shad as 25-fish composites. The sampling design will include consistent seasonal sampling events, species, sizes, and age classes of fish to the best practicable extent. The length, weight, and sex of each fish will be recorded during collection. A minimum of one size class will be specified per fish species.

Invertebrate Tissue Sampling

Invertebrate tissue sampling will be conducted on a "reach-wide" scale. Samples will be collected from each river reach (4 regions) and each zone of Green Bay (4 regions) to assess the bioaccumulation of contaminants in resident zebra mussels and/or caged mussels. The focus will be to assess temporal changes in contaminant uptake from fixed locations over time and spatial variability between reaches and zones. The long-term goal of the sampling program will be to determine the rate of decline in PCB concentrations to sessile invertebrate organisms.

Resident zebra mussel samples or caged mussel samples will be collected in pre-remedial and post-remedial baseline sampling events and every 5 years thereafter, after initiation of the long-term monitoring program, and will be concurrent with the surface water sampling years. Resident whole body composite samples will be analyzed for PCB congeners, mercury, DDE and lipids. Statistical models will be used to determine the appropriate samples sizes, however, a minimum of seven composite samples will be expected per reach/zone for a total of 70 samples per sampling year. The size, location, and weight of each sample will be recorded during collection.

Although an extensive zebra mussel data set does not exist for the Lower Fox River and only one year of sampling has been conducted in Green Bay, zebra mussels will serve as a good indicator of PCB bioaccumulation potential for benthic organisms with small home ranges. Zebra mussels were specifically selected because they are relatively large with adequate tissue volume for analysis, they are found in all reaches of the Lower Fox River and Green Bay, they are easy to collect, and they readily uptake PCB contaminants after exposure. Caged mussels would also serve as valuable indicators of PCB exposure and uptake with minimal interference from the inherent site variability often associated with resident species.

Piscivorous Bird Tissue Sampling

Bird tissue sampling will be conducted on a "reach-wide" scale. Piscivorous bird tissue samples will be collected from each zone of Green Bay (5 regions—zones 1, 2, 3A, 3B, and 4) to assess changes in contaminant exposure and uptake by resident double-crested cormorants from fixed areas over time. The focus will be to assess temporal changes in contaminant uptake from fixed locations over time and spatial variability between reaches and zones. The long-term goal of the sampling program will be to verify if resident bird populations exhibit reduced exposure from site contaminants. Resident double-crested cormorants will serve as surrogate indicators of PCB exposure and uptake over time. However, they will not serve as good indicators of residual risk to other sensitive bird species (i.e., Forster's terns) since current populations are rapidly recovering and reproductive rates are not correlated to PCB levels (Custer *et al.*, 1999).

Bird tissue samples will be collected in pre-remedial and post-remedial baseline sampling events and every 5 years thereafter, after initiation of the long-term monitoring program and will be concurrent with the surface water sampling years. Discrete resident whole body samples will be analyzed for PCB congeners, mercury, DDE, and lipids.

Bald Eagle Tissue Sampling

Raptor egg and blood plasma sampling will be conducted on a "river-wide" scale. Samples will be collected from two sites along the Lower Fox River (2 locations) and two sites along the shores of Green Bay (2 locations) to assess the bioaccumulation of contaminants in resident bald eagles. The focus will be to assess temporal changes in contaminant uptake from fixed locations over time and spatial variability between the river and bay. The long-term goal of the sampling program will be to verify if the resident populations are at risk from PCB uptake. The location and number of sampling sites will be dependent upon field observations and the stability of the population, and may vary between sampling events. Sampling will be consistent with the previous work performed by Dykstra and Meyer (1996).

Bald eagle samples will be collected every 5 years after initiation of the long-term monitoring program and will be concurrent with surface water sampling years, if possible. Whole body egg and blood plasma samples will be analyzed for PCB congeners, mercury, and DDE. If possible, two or three field replicates per nest will be collected. In addition to whole body chemical analyses, a population assessment will be conducted during field collection events. This data will build upon the existing bald eagle tissue already recorded in the Fox River database and will be a continuation of WDNR sampling programs.

Bird Reproductive Assessment Monitoring

Nesting counts will be conducted on a "bay-wide" scale for double-crested cormorants and a "river-wide" scale for bald eagles during collection of tissue data. The focus will be to assess temporal changes in reproductive viability and population stability from fixed locations over time. The long-term goal of the sampling program will be to verify if the resident populations are increasing/declining. At each sampling station, the number of occupied/unoccupied nests and the number of eggs per nest will be recorded. Population counts will be collected every 5 years, concurrent with the tissue collection events. These data sets will build upon the existing double-crested cormorant and bald eagle data already recorded in the Fox River database and will be a continuation of WDNR sampling programs.

Mammal Habitat Evaluation

Mammal population assessments will be conducted on a "reach-wide" scale. The assessment will be conducted from multiple sites along the shores of Lower Fox River and Green Bay to assess the presence/absence of mink or river otter populations in the project area. Mink are predatory, semiaquatic mammals generally associated with stream and river banks, lake shores, and freshwater marshes (USFWS, 1986). Mink are known to readily bioaccumulate PCBs via consumption of fish, their main dietary staple. The focus will be to establish baseline conditions and assess temporal changes in population sustainability from fixed locations over time and spatial variability between the river and bay. A future long-term goal of the sampling program may be to verify if the resident populations are present in the project area after habitat suitability has been determined. The location and number of sampling sites will be dependent upon field observations and the site access, and may vary between sampling events.

Mink habitat assessments will be conducted every 5 years after initiation of the long-term monitoring within each river reach. The USFWS habitat suitability index model for mink (USFWS, 1986) will be used to: 1) first determine where suitable habitats exist along the shoreline of the Lower Fox River and Green Bay, then 2) observe each suitable habitat for presence/absence of mink populations.

5.2.4 Monitoring for Sediment Transport

Monitoring elements used to verify long-term achievement of "reduced potential for future transport of PCBs from the Lower Fox River to Green Bay" as defined in the Lower Fox River FS will consist primarily of water column sampling, surface sediment sampling, and bathymetry over time. Similar monitoring methods were used on almost every site-specific sediment remediation project reviewed, and many of the regional monitoring programs.

Water Column Sampling

Surface water column sampling will be conducted on a "reach-wide" scale in a combined effort with verification of surface water quality. The sampling frequency and technical design is modeled after the Green Bay Mass Balance Study. These samples will also serve as useful indicators of potential downstream transport of contaminants and mass-loading estimates.

Surface Sediment Sampling

Surface sediment sampling (0 to 10 cm) will be conducted on a "reach-wide" scale to primarily assess the potential downstream transport of contaminants to areas without active remediation. Areas selected for passive remediation will be monitored over time for attenuation, diffusion, dispersion, or burial of contaminants and are referred to as monitored natural recovery (MNR) areas. Sampling locations will be placed at fixed locations in depositional areas and will include six locations per river reach (24 locations) and six locations per zone in Green Bay—zones 2, 3A, 3B, and 4 (24 locations). The focus of this monitoring effort will be to verify that physical processes are decreasing the levels of PCBs, DDE and mercury in surface sediments over time via sediment burial, and chemical recovery.

Sediment samples will be collected every other year for the first 10 years following a baseline sampling event, and will coincide with surface water sampling years. At the 10-year mark, the sampling plan will be reevaluated based on the data collected. Sediment (0 to 10 cm) will be collected as discrete samples and submitted for physical (grain size and TOC) and chemical testing (PCB congeners, DDE, and mercury).

Bathymetry

Bathymetric soundings will be conducted every 3 to 5 years for the first 10 years. At the 10-year mark, the sampling plan will be reevaluated based on the data collected. This effort will compliment the USACE annual assessment of shoaling in the navigational channels of De Pere to Green Bay Reach and Green Bay Zone 2. Survey locations will include transects running perpendicular and parallel to shoreline and include a bisect of the Lower Fox River from one shoreline to the other. Survey locations will include areas of active remediation in addition to areas designated as MNR to assess potential scouring events that may inadvertently cause significant resuspension and downstream transport of residual contaminants in the surface and subsurface sediments.

5.2.5 Monitoring for Potential Contaminant Releases During Active Remediation

Potential releases of contaminants during active remediation (project RAO 5) is a short-term goal that will be covered during development of deposit-specific and/or reach-specific remediation and monitoring plans. An adequate verification sampling program will be developed as part of each selected remedy to verify the implementability and success of a selected remedial action. These programs will likely include many of the same monitoring elements selected for the long-term monitoring program. However, this long-term monitoring plan is not designed or intended to address contaminant releases during remediation.

Table 5-1 A Summary of Monitoring Elements for Verification of Project RAOs

Remedial Action Objective Lower Fox River and Green Bay	Proposed Monitoring Program Elements Used to Determine Verification of RAOs							
	Physical	Chemical [1]		Biological				
	Bathymetry	Surface Water	Surface Sediment	Fish Tissue	Invertebrate Tissue	Bird Tissue or Eggs	Bird Nest Counts	Mink Counts
1 Achieve, to the extent practicable, **surface water quality** throughout the Lower Fox River and Green Bay.		◆						
2 Protect **humans** who consume fish from exposure to COCs that exceed protective levels.				◆		◆		
3 Protect **ecological receptors** from exposure to COCs above protective levels.		◆	◆	◆	◆	◆	◆	◆
4 Reduce **transport of PCBs** from the Lower Fox River into Green Bay and Lake Michigan.[2]	◆	◆	◆					
5 Minimize the downstream movement of PCBs during implementation of the remedy.[3]	◆	◆	◆					

Notes:

[1] Sediment traps and air sampling stations were not included in the chemical list because they are not proposed monitoring elements in the long-term monitoring plan.

[2] The long-term monitoring plan does not discuss nor include verification of isolation and source control of sediment caps, CADs, and CDFs.

[3] RAO 5 is not included in the long-term

Table 5-2 Proposed Long-term Monitoring Plan for the Lower Fox River and Green Bay

RAO	Monitoring Element	Sample Type	Location [4, 5]	Frequency	Years with Historical Data	Expected Duration Over Time [2]	Analyses [3, 6]
Surface Water Quality (RAO 1)	Water column [1]	Depth composite sample through water column; fixed locations over time.	One station at end of each reach in LFR (4 stations), two stations in Green Bay - zones 2 and 3B (2 stations), and one station in Lake Winnebago (1 station) to quantify input loads.	Intensive sampling every 10 years with numerous samples collected over the year from each reach/zone. Collect most samples from March through November, with additional samples (up to 10) during periods of max flow events (approx. N = 20 per reach).	1989/1990 1994/1995	40 years	PCB congeners, coplanar congener PCBs, mercury, TSS, DOC, TOC; particulate and dissolved fractions.
Human Health (RAO 2)	Fish tissue (in LFR)	Resident whole fish and skin-on-fillet for walleye, carp, and white bass. Discrete samples.	Collect discrete samples from each reach. Rely on statistical models to determine sample sizes (approx. N = 8 per reach).	Every 5 years and concurrent with water sampling years.	1976–1998	40 years	PCB congeners, mercury, lipids
	Fish tissue (in Green Bay)	Resident whole fish and skin-on-fillet for walleye, carp, lake trout, white perch, and white bass. Discrete samples.	Collect discrete samples from each zone (zone 2, 3A, 3B and 4). Rely on statistical models to determine sample sizes (approx. N = 8 per zone).	Every 5 years and concurrent with water sampling years.	1976–1998	40 years	PCB congeners, mercury, lipids
	Waterfowl bird tissue	Resident whole body and breast for mallard ducks and one other bottom-feeding duck species (mergansers). Discrete samples.	Collect discrete samples from each zone. Rely on statistical models to determine sample sizes (approx. N = 8).	Every 5 years and concurrent with water sampling years.	1987	40 years	PCB congeners, mercury
Environment Health (RAO 3)	Fish tissue	Whole body for food web model fish (walleye, carp, emerald shiners, gizzard shad, alewife). Discrete samples except YOY. Collect YOY (for walleye and gizzard shad) as 25 fish composites.	Collect discrete samples from each reach and each zone (zones 2, 3A, 3B, and 4). Rely on statistical models to determine samples sizes (approx. N = 8).	Every 5 years and concurrent with water sampling years.	1976–1998	40 years	PCB congeners, mercury, DDE, lipids

Table 5-2 Proposed Long-term Monitoring Plan for the Lower Fox River and Green Bay (Continued)

RAO	Monitoring Element	Sample Type	Location [4, 5]	Frequency	Years with Historical Data	Expected Duration Over Time [2]	Analyses [3, 6]
Environment Health (RAO 3) (Continued)	Invertebrate tissue (benthos)	Whole body composites of zebra mussels. Fixed nearshore locations over time.	Collect samples from each reach near the dams (end of reach) and each Green Bay zone. When possible, co-locate near water sample locations (approx. N = 8 composites).	Every 5 years and concurrent with water sampling years.	1987/1988 Green Bay only	40 years	PCB congeners, mercury, DDE
	Bird tissue - piscivorous	Resident whole body common terns. Fixed locations over time.	Collect samples from Green Bay - zones 1, 2, 3A, 3B, and 4. Sample 2 to 3 nest sites (approx. N = 10 per nest site).	Every 5 years and concurrent with water sampling years	1986, 1996, 1997	40 years	PCB congeners, mercury, DDE, lipids
	Bird tissue-bald eagles	Collect eggs and blood plasma.	Collect from 2 sites along the LFR and 2 sites from Green Bay. If possible, three samples per site.	Every 5 years and concurrent with water sampling years.	Limited: 1985, 1987, 1990	40 years	PCB congeners, mercury, DDE
	Birds - reproductive assessment	Resident terns. Collect nest counts and egg counts per nest.	Collect samples from Green Bay - zones 1, 2, 3A, 3B, and 4.	Every 5 years concurrent with bird tissue sampling years	unknown	40 years	Compare to reference areas
	Birds - reproductive assessment for raptors	Resident bald eagles. Collect occupied nest counts, egg counts per nest, YOY counts per nest.	Collect from 2 sites along the LFR and 2 sites from Green Bay. If possible, three samples per site.	Every 5 years and concurrent with bird tissue sampling years.	unknown	40 years	Compare to reference areas
	Mammal reproductive assessment	Observational survey along shoreline of river and bay.	Collect data from multiple sites along river and bay in areas with suitable habitat.	Every other year for 10 years.	unknown	40 years	Compare to previous years

Table 5-2 Proposed Long-term Monitoring Plan for the Lower Fox River and Green Bay (Continued)

RAO	Monitoring Element	Sample Type	Location [4, 5]	Frequency	Years with Historical Data	Expected Duration Over Time [2]	Analyses [3, 6]
Contaminant Transport (RAO 4)	Surface sediment	0 to 10 cm discrete surface grabs at fixed stations over time.	Collect from 6 fixed locations per reach and per zone (Green Bay zones 2, 3A, 3B, and 4). Stations will be located in depositional areas.	Every 10 years and concurrent with water sampling years.	1987–1999	40 years	PCB congeners, mercury, DDE, grain size and TOC
	Bathymetry	Echo soundings.	Multiple transects per reach and zone and include nearshore areas.	Every 3 years for 10 years.	many	40 years	Compare to previous years
	Water column	Discussed under RAO 1.					
Releases During Remediation (RAO 5)	As appropriate [1]	Not included in the long-term monitoring plan.					

Notes:

[1] An adequate confimration/verification sampling program with physical, chemical, and biological elements will be in-place prior to initiation of the long-term program to verify implementation of an active remedy. Sediment, tissue, and water data will be collected during active remediation to supplement the baseline data set.
[2] Duration includes 10 years during before and during remediation for baseline, 10 years until angler fish consumption, and 20 years for general fish consumption.
[3] Use consistent sampling methods over time. For fish, sample same time of year. Include physical data about fish: size, length, weight, sex, and age of fish.
[4] The four reaches of the Lower Fox River include Little Lake Butte des Morts, Appleton to Little Rapids, Little Rapids to De Pere, and De Pere to Green Bay (also Zone 1). The four zones of Green Bay include 2, 3A, 3B, and 4.
[5] Most monitoring parameters will also include a background/reference station for comparison with Lower Fox River and Green Bay sampling station data.
[6] PCB congeners include Wisconsin State Laboratory PCB Congener List and coplanar dioxin-like PCB congeners.

[THIS PAGE LEFT INTENTIONALLY BLANK.]

6 References

Anderson, H. A., J. F. Amhrein, P. Shubat, and J. Hesse, 1993. Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory. Great Lakes Fish Advisory Task Force Protocol Drafting Committee. Wisconsin, Minnesota, and Michigan Departments of Health. September.

Amhrein, 2000. Personal communication with James Amhrein, fish biologist of Wisconsin Department of Natural Resources, conducted by Anne Fitzpatrick of ThermoRetec. June 30.

Custer, T. W., C. M. Custer, R. K. Hines, S. Gutreuter, K. L. Stromberg, P. D. Allen, and M. J. Melancon, 1999. Organochlorine contaminants and reproductive success of double-crested cormorants from Green Bay, Wisconsin, USA. *Environ. Tox. and Chem.* 18:1207–1217.

Day, 2000. Personal communication with Bob Day of Michigan Department of Environmental Quality-Surface Water Quality Division regarding fish sampling for fish consumption advisories. Conducted by Anne Fitzpatrick of ThermoRetec. May 18.

Dykstra, C. J. R. and M. W. Meyer, 1996. Effects of Contaminants on Reproduction of Bald Eagles on Green Bay, Lake Michigan. Prepared by U.S. Fish and Wildlife Service and Wisconsin Department of Natural Resources. February.

EcoChem, 2000. Draft Data Management Summary Report for the Lower Fox River RI/FS Project. Prepared for Wisconsin Department of Natural Resources. May 24.

Ecology, 2000. Puget Sound Ambient Monitoring Program (PSAMP). Washington State Department of Ecology. Website: http://www.wa.gov/ecology/eils/mar_sed/msm_intro.html.

EPA, 1988. *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA.* United States Environmental Protection Agency. Interim Final. EPA/540/G-89/004. October.

EPA, 1994. *Assessment and Remediation of Contaminated Sediments (ARCS) Program - Assessment Guidance Document.* U.S. Environmental Protection Agency Great Lakes National Program Office. EPA 905-B94-002. August.

EPA, 1995. *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume 1: Fish Sampling and Analysis.* Second edition. U.S. Environmental Protection Agency Office of Science and Technology and Office of Water. EPA-823-R-95-007. September.

EPA, 1998. *EPA's Contaminated Sediment Management Strategy.* U.S. Environmental Protection Agency Office of Water. EPA-823-R-98-001. April.

EPA, 1999a. *Introduction to Contaminated Sediments.* U.S. Environmental Protection Agency, Office of Science and Technology. EPA-823-F-99-006. September.

EPA, 1999b. *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites.* U.S. Environmental Protection Agency Office of Solid Waste and Emergency Response. Final Directive 9200.4-17P. EPA-540-R-99-009. April 21.

EPA, 2000a. Lake Michigan Lake Wide Management Plan (LaMP). Website: http://www/epa/gov/grtlakes/lakemich. Last updated April 2000.

EPA, 2000b. Great Lakes National Program Office (GLNPO). Website: http://www.epa.gov/glnpo/monitoring.

EPA, 2000c. Environmental Monitoring and Assessment Program. Website: http://www.epa.gov/emap/.

EPA, 2000d. U.S. Environmental Protection Agency Fish Consumption Advisories. Website: http://www.epa.gov/ceisweb1/ceishome/atlas/bioindicators/fishasindicators.htm.

Krantzberg, G., J. Hartig, L. Maynard, K. Burch, and C. Ancheta, 1999. *Deciding When to Intervene - Data Interpretation Tools for Making Sediment Management Decisions Beyond Source Control.* Sediment Priority Action Committee Great Lakes Water Quality Control Board. Report to the International Joint Commission. ISBN 1-894280-07-5. August.

MDEQ, 1999. *Michigan Fish Contaminant Monitoring Program 1999 Annual Report.* Michigan Department of Environmental Quality-Surface Water Quality Division. MI/DEQ/SWQ-99/164.

MDEQ, 2000. Michigan State Department of Environmental Quality Fish Consumption Advisory Listing. Website: http://www/mdch/state/mi/us/pha/fish/Charts/Michigan2.htm.

National Estuary Program, 2000. San Francisco Bay Estuary Program. National Estuary Program. Website: http://www.abag.ca.gov/bayarea/sfep/.

NOAA, 2000. NOAA National Status and Trends Program (NS&T). Website: http://ccmaserve.nos.noaa.gov/NSandT/New_NSandT.html.

NRC, 1990. *Managing Troubled Waters: The Role of Marine Environmental Monitoring.* Committee on a Systems Assessment of Marine Environmental Monitoring, Marine Board, Commission on Engineering and Technical Systems, National Research Council. National Academy Press, Washington, D.C. 125 p.

Peterson, 2000. Personal communication between ThermoRetec and Todd Peterson, wildlife section chief with Wisconsin DNR. June 30.

Stratus, 1999. Injuries to Avian Resources, Lower Fox River/Green Bay Natural Resource Damage Assessment Final Report. Prepared for the U.S. Fish and Wildlife Service. May 7.

ThermoRetec, 2000a. Draft Remedial Investigation: Lower Fox River, Wisconsin. Prepared for Wisconsin Department of Natural Resources. February.

ThermoRetec, 2000b. Draft Baseline Human Health and Ecological Risk Assessment: Lower Fox River, Wisconsin. Prepared for the Wisconsin Department of Natural Resources. February 24.

ThermoRetec, 2000c. Draft Feasibility Study: Lower Fox River, Wisconsin. Prepared for the Wisconsin Department of Natural Resources. February.

USACE, 1992. *Dredged Material Management Program.* U.S. Army Corps of Engineers, New England Division. Report NEDEP-360-1-21. May.

USFWS, 1986. *Habitat Suitability Index Models: Mink.* Revised. U.S. Fish and Wildlife Service. Biological Report 82(10.127). November.

WDNR, 2000. Wisconsin State Fish Consumption Advisory Listing 2000. Website: http://www.dnr.state.wi.us/org/water/fhp/fish/advisories/index.htm.

WDNR, 2000. Annual Hunting Pamphlet. Waterfowl Consumption Advisory Listing 2000.

Zar, H., 1995. Regulatory strategies for remediation of contaminated sediments. *Dredging, Remediation, and Containment of Contaminated Sediments.* ASTM STP 1293. K. R. Demars, G. N. Richardson, R. N. Yong, and R. C. Chaney, Eds. American Society of Testing and Materials, Philadelphia. p. 319–328.

Zarull, M. A., J. H. Hartzig, and L. Maynard, 1999. Sediment Priority Action Committee. Ecological Benefits of Contaminated Sediment Remediation in the Great Lakes Basin. Great Lakes Water Quality Board. Report to the International Joint Commission.

Attachment 1

Summary of Regional and National Monitoring Programs

Contaminated Sediment Monitoring Programs – Review of Monitoring Methods

Project Name: Disposal Area Monitoring System (DAMOS)

Location: New York, Connecticut, Rhode Island, Maine

Management Issues: Monitoring at open water disposal sites.

Water Body Type: Marine

Period of Performance: 1977 to Present

Background:
Dredged materials from numerous industrialized harbors in New England were placed in offshore subaqueous disposal sites between Long Island Sound and Maine. The contaminated material was subsequently capped with cleaner material. The New England district of the U.S. Army Corps of Engineers created the Disposal Area Monitoring System (DAMOS) in 1977. The DAMOS program was established to ensure disposal of dredged material had no adverse effect on the environment.

Project Goals and Objectives:
The DAMOS monitoring program was implemented to ensure the physical integrity and stability of disposal mounds, to measure the impacts to bottom organisms around the disposal mounds during placement and subsequent recolonization success, and to measure the effectiveness of capping in isolating disposed contaminated sediments (USACE, 1992).

Long-Term Monitoring:
Monitoring under the DAMOS program followed a tiered approach, under which techniques in the higher tiers were used only when monitoring results of lower tiers indicate the need for further monitoring. Although the schedule varied greatly depending on time and location, sampling generally occurred annually with additional sampling conducted after major storm events. Samples were routinely collected at reference sites to provide comparison with background results.

> *Physical:* High-resolution bathymetric surveys have been included in all monitoring surveys conducted under the DAMOS program. Additional physical monitoring included physical sediment description, grain size analysis, and sediment volume determinations made using diver surveys, and after 1982, the REMOTS® sediment-profiling camera.
>
> *Chemical:* Chemical monitoring was limited to routine analyses of surface sediments to assess contaminant levels (USACE, 1995). Sediments were collected using a 0.1-m^2 Smith-McIntyre mechanical grab sampler. Subsamples were collected with plastic core liners measuring approximately 6.5 cm in diameter by 10 cm in length. Occasionally, divers collected sediment samples for chemical analysis directly in plastic core liners.
>
> *Biological:* The biological component of the monitoring program has varied with respect to time and disposal site. Biological monitoring conducted under the DAMOS program included benthic infauna observations at all monitoring sites. Benthic infauna studies were conducted on surface grab samples obtained with a 0.1-m^2 Smith-McIntyre sampler. Samples were sieved through a 1.0-mm sieve and macrofauna were sorted, identified, and counted to measure community structure. Since 1982, the benthic community has been assessed using sediment profile imaging with the REMOTS® camera. In areas where monitoring demonstrated a decline in biological quality, the tiered approach triggered additional monitoring. Additional monitoring analyses

included measurements of bioaccumulation in caged mussels and resident worms (*Nephtys incisa*), and sediment amphipod toxicity tests.

Project Outcome:
Monitoring results obtained in the DAMOS program have not shown any evidence of physical or chemical breaching of capped areas. Physical data collection has shown that the sand caps are stable. Chemical data have shown the cap is effective in isolating contaminants, and biological measurements have demonstrated recolonization of the capped areas and the absence of toxicity.

Project Contact:
Marine Analysis Section
U.S. Army Corps of Engineers
New England District
696 Virginia Road
Concord, Massachusetts 01742-2751
(978) 318-8338

References:
USACE, 1995. Sediment Capping of Subaqueous Dredged Material Disposal Mounds: An Overview of the New England Experience, 1979-1993. U.S. Army Corps of Engineers, New England Division. Report No. SAIC-90/7573&C84. August.

USACE, 1992. Dredged Material Management Program. U.S. Army Corps of Engineers, New England Division. Report NEDEP-360-1-21. May.

Project Name: Environmental Monitoring & Assessment Program (EMAP)

Location: National

Management Issues: Condition of ecological resources.

Water Body: Estuarine

Period of Performance: Ongoing from 1984 to Present

Background:
The Environmental Monitoring and Assessment Program (EMAP) is an EPA research program used to develop the tools necessary to monitor and assess the status and trends of national ecological resources. EMAP's goal is to develop the scientific understanding for translating environmental monitoring data from multiple spatial and temporal scales into assessments of ecological condition and forecasts of future risks to the sustainability of our natural resources. EMAP's research supports the National Environmental Monitoring Initiative of the Committee on Environment and Natural Resources (CENR).

Project Goals and Objectives:
EMAP objectives are to advance the science of ecological monitoring and ecological risk assessment, guide national monitoring with improved scientific understanding of ecosystem integrity and dynamics, and demonstrate the CENR framework through large regional projects. EMAP will develop and demonstrate indicators to monitor the condition of ecological resources, and investigate multi-tier designs that address the acquisition and analysis of multi-scale data including aggregation across tiers and natural resources (EPA, 2000).

Long-Term Monitoring:
EMAP's sampling scheme consists of systematic, random, and fixed location sampling elements. Large, continuously distributed estuaries are sampled using a randomly placed systematic grid, with grid points about 18 km apart. Large tidal rivers are sampled along systematically spaced lateral transects. Transects are located about 25 km apart. Two sampling points are located on each transect, one randomly selected, and one using scientific judgement to identify sampling locations that may be indicative of degraded conditions in the system. Small estuaries are sampled by partitioning them in groups of four, selecting one estuary randomly from each group of four, and sampling at two stations in each small estuary selected. EMAP operates on a 4-year sampling cycle, with one-fourth of the sites in a region sampled each year. Sampling is undertaken only during the months of July and August (EPA, 1995). Monitoring elements selected for a project are site-specific but likely include the following physical, chemical and biological parameters:

> *Physical:* Monitoring data collected for physical parameters includes sediment grain size and water quality vertical profile data.
>
> *Chemical:* Sediment samples are analyzed for chemical parameters of concern in a project area.
>
> *Biological:* Biological monitoring is conducted on the benthic community, fish, invertebrates, and demersal trawl samples. Analyses include species abundance, community data, tissue chemistry, length data by taxa, and community abundance.

Project Outcome:
EMAP's Estuaries Group assessed the status and trends on the condition of the nation's estuaries extending from low to high tide elevations. In addition to coastal embayments, bays, inland waterways, and tidal rivers, the Estuaries Group also monitored coastal wetland areas and salt-water marshes. Monitoring and assessment activities were conducted jointly by the USEPA and the National Oceanic and Atmospheric Administration (NOAA). Monitoring results were not specified.

Project Contact:
None available

References:

EPA, 2000. Environmental Monitoring and Assessment Program. U.S. Environmental Protection Agency. Last updated April 27, 2000. Website. http://www.epa.gov/emap/.

EPA, 1995. Office of Water. NEP Monitoring Guidance. U.S. Environmental Protection Agency. Last updated September 15, 1995. Website. http://www.epa.gov/OWOW/estuaries/guidance/nmg43.html

EPA, 1997. Environmental Monitoring and Assessment Program (EMAP) Research Strategy. U.S. Environmental Protection Agency, Office of Research and Development. EPA/620/R-98/001. October.

Project Name: Great Lakes National Program

Location: Chicago, Illinois

Management Issues: Restore and preserve ecological resources in the Great Lakes and protect human health in accordance with the Great Lakes Water Quality Agreement between U.S. and Canada.

Water Body Type: Lacustrine

Period of Performance: 1972 to Present

Background:
The Great Lakes National Program Office (GLNPO) was created in 1978 to coordinate the U.S. response to the Great Lakes Water Quality Agreement with Canada mandated by the Clean Water Act. The GLNPO, located in Chicago, Illinois, is made up of scientists, engineers, and other professionals. The GLNPO works with EPA, Environment Canada, Ontario Provincial government, International Joint Commission, and other agencies to achieve specific environmental goals through coordinated activities. Surveillance and monitoring began in 1972 under the Great Lakes Water Quality Agreement between the United States and Canada to identify problems and to measure progress in solving problems. A new Great Lakes Water Quality Agreement was signed in 1978, continuing the basic features of the previous agreement. Biannual surveillance and monitoring are continuing to the present.

Project Goals and Objectives:
The Great Lakes Water Quality Agreement with Canada, signed in 1972 established the environmental goals to restore the chemical, physical, and biological of the Great Lakes, achieve healthy plant, fish, and wildlife populations, and to protect human health. After assessing risks to the Great Lakes ecosystem the following objectives were established:

- Reduction of the level of toxic substances in the Great lakes and the surrounding habitat, with an emphasis on persistent toxic substances, so that all organisms are adequately protected and the substances are virtually eliminated from the Great Lakes Ecosystem.

- Protection and restoration of habitats vital for the support of healthy and diverse communities of plants, fish, and wildlife, with an emphasis on interjurisdictional fish and wildlife habitats, wetland habitats, and those habitats needed by threatened and endangered species.

- Protection of human and non-human health by restoring and maintaining stable, diverse, and self-sustaining populations of fish and other aquatic organisms, wildlife, and plants.

Long-Term Monitoring:
Surveys are completed biannually from the R/V Lake Guardian. Samples are taken from eight to 20 stations in each lake.

Physical: Standard sampling locations were tested for conductivity, temperature, and depth. In some locations additional visual surveys were conducted by divers, a remotely operated vehicle, or a submersible probe.

Chemical: Surface water samples were collected with vertical water samplers and a rosette water sampler and analyzed for chemical contaminants. Sediment samples were collected with a box corer, vibracore, or Mudpuppy. Contaminants of concern analyzed in water and sediment samples included mercury, PCBs, and pesticides.

Biological: Plankton and zooplankton samples were collected with plankton nets. Fish samples were collected to assess populations and contaminant concentrations. A number of fish species were collected including Coho salmon, bloater chub, and lake trout. A benthic invertebrate sampling program was initiated for Great Lakes in 1997. Sampling is conducted annually at a minimum of 45 stations.

Project Outcome:
Significant advances have been made to eliminate pollutant sources and contaminant concentrations in the Great Lakes since the Great Lakes Nation Program Office was established. The organization continues to coordinate efforts between numerous agencies and the public.

Project Contact:
Glenn Warren
U.S. Environmental Protection Agency
Great Lakes National Program Office (G-17J)
77 West Jackson Boulevard
Chicago, Illinois 60604-3590
(312) 886-2405

References:
EPA, 2000a. Protecting the Great Lakes, A Joint Federal/State 5-Year Strategy (1992-1997). U.S. Environmental Protection Agency. April 1992 Draft. Website. http://www.epa.gov/glnpo/plans/5yrstrat.html.

EPA, 2000b. United States Great Lakes Program Report on the Great Lakes Water Quality Agreement. U.S. Environmental Protection Agency. Last Revised February 3, 1998. Website. http://www.epa.gov/glnpo/glwqa/usreport.

Sea Grant, 2000. Glossary of the Great Lakes. Last updated October 13, 1998. Website. http://www.d.umn.edu/seagr/pubs/GGL/G.html.

Project Name: National Status and Trends Program

Location: National

Management Issues: The program was established to measure the effect of human activities on coastal and estuarine waters.

Water Body Type: Estuarine and Marine

Period of Performance: National Benthic Surveillance Project from 1984 to present; Mussel Watch Project from 1986 to 1992

Background:
The National Status and Trends (NS&T) Program is administered by the National Oceanic and Atmospheric Administration (NOAA). The NS&T program was initiated in response to the need to gather information of the effect of human activities on environmental quality of coastal and estuarine areas. In October 1983, marine scientists from government, academia, and the private sector met to discuss the feasibility of a nationwide monitoring program. The workshop developed a list of contaminants of concern which have a demonstrated health risk, have been released into the environment in significant quantities, have long half-lives, and have a high potential for bioaccumulation. The NS&T sampling program was initiated in 1984 and continues to collect information from United States estuarine and coastal waters to date.

Project Goals and Objectives:
The NS&T program was developed to determine the status and trend of changes in the environmental quality of estuarine and coastal waters of the United States. In 1987, the program was expanded to measure the biological effects due to contaminant exposure (NOAA, 2000a).

Long-Term Monitoring:
Monitoring included in the NS&T program is divided into the National Benthic Surveillance Project (NBSP) and the Mussel Watch Project (MWP). The NBSP is responsible for quantification of contamination in fish tissue and sediment, and for developing and implementing new methods to define the biological significance of environmental contamination. The MWP monitors contaminant concentrations by quantifying chemicals in bivalve mollusks and sediments. These two subprograms are described below.

Physical: No physical monitoring parameters were included in these programs.

Chemical: Sediment samples were collected for both the NBSP and the MWP. Sediment samples were collected concurrently with fish samples at each NBSP site. Samples of the top 3 cm of sediment were collected using a specially constructed box corer or a Smith-MacIntyre grab sampler. At MWP sites, sediment samples of the top 1 cm of sediment were collected from three locations and composited. Samples were collected using a Kynar-coated Young-modified Van Veen grab sampler, stainless steel box-cores, or Kynar-coated scoops. Sediment samples for both programs were analyzed for organic and metal contaminants. Organic contaminants included PAHs, PCBs, and chlorinated pesticides.

Biological: Fish tissue samples were collected for the NBSP from 1984 to 1993 (unknown if fish samples are still being collected). Fish were usually collected with otter trawls, although hook and line or gill nets were occasionally used. Samples were collected from three stations at each

2-km diameter NBSP site. A number of different benthic fish were collected including flatfish at least 15 cm in length and roundfishes at least 12.5 cm in length. Tissues analyzed in the NBSP program included liver, muscle, and stomach contents. Liver tissue was the most commonly measured matrix in fish samples. Analyses included metals, histopathology, organics, aryl hydrocarbon hydroxylase, and xenobiotic-DNA adducts. Organic analyses included butyltins, PCBs, DDT and metabolites, and other chlorinated pesticides. PAHs were not analyzed in fish liver tissue because they are readily metabolized. Muscle analytical methods were similar to liver tissue. Stomach contents were analyzed for organic compounds, metals, and food item taxonomy (NOAA, 2000b).

Bivalve mollusks were collected on an annual basis from 1986 to 1992 for the MWP. After 1992, samples were collected biennially. Samples were collected from 150 sites in 1986 and over 250 sites in 1992. Samples were collected between mid-November and the end of March, and within three weeks of the date the site was first sampled to avoid effects of spawning on chemical concentrations. Several species were collected including blue mussels (*Mytilus edulis*) from the U.S. North Atlantic, blue mussels (*Mytilis sp.*) and California mussels (*M. californianus*) from the Pacific coast, American oysters (*Crassostrea virginica*) from the South Atlantic and the Gulf of Mexico, smooth-edge jewelbox (*Chama sinuosa*) from the Florida Keys, Caribbean oyster (*C. rhizophorae*) from Puerto Rico, tropical oysters (*Ostrea sandvicensis*) from Hawaii, and zebra mussels (*Dreissena polymorpha* and *D. bugensis*) from the Great Lakes (NOAA, 2000c). Bivalves were collected at intertidal sites by hand and at subtidal sites with an oyster dredge or oyster tongs. Zebra mussels were collected by snorkeling or with an epibenthic dredge. Composite samples of 30 mussels or 20 oysters (or approximately 200 zebra mussels) were analyzed for organic and metal contaminants. Organic contaminants included PAHs, PCBs, and chlorinated pesticides (NOAA, 1993).

Project Outcome:
The program established an extensive database with the attempt to evaluate the success of recent attempts to improve environmental quality. While the project maintained the same core of station sites and analytical parameters to establish long-term trends, the program evolved to included better analytical methods and new information.

Project Contact:
Tom O'Connor
1305 East West Highway
Silver Spring, Maryland 20910
(301) 713-3028 extension 151

References:
NOAA, 2000a. National Status and Trends Benthic Surveillance Project. Website. http://ccmaserver.nos.noaa.gov/NSandT/NsandTmethods.html.

NOAA, 2000b. National Status and Trends Mussel Watch Project. Website. http://ccmaserver.nos.noaa.gov/NSandT/NsandTmethods.html.

NOAA, 2000c. National Status and Trends Program. Website. http://ccmaserver.nos.noaa.gov/NSandT/NsandTmethods.html.

NOAA, 1993. Sampling and Analytical Methods of the National Status and Trends Program National Benthic Surveillance and Mussel Watch Projects, 1984-1992. Volume I. National Oceanic and Atmospheric Administration. Technical Memorandum NOS ORCA 71. July.

Project Name: Puget Sound Ambient Monitoring Program (PSAMP)

Location: Puget Sound, Washington

Management Issues: Measurement of effects of human activities on environmental conditions.

Water Body Type: Estuarine and Marine

Period of Performance: 1989 to Present

Background:
This program is managed by the Washington State Department of Ecology and often coordinates efforts with NOAA's NS&T program (NOAA and Ecology, 1999). An interdisciplinary group of sediment and water quality professionals was appointed by the Puget Sound Water Quality Authority to develop a comprehensive monitoring program for Puget Sound in 1986. The group designed the Puget Sound Ambient Monitoring Program (PSAMP) to provide long-term monitoring of water quality, sediment quality, biological resources, nearshore habitats, and rivers in the Puget Sound Basin (Llanso et. al, 1998a). Two subprograms of PSAMP include the Marine Sediment Monitoring Program (MSMP) and the Marine Water Column Ambient Monitoring Program. The Marine Sediment Monitoring Program (MSMP) operated under PSAMP from 1989 until 1995. The Marine Water Column Ambient Monitoring Program was initiated in 1967 and joined PSAMP in 1989. Details of the subprograms are discussed below.

Project Goals and Objectives:
The objectives of the MSMP were to collect data on Puget Sound sediments and macro-invertebrate communities in contaminated and uncontaminated areas and to evaluate the condition of Puget Sound benthic communities in relation to contaminant concentrations. The objectives of Marine Water Column Ambient Monitoring Program were to collect data for the maintenance of regulatory listings of various water bodies throughout the state and to implement marine water quality management activities based on water quality data (Ecology, 2000).

Long-Term Monitoring:
Sediment samples were collected from 76 stations throughout Puget Sound, Hood Canal, and the Strait of Georgia from 1989 to 1995. Thirty-four stations were sampled annually. Stations were analyzed using the sediment quality triad approach which included sediment chemistry, sediment toxicity, and benthic community structure assessments. The remaining 42 stations were sampled on a 3-year rotational basis in north, central, and south Puget Sound. Five replicate sediment samples were collected at each station using a double 0.1-m^2 stainless steel Van Veen grab sampler. The top 2 cm were composited and analyzed for physical, chemical, and biological parameters (Llanso et. al, 1998b).

Water column monitoring in 1996 consisted of 16 annually sampled stations and 13 stations sampled on a 3-year rotational basis. In 1997, water column monitoring took place at 19 stations annually and six stations on a rotational basis. The numbers of sampling stations in other years were not available. Water samples were collected at depths of 0.5, 10, and 30 meters with a 1.2-liter Niskin® bottle (Newton et. al, 1998).

Physical: Sediment samples were inspected for visual and olfactory character and analyzed for particle size. A Secchi disk was used to indicate water clarity at water column sampling stations.

Chemical: Sediment samples were analyzed for metals, volatile and semivolatile organic compounds, chlorinated pesticides, PCBs, total organic carbon (TOC), and total sulfides. Water column samples were analyzed for dissolved nutrients (ammonium-N, nitrate + nitrite-N, and orthophosphate-P), pigments (chlorophyll-a and phaeopigment), dissolved oxygen, and fecal coliform bacteria.

Biological: Sediment sample bioassays were conducted on the amphipod, *Rhepoxynius abronius*, as a measure of acute sediment toxicity. Bioassays were conducted on sediment from each sampling location, although no bioassays were conducted in 1994 or 1995. Benthic infauna enumeration was completed at all sediment sampling locations annually from 1989 through 1995 (Llanso et al., 1998a and 1998b).

Project Outcome:
Water column monitoring measured diverse conditions in Puget Sound. Open basins generally had good water quality, however, individual locations had reduced water quality. Estuarine water quality was good with the exception of chronic fecal coliform bacteria. Sediment monitoring succeeded in measuring the type of contamination in Puget Sound locations, although little is known of the extent of contamination. Overall the extent of contamination was low, but elevated contaminant concentrations were present in localized areas, particularly in urban bays.

Project Contact:
Margaret Dutch
Washington State Department of Ecology
Sediment Monitoring Supervisor
(360) 407-6021

References:

Ecology, 2000. Washington State Department of Ecology, Marine Sediment Monitoring. Last updated September 22, 1999. Website. http://www.wa.gov/ecology/eils/mar_sed/msm_intr.html.

Llanso, R. J., S. Aasen, and K. Welch, 1998a. Marine Sediment Monitoring Program, I. Chemistry and Toxicity Testing, 1989-1995. Washington State Department of Ecology. Publication No. 98-323. August.

Llanso, R. J., S. Aasen, and K. Welch, 1998b. Marine Sediment Monitoring Program, II. Distribution and Structure of Benthic Communities in Puget Sound, 1989-1993. Washington State Department of Ecology. Publication No. 98-328. September.

Newton, J. A., Albertson, S. L., K. Nakata, and C. Clishe, 1998. Washington State Marine Water Quality in 1996 and 1997. Washington State Department of Ecology. Publication No. 98-338. December.

NOAA and Ecology, 1999. Sediment Quality in Puget Sound Year 1 – Northern Puget Sound. Puget Sound Ambient Monitoring Program and NOAA NS&T. Publication No. 99-347. December.

Contaminated Sediment Monitoring Programs – Review of Monitoring Methods

Project Name: San Francisco Estuary Project/National Estuary Program

Location: San Francisco, California

Management Issues: Toxic compounds in sediment, habitat loss and alteration, species loss and decline, fisheries loss and decline, introduced and pest species, and problems with the quantity of freshwater inflow.

Water Body Type: Marine/Estuarine

Period of Performance: 1993 to Present

Background:
The San Francisco Estuary Project is part of the National Estuary Program which was established in 1987 by amendments to the Clean Water Act to identify, restore, and protect nationally significant estuaries of the United States. The NEP targets a broad range of issues and engages local communities in the process. The program focuses on improving water quality in an estuary through maintaining the integrity of the whole system including chemical, physical, and biological properties, as well as its economic, recreational, and aesthetic values.

Project Goals and Objectives:
The National Estuary Program (NEP) is designed to encourage local communities to take responsibility for managing their own estuaries. Each NEP is made up of representatives from federal, state and local government agencies responsible for managing the estuary's resources, as well as members of the community—citizens, business leaders, educators, and researchers. These stakeholders work together to identify problems in the estuary, develop specific actions to address those problems, and create and implement a formal management plan to restore and protect the estuary.

The Comprehensive Conservation Management Plan (CCMP) presents a blueprint of 145 specific actions to restore and maintain the chemical, physical and biological integrity of San Francisco Bay and Delta. It seeks to achieve high standards of water quality; to maintain an appropriate indigenous population of fish, shellfish and wildlife; to support recreational activities; and to protect the beneficial uses of the Estuary.

To assist in coordinating research and monitoring programs, the San Francisco Estuary Project has fostered the development of a Regiona1 Monitoring Strategy (Monitoring Strategy). Project staff have worked with representatives of government agencies and scientific institutions to establish the Monitoring Strategy, which fulfills an action recommended in the CCMP's Research and Monitoring Program. The primary purposes of the Regional Monitoring Strategy are: 1) to provide information to assess the effectiveness of management actions that have been taken, 2) to improve conditions in the Estuary to protect its resources, 3) to evaluate the ecological "health" of the Estuary, and 4) to enhance scientific understanding of the ecosystem (San Francisco Estuary Project, 1998).

Long-Term Monitoring:
The San Francisco Estuary Institute (SFEI) serves as the coordinating entity for the Regional Monitoring Strategy. Monitoring is performed annually by the SFEI under the Regional Monitoring Program (RMP). Monitoring began in 1993. In an effort to capture seasonal variability, samples are collected three times per year: during the rainy season (March-April), during a period of declining delta outflow (May-June), and during the dry season (August-September). Two dozen sampling stations are located throughout the Estuary and its major tributaries. Most station locations are chosen as far as possible from the influence of local contaminant sources to best represent "background" contaminant concentrations. Other stations

are close to wastewater outfalls or creek mouths for comparison purposes. To ensure that the data collected by different groups participating in the monitoring program are directly comparable, protocols that included performance-based and standardized sampling, analytical, and QA/QC protocols are employed (San Francisco Estuary Institute, 2000).

Physical: Sediment is analyzed for physical characteristics such as particle size.

Chemical: Chemical monitoring is conducted both for water and sediment. Conventional water quality data are collected including salinity, dissolved oxygen, and temperature. Water is also analyzed for chemical contaminants such as metals, pesticides, and other synthetic hydrocarbons.

Biological: The biological monitoring program includes sediment toxicity, benthic infauna, water column toxicity, and contaminant bioaccumulation. Sediment samples consist of the top 5 cm of grab samples. Benthic infauna is also measured from grab samples and sediment toxicity is evaluated through the effect of the sediment on laboratory organisms.

Water column toxicity is evaluated using a 48-hour bivalve embryo development test and a 7-day growth test using the estuarine mysid *Mysidopsis bahia*. The RMP uses two sediment bioassays: a 10-day acute mortality test using the estuarine amphipod *Eohaustorius estuarius* exposed to whole sediment, and a sediment elutriate test where larval bivalves are exposed to the material dissolved from whole sediment in a water extract. Water column samples are collected approximately 1 meter below the water surface.

Contaminant bioaccumulation is evaluated in transplanted shellfish. For the bivalve bioaccumulation sampling, bivalves are collected from uncontaminated sites and transplanted to 15 stations in the estuary during the wet season (February through May) and the dry season (June through September). Contaminant concentrations in the animals' tissues and the animals' biological condition are measured before deployment and at the end of the 90- to 100-day deployment period. Since the RMP sites encompass a range of salinities, three species of bivalves are used, according to the expected salinities in each area and the known tolerances of the organisms. Organisms used in the bioaccumulation studies are mussel (*Mytilus californianus*) with 49- to 81-mm shell length, oyster (*Crassostrea gigas*) with 71- to 149-mm shell length, and clams (*Corbicula fluminea*) with 25- to 36-mm shell length.

Project Outcome:
None specified. Results are ongoing.

Project Contact:
Craig Denisoff
Project Manager
San Francisco Estuary Project
(510) 286-0625

References:
San Francisco Estuary Project, 1998. Last updated July 1, 1998. Website. http://www.abag.ca.gov/bayarea/sfep/.

San Francisco Estuary Institute, 2000. Last updated March 18, 2000. Website. http://www.sfei.org.

Attachment 2

Draft Report on the Lake Michigan Tributary Monitoring Project

Assessment of the Lake Michigan Monitoring Inventory

A Report on the Lake Michigan Tributary Monitoring Project

Prepared by

Great Lakes Commission
Argus II Building
400 Fourth St.
Ann Arbor, MI 48103
Ph: 734-665-9135
Fax: 734-665-4370
Email: glc@great-lakes.net
Web: **http://www.glc.org/monitoring**

August 2000

This report was prepared by the Great Lakes Commission as part of the Lake Michigan Tributary Monitoring Project with funding assistance provided by the United States Environmental Protection Agency

Executive Summary

Introduction

Through a cooperative agreement, the Great Lakes Commission worked with the U.S. Environmental Protection Agency (U.S. EPA) Region 5, and its partners in the Lake Michigan Lakewide Management Plan (LaMP) process, to assess existing monitoring efforts in the Lake Michigan basin and subwatersheds, including the ten Lake Michigan Areas of Concern (AOC) and four other tributary watersheds. This report is one of the outcomes of the project, and includes a comprehensive review of monitoring programs at the federal, state and local levels for the targeted watersheds; an analysis of gaps, inconsistencies and unmet needs; an assessment of the adequacy of existing efforts to support critical ecosystem indicators; and recommendations for addressing major monitoring needs, particularly those considered most important for lakewide management decision making. The report has also been used to inform members of the Lake Michigan Forum, local public advisory councils (PACs), and other stakeholders about identifying current, local monitoring efforts and establishing community-based monitoring programs.

Monitoring was broadly defined for this project to include not only traditional water quality parameters, but also habitat, wildlife, land use, nonpoint source pollution and other measures of ecosystem health. It is intended that the report and future project outcomes will provide U.S. EPA, the PACs and other stakeholders with important tools for developing their Remedial Action Plans (RAPs) and will enable them to engage their community in a valuable dialogue regarding the status of knowledge on their local watershed. Working closely with the states and tribal authorities, they will benefit from the exchange of information and the opportunity to enhance local participation in state-sponsored monitoring programs.

Project participants were responsible for conducting this assessment at the local level in their watersheds. This consisted primarily of implementing a survey of potential local monitoring organizations and conducting follow-up interviews. The Great Lakes Commission, in collaboration with the U.S. EPA and other agencies, assessed monitoring being conducted by state and federal agencies. The Commission then compiled the results of this collaborative effort into an inventory database, which was the basis for this report. Please see the methodology chapter for a background on project participants, as well as methods used to gain information to build the inventory.

Results

The results from an analysis of the monitoring inventory are organized along several lines. First, each tributary watershed is reviewed separately, with an additional chapter on open lake and basinwide monitoring. Watersheds for the following tributaries are covered in this report:

Grand Traverse Bay	St. Joseph River	Fox-Wolf River Basin
White Lake	Grand Calumet River	Door County
Muskegon Lake	Waukegan Harbor	Menominee River
Grand River	Milwaukee River and Estuary	Manistique River
Kalamazoo River	Sheboygan River	

Within each of these chapters, findings from the inventory are presented in the following nine categories:

- LaMP pollutants
- Nutrients and bacteria
- Meteorological and flow monitoring
- Sediments
- Fish contaminants, fish health, and aquatic nuisance species
- Benthos monitoring
- Air monitoring
- Wildlife monitoring
- Land use

In addition to discussing findings for each of the watersheds, monitoring locations (where available) are also displayed for each watershed. The combination of database analysis and geographical analysis was designed to present the most complete assessment of monitoring within each watershed.

Following the open lake chapter, a more general analysis of monitoring coverage is presented in chapter 18, Overall Discussion. In this section, the monitoring infrastructure was analyzed for its ability to provide sufficient data for assessing the 70 Lake Michigan LaMP indicators. A qualitative rating is given to each LaMP indicator, based on the availability and specificity of monitoring related to the indicator.

Findings and Recommendations

The final section of this report centers on general issues that were uncovered throughout the course of research. There are three key areas under which the monitoring inventory provided valuable information and recommendations for improving overall monitoring in the Lake Michigan basin. These include data gaps and unmet needs; underutilized resources; and monitoring coordination and information sharing. Findings and recommendations within these areas are summarized below. More detail can be found in the last chapter of the report. For reference purposes, sections are labeled with letters and findings and recommendations are numbered.

A. Data Gaps and Unmet Needs

This report, and the inventory on which it is based, represent the first effort to account for the range of environmental monitoring in the Lake Michigan basin. The inventory represents the initial approach toward achieving this ambitious goal. It is a framework on which a more complete inventory will eventually be built.

(1) Finding: There are several gaps in the inventory that are listed below and throughout the report. While some of these gaps are areas that have not been well covered in the inventory, others may represent gaps in the monitoring coverage. At this point, it is difficult to tell which are gaps in the monitoring inventory and which are actual monitoring gaps. Further improvement of the inventory database is needed to better clarify this distinction.

(1.1) Recommendation: *Continue to update the inventory and expand data collection to include all tributaries.*

(2) Finding: There are several key monitoring areas where little information was received, but where more monitoring is believed to exist. These areas include monitoring for *E. coli*, fish population characteristics, aquatic nuisance species, benthic organisms, wildlife, and habitat.

(2.1) Recommendation: *Establish better lines of communication with state Departments of Natural Resources (DNR), U. S. Fsih and Wildlife Service (USFWS), U. S. Forestry Service (USFS), and U. S. Department of Agriculture (USDA).*

(2.2) Recommendation: *Better integrate habitat and wildlife monitoring with traditional water quality monitoring.*

(3) Finding: Another result of this initial approach to the monitoring inventory for the Lake Michigan basin was that much of the information included only general information about the geographic location of monitoring sites. Many organizations reported monitoring for parameters across a broad geographic area but did not include specific site references. Locational information is critical if the inventory is to be brought online in a geographically-searchable format.

(3.1) Recommendation: *Improve information on the geographic location of monitoring sites.*

(4) Finding: A further gap in the monitoring information obtained for this report, was the lack of complete and continuing coverage of Lake Michigan Mass Balance data. Data obtained for this report on the Lake Michigan Mass Balance Project was limited by the timing of the release of data to the public. However, information in the inventory database will be improved when the project is finalized. Additionally, the value of coordinated sampling data (as collected in the Mass Balance project) would be greatly enhanced by a repeat of the sampling event ten years following completion of the original sampling.

(4.1) Recommendation: *Initiate planning for a coordinated sampling event for ten years following the initial Mass Balance project, and share data and modeling results with the public in a timely fashion through numerous outlets.*

(5) Finding: This initial project specifically avoided attempting to collect information about university monitoring projects. However, some academic institutions conduct a number of important ongoing, long-term projects, and information on these projects should be included in the inventory. Other programs catalog the university work they fund. Closer ties need to be established with these programs and such efforts need to be expanded throughout the basin.

(5.1) Recommendation: *Include academic research and data collection efforts in future updates to the monitoring inventory*.

(6) Finding: While a number of LaMP pollutants, such as mercury and copper, are monitored extensively across the basin, it has been difficult to find monitoring information on some of the other pollutants. These under-monitored pollutants include all the emerging LaMP pollutants, along with DDT, HCBs, toxaphene, and PAHs.

(6.1) Recommendation: *Further examine the monitoring coverage of specific LaMP critical pollutants and emerging pollutants.*

B. Underutilized Resources

Along with the gaps in monitoring coverage identified in this project, some resources in the basin were also discovered that do not appear to be fully utilized. Monitoring is an area of environmental management that has often been underfunded in the past. Therefore, in order to achieve the most complete monitoring coverage possible, all available resources must work in concert.

(1) Finding: One of these underutilized resources is volunteer groups. Most of the volunteer groups currently engage in some form of monitoring, but often their efforts are not incorporated into state or regional monitoring plans, and the information collected is only reported internally or locally.

(1.1) Recommendation: *Take better advantage of relatively untapped volunteer monitoring resources.*

(2) Finding: Another group that is underutilized is local agencies. Examples of such agencies are health departments, conservation districts and planning agencies. In many cases, these agencies are already engaged in monitoring to serve their local needs.

(2.1) Recommendation: *Take better advantage of local agencies such as health departments, conservation districts and planning agencies.*

(3) Finding: To best capitalize on these underutilized resources, it is important that these local groups (both volunteer groups and local agencies) be linked into basinwide efforts, but at the same time retain their local focus and discretion.

(3.1) Recommendation: *Establish a better framework for bottom-up monitoring program linkages.*

(4) Finding: Part of the difficulty in using data collected at the local level is that there are few standards at the basinwide level to integrate data. The local focus of the data collection effort often will leave the data incompatible with other data from neighboring localities.

(4.1) Recommendation: *Standardize data collection and reporting*.

C. Monitoring Coordination and Information Sharing

The final issue area does not involve direct monitoring, but responds to the need to coordinate monitoring efforts. There are a wide array of organizations involved in monitoring at the federal, state and local levels. However, no single organization is responsible for planning, coordinating, or disseminating monitoring efforts for the entire Lake Michigan basin.

(1) Finding: A major coordination problem is the lack of a central source for monitoring information. The inventory that this report evaluates is the first step toward creating such a central source. However, this one-time inventory is currently not universally accessible and may quickly become dated if the database is not continually updated by monitoring organizations in the basin.

(1.1) Recommendation: *Encourage state, federal, tribal, and local agencies to report monitoring coverage and results to a meta-database with universal access.*

(1.2) Recommendation: *Develop an online database of monitoring information that is geographically-based, and content-searchable.*

(2) Finding: In general, organizations make most, if not all, decisions about their monitoring programs based on goals for their local coverage areas. Rarely does this area cover the entire Lake Michigan basin.

(2.1) Recommendation: *Develop and coordinate the implementation of comparable methods to collect indicator data in a coordinated network.*

Acknowledgments

The primary authors of this report were Ric Lawson of the Great Lakes Commission, and the Lake Michigan Tributary Monitoring Project participants from the 14 participating tributary watersheds around the Lake Michigan basin. Mr. Lawson compiled state and federal monitoring information; designed and analyzed the monitoring inventory survey and database; integrated all other information into this final report; and provided day-to-day project management. The project participants collected information on local monitoring programs in their watersheds; compiled this information for population of the inventory database; reported on their findings (much of which is included directly in this report); and provided review comments to Mr. Lawson. These project participants, and their respective watersheds, are as follows:

Chris Wright — Grand Traverse Bay
Susan Russell — Grand Traverse Bay
Kathy Evans — White Lake and Muskegon Lake
Dr. Janet Vail — Grand River
Melissa Welsh — Grand River
Bruce Merchant — Kalamazoo River
Andrew Laucher — Kalamazoo River
Al Smith — St. Joseph River
John Wuepper — St. Joseph River
Kathy Luther — Grand Calumet River
Dr. Greg Olyphant — Grand Calumet River
Susie Scheiber — Waukegan Harbor
Paul Geiselhart — Waukegan Harbor
Dr. Vicky Harris — Milwaukee, Sheboygan, and Menominee Rivers
Nate Hawley — Milwaukee, Sheboygan, and Menominee Rivers
Bruce Johnson — Fox-Wolf River Basin
Jim Pinkham — Fox-Wolf River Basin
Roy Aiken — Door County
Jim Anderson — Manistique River

Contact information for these individuals is included in Appendix B.

In addition to the authors, several individuals made important contributions to the development of the inventory and this report. Judy Beck, Lake Michigan Team Manager with U.S. EPA, Region 5, served as the technical contact. Through the U.S. EPA she provided funding for the project, as well as project guidance, federal contacts, and overall support of the project through the LaMP process. Matt Doss, Program Manager with the Great Lakes Commission, provided project leadership, oversight, administration, and extensive editorial and task support for all aspects of the project. Dr. Michael Donahue and Tom Crane with the Great Lakes Commission provided guidance and important contact information.

Finally, the authors would like to thank all the individuals who provided content and editorial comments on early drafts of this report. In this area, the authors would like to thank members of the Lake Michigan Monitoring Coordination Council, especially the co-chairs Charlie Peters with the U.S. Geological Survey and Gary Kohlhepp with the Michigan Department of Environmental Quality, for providing valuable content suggestions.

Table of Contents

List of Tables

List of Figures

1. Introduction and Background

Lake Michigan Background

Lake Michigan is the second largest Great Lake, by volume. The lake is 307 miles long and 118 miles wide, with an average depth of 279 feet and a maximum depth of 925 feet. The Lake Michigan drainage basin covers more than 45,000 square miles. The shoreline of the lake stretches 1,660 miles.

Lake Michigan flows into Lake Huron through the Straits of Mackinac. The flow rate into Lake Huron allows Lake Michigan to be recharged once every 100 years, which is considered a relatively slow recharge rate. The lake supports a unique ecology, with colder forested regions dominating the northern half of the basin, and more temperate, fertile regions in the southern section.

Lake Michigan is located entirely in the United States, which made it uniquely situated for this project. Four states border the lake – predominately Michigan to the east and north, and Wisconsin on the western shore. Indiana and Illinois make up the southern shore of the lake, and while a small proportion of the basin area exists in these states, these areas contain significant natural areas, and high population and pollution sources.

The Lake Michigan basin consists of a variety of land uses. About 44 percent of the land in the basin is taken up in agricultural production. Roughly 41 percent exists as managed or unmanaged forest land. Nine percent of the remaining land is divided up into residential units, with a variety of uses making up the remaining 6 percent of the basin.

Monitoring Relevance to the Lake Michigan LaMP

Pursuant to the 1987 protocol to the Great Lakes Water Quality Agreement (GLWQA), Lakewide Management Plans (LaMP) have been developed for four of the five Great Lakes. The Lake Michigan LaMP effort was led by the U.S. Environmental Protection Agency (U.S. EPA), Region 5, in cooperation with its partners in the states of Michigan, Indiana, Illinois and Wisconsin, the public and other federal and tribal agencies. Additionally, Remedial Action Plans (RAPs) are being prepared and updated for ten Lake Michigan tributaries designated as Areas of Concern by the parties to the GLWQA.

According to the 1987 protocol, "LaMPs shall embody a systematic and comprehensive ecosystem approach to restoring and protecting beneficial uses in ... open lake waters." The LaMP process involves setting goals to reduce toxics, improve habitat, and restore beneficial uses to the environment in the Lake Michigan basin. The RAPs follow a similar approach in specific geographic areas where significant pollution problems have impaired beneficial uses of the water body.

An additional feature of the LaMPs and RAPs is a strong emphasis on public consultation and local involvement. For the Lake Michigan LaMP, this is achieved through the Lake Michigan Forum, a broad-based stakeholder group with members from tribes, industry, environmental groups, local government agencies, community organizations, academia, recreational organizations, and the ten Lake Michigan AOCs. Public advisory councils (PACs) are the primary vehicle for facilitating public involvement in the AOCs. The PACs include broad representation from the AOC community and guide the RAP process at the local level.

While the original draft Lake Michigan LaMP focused strongly on toxic pollutants, the participating agencies and stakeholders recognized that other stressors contribute to impairments of the lake and the tributaries that feed into it. In response, the latest version of the LaMP expanded its scope to address a broader array of management issues, including loss of habitat and biodiversity and introduction of damaging exotic species. The year 2000 draft of the LaMP includes the results of a number of studies and monitoring efforts to determine the fate of pollutants entering the Lake, and how they move through air or water or sediments into the food chain.

A critical component of this broader approach will be a monitoring regime that is coordinated from one jurisdiction to another and sufficiently comprehensive to support the ecosystem indicators which inform management decisions. The Lake Michigan Mass Balance Study will provide important data on the amount of several critical pollutants entering the lake, their movement and how they are made available to fish and plant life. An outstanding need remains, however, to assess the status and scope of monitoring being conducted at the state and local levels on major tributaries to Lake Michigan; to develop a plan for coordinating and enhancing these efforts; and to address gaps and unmet needs in the collective monitoring and reporting regime that hamper decision making at all levels.

Project Goals

Through a cooperative agreement, the Great Lakes Commission worked with U.S. EPA Region 5, and its partners in the Lake Michigan LaMP process, to assess existing monitoring efforts in Lake Michigan basin and subwatersheds, including the ten AOCs and four other tributary watersheds. This report is one of the outcomes of the project. The report includes a comprehensive review of monitoring programs at the federal, state and local levels for the targeted watersheds; an analysis of gaps, inconsistencies and unmet needs; an assessment of the adequacy of existing efforts to support critical ecosystem indicators; and a plan for addressing major monitoring needs, particularly those considered most important for lakewide management decision making. The report has also been used in training members of the Lake Michigan Forum, PACs, and other stakeholders on determining current, local monitoring efforts and establishing community-based monitoring programs.

The project and report are consistent with the ecosystem approach of the LaMPs and RAPs as well as their emphasis on community involvement and participation. Monitoring has been viewed in the broadest sense, including not only traditional water quality parameters, but also habitat, wildlife, land use, nonpoint source pollution and other measures of ecosystem health. It is intended that the report and future project outcomes will provide the PACs and other stakeholders with important tools for developing their RAPs and will enable them to engage their community in a valuable dialogue regarding the status of knowledge on their local watershed.

Scope of the Assessment Effort

This report assesses monitoring efforts in the broadest sense, including not only traditional water quality parameters, but also habitat, wildlife, land use, nonpoint source pollution and other measures of ecosystem health. Project participants were responsible for conducting this assessment at the local level in their watersheds. There were fourteen major Lake Michigan tributaries selected for local analysis. The watersheds impacting these tributaries were selected as the base unit of analysis. These watersheds are illustrated in Figure 1. The Great Lakes Commission, in collaboration U.S. EPA and other agencies, assessed monitoring being conducted by state and federal agencies. Please see the methodology chapter for a background on project participants, as well as methods used to gain information to build the inventory.

Figure 1. Watersheds included in the Lake Michigan Monitoring Inventory.

Report Framework

This report is structured along the lines of a typical research report. This introduction is followed by a discussion of the methodologies used to collect the information in the inventory and this subsequent report. The methodology is followed by a series of chapters that present the project findings and inventory content. Summaries of inventory results from each of the fourteen tributaries included in this project are presented in the following categories:

- *LaMP pollutants:* This category includes substances classified as water quality pollutants at three levels. Critical pollutants are those that have been found to impair beneficial uses of the lake and its tributaries. Included in this category are polychlorinated biphenyls (PCB), dieldrin, chlordane, dichlorodiphenyltrichloroethane (DDT) and metabolites, mercury, and dioxins and furans. Pollutants of Concern are those toxic substances that are associated with local or regional use impairments. These include arsenic, cadmium, chromium, copper, cyanide, lead, zinc, hexachlorobenzene (HCB), toxaphene, and polynuclear aromatic hydrocarbons (PAH). Finally, Emerging Pollutants include those toxic substances that have characteristics that indicate a potential to affect the physical or biological integrity of Lake Michigan. These include atrazine, selenium, and PCB substitute compounds.[1]

- *Nutrients and bacteria:* Nutrients, when present in high levels, can impair water bodies by encouraging the overproduction of algae and other plant life, leading to low oxygen levels and ultimately eutrophication. Several organisms which proliferate in high nutrient conditions include *E. coli* and coliform forms of bacteria. These bacteria can locally impair beneficial uses of water bodies.
- *Meteorological and flow monitoring:* Meteorological and flow monitoring represent two types of physical parameters that can be measured for water bodies. Meteorology (mostly relating to precipitation) and flow data help researchers develop water quality models, which have many uses, including source determination, Total Maximum Daily Load (TMDL) development, and other types of predictive modeling, to name just a few.
- *Sediments:* Contamination of bottom sediments is a common source of water quality impairment in AOCs in the Lake Michigan basin. Monitoring these sediments is important for determining the overall quality of a waterbody and its adjoining ecosystems.
- *Fish contaminants, fish health, and aquatic nuisance species:* Many species of fish in the basin take up chemical pollutants through the food web. Often, the effect is a bioaccumulation or concentration of pollutants within the fish tissue. This presents a significant health hazard to humans who consume this fish. Also, the health of fish populations in the lake and tributaries serves to indicate the health of the ecosystem to some degree. Nonindigenous Aquatic nuisance species can affect native aquatic species in a variety of ways. Monitoring of all these aspects of fish populations is important for tracking the health of life in the lake.
- *Benthos monitoring:* Similar to fish, there are a wide number of other organisms that exist deep within lakes and streams within the Lake Michigan basin. Many of these organisms are very sensitive to pollution and other aspects of a healthy aquatic system. Monitoring for the health and diversity of these species helps to determine the overall health of the aquatic ecosystem.
- *Air monitoring:* While monitoring the content of the air is an important task to determine intrinsic air quality, it is also important for tracking potential sources of water quality impairment. Much research is ongoing in the basin to determine how pollutants can be passed through the air to water bodies through air deposition.
- *Wildlife monitoring:* Any effort to track the health and quality of ecosystems must include some measure of the diversity and health of wildlife populations. Several types of public and private organizations are monitoring a variety of wildlife populations.
- *Land use:* One of the measures of human impact on the natural world is tracking the development of land. Changing the use of land from a naturally-controlled environment to agricultural production or urban or suburban habitation can have a wide range of impacts on the surrounding ecosystems. It is important to track these changes, along with measures of ecosystem health, to help determine the overall impacts from changes in land use.

In addition, each chapter begins with background about the watershed or region of focus, and ends with a local assessment of monitoring efforts. Both of these sections were written directly by the local project participants. Actual survey results will be made available for public use via a geographically-searchable Internet database, which is currently under development.

The tributary chapters are followed by a chapter assessing the monitoring coverage of the open lake and a discussion of state and federal monitoring programs which have a multiple watershed focus. This chapter is followed by a general discussion of the monitoring coverage in the Lake Michigan basin, focusing on gaps

---

[1]Definitions for LaMP pollutants were excerpted from the *Lake Michigan Lakewide Management Plan (LaMP 2000)*; U.S. EPA, 2000.

and unmet needs. The final chapter contains recommendations from the project participants, in consultation with numerous monitoring stakeholders, such as members of the Lake Michigan Monitoring Coordination Council.

2. Methodology

Attempting to take an inventory of all ecological monitoring efforts in a basin as wide in area as the Lake Michigan basin is a mammoth undertaking. Thousands of separate efforts may be ongoing, and few people outside project participants may be aware of many of them. Striving to become aware of all of these efforts is high goal — a goal that one cannot expect to achieve on the first attempt. We view the products of Lake Michigan Tributary Monitoring Project as comprising a foundation of a monitoring inventory. Over time, if the foundation is strong enough and enough people become aware of it, the inventory can be built upon so that it will eventually become complete. We envision the inventory as a dynamic product that should constantly be updated to reflect new discoveries and changes in monitoring efforts.

In this vein, the methods used to collect information and develop the inventory consisted of the following general elements:

- A two-tiered survey of potential monitoring organizations;
- Review and collection of supplemental or specific geographic monitoring information; and
- Development of an organizing framework for the inventory.

Monitoring Inventory Survey

A short survey (25 questions, 2 pages) was developed to solicit information about possible monitoring projects in the basin (See Appendix C for the survey). Questions in the survey ask respondents to provide information on a variety of characteristics about monitoring projects. Generally, these characteristics include basic contact information, locational information, indicators monitored, logistical information, quality assurance and controls, and staff and training information.

The survey was distributed on two levels – local and state/federal. In an effort to collect a greater amount and higher quality of local monitoring information, the Great Lakes Commission partnered with local groups in 14 key tributaries to Lake Michigan. The tributaries included all ten Areas of Concern (AOCs), as well as Grand Traverse Bay, Grand River, St. Joseph River, and Door County (see Appendix B for a list of project participants). The GLC conducted the survey of state, federal and other basinwide organizations.

Two workshops were conducted to provide training and technical assistance to project participants so that the survey could be administered as effectively as possible. At the first workshop, the survey, along with a set of supporting materials, was distributed to project participants. These materials were reviewed and subsequently adapted to reflect participant feedback. A process was established at the meeting, whereby participants committed to carry out the following steps:

- *Develop a contact list for delivering surveys.* Participants were encouraged to meet with their local advisory groups and develop a list of entities in the watersheds that might be conducting monitoring programs, including local municipalities, utilities, educational institutions, business/industry groups, environmental and conservation organizations and recreational groups among others.
- *Distribute surveys with informational materials.* Participants were subsequently sent a set of materials that could be tailored to their local area. Methods to encourage high response were also discussed.
- *Enter returned surveys into electronic format.* Participants were given a database template to be used for data entry. The final datasets were sent to the GLC for encorporation into the project database. The final database is being developed for public use on the Internet as a geographically-searchable database.
- *Follow up to encourage high response.* Several strategies were discussed to increase the response rate.

- *Report findings.* A framework and timeline were established for reporting on local survey results. These reports were submitted to the GLC for integration into this final report.
- *Final workshop.* A workshop was held to review the overall findings of the project and to share information and ideas about how local groups could build on the results in future projects.

A second meeting was held midway through the project to troubleshoot survey and reporting difficulties. The main difficulty was determined to be response rate. Following the meeting, GLC crafted a press release that the project participants adapted and sent out to local media outlets. This was used to create greater awareness of the project, thereby encouraging better response.

Local Methodologies

Each project participant tailored the general methodology to achieve the best results for their watersheds. The specific methodologies used by the project participants, along with general information about survey results, are provided below.

Grand Traverse Bay

Description of the Research Process

The purpose of this research project is to identify the overall state of ecosystem monitoring being conducted in the Grand Traverse Bay watershed. In addition to water quality monitoring, ecosystem monitoring includes collecting data on selected parameters that effect the biological, physical, chemical, and human health condition of the watershed**.** Parameters such as fish and wildlife habitat, wetland coverage, land use development patterns, construction of infrastructure, atmospheric deposition, climatic conditions, groundwater contamination, watershed hydrology, and others are useful in assessing the condition of a watershed.

Collaboration and Communication With Watershed Groups

The survey project was presented to the Grand Traverse Bay Water Quality Monitoring Team to solicit their support and assistance in identifying organizations to receive the survey. Promotion of the survey was also made at public meetings, monthly meetings with natural resource managers, monthly meetings with the Grand Traverse Regional Environmental Health Committee, and presentations about Grand Traverse Bay sponsored by Grand Traverse Bay Watershed Initiative (GTBWI).

Number of Entities Contacted and Number of Responses

The Grand Traverse Bay Watershed Monitoring Inventory Form was mailed to 96 selected organizations located in the Grand Traverse Bay Watershed.

Of the 96 organizations receiving the survey, 24 returned the survey. Of the 24 respondents, 17 administer a monitoring program.

Muskegon and White Lakes

Surveys were mailed to over 275 potential monitoring entities in the Muskegon and White Lake AOC/River Watersheds. All county level governments, drain commissions, health departments, road commissions and conservation districts were surveyed. Contacts with the PACs and other conservation organizations initially helped to form a mailing list of townships, planning commissions, schools, sport fishing/conservation and lake associations with an interest in water quality, habitat and environmental education projects. This mailing list was compiled and used in the survey. Through a network of conservation districts, individuals and organizations throughout the watershed, a list of individuals, businesses, city governments, schools and university contacts was developed and used in the survey. Personal contacts, phone calls and follow up mailings were performed as more information became available.

Of the survey contacts made, 70 responses were received by the Muskegon Conservation District. Of these, 23 responded with monitoring information. Thirteen of these respondents were from the Muskegon Lake AOC/River Watershed and eight were from the White Lake AOC/River Watershed. A total of 47 respondents indicated that they did not perform any monitoring.

Four public meetings were held to support the RAPs and two newsletters were developed in conjunction with the Muskegon and White Lake Public Advisory Councils to raise awareness and solicit participation for this project. The newsletters were mailed and/or distributed to over 2000 members of the public. An additional survey mailing about the occurrence of "projects" in the Muskegon River Watershed was completed to supplement knowledge about activities and opportunities which could be useful to the Muskegon River Watershed Assembly. A meeting to discuss public involvement in contaminated sediments remediation will be held in the White Lake area as part of this project as well. An educational brochure about Muskegon County watersheds (Muskegon and White being the two largest) is also being developed to promote watershed awareness and public involvement opportunities.

Grand River

Research began with contacting Grand Valley State University-Water Resources Institute (GVSU-WRI) and obtaining mailing lists for different individuals involved in water related projects that were already known to the Institute. This proved to be the best resource since the Grand River does not have a public advisory council or committee established at the time of this study.

A list was also comprised from the Michigan Water Environment Association's 1998-99 membership directory. Surveys sent to these organizations were asked to provide information on monitoring that was above and beyond what they report for compliance purposes.

Contacts were obtained by searching through publications, reports, and news articles for individuals and groups that were in the media. Internet sites were also searched, but unfortunately most of the information found was outdated and websites did not give a good representation of the watershed as a whole. Another search method was the Know Your Watershed software published by Conservation Technology Information Center, which can be found at **http://www.ctic.purdue.edu/KYW/**. The information was obtained for local groups working within different watersheds. The publication date was in 1996, so some of the groups were no longer active. Other names came from individuals that completed the survey.

A total of 325 surveys were sent out in two bulk mailings. Additional surveys were mailed individually as more contacts were discovered. The University had 25 successful responses and 28 negative responses. The majority of surveys sent out were never returned. Inquiries were made by non-monitoring groups on the project, and results will be sent to them.

Kalamazoo River

In an effort to share responsibilities on this project, as well as avoid repetition of surveying, the Kalamazoo River Watershed Public Advisory Council (KRWPAC) partnered with a local project known as the Watershed Information Management Project (WIMP). This group seeks to compile monitoring data and store it in a publically accessible format. After several initial meetings with this group, it became evident that the decision making process between the two groups was preventing our project from commencing on schedule for our November 1, 1999 deadline. We decided to go ahead with our surveying efforts, and agree to share the information acquired with the WIMP group when the time had come.

Utilizing a mailing list obtained from the Michigan Department of Environmental Quality (MDEQ) for the Allegan Lake TMDL project, our first contact included a mailing of 272 surveys to the various contact persons on the list. Initial response yielded about 20 surveys. The surveys requested a two week turnaround time. At four weeks past the date they were mailed an intern conducted follow up calls. Most agencies did not respond to the surveys because they are not conducting any monitoring. We did receive a few surveys that were mailed or faxed back indicating that no monitoring efforts were taking place. The follow up calls did yield an additional four surveys.

A second mailing utilized a list obtained from the Kalamazoo Foundation, a private non-profit foundation that had recently held a Sustainable Community Watershed Conference. Using a list generated from those attending the conference, an additional 50 surveys were sent out. Response from this mailing yielded approximately five responses. Follow up calls did not yield any responses.

In early August, a press release was sent to the major newspapers in the Watershed as well as a few news-oriented radio stations. It is unclear as to how many of these publications actually ran the article. A few responses were received via phone, but these were general inquiry about the Watershed Council. No survey results were attained from the press release.

St. Joseph River

The first stage of the assessment was to identify various organizations that might be monitoring for information on the St. Joseph River watershed, either on water, land, wildlife or any other benchmark. Numerous telephone calls were made to speak with individuals involved in some kind of watershed monitoring. Newspapers serving all watershed counties except Berrien published the press release, proposed by the GLC. The next step was to utilize the survey form designed by the GLC/EPA. Telephone interviews were conducted with several individuals. If they did not return the survey form, the details of their programs were not made available. Comments from some of the organizations that did not return forms are included in the Excel spreadsheet under the comment column. A few personal interviews were conducted and these actually are most effective way to conduct surveys but time or lack of available resources did not permit this as a routine method. The names of the contacts are listed in the Excel spreadsheet even if they did not respond. The ones that responded with a completed form are designated in italics.

A total of about 40 organizations were contacted but only nine completed survey forms were returned. The organizations that were contacted included county health departments, wetland conservation groups, nature centers, volunteer “water watchers”, lake and stream association members, river environmental groups, “steelheaders”, county conservation offices, colleges and newspapers. The small number of returned forms reflects what appears to be a low level of formal programs that are in place that possess the discipline and resources required to monitor the parameters listed on the survey form. For example, only one organization, “Water Watcher”, of Indiana, reported monitoring Atrazine and Acetichlor.

Grand Calumet River

An initial list of likely monitoring organizations or contact people was constructed from the membership of the Citizens Advisory for the Remediation of the Environment (CARE) Committee, the Interagency Task Force on *E. coli* member lists, participants in the TMDL stakeholder process, and other local partnership efforts. The Indiana Department of Environmental Management (IDEM) Volunteer Monitoring Coordinator and the Indiana Department of Natural Resources Hoosier Riverwatch Coordinator was also consulted for a list of local participants in their volunteer water quality monitoring programs. The Riverwatch program did supply a list of past participants in their projects in Lake, Porter, and LaPorte County, Indiana. This information confirmed that in fact, no volunteer water quality or aquatic biota monitoring actually occurs in the Grand Calumet River system. This is most likely the result of the real or perceived dangers of exposing volunteers to a waterbody with a large accumulation of highly contaminated sediments. Despite this limitation, a substantial list of contacts and organizations was constructed. Groups which might be collecting water quality data in other Lake Michigan tributaries and those which might collect other types of environmental information where added to the list. An internet search was conducted for local chapters of national organization such as Audubon and Sierra Club which might participate in bird and wildlife counting activities. Faculty members involved in ecological or environmental research at local universities were also included. In addition, lists of local governments such as park departments, water departments, and others were provided by the Northwest Indiana Regional Planning Commission. Most of the lists provided by others provided addresses only.

In addition to Internet and phone research, information about this project was presented at a number of local meetings and partnerships. Members of the CARE Committee, the Interagency Task Force on *E. Coli*, and the TMDL stakeholders were informed of the project and advised that they would likely be receiving surveys. Presentations and surveys where also distributed at the annual meeting of the Indiana Hub of the Great Lakes Aquatic Habitat Network, a consortium of local environmental organizations and individuals interested in environmental issues.

An initial mailing of letters, fact sheets, and surveys was distributed to 20 individuals and organizations. Since project funding was actually received by Indiana University as a member of the *E. Coli* Task Force, the letters where sent on Task Force letterhead and signed by Kathy Luther as the Task Force Co-Chair. No responses where received as a result of this initial mailing.

Limited follow up calling was done to those organizations known to be conducting monitoring. A total of two responses were received as a result of this calling effort. Because of earlier decisions regarding project funding, there was insufficient staff time dedicated to this project to permit more extensive calling efforts. Based on conversations with other project participants, 10 percent seems to be a fairly consistent response rate. Follow up phone calls indicated that many recipients did not consider the work they might be doing to be monitoring. This may be one reason for poor survey response rates.

After a mid-term Lake Michigan Tributary Monitoring Project participant meeting in Chicago revealed that GLC was having limited response from state and federal agencies, an effort was made to contact local branches ofsome of these agencies by phone and fax out surveys. Surveys where sent to the IDNR, to Illinois-Indiana Sea Grant, and the USGS Research Station at the Indiana Dunes National Lakeshore. No responses where received as a result of these surveys. IDEM completed survey forms for those partnerships and organizations for which IDEM is a substantial participant. Despite limited responses to surveys IDEM is confident that a comprehensive list of state agency efforts will capture most if not all ongoing water quality monitoring that is occurring in the Grand Calumet River and this Area of Concern. As a result staff time was largely dedicated to completing online the surveys for all IDEM monitoring programs.

Initially, IDEM believed that all information necessary for the Tributary Monitoring Project would be collected in the TMDL process. While this was not the case, some important data was discovered which might not have been learned from the survey project. Information was collected about data that National Pollutant Discharge Elimination System (NPDES) dischargers have collected during discrete time periods as part of special projects. This information is not part of ongoing continuous data collection efforts or any organized monitoring programs and so is not a good fit with the database format of this project. The information was included because it might be useful for any efforts to compile historical data. The regular monitoring of operations and outfalls which NPDES holders undertake as part of the regulatory requirements of their permits is not included in this report. However, it may be useful to remember that information of this type is collected regularly and reported to state agencies.

Waukegan Harbor
The following steps were implemented prior to contacting a company or agency:

- A press release was sent to all local newspapers. Lake County Chamber of Commerce Newsletter published the press release.
- Announcements of the survey were made at the Audubon Society, Waukegan Harbor Citizens Advisory Group, and Liberty Prairie Conservancy meetings.
- Networking was done by telephoning approximately 150 companies, agencies, schools, and lead contacts furnished by telephone contacts. For future reference of sources for information, a database of 52 contacts was developed. Some contacts expressed interest in being a part of future monitoring programs. There were eight surveys returned out of fourteen mailed.

Milwaukee River
Meetings were held with Wisconsin Department of Natural Resources (WDNR) staff, RAP leaders, and others to develop a list of stakeholders and managers working in the basin (DNR, County Land Conservation Departments, University of Wisconsin-Extension Offices, Non-Governmental Organizations (NGOs) etc.). Identified organizations were then contacted by telephone to describe the goals and objectives of the project. Some of the entities contacted provided valuable information regarding their monitoring activities and mentioned some other entities that should be contacted. In most cases however this was not the case, either the groups were no longer active or they were monitoring for compliance with state and federal regulations. In total, over 200 entities were contacted with only 63 actively monitoring. However, of the 63 active programs, only 16 were applicable and responded to this project. After further investigation it was apparent that many of the applicable programs were connected in some way or form to state agencies, mainly the DNR and UW-Extension.

Sheboygan River
A procedure similar to the one used for the Milwaukee River watershed was used to collect information on the Sheboygan River watershed. In total, over 100 entities were contacted with only 28 actively monitoring. However, of the 28 active programs, only 12 were applicable to this project, as many were subsets of a broader program. For example, Testing the Waters involves numerous schools, teachers, and students in the basin. After further investigation it was apparent that many of the applicable programs were connected in some way or form to state agencies, mainly the DNR and the UW-Extension.

The two largest and most active monitoring programs in the Sheboygan River Basin, Testing the Waters and the Pigeon River Water Action Volunteers (WAV), fit the trend previously mentioned. The DNR and the UW-Extension have played active roles in providing equipment and technical guidance for both programs. The Testing the Waters program incorporates local high school and middle school students to actively monitor various tributaries throughout the Sheboygan River Basin (Pigeon, Sheboygan, and Mullet River Watersheds). This program has been very successful, involving several schools over the past eight years. The WAV program, very similar to the Testing the Waters program, utilizes local citizens to monitor water quality. WAV monitoring teams consisted of either adult volunteers or school classes. In both cases, the DNR and UW-Extension provided the initial support and training to develop these programs, but now rely on their local team leaders (teachers and others) to facilitate the efforts. This initial involvement by the DNR and UW-Extension (training, quality control, and equipment) has provided the assurance that the data collected by Testing the Waters and WAV are deemed worthy for ecological assessment, as stated by various stakeholders.

Other smaller programs were also found monitoring in the Sheboygan River Basin. These programs or projects involved land trust and conservation offices, local colleges/universities, as well as a few industrial facilities.

Fox-Wolf Basin
Fox-Wolf Basin 2000 established a list of 131 individuals or entities thought to be conducting some kind of ongoing monitoring program in the basin. This list was derived from our database--focusing on agencies, organizations and university researchers. Additional contacts were provided through a Wisconsin Department of Natural Resources Water Action Volunteer (WAV) database.

Cover letters and survey forms were distributed to those for whom addresses were readily available. After waiting a few weeks, follow-up calls were made to selected contacts. Additional e-mail requests were made in early January prior to the compilation of this report. Seventeen responses were received from eight different individuals and entities. The lack of adequate monitoring in the Fox-Wolf basin has long been lamented by citizens and resource managers alike. However, it is likely there are additional monitoring programs being conducted in a Basin of this size. The limited response in this survey is believed to be more the result of FWB 2000 not having the staff or time available to be more diligent in making additional, repeated contacts.

Door County
Research as to the degree to which monitoring or collecting of data is done on a regular basis was conducted in three modes: personal contact; written communications to determine what, if any, monitoring was being done; and personal interviews with key personal in local and state agencies.

There are no specific nonprofit or volunteer watershed groups in the area, other than two lake associations.

Pursuant to 21 telephone and personal contact interviews, ten letters of inquiry were sent to local organizations and individuals. Personal contact interviews were conducted with three staff personal within the Department of Natural Resources, each with different areas of responsibility. Companies located in Sturgeon Bay's Industrial Park gave indications that their activities were not of a nature that monitoring would be a concern.

Menominee River
A procedure similar to the one used for the Milwaukee River watershed and Sheboygan River watershed was used to collect information on the Menominee River watershed. Many of the national environmental organizations (Isaac Walton League, Trout Unlimited, etc) had representatives or chapters in the basin, but were not actively monitoring at the present time. In total, over 50 organizations were contacted with only 8 actively monitoring. After reviewing the list with County Land Conservation managers and WDNR staff, it was apparent that the list was comprehensive.

Manistique River
Description of the research process
Schoolcraft County Economic Development Corporation coordinated research to determine groups, agencies, businesses, governmental entities, and individuals conducting research and monitoring within the Manistique River Watershed.

The following was the process used to collect data for this process:

1) List of potential contacts generated by the Corporation and Manistique River/Harbor Public Advisory Council.
2) Initial mailing sent to entire mailing list. Mailing included an introductory letter, background document describing basin-wide project, and a survey form. All three of these documents were developed by the Great Lakes Commission with comment by all partners.

3) Follow-up mailings of the same packets were delivered to new persons identified by respondents identified and contacted during step two.
4) Surveys returned to the Corporation were entered into the required Excel spreadsheet. Respondents were contacted for additional information if needed.
5) James Anderson met with Michael Tansy, chairperson of the Manistique River Watershed, and director of the Seney National Wildlife Refuge, and George Lyon with the Luce-Mackinac-Schoolcraft Soil and Water Conservation District office.
6) Telephone or personal contacts were made to recipients of the survey who did not respond to determine their level of monitoring activities within the Watershed.

Collaboration / communication with the public advisory council or other watershed groups

During the course of the research the Corporation worked with the Manistique River/Harbor Public Advisory Council to brainstorm monitoring activities occurring within the Watershed, and to develop an initial mailing list for the survey instrument.

The Corporation met with the lead staff person with the local Soil and Water Conservation office, and the chairperson of the organization and director of the Seney Wildlife Refuge to discuss their activities within the watershed. Both shared that beyond the activities of the Refuge, there are very few monitoring activities happening within the watershed. The response from the survey instrument verifies that the assessment made by Mr. Tansy and Mr. Lyon was correct.

Other outreach efforts

In addition to the above activities, a press release developed by the Great Lakes Commission was modified for local informational content, and sent to the local media including radio (WTIQ), and the local newspapers - *Pioneer Tribune* (Manistique / Schoolcraft County), *Munising News* (Alger County), and the *Newberry News* (Luce County). James Anderson, executive director provided updates and information at Corporation board meetings concerning the project which were covered by the media, and discussed the project during a quarterly half-hour interview on WTIQ AM 1490 Community Focus program.

Number of entities contracted and number of responses

Of the 34 surveys sent out, six (6) responses were received. George Lyon with the Soil and Water Conservation indicated that he did not believe either dam operator was involved with any monitoring activities.

General comments on results

Only five surveys were returned indicating that a rather large watershed has very little monitoring or coordination of conservation activities occurring within it. Further, the data returned indicated that most monitoring is for regulatory requirements, with some additional data collection beyond the required level. There does not appear to be any monitoring in terms of land use, soil, and very little monitoring of Fish and Biota / Wildlife beyond that of the Seney National Wildlife Refuge and the United States Department of Agriculture - Hiawatha National Forest.

In terms of the indicators being collected, all 18 indicators are being collected by at least one organization - City of Manistique, Department of Public Works. Further, most monitoring appears to be completed by paid staff who are trained in data collection methodology as well as quality assurance / quality control methods.

Further, the Corporation was surprised to find that only one of three universities in the region has any interest in conducting research within the watershed, and the only effort is driven primarily due to the contamination of the lower watershed with PCB’s.

Federal and State Data Collection

The GLC was primarily responsible for collecting data from federal, state, and other organizations conducting monitoring programs basinwide. This was accomplished through two efforts — a survey, and supplemental data search. First, the GLC, in consultation with project participants and members of the Lake Michigan Monitoring Coordination Council (LMMCC), developed a list of federal and state entities that were likely to be conducting monitoring efforts in the basin (see Appendix D for the LMMCC membership list, and Appendix E for a list of survey contacts). In an effort to maintain efficiency, every effort was made to select specific contacts who could respond generally about monitoring programs in their agency, or who would collect information from relevant people in their agency. Follow up phone calls and e-mails were made to non-respondents to solicit a higher response rate. These phone calls led to further contacts (sometimes in other agencies), and additional surveys were distributed. In addition, the survey form was transformed into a web-based format to ease completion by respondents. This generated further responses, as agency contacts often asked multiple people within their agency to complete the web-based form. From an initial distribution of 72 surveys, the GLC received 27 responses. An accurate response rate cannot be calculated, since some agencies returned several surveys (some not directly solicited), while others returned none. The full database of survey responses (including local responses) can be obtained upon request.

The data received from the surveys was supplemented with information on monitoring collected through a general information search. This consisted of a general web review, as well as follow-up from conversations with agency and participant contacts. In many cases, the information collected through this method made it unnecessary to pursue further contacts with specific agencies. Several databases of monitoring information were discovered through this process. The most useful database was the *Better Assessment Science Integrating Point and Nonpoint Sources (BASINS)* system developed by Tetra Tech, Inc. for the U.S. EPA, Office of Water. This system consolidates a number of federal databases to allow easy extraction and use of ecological information on a watershed basis. Several datasets were used in the analysis for this report.

Datasets used to provide monitoring information for this report (including those extracted from BASINS and those obtained elsewhere, are included below. Where possible, dataset summaries are taken directly from metadata provided with the dataset.

The Storage and Retrieval (STORET) System
This dataset provided statistical summaries of water quality monitoring for 47 physical and chemical-related parameters. The parameter specific statistics were computed by station for five-year intervals from 1970 to 1994 and a three-year interval from 1995 to 1997. The data are contributed by a number of organizations including federal, state, interstate agencies, universities, contractors, individuals and water laboratories. Information was extracted from the STORET system for analysis of monitoring coverage for all LaMP pollutants, bacteria, nutrients, and some physical characteristics.

Permit Compliance System (PCS)
PCS is a national computerized management information system that automates entry, updating, and retrieval of National Pollutant Discharge Elimination System (NPDES) data and tracks permit issuance, permit limits and monitoring data, and other data pertaining to facilities regulated under the NPDES program. PCS records water-discharge permit data on more than 75,000 facilities nationwide.

The NPDES permit program regulates direct discharges from municipal and industrial wastewater treatment facilities that discharge into the navigable waters of the United States. Wastewater treatment facilities (also called "point sources") are issued NPDES permits regulating their discharge. Information on the point locations of sites reporting discharges from 1991 through 1996 were included in the analysis for this report.

Toxic Release Inventory (TRI)
This database contains data on annual estimated releases of over 300 toxic chemicals to air, water, and land by the manufacturing industry.

Industrial facilities provide the information, which includes the location of the facility where chemicals are manufactured, processed, or otherwise used; amounts of chemicals stored on-site; estimated quantities of chemicals released; on-site source reduction and recycling practices; and estimated amounts of chemicals transferred to treatment, recycling, or waste facilities.

The TRI data for chemical releases to land are limited to releases within the boundary of a facility. Releases to land include landfills; land treatment/application farming; and surface impoundments, such as topographic depressions, man-made excavations, or diked areas. Air releases are identified as either point source releases or as non-point (i.e. fugitive) releases, such as those occurring from vents, ducts, pipes, or any confined air stream. Surface water releases included discharges to rivers, lakes, streams, and other bodies of water. In addition, the database covers releases to underground injection wells (where chemicals are injected into the groundwater) and off-site transfers of chemicals to either publicly owned treatment works (POTWs) or any other disposal, treatment, storage, or recycling facility.

For use in the assessment for this report, information on the locations of facilities discharging pollutants through any of the above media streams from the years 1987 through 1995 were included.

National Sediment Inventory
This dataset describes the accumulation of chemical contaminants in river, lake, ocean, and estuary bottoms and includes a screening assessment of the potential for associated adverse effects on human and environmental health. The U.S. EPA evaluated more than 21,000 sampling stations nationwide using sediment chemistry data, chemical residue levels in edible tissue of aquatic organisms, and sediment toxicity data. Of the sampling stations evaluated, 5,521 stations were classified as Tier 1 (associated adverse effects are probable), 10,401 stations were classified as Tier 2 (associated adverse effects are possible, but expected infrequently), and 5,174 stations were classified as Tier 3 (no indication of associated adverse effects). Ninety-six watersheds were identified as areas of probable concern for sediment contamination. U.S. EPA believes that these watersheds represent the highest priority for further ecotoxicological assessments, risk analysis, temporal and spatial trend assessments, contaminant source evaluation, and management action because of the preponderance of evidence in these areas (although further evaluation is necessary). Also see the related report entitled the *Incidence and Severity of Sediment Contamination in Surface Waters of the United States, Volume 1, National Sediment Quality Survey* (EPA 823-R-97-006, **http://www.epa.gov/OST**) that was published in September 1997.

Stations monitoring for sediment chemistry data, chemical residue levels in edible tissue of aquatic organisms, and sediment toxicity data were used for the inventory. For this report, information on monitoring station locations, monitoring agency, and type of sampling conducted (i.e. sediment chemistry or biotoxicity/tissue residue).

U. S. Geological Survey Gage Stations
This dataset contains the locations and summary data from USGS stream gaging stations. The gage data were retrieved from the Gage File database. These stations are used primarily to collect continuous stream flow and water level information on target waterbodies. Only gage locations were used in this report.

Aerometric Information Retrieval System (AIRS)
The AIRS system inventories and summarizes air pollutant data from air monitoring stations throughout the United States. The system is funded and maintained by U.S. EPA Office of Air Quality Planning and Standards (OAQPS). The system contains information about and from stations that monitor the following criteria pollutants:

CO - carbon monoxide (gas)
NO2 - nitrogen dioxide (gas)
O3 - ozone (gas)
SO2 - sulfur dioxide (gas)
PB - lead (a constituent of particulate matter)
PM10 - particulate matter (particles smaller than 10 micrometers)

Additionally, AIRS data includes emissions estimates for two more pollutants:

PT - particulate matter (total, all particle sizes - reported in lieu of PM10)
VOC - volatile organic compounds (precursors that can lead to the formation of ground level ozone)

Data on site locations and pollutant monitored were extracted for use in this report.

National Oceanic and Atmospheric Administration (NOAA) Weather Stations and Weather Data Management (WDM) Sites
This data set provides a location map in ARCVIEW Shapefile format of weather stations and WDM stations for the entire United States and U. S. territories. The spatial data was prepared from the National Climatic Data Center Hourly Precipitation database available from EarthInfo, Inc. (**http://www.earthinfo.com/earthinfo/**). The shapefile is prepared and distributed by U.S. EPA regions or states. Information on site locations of weather stations was used for this report.

Fish and Wildlife Consumption Advisory Database
The 1996 update for the database, *Listing of Fish Consumption Advisories*, is now available from the U.S. Environmental Protection Agency. This database includes all available information describing state-, tribal-, and federally issued fish consumption advisories in the United States for the 50 states, the District of Columbia, and four U.S. Territories, and has been expanded to include the 12 Canadian provinces and territories. The database contains information provided to U.S. EPA by the states, tribes, and Canada as of December 1996. This includes advisories issued by several Native American tribes.

The number of advisories in the United States rose by 453 in 1996 to a total of 2,193 representing a 25 percent increase over 1995. The number of waterbodies under advisory represents 15 percent of the nation's total lake acres and 5 percent of the nation's total river miles. In addition, 100 percent of the Great Lakes waters and their connecting waters and a large portion of the nation's coastal waters are also under advisory. The number of advisories in the United States increased for four major contaminants (mercury, PCBs, chlordane, and DDT). In 1996, the U.S. EPA contacted health officials in Canada in an effort to identify fish consumption advisories in effect. In Canada, a total of 2,617 advisories were in effect in 1996. All of the Canadian advisories resulted from contamination from five pollutants: mercury, PCBs, dioxin/furans, toxaphene, and mirex. Ninety-six percent of all the advisories resulted from mercury contamination in fish tissues. In addition, 87 percent of the advisories were issued by the provinces of Ontario and Quebec. Information on the location of advisories, species affected, and flagged pollutants were used in this report.

Lake Michigan Mass Balance (LMMB) Monitoring Sites
This is an unpublished dataset that contains information on sites providing information for the Lake Michigan Mass Balance Project. Information includes locations, and purposes for sampling stations, project names and organizations, and indicators analyzed. The information is contained in three separate datasets, and linkages are based only on project names. Data quality is undefined. Information for this report was extracted from this dataset for monitoring locations, media and pollutants monitored, and organizations conducting the monitoring. The sample data itself has been quality assured and is available upon request from GLNPO.

National Water Quality Assessment Monitoring Sites (NAWQA)
This dataset includes the monitoring stations used in the Western Lake Michigan Drainages study unit for the NAWQA program. Information was collected through the study unit's online database, found through **http://wwwdwimdn.er.usgs.gov/nawqa/index.html**. Information included station identification, location, and flags for one of four types of monitoring conducted: surface water, ground water, sediment and tissue, and biological. More extensive data can also be obtained from this site, including parametric measurements.

Additional Federal/State Datasets

Several monitoring data sets were discovered just prior to final publication of this report. Discussion and general analysis of these sets have been included in the report, but in the interest of time, geographic analysis of monitoring site locations was not completed. Geographic locations of monitoring stations in these data sets will be included in the online version of the monitoring inventory when it is released. General information on these data sets are included below.

Regional Toxic Air Emissions Inventory
This is a multijurisdictional inventory of point, area, and mobile sources of toxic air emissions that have the potential to impact environmental quality in the Great Lakes basin. This initiative was undertaken through an intergovernmental partnership involving the eight Great Lakes states, the province of Ontario, and the U.S. Environmental Protection Agency (U.S. EPA). The objective of this ongoing initiative is to present researchers and policy makers with detailed, basin wide data on the source and emission levels of 82 toxic contaminants. Source and emission levels are projected by each state or province using the *Regional Air Pollutant Inventory Development System (RAPIDS).* The most recent inventory report uses 1996 data and can be found at: **http://www.glc.org/air/1996/1996.html**.

Integrated Atmospheric Deposition Network (IADN)
The Integrated Atmospheric Deposition Network is a joint effort of the United States and Canada to measure atmospheric deposition of toxic materials to the Great Lakes. This network includes a number of stations throughout the Great Lakes, but only one is found in the Lake Michigan basin at Sleeping Bear Dunes National Lakeshore. This station monitors for PCBs, chlorinated pesticides, PAHs, and trace metals in air and precipitation. This site was also included in the analysis of the Lake Michigan Mass Balance Project. Please see discussions on that program for more details.

Sea Lamprey Assessment
Through the Great Lakes Fishery Commission, the Sea Lamprey Integration Committee (SLIC) was established to monitor and control Sea Lamprey infestation throughout the Great Lakes. The Sea Lamprey Assessment Task Force within SLIC establishes plans for monitoring to assess the extent of infestation. In general, tributaries of the Great Lakes systematically are assessed for abundance of sea lamprey larvae (quantitative surveys) and distribution (qualitative surveys) to determine when and where lampricide

treatments are required and effectiveness of past treatments. Results of these assessments are published in annual reports.

***R/V Lake Guardian* Sampling**

The U.S. EPA's Great Lakes National Program Office (GLNPO) annually tours the Great Lakes and samples for phyto- and zooplankton at specified locations. The *R/V Lake Guardian* is used to conduct sampling tows at different depths to obtain data on changes in plankton populations. In addition, the vessel takes a set of standard baseline measurements including conductivity, temperature and depth.

Lakewide Assessment Plan for Lake Michigan Fish Communities

This plan was developed through the Great Lakes Fishery Commission (GLFC) by Departments of Natural Resources from Wisconsin, Michigan and Illinois, as well as the USFWS and USGS-BRD. The plan establishes guidelines for annual sampling of lake trout, chinook salmon, and burbot populations throughout Lake Michigan. For lake trout and burbot, six sampling sites are randomly selected from within eleven regions each year for a total of 66 sampling locations. For chinook salmon, randomly-selected sites are selected along the length (south to north) of the lake in the spring and summer, with 22 sites selected in each season.

Status and Trends of Prey Fish Populations in Lake Michigan, 1999

This report from the USGS Great Lakes Science Center details the monitoring and findings related to sampling of prey fish populations through 1999. The surveys are performed using standard 12-meter bottom trawls towed along contour at depths of 9 to 110 m at each of seven to nine index transects. Information is collected on abundance, species composition, population characteristics, and general fish health.

3. Inventory Results

The ultimate result of nearly one year's work by the GLC, 14 local tributary groups, and other stakeholders, this report represents an inventory of ecological monitoring projects throughout the Lake Michigan basin. The results that follow originate from two basic sources — the survey data, and a supplementary search of relevant datasets. All data is combined into analyses for each of the 14 tributaries, as well as one for the open waters of Lake Michigan.

General Survey Results

Altogether 334 surveys were returned from efforts made by local groups and the GLC. Agencies from all levels of government (federal, state, and local), as well as business, academic, and volunteer organizations from diverse regions of the basin participated in this survey, and added their information to the inventory. Of the responses, 63 percent of the projects primarily monitor water, 5 percent monitor land, 2 percent monitor air, 3 percent monitor soils, 18 percent primarily monitor biota or wildlife, and 9 percent primarily monitor other media (see Figure 2). See specific watershed chapters for discussions about general monitoring characteristics. The frequency of monitoring broke down as follows: daily – 6 percent, weekly – 8 percent, monthly – 10 percent, semiannually – 12 percent, annually – 16 percent, other – 48 percent. Projects staffed the monitoring as follows: paid staff – 65 percent, volunteers – 17 percent, students – 11 percent, other – 7 percent (see Figure 3). The number of staff on monitoring projects range from one to 1000, with the median equal to three people. Nearly 93 percent of the programs provide some sort of training to staff. Budgets for the monitoring projects surveyed range from zero to $12 million, with a median budget of $15,000. Nearly 63 percent reported that funding for the monitoring project was relatively reliable.

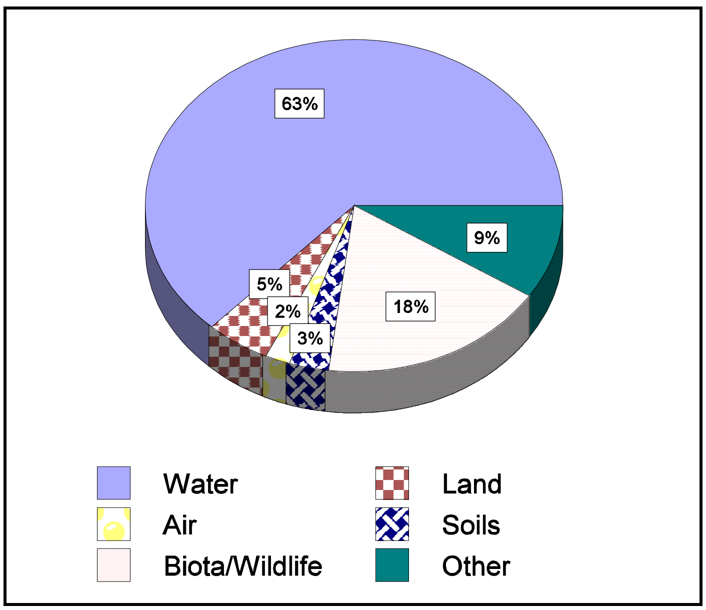


Figure 2. Proportion of survey responses by the primary medium monitored.

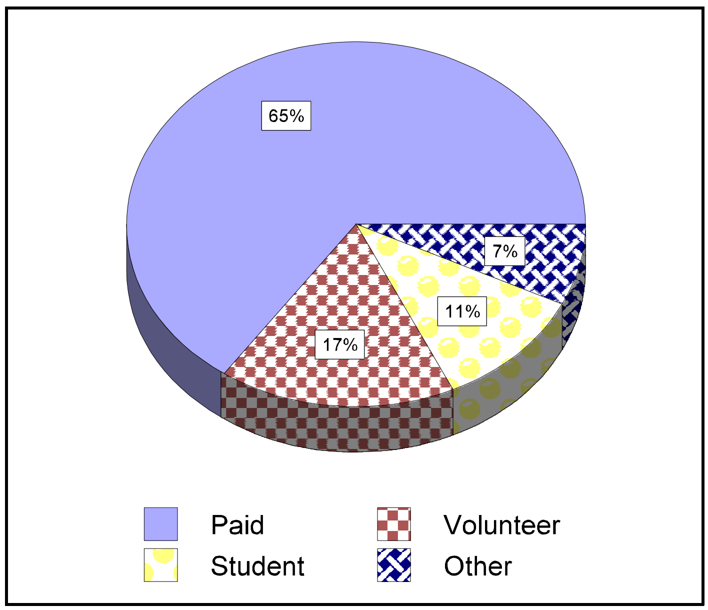


Figure 3. Proportion of survey responses by the type of monitoring staff.

Results Framework

The following chapters contain the analysis of inventory results for all 14 tributaries and the open waters of Lake Michigan, as well as generalized projects which cover multiple watersheds. The chapters are segmented as follows:

- Background
- LaMP pollutants
- Nutrients and bacteria
- Meteorological and flow monitoring
- Sediments
- Fish contaminants, fish health, and aquatic nuisance species
- Benthos monitoring
- Air monitoring
- Wildlife monitoring
- Land use
- Local assessment

Information in the background and local assessment sections was provided by the project participants, with editing by GLC to establish a continuity of flow. The other results-based sections contain integrated information from local project participant surveys, GLC surveys, and external datasets. Where possible, data is geographically displayed. However, each section discusses all monitoring projects, including those for which no specific geographic information was available.

13. Fox-Wolf River Basin

Background

The Fox-Wolf River basin of Northeast Wisconsin is a 6,400 square mile drainage area with three distinct sub-basins: the Wolf River, the Upper Fox and Lower Fox River. The Wolf and Upper Fox Rivers drain south and east (respectively) into the Lake Winnebago "pool" lakes and then north through the Lower Fox River to the bay of Green Bay. The Fox-Wolf Basin is the largest drainage basin to Lake Michigan and the third largest to the Great Lakes.

For purposes of this report, the discussion will address all three sub-basins and Lake Winnebago. However, the graphic display and majority of the discussion will focus on the Lower Fox River watershed. Lower Green Bay is also part of the AOC in this area, however, the bay is assessed as part of greater Lake Michigan Open Water chapter. Please see that chapter for further information.

Status of Watershed Management Efforts in the Study Area

Watershed management in the Fox-Wolf basin is conducted under a variety of program initiatives – primarily Wisconsin's Nonpoint Source Pollution Abatement Program (a.k.a. the Priority Watershed Program) and the Wisconsin Pollution Discharge Elimination System program. Ten of the basin=s 41 watersheds have been identified as priority watersheds. County Land Conservation Departments are provided with state funds for staff and overhead to conduct watershed inventories, develop management plans, contact landowners, and offer cost-share funds to install BMPs.

Funds are also available to other local units of government in urban or urbanizing areas of the watershed. Recently, this program has undergone a re-design which has yet to be completed. No additional watersheds are expected to be selected under the new program, but efforts will continue through local governments on a more limited scope and time frame.

Many other local, state and federal initiatives work on some component of watershed management in the Fox-Wolf basin, too numerous to mention in this introduction. Initiatives range in function from voluntary cost-share programs to local ordinances to state and federal permitting. A recent reorganization of the Department of Natural Resources has established geographic management units (GMUs) designed to better coordinate programs and involve all agencies and individuals. GMU (or Basin) Partner Teams have been established in the Upper Fox, Lower Fox and Wolf River Basins.

Pollutants of Concern

Aquatic Monitoring

Monitoring coverage for LaMP pollutants reported into the STORET system is shown in Figure 43. This maps indicates that stations exist for two (mercury and PCBs) of seven critical pollutants, six out of ten pollutants of concern, and none of the listed emerging pollutants. Monitoring for all pollutants is relatively light compared to other watersheds in this analysis. The monitoring is heaviest along the lowest section of the Fox River where it flows out into Green Bay. There are 12 stations monitoring mercury at our near the Fox River outfall, while there are 28 stations for the rest of the Fox-Wolf basin (four in the Lower Fox, three at the entrance and exit of the Fox River to Lake Winnebago, three in the Upper Fox, and 18 in the Wolf River watershed). Ten PCB stations have been placed along the Lower Fox, with one on the shore of Lake

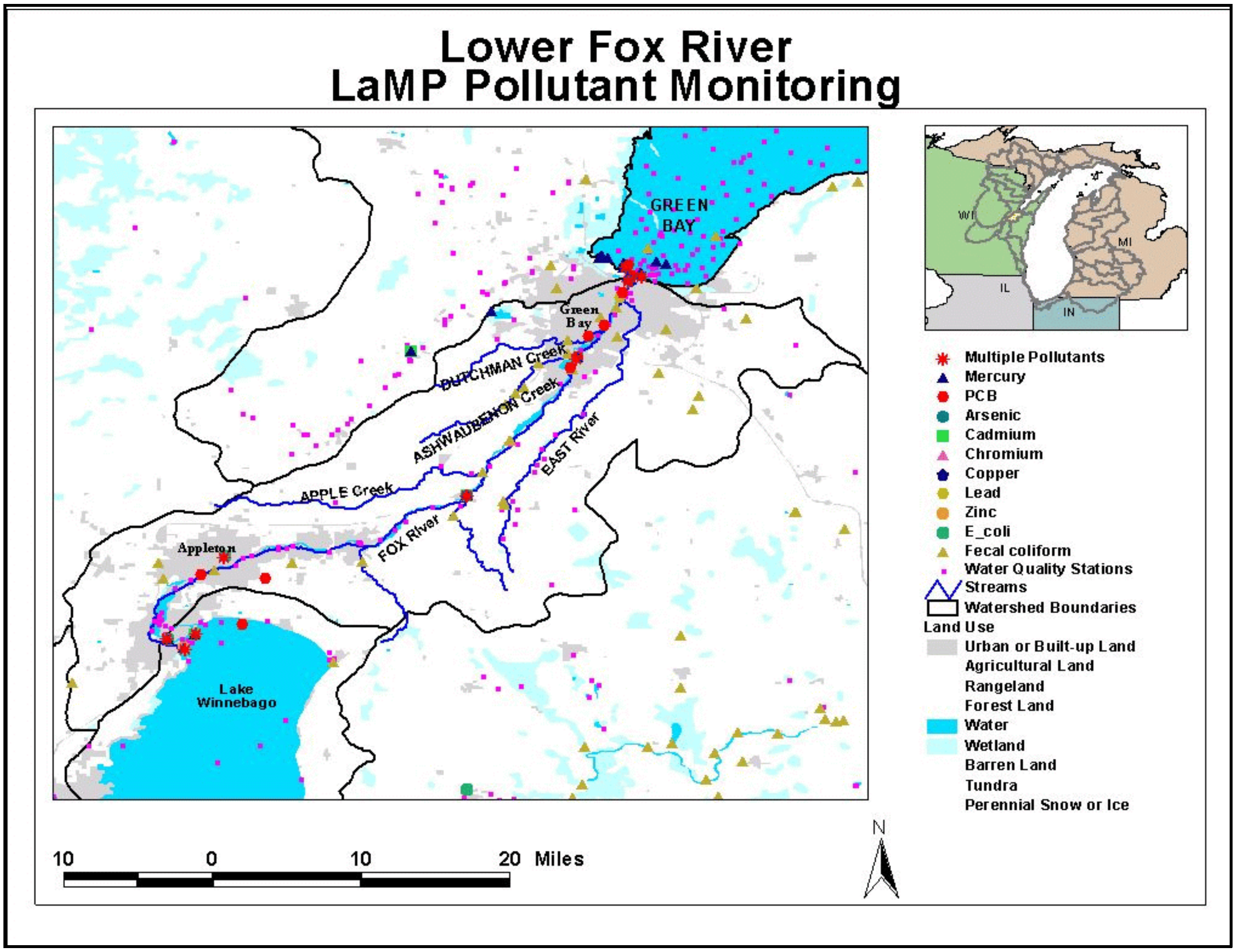


Figure 43. The Lower Fox River watershed with ambient water quality and bacteria monitoring stations from U.S. EPA's STORET system displayed by indicators measured.

Winnebago. The stations monitoring for LaMP pollutants are maintained by WDNR, U.S. EPA (3 programs), COE, USGS-WRD (NAWQA and baseline stations), or EPRI.

In addition, surveys indicate that the Green Bay MSD monitors for all LaMP pollutants with the exceptions of dioxins/furans, hexachlorobenzene, PAHs, and atrazine. This monitoring is conducted on the Lower Fox River at its outflow to Green Bay. Also, the University of Wisconsin-Stevens Point tracks atrazine in the Tomorrow-Waupaca River watershed.

Pollutant Release Monitoring

An examination of Permit Compliance System and Toxic Release Inventory reporting locations in the Fox-Wolf basin indicates a large number of monitoring locations for potential pollution sources throughout the basin (see Figure 44). Clusters of these locations can be found all along the Lower Fox River, as well as in Oshkosh on the western shore of Lake Winnebago, in Fond du Lac on the south shore, and on the shore of Shawano Lake in the Wolf River watershed.

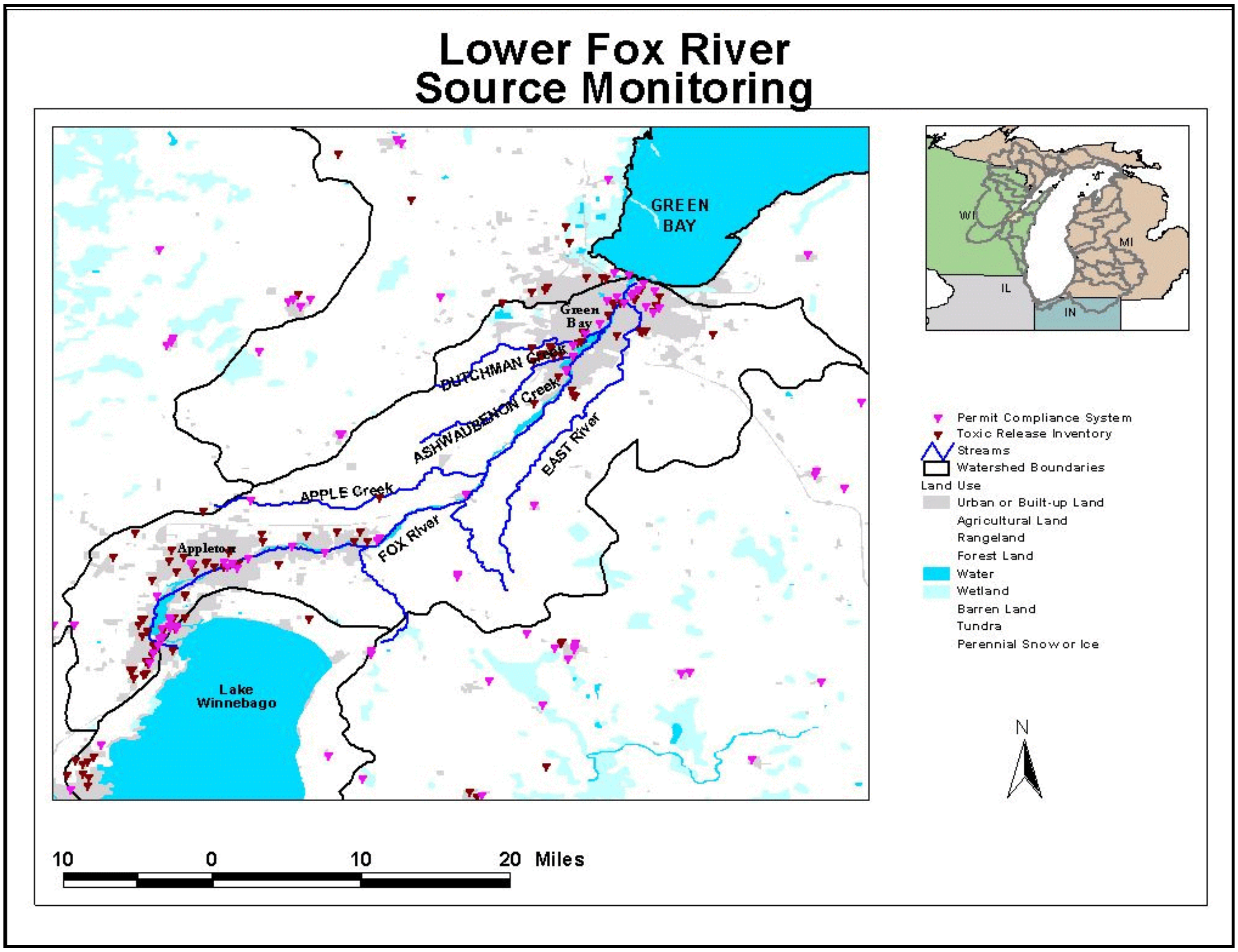


Figure 44. Lower Fox River watershed with pollutant sources from the Permit Compliance System and Toxic Release Inventory databases indicated.

Nutrients and Bacteria

There are more than 120 water quality monitoring stations within the Lower Fox River watershed listed in the STORET system. An additional 720 stations are located throughout the remaining watersheds in the Fox-Wolf basin. Also, there are a large number of stations in the near shore region of Green Bay. A vast majority of these stations (shown in Figure 43) monitor for some form of nitrogen and phosphorus, the chief nutrients impacting water quality. Thus, where monitoring stations exist, they are likely tracking nitrogen and phosphorus. The density of stations is greater at the Fox River outfall to Green Bay, but the rest of the stations are distributed fairly evenly throughout the basin. According to our surveys, there are several other organizations in the basin monitoring for nutrients. These include the Brown County Land Conservation Department, the University of Wisconsin-Stevens Point, the Green Bay MSD, Waupaca County Land Conservation Department, University of Wisconsin-Milwaukee, Green Bay RAP, and Green Bay Public Schools WAV.

Eleven stations monitor *E. coli* in the Fox-Wolf basin — three in the Lower Fox, six in the Upper Fox (including three on Lake Butte Des Morts), and two in the Wolf watershed. All 11 stations are maintained by WDNR. Monitoring for fecal coliform is significantly more extensive. About 120 stations can be found throughout the basin. As with other monitoring coverage in the basin, monitoring of fecal coliform levels is

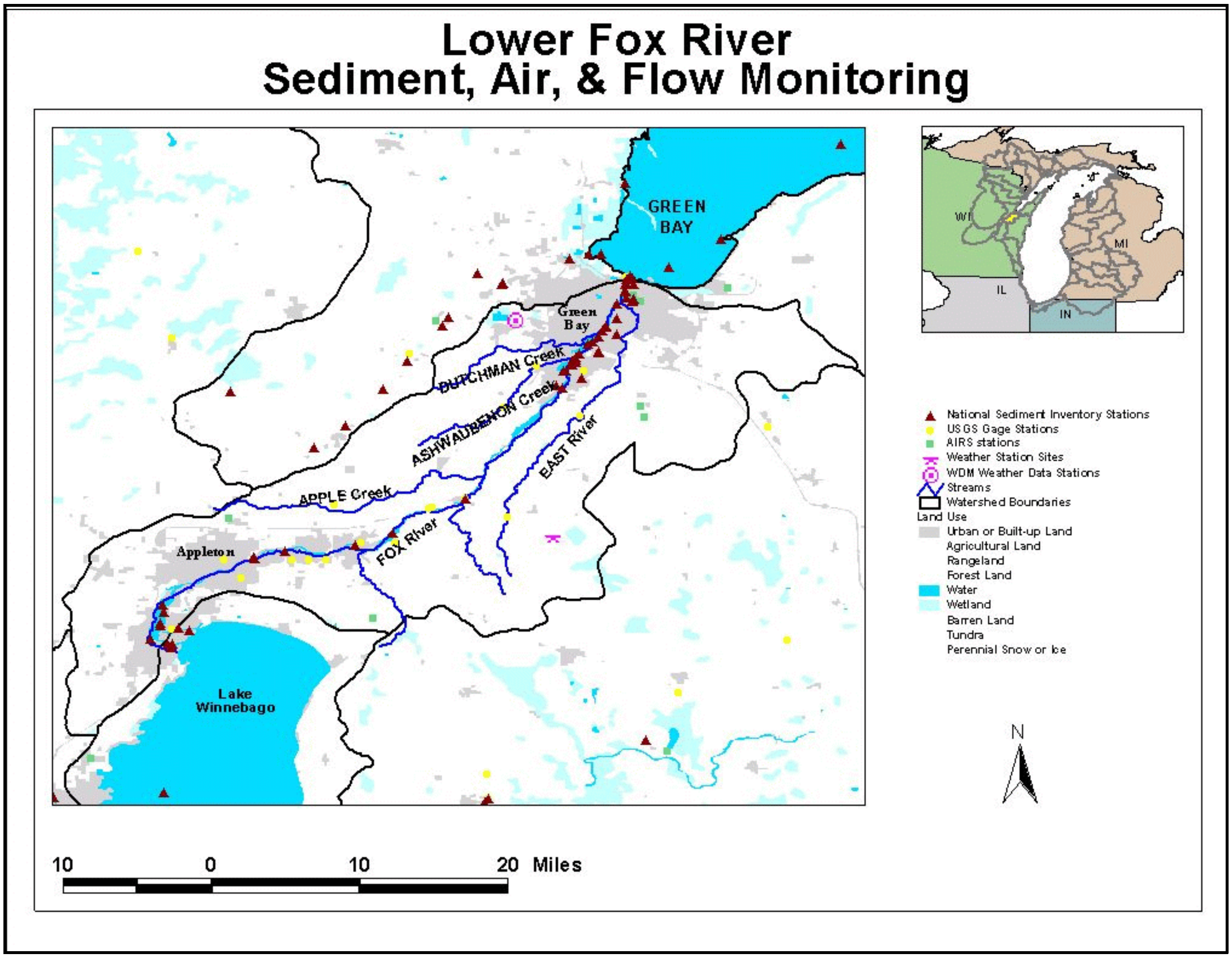


Figure 45. Lower Fox River watershed with National Sediment Inventory stations, USGS gage stations, U.S. EPA's Aerometric Information Retrieval System (AIRS) stations, and NOAA weather stations indicated.

clustered near Green Bay. However, there are numerous stations distributed throughout the rest of the basin. Organizations monitoring for fecal coliform in the watersheds include WDNR, USGS-WRD, U.S. EPA, and the U.S. Forest Service (USFS). In addition, two other organizations report through surveys to monitor bacteria in the basin. These include Brown County Land Conservation Department and Brown County Health Department.

Meteorological and Flow Monitoring

USGS maintains 85 gage stations throughout the Fox-Wolf basin to measure flow rates and various other physical characteristics of streams (see Figure 45). Some of these stations have been used for physical and chemical monitoring through the NAWQA program. Gage stations are located on all major rivers and streams in the watershed.

Several organizations also reported that they monitor numerous physical properties in streams in the basin. These include the Brown County Land Conservation Department, WDNR, the Oneida Tribe of Indians, and Green Bay MSD. Paper mills also monitor physical properties through their Industry Rivers Study

Committee. Physical properties measured by all these organizations include stream flow, temperature, pH, dissolved oxygen, biological oxygen demand, chlorophyll, suspended solids, and turbidity.

Three NOAA weather stations are located in the Fox-Wolf basin, and one other station is located just outside the northern boundary of the Wolf watershed. The stations inside the watershed are located within and south of Green Bay in the Lower Fox, and in New London in the southern portion of the Wolf watershed. The station north of the Wolf is located at the Laona Ranger Station in the Nicolet National Forest. These stations measure continuous precipitation data, as well as other meteorological data.
Sediments

There are 97 National Sediment Inventory sites within the Fox-Wolf basin (see Figure 45). The sites are clustered along the Lower Fox, at the inlets and outlets of the "pool" lakes, and along the Red River in the Wolf watershed. Other sites are located more randomly throughout the watersheds in the basin. These sites are administered by the WDNR, USGS-WRD, and U.S. EPA. Some of these sites are involved in cooperative projects between USGS-WRD, WDNR, and Oneida and Menominee Tribes, involving PCB sediment remediation, agricultural BMPs, and trace elements from the Crandon Mine. The Green Bay MSD also reports to conduct some sediment sampling. About 50 of the sites monitor sediment chemistry to assess human health and aquatic life impacts. A total of 48 sites monitor benthic organism tissue, discussed below.

Fish Contaminants, Fish Health, and Aquatic Nuisance Species

As discussed earlier, we have been unable to find specific locational information (i.e. sampling locations) for programs monitoring fish populations or their health. There are statewide programs in existence, but these are discussed in the overall findings discussion. The National Sediment Inventory lists 48 stations that monitor fish tissue to assess the impacts of sediment contamination. These are located throughout the basin, and are administered by WDNR and the U.S. EPA. USGS also maintained NAWQA stations in the basin to examine fish tissue. Two organizations also conduct fish habitat assessments. These include WDNR and the Oneida Tribe of Indians.

A search of the Fish and Wildlife Advisory database on all major Fow-Wolf basin waterbodies revealed fish consumption advisories for nine locations in the basin. Advisories had been issued for six sections of the Fox River, all of the Lake Winnebago "pool" lakes, Shawano Lake, and a section of the Wolf River. In addition, fish advisories have been issued for most of Green Bay. The advisories were all state issued, covered a variety of fish species and related to PCB and mercury levels.

One program was discovered to be monitoring for zebra mussels within the Fox-Wolf basin. The WDNR monitors zebra mussel veligers in the Fox River. Refer to the overall discussion of Lake Michigan monitoring for a discussion about programs that cover multiple tributary watersheds.

Benthos Monitoring

No specific locational information was discovered for state or national programs monitoring benthic organisms. However, several organizations report that they collect macroinvertebrate data (including community composition, and structural and functional integrity) in numerous locations in the basin. These organizations include WDNR (for the Index of Biotic Integrity (IBI)), Brown County Land Conservation Department, Integrated Paper Services, Inc. Other organizations may be monitoring benthic organisms generally in the watershed, among others. These are discussed in the overall discussion of Lake Michigan monitoring (see the NAWQA discussion, for example).

Air Monitoring

Figure 45 illustrates the locations of the 13 air monitoring stations in the basin, according to the U.S. EPA's AIRS database. The stations are distributed evenly throughout the basin. The stations monitor for three of eight indicators in the database, including low-level ozone, particulate matter, and sulfur dioxide.

Wildlife Monitoring

Several organizations are monitoring wildlife in the basin. The Northeast Wisconsin Audubon cunducts an annual bird count; the University of Wisconsin-Green Bay Richer Museum monitors colonial nesting birds; Long Point Bird Observatory monitors breeding marsh birds and amphibians at a couple of sites; and Barkhausen and Green Bay Wildlife Sanctuaries track various bird populations. In addition, there are organizations monitoring wildlife species in the basin on a more regional basis. These are discussed in the overall discussion of Lake Michigan monitoring.

Land Use

The Lower Fox watershed consists of a large portion of urbanized land with relatively few wetlands. Large developments include Green Bay, Appleton, Menasha, Oshkosh, Neenah and Fond du Lac. A substantial portion of the rest of the basin does exist as wetlands. Large wetland areas can be found throughout the Wolf watershed, especially around the headwaters of the Wolf River. The wetlands are not extensively monitored, except in the Wolf headwaters.

Local Assessment

One of the best examples of monitoring data put to beneficial use is "The State of the Bay: A Watershed Perspective" produced by UW-Green Bay's Bud Harris. This very simple, graphicly based format has been an exceptional education tool in a variety of contexts. Dr. Harris is initiating, with Fox/Wolf Basin 2000 assistance, a Strategic Data Acquisition Task Force to help expand monitoring coordination, improve data analysis and guide future activity.

From the perspective of a non-profit watershed alliance (Fox/Wolf Basin 2000), there are several important points to be made with regard to monitoring in the Fox-Wolf basin. First, where data is collected and disseminated, it has been particularly helpful in making the case for enhanced watershed management efforts as well as adding to the understanding of watershed functions and conditions. However, there is likely a large amount of monitoring that was not discovered through this project. Further efforts need to be made to complete the Fox-Wolf basin content in the monitoring database.

When the data collection is not coordinated from a geographic perspective consistently over the years, the ability to effectively manage resources on a watershed basis is lost. Evidence of this is found in this statement taken from the Lake Winnebago Comprehensive Management Plan compiled by the Wisconsin Department of Natural Resources in 1989:

> "There are no current ongoing programs in DNR or other agencies to collect the short- or long-term information necessary to allow adequate assessment of any efforts to reduce nutrient or sediment loading."

Granted, there are some monitoring programs designed to help resource managers, for example the "Single Sites Program" initiated by the WDNR and assisted by USGS. However, according to an observation made by a WDNR employee during a recent Fox-Wolf Basin Strategic Data Acquisition Task Force meeting, WDNR's current "Baseline Monitoring Program" is constrained by U.S. EPA guidelines for data collection in support of Clean Water Act Section 305(b) reports — guidelines that may not be conducive to monitoring to understand ecosystems, evaluate programs or enhance watershed resource management.

Fox-Wolf Basin 2000's own experience in the Pigeon River Watershed (Wolf sub-basin) provides an example. Data collected on the watershed and its impoundment were somewhat scattered among a variety of locations and program files. When brought together, the information was helpful in developing an understanding of the condition of the watershed and the history leading to those conditions. Two data points 20 years apart suggested an annual sedimentation rate in the impoundment near the outlet of the watershed. But because little assessment was done upstream of the impoundment in that time, interpretations of the problem ranged from blaming eroded stream banks to poor farmland management to a golf course upstream to shoreline erosion on the impoundment itself. While those arguments ensued, many citizens responded to additional monitoring efforts by calling for action in the place of monitoring. One recent action, at a cost of about $100,000, was a series of highly visible shoreline stabilization projects that will do little to address the upstream soil and nutrient inputs.

It should also be noted that the information that was derived from the limited data available in the Piegeon River Watershed paralleled some of the "gut" feelings of long-time users or managers of the resource. This suggests anecdotal data and information also needs to be recorded and made accessible. However, this gives rise to another limitation we have encountered – the "quality" of data. The state has a Self-Help Monitoring Program and a Water Action Volunteer Program that encourages citizens to collect basic data (water clarity, phosphorus concentrations and temperature, for example). Efforts to expand such activity have been met with staunch criticism because the data collected would not be reliable and could not meet the rigors of quality assurance and control. Indeed, the uncertainty of anecdotal or non-professionally gathered data have made it easy for those asked to change land use practices or behaviors to question whether they are really the problem.

Another limitation has to do with the measurement of the efficacy of nonpoint source best management practices (BMPs) on a broader (subwatershed or catchment) scale. Much of the research available on BMPs was done in very narrowly defined contexts, which creates a lot of uncertainty when applying pollution reduction efficacy on a broader scale. Little, if any, of the studies look at long term efficiency – how well a practice performs after several years or what kind of maintenance needs and costs can be expected. In addition, literature reviews generally provide a broad range of efficacy estimates. For example, nutrient and sediment reduction rates of 5-90 percent were reported in studies assessing the effectiveness of vegetative filter strips (or buffers). Paired watershed study-designs have been proposed (and implemented in some areas) to address this deficiency. However, they are longer term, a bit unwieldy in garnering adequate participation and quite costly to conduct.

Several observations have been made in the past that there is plenty of data, but little information. The current movement in the Fox-Wolf basin to develop a coordinated monitoring framework is indicative of the inadequate quantity of data, quality of analysis and availability of information necessary to improve watershed management activity.

14. Door County

Background

The study area, Door County, is located in northeast Wisconsin and lies entirely on the Door Peninsula in the Door-Kewaunee watershed. The peninsula is bordered by Lake Michigan on one side and Green Bay on the other. The geology of the peninsula is comprised primarily of dominantly Silurian-aged dolomite. This fractured, calcareous bedrock is easily modified by the dissolution of the bedrock into karst features. These karst features, combined with the relatively thin soil layer found through much of the peninsula, create a high potential for groundwater and surface water contamination.

Status of Watershed Management Efforts in the Study Area

The nature of the geology has been a concern for soil and water conservationists. In particular, these concerns have in large part been at the heart of many of the initiatives and projects of the county's Soil and Water Conservation Department (SWCD). Additionally, the Wisconsin Department of Natural Resources developed a *Water Quality Management Plan* in March of 1995 serving as a guide to water resource activities with a focus on the Door-Kewaunee watershed. Initiatives of the SWCD and the WDNR remain in place as part of a comprehensive watershed management program. These have been the more visible efforts at resource management on the peninsula.

Pollutants of Concern

Aquatic Monitoring

Monitoring coverage for LaMP pollutants reported into the STORET system is shown in Figure 46. As should be obvious from the map, there appears to be no monitoring of LaMP pollutants on the penninsula. In total, there are only 57 water quality monitoring stations in the entire peninsular watershed.

Pollutant Release Monitoring

An examination of Permit Compliance System and Toxic Release Inventory reporting locations in Door County indicates only a few monitoring locations for potential pollution sources throughout the county (see Figure 47). There are now distinct clusters of these locations.

Nutrients and Bacteria

As mentioned previously, there are 57 water quality monitoring stations within the Door-Kewaunee watershed listed in the STORET system. Several others can be found around the peninsula in Green Bay and Lake Michigan. A vast majority of these stations (shown in Figure 46) monitor for some form of nitrogen and phosphorus, the chief nutrients impacting water quality. Thus, where monitoring stations exist, they are likely tracking nitrogen and phosphorus. The stations are distributed fairly evenly across the peninsula. These stations are maintained by WDNR, U.S. EPA, and USGS-WRD. According to our surveys, the Village of Ephraim WWTP monitors phosphorus inputs into Green Bay. The Fish Creek Watershed Study Committee may also be conducting some nutrient tracking along Fish Creek. Additionally, the Door County Sanitation Department monitors ground water for unspecified contamination.

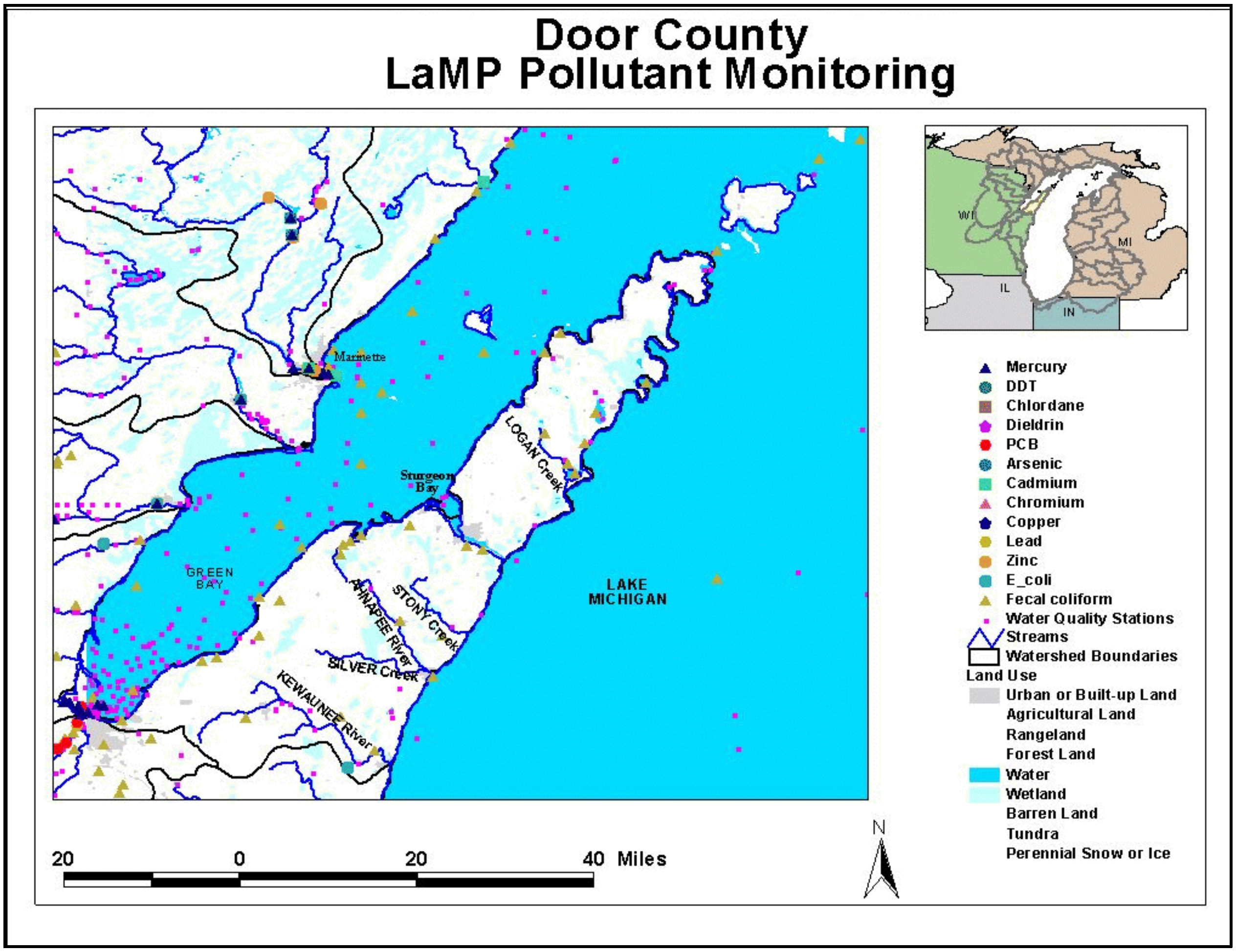


Figure 46. The Door-Kewaunee watershed with ambient water quality and bacteria monitoring stations from U.S. EPA's STORET system displayed by indicators measured.

One station monitors *E. coli* in the watershed on the Kewanee River. The station is maintained by WDNR. Monitoring for fecal coliform is significantly more extensive. About 29 stations can be found throughout the watershed. Most of the stations are located along the shoreline, but there are a number of stations distributed throughout the rest of the peninsula. WDNR maintains all the fecal coliform monitoring stations in the watershed.

Meteorological and Flow Monitoring

USGS maintains five gage stations throughout the Door-Kewaunee watershed to measure flow rates and various other physical characteristics of streams (see Figure 48). All gage stations are located on the Lake Michigan side of the watershed. In addition, the Village of Ephraim WWTP monitors suspended solids near their output into Green Bay.

One NOAA weather station is located on the peninsula. The station is located in Kewaunee at the southeastern corner of the watershed. NOAA stations measure continuous precipitation data, as well as other meteorological data.

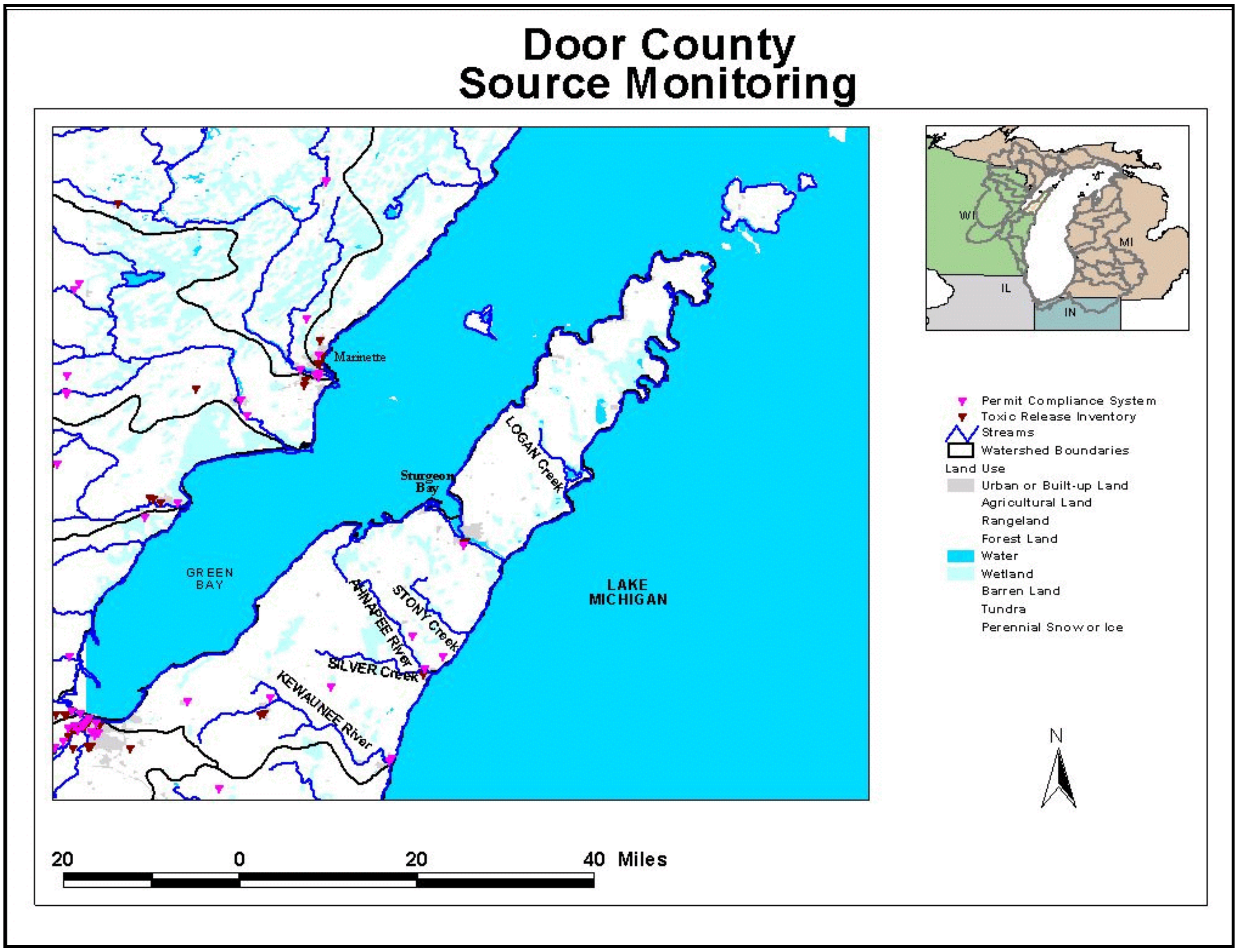


Figure 47. Door-Kewaunee watershed with pollutant sources from the Permit Compliance System and Toxic Release Inventory databases indicated.

Sediments

There are 20 National Sediment Inventory sites within the watershed (see Figure 48). A cluster of sites are located in Sturgeon Bay and the rest are distributed along the shoreline around the peninsula. These sites are all administered by the WDNR. About half of the sites monitor sediment chemistry to assess human health and aquatic life impacts. A total of 11 sites monitor benthic organism tissue, discussed below.

Fish Contaminants, Fish Health, and Aquatic Nuisance Species

As discussed earlier, we have been unable to find specific locational information (such as sampling locations) for programs monitoring fish populations or their health. There are statewide programs in existence, but these are discussed in the overall findings discussion. The National Sediment Inventory lists 11 stations that monitor fish tissue for bottom contamination. These are located throughout the basin, and are administered by the WDNR.

A search of the Fish and Wildlife Advisory database on all major Door County waterbodies revealed fish consumption advisories for two locations in the basin. Advisories had been issued for the Kewaunee River,

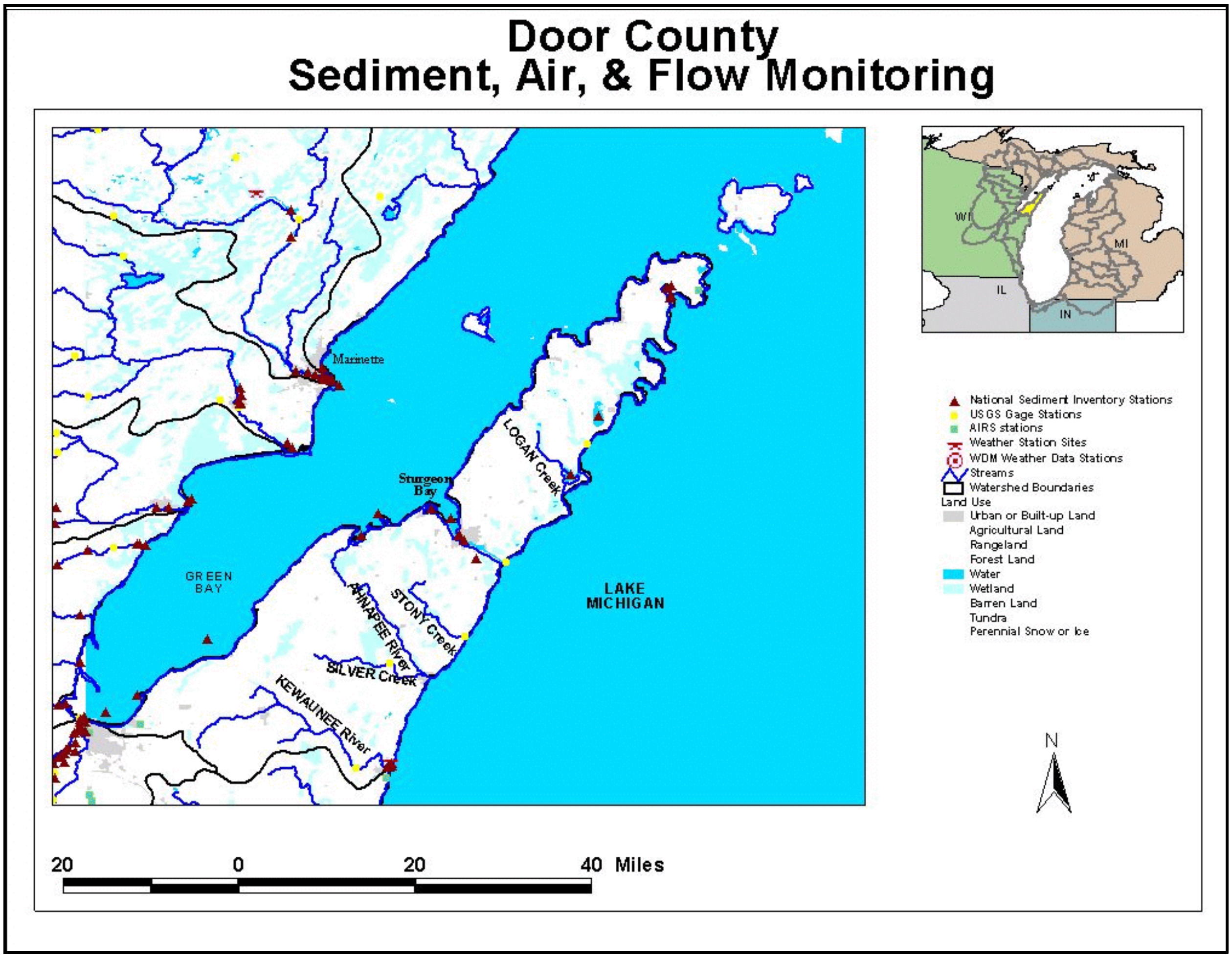


Figure 48. Door-Kewaunee watershed with National Sediment Inventory stations, USGS gage stations, U.S. EPA's Aerometric Information Retrieval System (AIRS) stations, and NOAA weather stations indicated.

and the Ahnapee River. The advisories were all state issued, covered a variety of fish species and related to PCB levels.

No programs were discovered to be monitoring for aquatic nuisance species within the watershed. Refer to the overall discussion of Lake Michigan monitoring for a discussion about programs that cover multiple tributary watersheds.

Benthos Monitoring

No specific locational information was discovered for state or national programs monitoring benthic organisms. Several organizations may be monitoring benthic organisms generally in the watershed, among others. These are discussed in the overall discussion of Lake Michigan monitoring.

Air Monitoring

Figure 48 illustrates the locations of the two air monitoring stations on the peninsula, according to the U.S. EPA's AIRS database. One station is paced at the far western border of the watershed, while the other is on the easternmost tip of the peninsula. Both stations monitor low-level ozone.

Wildlife Monitoring

One private citizen reports to be monitoring wildlife abundance at an unspecified site on the peninsula. There are other organizations monitoring wildlife species generally throughout the Lake Michigan basin. These are discussed in the overall discussion of Lake Michigan monitoring.

Land Use

Many large wetland areas exist across the peninsula. The Lower Fox watershed consists of a large portion of urbanized land with relatively few wetlands. The wetlands are not extensively monitored by water quality stations. The only urbanized development in the watershed is Sturgeon Bay. Most of the watershed consists of agricultural and forest lands.

Local Assessment

Three of the seven area watersheds are designated as Priority Watershed Projects and continue to receive attention through multiple state and local programs designed to reduce water pollution. These programs include nutrient and pest management, soil erosion, and pollution abatement cost-share programs. Door County recently prepared a *Land and Water Resource Management Plan* setting goals and objectives in moving toward improved management of the landscape and protection of water and other natural resources in the county.

The *Water Quality Management Plan* developed for the Door-Kewaunee Basin (1995) identified a number of problem areas and offered a number of recommendations, many of which are in process of implementation. However, a comprehensive area-wide monitoring initiative involving broad collaboration between volunteer organizations and local and state agencies may prove to be a possibility in light of the increasing pressures of development.

Duplication of monitoring efforts does not appear to be an issue, but rather the issue is one of a consistent set of monitoring programs directed toward lakes and streams.

There are several particular areas where attention could be beneficial:

- Improvement in data collection from water quality sampling and well drilling operations, wherein data could be assembled in a form that would allow for qualitative and quantitative analysis on a county-wide basis.

- Creation of additional lake associations, whose members and volunteers could institute regular water monitoring programs. Preliminary work is in process to organize additional lake associations and energize the two that exist to help develop monitoring programs similar to others throughout the state. The Wisconsin Association of Lakes is the reference source for this work.

- The most significant of emerging issues focus on growth and development and the implication toward development pressure from the planned expansion of Highway 42-57. This highway runs from Green Bay to Sturgeon Bay, and is planned for expansion from the current two lane road to a four lane divided highway.

- Collaborative partnerships such as the Door County Stewardship Council offer opportunities to enhance coordination of long-term monitoring programs.

- The Stewardship Council is working to develop coherent strategies that leverage the resources of all local and state agencies and some federal agencies. While we are moving toward cooperative relationships with various organizations, including local governments, a number of people foresee opportunities for coordinated programs that will leverage current standard or routine programs. One missing piece is for the council activities to bridge connections to neighborhood and Lake Associations that would generate an increased interest in watershed protection issues.

19. Findings and Recommendations

The final section of this report centers on general issues that were uncovered throughout the course of research. There are three key areas under which the monitoring inventory provided valuable information and recommendations for improving overall monitoring in the Lake Michigan basin. These include data gaps and unmet needs; underutilized resources; and monitoring coordination and information sharing. Findings are summarized below for these areas, followed by recommendations for improving monitoring infrastructure and use. For reference purposes, sections are labeled with letters and findings and recommendations are numbered.

A. Data Gaps and Unmet Needs

This report, and the inventory on which it is based, represent the first effort to account for the range of environmental monitoring in the Lake Michigan basin. The inventory represents the initial approach toward achieving this ambitious goal. It is a framework on which a more complete inventory will eventually be built.

(1) Finding: There are several gaps in the inventory that are listed below and throughout the report. While some of these gaps are areas that have not been well covered in the inventory, others may represent gaps in the monitoring coverage. At this point, it is difficult to tell which are gaps in the monitoring inventory and which are actual monitoring gaps. Further improvement of the inventory database is needed to better clarify this distinction.

(1.1) Recommendation: *Continue to update the inventory and expand data collection to include all tributaries.* Fourteen tributaries were covered extensively in this project. The update should carry out the same research process with the other tributary watersheds in the basin.

(2) Finding: There are several key monitoring areas where little information was received, but where more monitoring is believed to exist. These areas include monitoring for *E. coli*, fish population characteristics, aquatic nuisance species, benthic organisms, wildlife, and habitat. We received some information about *E. coli* monitoring from county health departments and other local agencies, but believe more local agencies conduct such monitoring. For the other areas, we have some evidence to believe that state Departments of Natural Resources and federal agencies such as the U.S. Fish and Wildlife Service, U.S. Forest Service, and U.S. Department of Agriculture conduct monitoring programs in these areas. We received limited information about efforts made in specific watersheds by these agencies, but most of this information came from indirect sources. It is important that these agencies supply more complete information on their monitoring efforts to improve the overall completeness inventory.

(2.1) Recommendation: *Establish better lines of communication with state DNRs, USFWS, USFS, and USDA.* Further work needs to be carried out in order to obtain information from these agencies on their monitoring programs. This will fill in some of the major gaps in the inventory database.

(2.2) Recommendation: *Better integrate habitat and wildlife monitoring with traditional water quality monitoring.* One of the most difficult tasks needed to complete the monitoring inventory was to convince natural resource agencies that wildlife and habitat monitoring should be included in the inventory along with more traditional water quality monitoring. Agencies conducting monitoring in these areas must develop a better understanding of how all monitoring information can fit together so that policy makers, residents, and other stakeholders have access to a complete database of environmental monitoring information.

(3) Finding: Another result of this initial approach to the monitoring inventory for the Lake Michigan basin was that much of the information included only general information about the geographic location of monitoring sites. Many organizations reported monitoring for parameters across a broad geographic area but did not include specific site references. Locational information is critical if the inventory is to be brought online in a geographically-searchable format.

(3.1) Recommendation: *Improve information on the geographic location of monitoring sites.* This is especially true for monitoring programs at the local level. This will require extensive follow-up communication with those who originally reported into the inventory database.

(4) Finding: A further gap in the monitoring information obtained for this report, was the lack of complete and continuing coverage of Lake Michigan Mass Balance data. The Mass Balance project was a first of its kind sampling event designed to collect data across several variables in a coordinated fashion. The information produced by a project of this magnitude is valuable throughout the monitoring community. However, a project as large and complex as the Mass Balance project requires substantial time to collect, verify, validate, integrate, analyze, and report on the data. At the time the research for this report was conducted, most of the data from the Mass Balance project was not readily available for public consumption. Therefore, information contained in this report on sampling within the Lake Michigan Mass Balance project is incomplete and limited mostly to sampling location and general sampling focus. The data collected for the project has been quality assured, and, when released, will be more detailed. When these results are released, they will be added to the online version of the inventory database. Additionally, the value of coordinated sampling data (as collected in the Mass Balance project) would be greatly enhanced by a repeat of the sampling event ten years following completion of the original sampling.

(4.1) Recommendation: *Initiate planning for a coordinated sampling event for ten years following the initial Mass Balance project, and share data and modeling results with the public in a timely fashion through numerous outlets.*

(5) Finding: This initial project specifically avoided attempting to collect information about university monitoring projects. There were two reasons for this. First, much academic research is conducted in one-time, short-term projects, and therefore does not meet the need for baseline information and ongoing monitoring. Second, universities are complex environments with numerous independent research projects being conducted across each campus. However, some academic institutions conduct a number of important ongoing, long-term projects, and information on these projects should be included in the inventory. Sea Grant programs and other institutes catalog the university work they fund. Closer ties need to be established with these programs and such efforts need to be expanded throughout the basin.

(5.1) Recommendation: *Include academic research and data collection efforts in future updates to the monitoring inventory.*

(6) Finding: While a number of LaMP pollutants, such as mercury and copper, are monitored extensively across the basin, it has been difficult to find monitoring information on some of the other pollutants. These under-monitored pollutants include all the emerging LaMP pollutants, along with DDT, HCBs, toxaphene, and PAHs. The need for monitoring of these pollutants should be clarified.

(6.1) Recommendation: *Further examine the monitoring coverage of specific LaMP critical pollutants and emerging pollutants.*

B. Underutilized Resources

Along with the gaps in monitoring coverage identified in this project, some resources in the basin were also discovered that do not appear to be fully utilized. Monitoring is an area of environmental management that has often been underfunded in the past. Therefore, in order to achieve the most complete monitoring coverage possible, one must take advantage of all available resources. If resources, such as monitoring personnel, go unutilized, then some aspects of a complete monitoring coverage must be sacrificed. To avoid such a sacrifice, creative methods must be used to combine these underutilized resources with other monitoring programs.

(1) Finding: One of these underutilized resources is volunteer groups. These groups represent a vast pool of potential data collection personnel. Most of the volunteer groups currently engage in some form of monitoring, but often their efforts are not incorporated into state or regional monitoring plans, and the information collected is only reported internally or locally. These volunteers need to be better enabled to contribute to regional monitoring efforts. The challenge lies in preparing volunteers to collect environmental information in such a way that it is both accurate and relevant to regional needs, and of sufficient quality to be useful for resource managers and policy makers.

(1.1) Recommendation: *Take better advantage of relatively untapped volunteer monitoring resources.*

(2) Finding: Another group that is underutilized is local agencies. Examples of such agencies are health departments, conservation districts, and planning agencies. In many cases, these agencies are already engaged in monitoring to serve their local needs. Most of the agencies employ professionals trained to accurately monitor environmental parameters. These groups were discovered sporadically in the process of constructing the monitoring inventory. Several health departments reported monitoring of surface and ground waters for *E. coli*, coliform, and other contaminants of special interest to public health officials. Conservation districts may individually be monitoring for a number of parameters related to nonpoint source pollution, general water quality, or other issues. Planning agencies or commissions track population, mass transportation status and other land use characteristics for planning and funding purposes. It is likely that other similar agencies are also conducting monitoring programs. Information on these programs needs to be incorporated into the inventory. Also, there is an opportunity to link these agencies into basinwide monitoring efforts.

(2.1) Recommendation: *Take better advantage of local agencies such as health departments, conservation districts and planning agencies.*

(3) Finding: To best capitalize on these underutilized resources, it is important that these local groups (both volunteer groups and local agencies) be linked into basinwide efforts, but at the same time retain their local focus and discretion. Much of the energy that maintains these groups arises from a focus on local problems. While this is important, the value of their data to the larger basin is often overlooked. Linkages need to be made between local groups throughout the basin. However, such a basinwide focus needs to incorporate local data collectors in a way that is locally-driven.

(3.1) Recommendation: *Establish a better framework for bottom-up monitoring program linkages.*

(4) Finding: Part of the difficulty in using data collected at the local level is that there are few standards at the basinwide level to knit the data together. The local focus of the data collection effort often will leave the data incompatible with other data from neighboring localities. In order to use locally-driven data, the aspects of the collection and reporting processes need to be standardized across the basin. This standardization will make local monitoring results more widely usable and allow for aggregation and analysis across the basin as a whole.

(4.1) Recommendation: *Standardize data collection and reporting*.

C. Monitoring Coordination and Information Sharing

The final issue area does not involve direct monitoring, but responds to the need to coordinate monitoring efforts. As should be obvious from this report, there are a wide array of organizations involved in monitoring at the federal, state and local levels. However, no single organization is responsible for planning, coordinating, or disseminating monitoring efforts for the entire Lake Michigan basin. In the absence of a single organization, a council of organizations has formed to take on this task — the Lake Michigan Monitoring Coordination Council. The council's task — to coordinate monitoring efforts for basinwide goals — is a difficult one. However, several steps could be taken to improve the prospects of this coordination.

(1) Finding: A major coordination problem is the lack of a central source for monitoring information. The inventory that this report evaluates is the first step toward creating such a central source. However, this one-time inventory is currently not universally accessible and may quickly become dated if the database is not continually updated by monitoring organizations in the basin. Therefore, these monitoring organizations need to be encouraged to report on their monitoring projects continually into a universally-accessible database. This database should contain proper metadata about the monitoring program and the data that is reported. Eventually, this database should directly link to monitoring data, wherever possible. The database should be developed for the Internet and allow for the metadata to be searched geographically and by metadata content.

(1.1) Recommendation: *Encourage state, federal, tribal, and local agencies to report monitoring coverage and results to a meta-database with universal access.*

(1.2) Recommendation: *Develop an online database of monitoring information that is geographically-based, and content-searchable.*

(2) Finding: Beyond creating and reporting to a shared database of monitoring program information, it would be most effective to link monitoring programs into a coordinated network. As it is, organizations make most, if not all, decisions about their monitoring programs based on goals for their local coverage area. Rarely does this area cover the entire Lake Michigan basin. Without a coordinated network, basinwide goals may go unmet. Several actions must be taken to make sure this network can successfully address basinwide goals. First, the network must contain all the necessary components for complete coverage. This means that common indicators need to be agreed upon for the basin, and all organizations monitoring for indicator data need to be included in the network. State of the Lake Ecosystem Conference (SOLEC) and LaMP indicators have already been established and should be adapted or condensed for use in the network. After this, a set of standard methods should be established for monitoring the agreed upon indicators within the basin. Standard methods will ensure that data is comparable and able to be combined for analysis across the basin.

(2.1) Recommendation: *Develop and coordinate the implementation of comparable methods to collect indicator data in a coordinated network.*

Appendix A.

Acronyms and Glossary

AOC	Area of Concern
AIRS	U.S. EPA's Aerometric Information Retrieval System
BMP	Best Management Practice
BSFWD	Bureau of Sport Fisheries and Wildlife Data
CLMP	Cooperative Lakes Management Program
COE	U.S. Army Corps of Engineers
EPRI	Electric Power Research Institute
GLC	Great Lakes Commission
GLFC	Great Lakes Fishery Commission
GLNPO	Great Lakes National Program Office
GLERL	Great Lakes Environmental Research Laboratory
IDEM	Indiana Department of Environmental Management
IEPA	Illinois Environmental Protection Agency
IJC	International Joint Commission
LMMCC	Lake Michigan Monitoring Coordination Council
MDEQ	Michigan Department of Environmental Quality
MDNR	Michigan Department of Natural Resources
MMSD	Milwaukee Metropolitan Sewage District
MSD	Metropolitan Sanitary District or Metropolitan Sewage District
NCDC	National Climatic Data Center
NIPC	Northeast Illinois Planning Commission
RAP	Remedial Action Plan
SLIC	Sea Lamprey Integration Committee
TMDL	Total Maximum Daily Load
U.S. EPA	U.S. Environmental Protection Agency
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service

USGS-WRD	U.S. Geological Survey – Water Resources Division
WAV	Water Action Volunteers
WDNR	Wisconsin Department of Natural Resources
WWTP	Waste-water treatment plant

Appendix B.

Lake Michigan Tributary Monitoring Project Participants

Project Coordinators

Judy Beck
Lake Michigan Team Manager
U.S. Environmental Protection Agency
77 W. Jackson Blvd., T-13J
Chicago, IL 60604-3590
312-353-3849
fax: 312-886-9697
beck.judy@epamail.epa.gov

Matt Doss
Program Manager
Great Lakes Commission
Argus II Bldg.
400 Fourth St.
Ann Arbor, MI 48103
734-665-9135
734-665-4370 fax
modss@glc.org

Ric Lawson
Project Manager
Great Lakes Commission
Argus II Bldg.
400 Fourth St.
Ann Arbor, MI 48103
734-665-9135
734-665-4370 fax
rlawson@glc.org

Local Participants

Michigan

Grand River

Dr. Janet Vail
Robert B. Annis Water Resources Institute
Grand Valley State University
118 Padnos Hall
Allendale, MI 49401-9403
616-895-3048
Fax: 616-895-3864
vailj@gvsu.edu

Melissa Welsh
Robert B. Annis Water Resources Institute
Grand Valley State University
740 W. Shoreline Dr.
Muskegon, MI 49441
Ph: 231-728-3285
Fax: 231-728-2847

Kalamazoo River

Bruce Merchant
President, Kalamazoo River Watershed Public Advisory Council
1415 North Harrison
Kalamazoo, MI 49007
616-337-8711
Fax: 616-337-8699
brucemerch@AOL.com

Andrew Laucher
Program Assistant
Kalamazoo River Watershed Public Advisory Council
132 N. Bordick St.
Kalamazoo, MI 49007
616-373-1157
Fax: 616-373-1834
krwpac@helpfull.com

Manistique River

James R. Anderson, III
Executive Director
Schoolcraft County Economic Development Corp.
321 Deer Street, P.O. Box 277
Manistique, MI 49854
906-341-5126
Fax: 906-341-5555
scedc@up.net

Muskegon Lake and White Lake

Kathy Evans
Water Quality Coordinator
Muskegon Conservation District
1001 E. Wesley
Muskegon, MI 49442
231-773-0008
231-773-1210 fax
kevansmcd@msn.com

St. Joseph River

Al Smith
Friends of the St. Joseph River Association, Inc.
P.O. Box 354
Athens, MI 49011
616-729-5174
fax: 616-729-5045
algs@net-link.net
website: www.fotsjr.org

John Wuepper
4221 Landings Lane St.
St. Joseph, MI 49085
616-429-7757
john_L_wuepper@email.whirlpool.com

Grand Traverse Bay

Chris Wright
Executive Director
Grand Traverse Bay Watershed Initiative
715 East Front St.
Traverse City, MI 49686
231-935-1514
Fax: 231-935-3829
GTBWI@traverse.com
http://www.GTBay.org

Susan Russell
PO Box 244
Kalkaska, MI 49646
Ph: 231-258-8457
srussell001@msn.com

Indiana

Grand Calumet River

Kathy Luther
NW Regional Office
IN Dept. of Environmental Management
504 Broadway, #418
Gary, IN 46402
219-881-6730
KLUTHER@dem.state.in.us

Dr. Greg A. Olyphant
Center for Geospatial Data Analysis
Indiana Geological Survey
611 N. Walnut Grove
Bloomington, Indiana 47405
812-855-5154
812-855-7899
olyphant@indiana.edu

Illinois

Waukegan Harbor

Susie Scheiber, Chair
Waukegan Harbor Citizens Advisory Group
152 Glennwood Ave.
Winnetka, IL 60093
847-835-2517
Fax: 847-835-1263
jschreiber@ameritech.net

Paul Geiselhart
Waukegan Harbor Citizens Advisory Group
Hart Marketing
1408 Bull Creek Dr.
Libertyville, IL 60048
847-362-1690
Fax: 847-362-5134
pgeisel@aol.com

Wisconsin

Milwaukee Estuary
Sheboygan River
Menominee River (Michigan and Wisconsin)

Vicky Harris
University of Wisconsin Sea Grant Institute
University of Wisconsin, Green Bay
2420 Nicolet Dr., ES-105
Green Bay, WI 54311-7001
920-465-2795
Fax: 920-465-2376
harrisv@uwgb.edu

Nate Hawley
Graduate Student
University of Wisconsin, Green Bay
2420 Nicolet Dr., ES-105
Green Bay, WI 54311-7001
920-465-2795
Fax: 920-465-2376
nbhawley@hotmail.com

Lower Green Bay and Fox River

Jim Pinkham
Fox-Wolf Basin 2000
Box 1861
Appleton, WI 54913-1861
Ph: 920-738-7025
Fax: 920-738-7037
jpinkham@athenet.net

Door County

Roy Aiken
Door County Stewardship Council
5689 Gordon Rd.
Sturgeon Bay, WI 54235
Phone: 920-743-3020
Fax: 920-743-4353
raiken@mail.wiscnet.net

Appendix C.

Lake Michigan Monitoring Inventory Form

Following is the form that was distributed to organizations thought to be possibly conducting monitoring programs. The form was slightly tailored for use in local areas. A web-based form was also developed to enhance return rates. This form can currently be found at: http://www.glc.org/projects/lamps/monitor.html.

Lake Michigan Monitoring Inventory Form

The following form is intended to provide us with an inventory of federal and state agency monitoring programs in the Lake Michigan Basin. Please complete this form to the best of your ability, indicating the monitoring efforts that your agency currently undertakes, and return it to us as soon as possible. If you conduct more than one monitoring effort, please copy and complete a separate form for each program. This should take less than 20 minutes to complete.

General Information

The questions below will provide us with important background on your organization and monitoring efforts and may eventually result in greater use of your monitoring results.

1) Please provide your primary contact information.

Name: ____________________

Organization: ____________________

Address: ____________________

City: ____________________ State: _____ Zip Code: __________

Phone: ____________________ Fax: ____________________

E-mail: ____________________ Website: ____________________

Watersheds covered: ____________________

____

2) Who is the manager for the monitoring program?

____

3) Briefly describe the overall purpose or goal of the monitoring/information collection effort.

____

____

4) Approximately, when did the monitoring program begin? (month / year) ______/______

Monitoring Information

The following questions ask about specific details of your monitoring program. They will help us understand what is being done in your area to monitor the health of the ecosystem.

5) As specifically as possible, please describe the boundary of the location or geographic scope of your monitoring effort (e.g., named or numbered river reach, watershed, county or township boundary, latitude/longitude). Please include as much descriptive information as possible.

____

____

6) Medium being monitored:

❑ Water ❑ Land ❑ Air ❑ Soil ❑ Biota/Wildlife ❑ Other (specify: ________________)

7) Please select the category that best fits the type of information being collected.

- ❑ Chemical (e.g. pH, BOD, mercury, phosphorus, PCBs)
- ❑ Microbiological (e.g. bacteria or other microbial organisms)
- ❑ Fish or aquatic invertebrates
- ❑ Other wildlife (e.g. turtles, beavers, deer, etc)
- ❑ Physical characteristics (e.g. hydrology, habitat, geology, soil, vegetation, forests, wetlands)
- ❑ Land uses (e.g. urbanized, agricultural, residential, industrial, brownfields sites)
- ❑ Other (specify: ____________________ ____________________)

8) Do you collect data on any of the following? ❑ PCBs ❑ Dieldrin ❑ Chlordane

❑ DDT ❑ Lead ❑ Zinc ❑ Cyanide ❑ PAHs ❑ None of the above

❑ Mercury ❑ Cadmium ❑ Chromium ❑ Hexachlorobenzene ❑ Atrazine

❑ Dioxins/Furans ❑ Copper ❑ Arsenic ❑ Toxaphene ❑ Selenium

9) Please give a specific description of any other information being collected (i.e. list specific indicators measured).

____

____

10) How often is the information collected?

❑ Daily ❑ Weekly ❑ Monthly ❑ Semiannually ❑ Annually ❑ Other (specify: ________________)

Program Information

We need some final information about your monitoring program so that we can assess the extent and needs for monitoring funding and training.

11) **Please list the name or type of any standardized methodology used (e.g. EPA guidelines, standard methods texts, or kit procedures).**

____

12) **Please list any standardized quality assurance or quality control procedures that are followed.**

____

____

13) **Select the classification that best describes the individuals who collect monitoring data.**

❑ Paid staff ❑ Volunteers ❑ Students ❑ Other (specify: ______________________)

14) **How many staff or volunteers participate in the monitoring project, on average?** ____________

15) **Was training provided to data gatherers?** ❑ Yes ❑ No

16) **If yes, who provided the training?** ____

17) **Where is the monitoring data reported and stored (e.g., which office or agency)?**

____

18) **Which format is used to store the data (i.e., which electronic format or software is used, or is it stored in a hard copy format)?**

____

19) **Is the data stored indefinitely?** ❑ Yes ❑ No

20) **If no, how long is the information stored?** ____

21) **How is the monitoring data ultimately used (e.g. in Remedial Action Plans, educational materials, research, watershed planning, regulatory compliance)?**

____

____

22) **(Optional) Please list the approximate annual budget for the monitoring effort.** $____________.00

23) **Is this funding ongoing and reliable?** ❑ Yes ❑ No

24) **Please list any other parameters that you would like to monitor or other areas that you feel need additional monitoring in your region.**

____

____

25) **Please provide us with any other relevant information that you think would give us a more complete understanding of your monitoring efforts. Feel free to append any additional documentation that you think would be helpful.**

____

____

____

Thank you for your assistance.
Your input will help us better determine the scope and need
for monitoring efforts in the Lake Michigan basin.

When completed, please return this form by mail or fax, to:

Ric Lawson
Great Lakes Commission
400 Fourth Street
Ann Arbor, MI 48103
Fax: (734) 665-4370

Attachment 3

Cost Estimate for Long-term Monitoring

Table C.1 - MNR Costs for Sampling (One Event/ 5 Yrs) - Long-Term Monitoring Plan Lower Fox River/Green Bay

Task 100 - Surface Water Sampling (30 days, 4 people)
Task 200 - Surface Sediment Sampling (2 weeks, 4 people)
Task 300 - Fish and Invertebrate Tissue Sampling (8 weeks,3 people - J.Amrhein) (also for Institutional Controls)
Task 400 - Mallard duck, Bald Eagle and Cormorant Bird Tissue Sampling (4 weeks, 4 people)
Task 500 - Mink Habitat Chacterization (one month, 2 people)
Task 600 - Data Analysis

LABOR/PERSONNEL (HOURS)	Task 100	Task 200	Task 300	Task 400	Task 500	Task 600	Hours	Rate	Cost
Director E12	10	10	10	10	10	20	70	$125	$8,750
Sr.Tech Manager E11	50	50	50	50	50	20	270	$110	$29,700
Tech Manager E10	50	50	50	50	50	80	330	$98	$32,340
Project E8	350	120	350	180	180	80	1260	$75	$94,500
Senior Staff E7	350	120	350	180	180	300	1480	$62	$91,760
Staff Scientist E6	350	120	350	180	180	300	1480	$52	$76,960
Scientist1 E5	350	120	350	180	180	120	1300	$45	$58,500
P.A./Technician E4	150	50	160	80	80	80	600	$50	$30,000
Drafter E2	150	50	160	80	80	150	670	$38	$25,460
Word Processing E1	150	50	160	80	80	150	670	$40	$26,800
Labor Subtotal	$112,750	$46,130	$114,030	$64,010	$64,010	$73,840	Labor Subtotal:		$474,770
DIRECT COSTS									
Travel/per diem	$5,000	$5,000	$5,000	$5,000	$5,000	$0			$25,000
Supplies/Phone/Repro	$7,000	$7,000	$7,000	$7,000	$20,000	$30,000			$78,000
Equipment	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000			$60,000
Sampling vessel	$30,000	$20,000	$30,000	$30,000	$10,000	$0			$120,000
Other	$5,000	$5,000	$5,000	$5,000	$5,000	$30,000			$55,000
Location control	$2,000	$2,000	$2,000	$2,000	$2,000	$0			$10,000
Direct Costs Subtotal	$59,000	$49,000	$59,000	$59,000	$52,000	$70,000	Direct Subtotal:		$348,000
							(add 8% to subs):		$0
Task Total	$171,750	$95,130	$173,030	$123,010	$116,010			Total:	$822,770

ANALYTICAL COSTS	No. of samples					Sum	Unit Cost	Total
PCB congeners	260	100	900	460	0	1720	$900	$1,548,000
mercury	260	100	900	460	0	1720	$200	$344,000
%lipids	0	0	450	230	0	680	$50	$34,000
TOC	260	100	0	0	0	360	$30	$10,800
Grain Size	0	100	0	0	0	100	$150	$15,000
DDE	0	0	550	440	0	990	$150	$148,500
Conventionals	260	100	0	0	0	360	$100	$36,000
Analytical Subtotal	$319,800	$138,000	$1,095,000	$583,500	$0			$2,136,300
Task Total (for 5 years)	$491,550	$233,130	$1,268,030	$706,510	$116,010		**5 YR TOTAL:**	**$2,959,070**
							Cost per year:	**$591,814**

Notes:

1) Assume 550 fish samples for human health,250 fish for environment, 100 mussels

2) Assume 320 duck samples, 120 DCC samples, and 20 eagle samples

3) Conduct this sampling event once every five years

4) PCB congener analysis cost estimate from Triangle Lab ($500) and J. Amhrein of WDNR ($900)

Table C.2 - Estimated Costs for CDF or CAD Sampling (Per Year) - Lower Fox River/Green Bay

Task 100 - CDF Groundwater Monitoring (3 events/year, 6 wells/ CDF, 6 CDF, 3 people - 108 days at 10hr/day)
Task 200 - CDF Surface Water Sampling (2 events/year, 1 station/CDF, 6 CDF, 2 people)
Task 300 - CDF Surface Sediment Sampling (1 event/year, 5 to 10 stations/CDF, 4 people)
Task 400 - CDF Seep Sampling (same as above)
Task 500 - Data Analysis

LABOR/PERSONNEL (HOURS)	Task 100	Task 200	Task 300	Task 400	Task 500	Hours	Rate	Cost
Director E12	5	5	5	5	5	25	$125	$3,125
Sr.Tech Manager E11	10	10	10	10	10	50	$110	$5,500
Tech Manager E10	20	20	20	20	20	100	$98	$9,800
Project E8	1080	80	80	80	70	1390	$75	$104,250
Senior Staff E7	1080	80	80	80	70	1390	$62	$86,180
Staff Scientist E6	1080	30	80	80	120	1390	$52	$72,280
Scientist1 E5	100	30	80	80	120	410	$45	$18,450
P.A./Technician E4	80	5	5	5	40	135	$50	$6,750
Drafter E2	80	5	5	5	40	135	$38	$5,130
Word Processing E1	80	5	5	5	40	135	$40	$5,400
Labor Subtotal	$222,545	$18,195	$23,045	$23,045	$30,035		Labor Subtotal:	$316,865
DIRECT COSTS								
Travel/per diem	$5,000	$1,000	$1,000	$1,000	$0			$8,000
Supplies/Phone/Repro	$2,000	$2,000	$2,000	$2,000	$5,000			$13,000
Equipment	$5,000	$5,000	$5,000	$5,000	$10,000			$30,000
Sampling vessel	$5,000	$10,000	$10,000	$10,000	$0			$35,000
Other	$5,000	$5,000	$5,000	$5,000	$5,000			$25,000
Location control	$1,000	$1,000	$1,000	$1,000	$0			$4,000
Direct Costs Subtotal	$23,000	$24,000	$24,000	$24,000	$20,000		Direct Subtotal:	$115,000
							(add 8% to subs):	$0
Task Total	$245,545	$42,195	$47,045	$47,045	$50,035		Total:	$431,865
ANALYTICAL COSTS	No. of samples					Sum	Unit Cost	Total
PCB congeners	110	15	15	10	6	156	$900	$140,400
mercury	110	15	15	10	6	156	$200	$31,200
% lipids	0	0	0	0	0	0	$50	$0
TOC	110	15	15	10	6	156	$30	$4,680
Grain Size	0	0	15	0	6	21	$150	$3,150
DDE	110	15	15	10	6	156	$150	$23,400
Conventionals	110	15	15	10	6	156	$100	$15,600
Analytical Subtotal	$151,800	$20,700	$22,950	$13,800	$9,180			$218,430
Task Total (for 5 years)	$397,345	$62,895	$69,995	$60,845	$59,215		**TOTAL:**	**$650,295**
							Cost per year:	**$650,295**

Notes:
1) All values are ballpark estimates
2) Costs do not include monitoring well installations
3) Conduct this sampling event every year for the first 5 years, but frequency may diminish over the years
4) PCB congener analysis cost estimate from Triangle Lab ($500) and J. Amhrein of WDNR ($900)

Table C.3 - Estimated Costs for *In Situ* Cap Sampling (Per Year) - Lower Fox River/Green Bay

Task 100 - Visual Assessments (bathymetry, camera surveys) (1 event/year, 2 people, 1 week)
Task 200 - Surface Water Sampling (2 event/year, 1 station/cap, 2 people)
Task 300 - Surface Sediment and PoreWater Sampling (1 event/year, 5 to 10 stations/cap, 4 people)
Task 400 - Sediment Cores through CAP (1 event/year, 5 to 10 stations/cap, 4 people)
Task 500 - Data Analysis

LABOR/PERSONNEL (HOURS)	Task 100	Task 200	Task 300	Task 400	Task 500	Hours	Rate	Cost	
Director E12	5	5	5	5	5	25	$125	$3,125	
Sr.Tech Manager E11	10	10	10	10	10	50	$110	$5,500	
Tech Manager E10	20	20	20	20	20	100	$98	$9,800	
Project E8	40	80	80	80	70	350	$75	$26,250	
Senior Staff E7	100	80	80	120	150	530	$62	$32,860	
Staff Scientist E6	100	30	80	120	150	480	$52	$24,960	
Scientist1 E5	20	30	80	120	120	370	$45	$16,650	
P.A./Technician E4	5	5	5	5	40	60	$50	$3,000	
Drafter E2	5	5	5	5	40	60	$38	$2,280	
Word Processing E1	5	5	5	5	40	60	$40	$2,400	
Labor Subtotal	$19,625	$18,195	$23,045	$29,405	$36,555		Labor Subtotal:	$126,825	
DIRECT COSTS									
Travel/per diem	$1,000	$1,000	$1,000	$1,000	$0			$4,000	
Supplies/Phone/Repro	$2,000	$2,000	$2,000	$2,000	$10,000			$18,000	
Equipment	$15,000	$5,000	$5,000	$5,000	$10,000			$40,000	
Sampling vessel	$10,000	$10,000	$10,000	$10,000	$0			$40,000	
Other	$5,000	$5,000	$5,000	$5,000	$10,000			$30,000	
Location control	$1,000	$1,000	$1,000	$1,000	$0			$4,000	
Direct Costs Subtotal	$34,000	$24,000	$24,000	$24,000	$30,000		Direct Subtotal:	$136,000	$136,000
							(add 8% to subs):	$0	
Task Total	$53,625	$42,195	$47,045	$53,405	$66,555		Total:	$262,825	$262,825
ANALYTICAL COSTS	No. of samples					Sum	Unit Cost	Total	
PCB congeners		6	45	50		101	$900	$90,900	
mercury		6	45	50		101	$200	$20,200	
% lipids		0	0	0		0	$50	$0	
TOC		6	45	50		101	$30	$3,030	
Grain Size		0	45	0		45	$150	$6,750	
DDE		6	45	50		101	$150	$15,150	
Conventionals		6	45	50		101	$100	$10,100	
Analytical Subtotal	$0	$8,280	$68,850	$69,000	$0			$146,130	$146,130
Task Total (for 5 years)	$53,625	$50,475	$115,895	$122,405	$66,555		**TOTAL:**	**$408,955**	$408,955
							Cost per year:	**$408,955**	

Notes:

1) All values are ballpark estimates

2) Costs do not include monitoring well installations

3) Conduct this sampling event every year for the first 5 years, but frequency may diminish over the years

4) PCB congener analysis cost estimate from Triangle Lab ($500) and J. Amhrein of WDNR ($900)

Table C.4 - Estimated Costs for Institutional Controls and No Action Alternatives (Per Year)

Maintain fish consumption advisories and deed restrictions (No Action and Institutional controls)

Task 100 - Deed restrictions
Task 200 - NA
Task 300 - Fish and Invertebrate Tissue Sampling (8 weeks,3 people - J.Amrhein) (also for Institutional Controls)
Task 400 - Data Analysis
Task 500 - NA

LABOR/PERSONNEL (HOURS)	Task 100	Task 200	Task 300	Task 400	Task 500	Hours	Rate	Cost
Director E12	10		20	20		50	$125	$6,250
Sr.Tech Manager E11	10		60	50		120	$110	$13,200
Tech Manager E10	20		60	50		130	$98	$12,740
Senior Project E9						0	$87	$0
Project E8	100		400	200		700	$75	$52,500
Senior Staff E7	100		400	200		700	$62	$43,400
Staff Scientist E6	100		400	200		700	$52	$36,400
Scientist1 E5			400	200		600	$45	$27,000
P.A./Technician E4	20		200	200		420	$50	$21,000
Drafter E2	20		200	100		320	$38	$12,160
Word Processing E1	10		200	100		310	$40	$12,400
Labor Subtotal	$26,370	$0	$134,180	$77,500	$0	Labor Subtotal:		$238,050
DIRECT COSTS								
Travel/per diem	$0	$0	$5,000	$0	$0			$5,000
Supplies/Phone/Repro	$0	$0	$7,000	$0	$0			$7,000
Equipment	$20,000	$0	$10,000	$10,000	$0			$40,000
Sampling vessel	$0	$0	$20,000	$0	$0			$20,000
Other	$10,000	$0	$5,000	$20,000	$0			$35,000
Location control	$0	$0	$2,000	$0	$0			$2,000
Direct Costs Subtotal	$30,000	$0	$49,000	$30,000	$0	Direct Subtotal:		$109,000
						(add 8% to subs):		$0
Task Total	$56,370	$0	$183,180	$107,500	$0	Total:		$347,050
ANALYTICAL COSTS	No. of samples					Sum	Unit Cost	Total
PCB congeners	0	0	900	0	0	900	$900	$810,000
mercury	0	0	900	0	0	900	$200	$180,000
%lipids	0	0	450	0	0	450	$50	$22,500
TOC	0	0	0	0	0	0	$30	$0
Grain Size	0	0	0	0	0	0	$150	$0
DDE	0	0	550	0	0	550	$150	$82,500
Conventionals	0	0	0	0	0	0	$100	$0
Analytical Subtotal	$0	$0	$1,095,000	$0	$0			$1,095,000
Task Total (for 5 years)	$56,370	$0	$1,278,180	$107,500	$0		**TOTAL:**	**$1,442,050**
							Cost per year:	**$288,410**

Notes:
1) Assume 550 fish samples for human health,250 fish for environment, 100 mussels
3) Conduct this sampling event once every five years
4) PCB congener analysis cost estimate from Triangle Lab ($500) and J. Amhrein of WDNR ($900)

Table C.5 - Estimated Costs for No Action (Per Year)

Maintain fish consumption advisories and deed restrictions (No Action and Institutional controls)

Task 100 - Deed restrictions
Task 200 - NA
Task 300 - Fish and Invertebrate Tissue Sampling (8 weeks,3 people - J.Amrhein) (also for Institutional Controls)
Task 400 - Data Analysis
Task 500 - NA

LABOR/PERSONNEL (HOURS)	Task 100	Task 200	Task 300	Task 400	Task 500	Hours	Rate	Cost
Director E12	10		20	20		50	$125	$6,250
Sr.Tech Manager E11	10		60	50		120	$110	$13,200
Tech Manager E10	20		60	50		130	$98	$12,740
Senior Project E9						0	$87	$0
Project E8	100		400	200		700	$75	$52,500
Senior Staff E7	100		400	200		700	$62	$43,400
Staff Scientist E6	100		400	200		700	$52	$36,400
Scientist1 E5			400	200		600	$45	$27,000
P.A./Technician E4	20		200	200		420	$50	$21,000
Drafter E2	20		200	100		320	$38	$12,160
Word Processing E1	10		200	100		310	$40	$12,400
Labor Subtotal	$26,370	$0	$134,180	$77,500	$0	Labor Subtotal:		$238,050
DIRECT COSTS								
Travel/per diem	$0	$0	$5,000	$0	$0			$5,000
Supplies/Phone/Repro	$0	$0	$7,000	$0	$0			$7,000
Equipment	$20,000	$0	$10,000	$10,000	$0			$40,000
Sampling vessel	$0	$0	$20,000	$0	$0			$20,000
Other	$10,000	$0	$5,000	$20,000	$0			$35,000
Location control	$0	$0	$2,000	$0	$0			$2,000
Direct Costs Subtotal	$30,000	$0	$49,000	$30,000	$0	Direct Subtotal:		$109,000
						(add 8% to subs):		$0
Task Total	$56,370	$0	$183,180	$107,500	$0		Total:	$347,050

ANALYTICAL COSTS	No. of samples					Sum	Unit Cost	Total
PCB congeners	0	0	900	0	0	900	$900	$810,000
mercury	0	0	900	0	0	900	$200	$180,000
%lipids	0	0	450	0	0	450	$50	$22,500
TOC	0	0	0	0	0	0	$30	$0
Grain Size	0	0	0	0	0	0	$150	$0
DDE	0	0	550	0	0	550	$150	$82,500
Conventionals	0	0	0	0	0	0	$100	$0
Analytical Subtotal	$0	$0	$1,095,000	$0	$0			$1,095,000
Task Total (for 5 years)	$56,370	$0	$1,278,180	$107,500	$0		**TOTAL:**	**$1,442,050**
							Cost per year:	**$288,410**

Notes:
1) Assume 550 fish samples for human health,250 fish for environment, 100 mussels
3) Conduct this sampling event once every five years
4) PCB congener analysis cost estimate from Triangle Lab ($500) and J. Amhrein of WDNR ($900)

Table C.6 - Sampling Costs During Dredging Per Alternative (Assume 5 years duration)

Task 100 - Surface Water Sampling (30 days, 4 people)
Task 200 - Caged Tissue Sampling
Task 300 - Surface Sediment Sampling
Task 400 - Data Analysis
Task 500 - NA

LABOR/PERSONNEL (HOURS)	Task 100	Task 200	Task 300	Task 400	Task 500	Hours	Rate	Cost	
Director E12	5	5	5	5		20	$125	$2,500	
Sr.Tech Manager E11	50	50	50	50		200	$110	$22,000	
Tech Manager E10	50	50	50	50		200	$98	$19,600	
Senior Project E9				0		0	$87	$0	
Project E8	500	100	400	160		1160	$75	$87,000	
Senior Staff E7	500	100	400	160		1160	$62	$71,920	
Staff Scientist E6	500	100	400	160		1160	$52	$60,320	
Scientist1 E5	500	100	400	160		1160	$45	$52,200	
P.A./Technician E4	200	50	160	80		490	$50	$24,500	
Senior Drafter E3				0		0	$50	$0	
Drafter E2	200	50	160	80		490	$38	$18,620	
Word Processing E1	200	50	160	80		490	$40	$19,600	
Labor Subtotal	$153,625	$40,825	$125,105	$58,705	$0	Labor Subtotal:		$378,260	
DIRECT COSTS									
Travel/per diem	$10,000	$5,000	$10,000	$0	$0			$25,000	
Supplies/Phone/Repro	$10,000	$7,000	$10,000	$0	$0			$27,000	
Equipment	$40,000	$20,000	$40,000	$10,000	$0			$110,000	
Sampling vessel	$50,000	$20,000	$50,000	$10,000	$0			$130,000	
Other	$5,000	$5,000	$5,000	$5,000	$0			$20,000	
Location control	$2,000	$2,000	$2,000	$0	$0			$6,000	
Direct Costs Subtotal	$117,000	$59,000	$117,000	$25,000	$0	Direct Subtotal:		$318,000	$318,000
						(add 8% to subs):		$0	
Task Total	$270,625	$99,825	$242,105	$83,705	$0		Total:	$696,260	$696,260
ANALYTICAL COSTS	No. of samples					Sum	Unit Cost	Total	
PCB congeners	600	60	200	0	0	860	$900	$774,000	
mercury	600	60	200	0	0	860	$200	$172,000	
%lipids	0	60	0	0	0	60	$50	$3,000	
TOC	0	0	200	0	0	200	$30	$6,000	
Grain Size	0	0	200	0	0	200	$150	$30,000	
DDE	0	0	200	0	0	200	$150	$30,000	
Conventionals	600	0	200	0	0	800	$100	$80,000	
Analytical Subtotal	$720,000	$69,000	$306,000	$0	$0			$1,095,000	$1,095,000
Task Total	$990,625	$168,825	$548,105	$83,705	$0		**TOTAL:**	**$1,791,260**	$1,791,260
						Cost per year:		**$358,252**	

Notes:
4) PCB congener analysis cost estimate from Triangle Lab ($500) and J. Amhrein of WDNR ($900)

Appendix D

Summary of Capping Projects

Appendix D Summary of Contaminated Sediment Capping Projects

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (feet)	Cap Material	Year Constructed	Performance	Comments
Puget Sound							
Duwamish Waterway Seattle, Washington	Heavy metals, PCBs		1–3	Sand (4,000 cy)	1984	• No chemical migration • No erosion of cap	Monitoring as recent as 1996 showed cap remains effective and stable. Split-hull dump barge placed sand over relocated sediments (CAD site) in 70' water.
One Tree Island Olympia, Washington	Heavy metals, PAHs		4	Sand	1987	• No chemical migration • No erosion of cap	Last monitoring occurred in 1989 showed that sediment contaminants were contained.
St Paul Waterway Tacoma, Washington	Phenols, PAHs, dioxins		2–12	Coarse sand	1988	• No chemical migration • Cap within specifications	Some redistribution of cap materials has occurred, but overall remains >1.5 m (4.9'). C. californieus found in sediments, but never >1 m (3.3').
Pier 51 Ferry Terminal Seattle, Washington	Mercury, PAHs, PCBs		1.5	Coarse sand (4 acres) (*in situ*)	1989	• No chemical migration • Cap within specifications • Recolonization observed	As recent as 1994, cap thickness remained within design specifications. While benthic infauna have recolonized the cap, there is not indication of cap breach due to bioturbation.
Denny Way CSO Seattle, Washington	Heavy metals, PAHs, PCBs	Water depth 18 - 50 ft	2–3	Sand (3 acres)	1990	• No data available	Cores taken in 1994 show that while cap surface chemistry shows signs of recontamination, there is no migration of isolated chemicals through the cap.
Piers 53–55 CSO Seattle, Washington	Heavy metals, PAHs		1.3–2.6	Sand (4.5 acres) (*in situ*)	1992	• No chemical migration • Cap stable, and increased by 15 cm (6") of new deposition	Pre-cap infaunal communities were destroyed in the rapid burial associated with cap construction.
Pier 64 Seattle, Washington	Heavy metals, PAHs, phthalates, dibenzofuran		0.5–1.5	Sand	1994	• Some loss of cap thickness • Reduction in surface chemical concentrations	Thin-layer capping was used to enhance natural recovery and to reduce resuspension of contaminants during pile driving.
GP lagoon Bellingham, Washington (insitu)	Mercury	Shallow intertidal lagoon	3	Sand	2001	• No chemical migration at 3-months • Cap successfully placed	Ongoing monitoring
East Eagle Harbor/Wyckoff Bainbridge Island, Washington	Mercury, PAHs		1–3	Sand (275,000 cy)	1994	• No chemical migration • Cap erosion in ferry lanes • Some chemicals observed in cap	Cap erosion measured within first year of monitoring only in area proximal to heavily-used Washington ferry lane. Chemicals also observed in sediment traps. Ongoing monitoring.
West Eagle Harbor/Wyckoff Bainbridge Island, Washington (in situ)	Mercury, PAHs	500 acre site	Thin cap 0.5' over 6 acres and Thick cap 3' over 0.6 acres	Sand (22,600 tons for thin cap and 7,400 tons for thick cap)	Partial dredge and cap 1997	• No chemical migration	To date, post-verification surface sediment samples have met the cleanup criteria established for the project. Ongoing monitoring.

Appendix D Summary of Contaminated Sediment Capping Projects

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (feet)	Cap Material	Year Constructed	Performance	Comments
California and Oregon							
PSWH Los Angeles, California	Heavy metals, PAHs		15	Sand	1995	• No data to date	Overall effective cap was >15'. This was not a function of design, but rather a function of the low contaminated-to-clean sediment volume.
Convair Lagoon San Diego, California	PCBs	5.7 acre cap in 10 acre site; water depth 10-18 ft	2' of sand over 1' rock	Sand over crushed rock	1998	• No chemical migration • Cap was successfully placed in very shallow water • Some chemicals observed in cap	Ongoing monitoring for 20 to 50 years including diver inspection, cap coring, biological monitoring
CAD Long Beach, California	Heavy metals, PAHs		5	Sand	planned, but not constructed	• No data to date	Design cap thickness was a function of deepest depth for prevention of bioturbation by thallassinid burrowing shrimp.
McCormick and Baxter Portland, Oregon	Heavy metals, PAHs	15 acres of nearshore sediments and soils	NA	Sand	planned, but not constructed	• No data to date	Long-term monitoring, OMMP, and institutional controls were also specified
Great Lakes							
Sheboygan Falls Wisconsin (pilot)	PCBs	9 hotspots totalling 1,200 sq yds	1 ft of coarse material and upper geotextile over lower geotextile	Composite	1992	• No monitoring data	Composite armored cap required as sediments were located in high-energy river environment. Gabions placed around the corners for anchoring. Additional course material placed into voids/gaps.
Sheboygan River/Harbor Wisconsin	PCBs		unknown	Armored stone composite	1989–1990	• Undetermined cap • effectiveness Some erosion of fine-grained	Demonstration bench-scale project.
Areas C and D Manistique, Michigan	PCBs		2.7	Composite	planned, but not implemented (site remediation was dredging)	• Project is unbuilt	Composite cap over a 17-acre site that includes armoring and geotextiles.
Manistique Capping Project Wisconsin	PCBs		40-mil (0.1')	HDPE	1993	• Physical inspection of the temporary cap approximately 1 year after installation showed cap was physically intact and most anchors still in place	A 240' by 100' HDPE temporary cap was anchored by 38 2 ton concrete blocks placed around the perimeter of the cap. This temporary cap was installed to prevent erosion of contaminated sediments within a river hotspot with elevated surface concentrations.
Hamilton Harbor Ontario, Canada	PAHs		1.6	Sand (2.5 acres) (*in situ*)	1995	• No monitoring data	Cap recently completed.

Appendix D Summary of Contaminated Sediment Capping Projects

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (feet)	Cap Material	Year Constructed	Performance	Comments
New England/New York							
Stamford-New Haven-N New Haven, Connecticut	Metals, PAHs		1.6	Sand	1978	• No chemical migration	Cores collected in 1990.
Stamford-New Haven-S New Haven, Connecticut	Metals, PAHs		1.6	Silt	1978	• No chemical migration	Cores collected in 1990.
New York Mud Dump Disposal Site New York	Metals (from multiple harbor		unknown	Sand (12 million cy)	1980	• No chemical migration	Cores taken in 1993 (3.5 years later) showed cap integrity over relocated sediments in 80' of water.
Mill-Quinniapiac River Connecticut	Metals, PAHs		1.6	Silt	1981	• Required additional cap	Cores collected in 1991.
Norwalk, Connecticut	Metals, PAHs		1.6	Silt	1981	• No problems	Routine monitoring.
Central Long Island Sound Disposal Site (CLIS) New York	Multiple harbor sources		unknown	Sand	1979–1983	• Some cores uniform structure with low-level chemicals • Some cores no chemical migration • Some slumping	Extensive coring study at multiple mounds showed cap stable at many locations. Poor recolonization in many areas.
Cap Site 1 Connecticut	Metals, PAHs		1.6	Silt	1983	• No chemical migration	Cores collected in 1990.
Cap Site 2 Connecticut	Metals, PAHs		1.6	Sand	1983	• Required additional cap	Cores collected in 1990.
Experimental Mud Dam New York	Metals, PAHs		3.3	Sand	1983	• No chemical migration	Cores collected in 1990.
New Haven Harbor New Haven, Connecticut	Metals, PAHs		1.6	Silt	1993	• No chemical migration	Extensive coring study.
Port Newark/Elizabeth New York	Metals, PAHs		5.3	Sand	1993	• No chemical migration	Extensive coring study.
52 Smaller Projects New England	Metals, PAHs		1.6	Silt	1980–1995	• No chemical migration	Routine monitoring.

Appendix D Summary of Contaminated Sediment Capping Projects

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (feet)	Cap Material	Year Constructed	Performance	Comments
International Projects							
Rotterdam Harbor Netherlands	Oils	Water depth 5 to 12 m	2–3	Silt/Clay sediments	1984	• No available monitoring data	As pollution of groundwater was a potential concern, the site was lined with clay prior to sediment disposal and capping.
Hiroshima Bay Japan		Water depth 21 m	5.3	Sand	1983	• No available data	

References:

EPA, 1998. *Manistique River/Harbor AOC Draft Responsiveness Summary, Section 4: In-place Containment at Other Sites.* Sent by Jim Hahnenberg of United States Environmental Protection Agency Region 5 and Ed Lynch of Wisconsin Department of Natural Resources on September 25, 1998.

SAIC, 1996. *Year 11 Monitoring of the Duwamish CAD Site, Seattle, Washington.* Report prepared for the United States Army Corps of Engineers, Seattle District by Science Applications International Corporation, Bothell, Washington.

Sumeri, A., 1984. Capped in-water disposal of contaminated dredged material: Duwamish Waterway site. In: *Proceedings of the Conference Dredging '84, Dredging and Dredged Material Disposal, Volume 2.* United States Army Corps of Engineers, Seattle, Washington.

Truitt, C. L., 1986. *The Duwamish Waterway Capping Demonstration Project: Engineering Analysis and Results of Physical Monitoring.* Final Report. Technical Report D-86-2. United States Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi. March.