SCENIC HUDSON

RESULTS OF CONTAMINATED SEDIMENT CLEANUPS RELEVANT TO THE HUDSON RIVER

An Update to Scenic Hudson's Report *Advances in Dredging Contaminated Sediment*

October 2000

Results of Contaminated Sediment Cleanups Relevant to The Hudson River

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ABOUT SCENIC HUDSON

Scenic Hudson. is a 37 year-old non-profit environmental organization and separately incorporated land trust dedicated to protecting and enhancing the scenic, natural, historic, agricultural, and recreational treasures of the Hudson River and its Valley. To date, we have protected more than 15,500 acres of land in nine counties and created or enhanced 24 parks and preserves for public enjoyment. For more information about Scenic Hudson's programs and accomplishments, please visit www.scenichudson.org.

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EXECUTIVE SUMMARY

In the coming months, the U.S. Environmental Protection Agency (EPA) will complete an extensive ten-year reassessment of the Hudson River PCBs Superfund site. Studies already released by EPA document unacceptable human health and environmental risks from PCBs that are continually released from contaminated sediment "hot spots" in the Upper Hudson River. For example, EPA estimates that an adult who eats a half-pound meal per week of fish caught in the Upper Hudson River, over a 40 year period beginning in 1999, would have an increased risk of cancer that is 700 times greater than EPA's goal for protection of human health. If EPA determines that action should be taken to address these risks, its cleanup plan is likely to include dredging of some or all of the hot spots.

To enable a more factually-grounded public dialogue on contaminated sediment dredging, Scenic Hudson in 1997 prepared the report *Advances in Dredging Contaminated Sediment: New Technologies and Experience Relevant to the Hudson River PCBs Site*. *Advances in Dredging* described available dredging technologies, operational methods to control dredging impacts, and the key factors affecting dredging decisions. *Advances in Dredging* showed that contaminated sediments can be dredged without simply spreading contamination downstream.

This report updates the findings of *Advances in Dredging* based on new information that has become available since 1997. More importantly, this report examines issues that were outside the primary focus of *Advances in Dredging*. For example, this report provides more information on options for transporting, treating, and disposing sediment and water generated by environmental dredging, and discusses these options in relation to the Hudson River PCBs site. In addition, this report presents the results of several cleanups in terms of post-cleanup contaminant concentrations in sediment and fish. Also, the report provides detailed case studies for four contaminated sediment cleanups, and summary information (e.g., sediment removal and disposal options, sediment volumes, and project status) for 89 contaminated sediment cleanups.

Further Progress in Environmental Dredging

Dozens of contaminated sediment sites have been cleaned up in the U.S. Contaminated sediment cleanup technologies and methods are well developed, as are the engineering and environmental criteria used to select appropriate cleanup plans. To assess how the available methods have been put in practice, basic remedy information is presented for 89 contaminated sediment cleanups. Almost 90 percent of the 89 complete, ongoing, or planned projects involve dredging or excavation instead of in-place remedies such as capping or "no action." Among the removal remedies, at least 72 percent include dredging or wet excavation. At least 1.7 million cubic yards[1] of contaminated sediment have been remediated with dredging or wet excavation, and at least 1.4 million cubic yards have been removed with dry excavation. At least five

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[1] This total does not include 2.8 million cubic yards of contaminated sediment removed in the Commencement Bay, Sitcum Waterway navigational dredging project.

dredging cleanups larger than 100,000 cubic yards are complete, and several more large-scale dredging cleanups are planned.

Advances in Dredging identified several innovative dredges designed specifically for contaminated sediment cleanups. With few exceptions, innovative dredges have not been used in the cleanups completed so far. Instead, sediment cleanups usually involve conventional hydraulic dredges (e.g., cutterhead, horizontal auger), which also are suitable for contaminated sediment cleanups and are more readily available than innovative dredges.

Large contaminated sediment cleanups usually include land-based facilities for sediment dewatering and water treatment. These facilities use low-technology equipment (e.g., settling tanks, screens, belt presses, sand and carbon water filtration) and processes that have been used for decades in common, large-scale industrial applications (e.g., mineral processing, wastewater treatment). In hydraulic dredging cleanups, sediments usually are transported from dredging sites to the land-based facilities through semi-flexible, floating pipelines. Dredge discharge pipelines in lengths up to 15 kilometers (9.3 miles) are commonly used in navigational dredging projects.

Although significant progress has been made in recent years to develop and commercialize contaminated sediment treatment methods, treatment remains infrequent. About a quarter of the cleanups identified in this report included some form of treatment, usually stabilization. Cost remains a limiting factor in the use of treatment technologies. Treatment costs range from approximately $30 per cubic yard for soil washing to several hundred dollars per cubic yard for thermal destruction. Unless contaminant levels are exceptionally high, landfilling is generally considered adequately protective in contaminated sediment cleanups.

Treated or not, contaminated sediments usually are disposed of in upland landfills. About 81 percent of the projects identified in this report included upland disposal. About 50 percent of the projects included off-site disposal (usually in existing landfills), 29 percent included on-site disposal (usually in newly-constructed landfills), and about 3 percent included on-site and off-site disposal. Although new landfill construction near the Upper Hudson would be logical and consistent with cleanup decisions elsewhere, EPA is unlikely to include it in a cleanup plan for the Hudson River PCBs site because of local opposition.

Results of Contaminated Sediment Cleanups

To provide specific information on the nature of contaminated sediment cleanups and their outcomes, this report includes detailed case studies for four projects and pre- and post-dredging results for eleven sites. The case studies include a range of ex-situ cleanup methods that might be relevant to the Hudson River PCBs site.

Monitoring results presented in this report include sediment contamination results for eight sites and fish contamination data for nine sites. Other results, such as contaminant mass removal and attainment of cleanup goals are included when data are available. The results clearly demonstrate that contaminated sediment cleanups can reduce contamination in sediment and fish. For example, average PCB concentrations in white perch in the South Branch of the

Shiawassee River decreased from 19 ppm in the year before dredging to 4.2 ppm two years after dredging. Average PCB concentrations in Hudson River fish at the Niagara Mohawk Queensbury site ranged from about 7 to 11 ppm at the start of remedial activities and have been below 1 ppm since the end of the cleanup.

Post-cleanup contaminant reductions in sediment and fish at most of the sites are at least partially attributable to gradual background attenuation of contaminants (e.g., due to diffusion from contaminated sediments or microbial decomposition) or other cleanup activities (e.g., upland source control). For these reasons, it is difficult or impossible to precisely determine the percentage reductions in sediment and fish tissue contamination at these particular sites that are attributable only to sediment removals. At some sites, however, pre- and post-dredging contamination at cleanup locations can be compared to pre- and post-dredging contamination at background locations. At these sites, much larger benefits are seen at the cleanup locations than at background locations. At Lake Jarnsjon, Sweden, for example, dredging removed 97 percent of the PCB mass at the cleanup location and reduced PCB concentrations in fish by 56 percent. PCB concentrations in fish at two upstream background locations decreased by 33 and 36 percent. At the Ruck Pond site in Wisconsin, where a dry excavation cleanup removed 96 percent of the PCB mass, PCB concentrations in fish decreased 83 percent from 24 ppm before dredging to about 4 ppm after dredging. At a control location upstream from Ruck Pond, PCB concentrations decreased 25 percent.

Dredging Decision Factors

Based on the environmental dredging literature, *Advances in Dredging* described eight factors that are considered in contaminated sediment cleanup decisions:

- Sediment resuspension;
- Sediment characteristics;
- Water depth and site access;
- Water current;
- Depth of contaminated sediment and dredge accuracy;
- Production rate and sediment density;
- Dredge availability; and
- Cost.

Where possible, these factors were related to the conditions of the Upper Hudson River to develop a general assessment of the suitability of environmental dredging as a potential remedy for the Hudson River PCBs site. This report updates the discussions of each of the eight factors and adds discussions of two more factors:

- Sediment dewatering and water treatment; and
- Sediment treatment/disposal.

Neither *Advances in Dredging* nor this report evaluate the impacts or feasibility of a Hudson River cleanup in detail. EPA has not yet provided information that would be required for such an evaluation, such as magnitude and scope of the cleanup (e.g., number of hot spots to be cleaned up; amount of sediment dredged) and the cleanup methods (e.g., number, types, and production rates of the dredges; sediment disposal option).

Summary and Conclusion

Based on the information presented in this report, as well as *Advances in Dredging*, Scenic Hudson concludes the following:

- Recent EPA findings suggest that the Upper Hudson River should be cleaned up;
- Dredging is still the preferred remedy for sediment contamination at other sites;
- Several large-scale contaminated sediment cleanups have been performed with dredging and/or excavation;
- Contaminated sediment resuspension can be controlled;
- Monitoring data show reductions in sediment and fish contamination following sediment cleanups;
- Options for large-scale sediment dewatering, water treatment, and sediment disposal are well developed; and
- There are many potential options for cleaning up the Hudson River PCBs site.

The basis of each of these conclusions is documented in the main body of this report.

1. INTRODUCTION

Since the Superfund program was created in 1980, many of America's most hazardous pollution sites have been cleaned. The Hudson River was one of the first sites named to the National Priorities List (NPL) of Superfund sites because of PCB pollution in 40 sediment "hot spots" in the Upper Hudson and in fish for 200 miles downstream to New York Harbor. But after 20 years of Superfund progress, the Hudson River PCBs site, one of the largest on the NPL, has not been restored. However, the U.S. Environmental Protection Agency (EPA) is scheduled to propose a cleanup plan for the site in December 2000, completing more than ten years of exhaustive data collection and analysis.

In 1984, when the Superfund program was still new and no major contaminated sediment sites had been cleaned, EPA issued an interim "no action" decision for the Hudson River sediment contamination based on uncertainty about the effects of dredging. The 1984 decision suggested a future reassessment of the "no action" decision if techniques for remediating contaminated sediment were further developed. As shown in Exhibit 1, advances in contaminated sediment cleanup methods contributed to EPA's decision to initiate the Hudson River PCBs Reassessment six years later in 1990.

Through the 1980s and 1990s, the EPA, the U.S. Army Corps of Engineers (USACE), and others have advanced contaminated sediment remediation technologies and strategies through engineering studies, pilot tests, and full-scale cleanups. For example, the USACE reviewed dredging technologies and conducted field tests under the Environmental Effects of Dredging Program (EEDP) and other programs (Zappi and Hayes, 1991). EPA and Environment Canada tested dredging and sediment remediation technologies at sites in the Great Lakes under the Assessment and Remediation of Contaminated Sediments (ARCS) program (U.S.) and the Great Lakes Cleanup Fund (Canada). In 1997, USACE established the Dredging Operations and Environmental Research (DOER) Program to address environmental research needs associated with dredging related issues in the Nation's navigation system (Francinques et al., 1998).

Despite their relevance to the Hudson River PCBs site, this research and cleanup experience remained largely unknown to the general public, Hudson Valley decision makers, and other stakeholders. As a result, the controversial issue of dredging remained stagnant for nearly 20 years, often with strong opinions based on hearsay or vague and outdated ideas about the equipment, techniques, and track record of sediment cleanups.

To enable a more active and scientifically-grounded public discourse on dredging as a potential remedy for the Hudson River PCBs site, Scenic Hudson in 1997 prepared the report *Advances in Dredging Contaminated Sediment: New Technologies and Experience Relevant to the Hudson River PCBs Site* (hereafter referred to as *Advances in Dredging*). *Advances in Dredging* included descriptions of available dredging technologies, operational methods to control dredging impacts, essential factors in dredge selection, and frank descriptions of contaminated sediment dredging projects elsewhere. The environmental concerns about dredging, alternatives to dredging, and historical context also were included for perspective.

Exhibit 1
Circumstances Leading to the EPA's Reassessment of the Hudson River PCBs Site

In one of its early Superfund decisions, the EPA cited doubts about dredging Hudson River sediments, but envisioned a re-evaluation after further research:

> *"The most feasible and reliable alternative assessed by EPA [i.e., hot spot dredging] would be likely to decrease the level of risk somewhat. However, ... the actual reliability and effectiveness of current dredging technologies in this particular situation is subject to considerable uncertainty. For this reason the no-action alternative is recommended at this time. The decision may be reassessed in the future if, during the interim evaluation period, the reliability and applicability of in-situ or other treatment methods is demonstrated, or if techniques for dredging of contaminated sediment from an environment such as this one are further developed."* (EPA, 1984)

Changing circumstances led the EPA to a reassessment starting in 1990:

- *"With the Superfund Amendments and Reautorization Act of 1986 (SARA) came the indication that preferred remedies were those which 'permanently and significantly reduce the volume, toxicity or mobility of the hazardous substance involved..'*

- *USEPA policy is to perform periodic review for both pre- and post-SARA [cleanup decisions] at least every five years for as long as hazardous substances, pollutants, or contaminants that may pose a threat to human health or the environment remain at the site.*

- *Technological advances have been made in processes and techniques for treating and removing PCB-contaminated sediment.*

- *New York State Department of Environmental Conservation (NYSDEC) requested a reassessment of the No Action Decision."* (EPA, 1991)

Since 1997, there has been growing interest in dredging as a potential solution for the Hudson River site and several other large-scale contaminated sediment sites (e.g., the Lower Fox River, Grand Calumet Harbor/Indiana Ship Canal). Some of the largest contaminated sediment cleanup projects ever undertaken are now underway, and even larger cleanups are under evaluation. In addition, important new information about other contaminated sediment cleanups has become available. The purpose of this report is to update the topics covered in *Advances in Dredging* and to cover additional topics relevant to the forthcoming cleanup decision for the Hudson River PCBs site.

The rest of Section 1 provides background information for this report. Section 1.1 provides background information about the Hudson River PCBs site. Section 1.2 summarizes the findings of *Advances in Dredging*. Section 1.3 summarizes key results of EPA's Hudson River PCBs Reassessment since 1997.

Section 2 of this report describes further progress in contaminated sediment cleanups. Section 3 presents the results of cleanup effectiveness monitoring at eleven sites and detailed cleanup case studies for four sites. Section 4 reevaluates dredging decision factors introduced in *Advances in Dredging*, and Section 5 provides a summary and the conclusions. Literature cited in the report is identified in Section 6. Recent contaminated sediment remediation information resources are listed in Appendix A.

1.1 Hudson River PCB Contamination

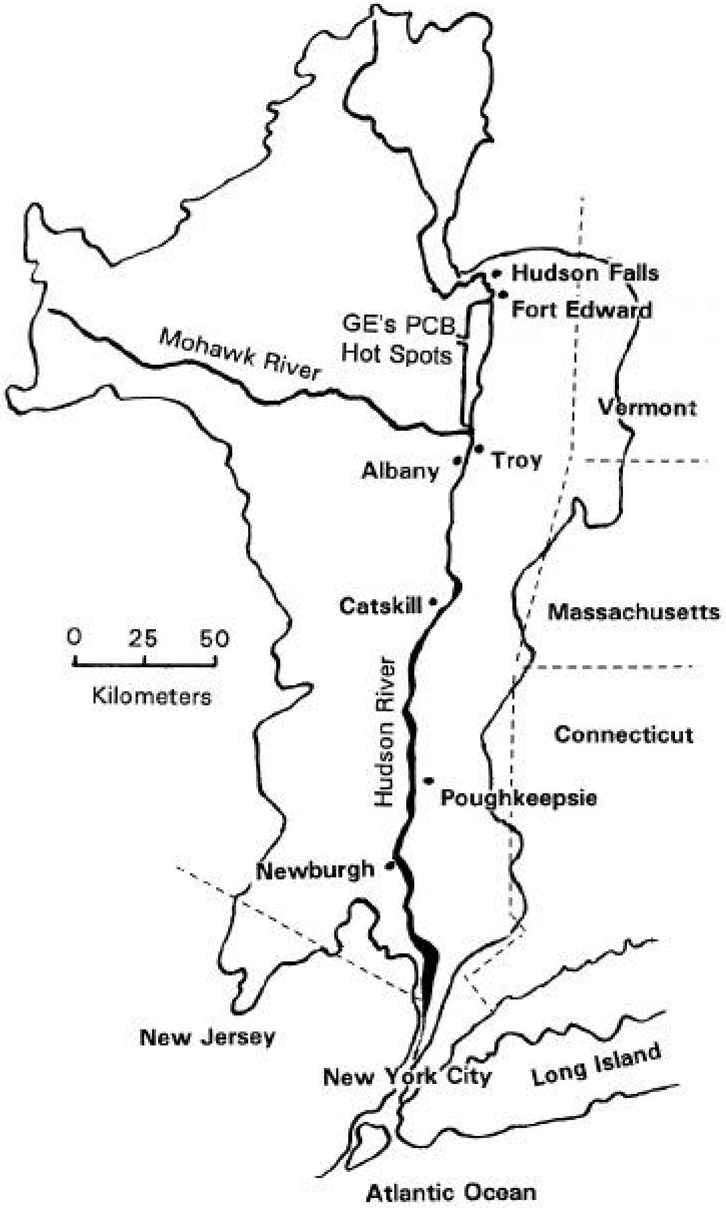
The Hudson River PCBs Superfund site encompasses approximately 200 miles of the Hudson River from the city of Hudson Falls, New York to New York Harbor. The Hudson and its drainage basin are shown in Exhibit 2. PCBs discharged from two General Electric (GE) plants over a period of more than 30 years contaminated sediments and fish in the river. Although permitted PCB discharges ended in 1977, fish remain unsafe to eat in much of the river because contaminated sediment “hot spots” downstream from the GE plants are a continuing source of contamination to the food chain.

PCB contamination in the Hudson River was first identified as a public health issue in the early 1970s. Beginning in 1976, New York State has issued health advisories and commercial fishing bans to limit consumption of PCB-contaminated fish. Included in the current advisory is a recommendation that children and women of childbearing age eat no fish from the river. For others, the health advisories vary by location and fish species, but generally limit fish consumption to one meal per week or per month.

PCBs are a family of man-made chemicals that were used widely as coolants and lubricants in electrical equipment until banned in the U.S. in 1977. PCBs break down very slowly in the environment and concentrate thousands of times as they pass up the food chain. As endocrine disruptors, neurotoxins, and probable carcinogens, PCBs cause a wide array of adverse health effects in humans and wildlife. These adverse heath effects include hazards to intellectual functions and to the nervous, immune, and reproductive systems. PCBs pose special risks to pregnant women and newborns because they pass from mother to child through the umbilical cord and breast milk, and have been linked to premature births and lowered IQs in children. A summary of the documented cancer and non-cancer health effects of PCBs can be found on EPA’s Internet site (i.e., http://www.epa.gov/opptintr/pcb/effects.htm).

More information about the Hudson River and the history of the contaminated sediment site can be found in *Advances in Dredging*.

Exhibit 2
The Hudson River

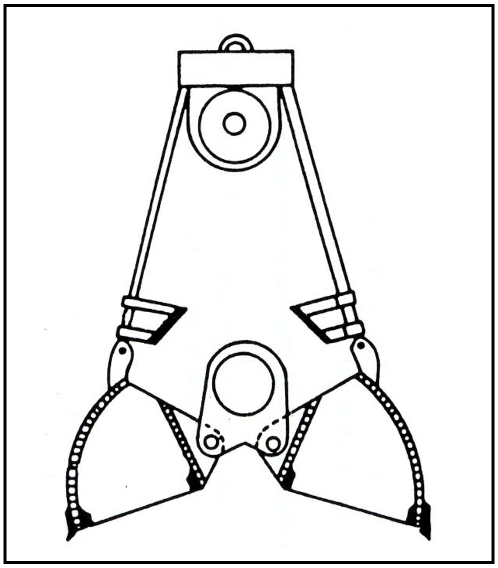


1.2 Summary of *Advances in Dredging*

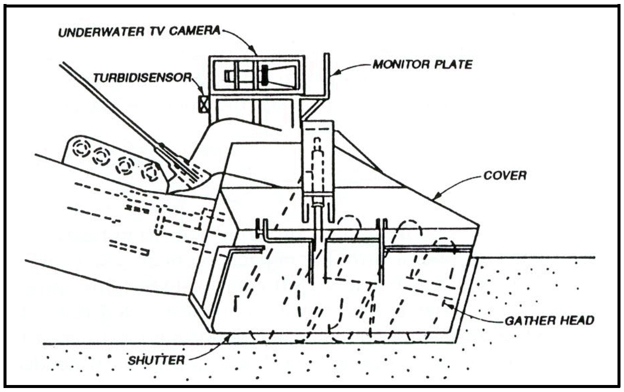
The purpose of *Advances in Dredging* was to investigate the common perception that dredging in the Hudson River would make matters worse by redistributing PCBs. The report summarized the capabilities and performance of more than 20 types of dredges; described 23 sediment cleanup projects; reviewed trends in cleanup decisions and expert opinion on the advisability of contaminated sediment dredging versus alternatives; and listed dredge selection factors, along with a discussion of the relevance of those factors to the Hudson River PCBs site.

Advances in Dredging described the capabilities and limitations of two distinct categories of dredges.

- **Mechanical dredges –** Mechanical dredges are related to the familiar earth moving equipment used in construction. When used in contaminated sediment cleanups, mechanical dredges scoop sediment batch-by-batch and load it onto a barge or truck or directly into a land-based containment area. Examples of mechanical dredges include the clamshell (pictured at right), dragline, and bucket ladder dredges. Advantages of mechanical dredges are availability, ability to remove large debris, and ability to remove sediment at near in-situ density (EPA, 1994). However, mechanical dredges have the potential to leak or resuspend contaminated sediment as they scoop and lift it through the water column. Some mechanical dredges (e.g., the closed-bucket clamshell dredge) have been designed to minimize sediment loss.



Enclosed Bucket Clamshell Dredge
(Source: Herbich and Brahme, 1991)



Refresher Dredge
(Source: Zappi and Hayes, 1991)

- **Hydraulic and pneumatic dredges –** Hydraulic and pneumatic dredges use strong pumps to collect sediment through a piping system. Hydraulic dredges use continuous water suction pumps, and pneumatic dredge pumps use an alternating cycle of negative and positive air pressure. Both dredge types remove sediment below in-situ density in a water slurry, and most have mechanical dredge heads for loosening sediment. Contaminated sediment dredging commonly uses hydraulic dredges developed for navigational and construction applications. Several hydraulic and pneumatic dredges have been developed specifically for contaminated sediment cleanups. Examples of hydraulic and pneumatic dredges described in more detail in *Advances in Dredging* include the cutterhead dredge, the Eddy Pump, the horizontal auger dredge, and the refresher dredge (pictured above).

With data compiled from previously-published sources, *Advances in Dredging* compared the capabilities (i.e., the minimum and maximum dredging depths, sediment production rates, slurry densities) of 18 mechanical, hydraulic, and pneumatic dredges. In addition, eight dredge selection factors (e.g., dredge availability, water current) were discussed and related to conditions in the Upper Hudson River. Section 4 of this report reevaluates the eight dredge selection factors and adds discussions of two additional factors related to the processing and disposal of dredged sediment and water.

The four key conclusions of *Advances in Dredging* were that:

(1) Between 1984 and 1997, uncertainty about dredging as a method for contaminated sediment remediation has been replaced by extensive literature and governmental guidance;

(2) The preferred remedies at PCB-contaminated sites include dredging and/or excavation;

(3) Several dredge types are capable of effective cleanup with virtually no resuspension of contaminated sediments; and

(4) Alternatives – i.e., in-situ capping or treatment – are less proven than dredging, and in-situ treatment has proven unsuccessful.

Advances in Dredging did not recommend a specific remedy for the Hudson River PCB site. Instead, the report provided recommendations about the selection and use of dredges for contaminated sediment cleanups. The recommendations are paraphrased below.

- **Do not rule out dredges based on initial availability** – Although specialty dredges are more difficult to obtain than conventional dredges, efforts to obtain the best dredge are warranted by the unique size and significance of the Hudson River PCBs site.

- **Choose a dredge operator experienced in contaminated sediment removal** – Operator experience is an important factor in successful dredging (e.g., minimizing sediment resuspension, efficiently operating the dredge).

- **Evaluate combinations of dredges –** It may be advisable to use more than one type of dredge if different dredges would be best suited to conditions in various areas of the Hudson River PCBs site.

- **Optimize production rates without compromising environmental protection –** Although cleanup costs generally increase with project duration, worker safety and dredging effectiveness must be given top priority over project duration and cost. It may be possible to shorten a cleanup in the Upper Hudson River by operating more than one dredge simultaneously.

- **Careful dredging is preferable to mitigation –** Silt curtains, sheet piling, and other physical barriers can help to mitigate contaminated sediment resuspension. These should be used as needed, but it is better to prevent sediment resuspension with careful equipment selection and operation than to rely on mitigation.

1.3 Recent Hudson River PCBs Reassessment Findings

Since *Advances in Dredging*, EPA has published several key reports of the Hudson River PCBs Reassessment, including model results and human health and ecological risk assessments. These reports contain important findings about the sources and dynamics of PCBs in the river, and the current and future impact of PCB contamination on human and ecological health. Overall, the reassessment has concluded that PCB contamination in the Hudson River poses unacceptably high cancer risk and non-cancer hazards for humans, and may adversely affect the survival, growth, and reproduction of a wide range of animal species. In addition, the reassessment contradicts three of GE's long-standing arguments against sediment remediation: (1) that natural bacteria are eliminating PCBs from the sediment; (2) that deposition of clean sediment is isolating the hot spots as a source of contamination to the river above; and (3) that PCB loading from GE's Hudson Falls plant (which GE is remediating) is the dominant source of PCBs in fish. The key findings of the reassessment reports released since the publication of *Advances in Dredging* are summarized below.

The reassessment reports are subjected to intensive peer review by panels of independent experts. Peer reviewers for the human health risk assessment agreed with the EPA's overall conclusion that PCB exposures exceed levels of concern for both cancer and non-cancer health effects in humans. Peer reviews raised several concerns about the adequacy of the ecological risk assessment. EPA is currently preparing a responsiveness summary for the ecological assessment that will act on peer reviewer recommendations and may revise the risk assessment conclusions (Hess, 2000).

Low Resolution Sediment Coring Report, July 1998 (EPA, 1998a)

- While there is some burial of PCB-contaminated sediment at limited locations in the Thompson Island Pool, burial is not occurring universally.

- From 1984 to 1994, there was a statistically significant loss of hot spot PCBs in the Thompson Island Pool, which indicates that PCBs are being redistributed in the Hudson River ecosystem.

- Burial of sediments will not resolve the PCB problem, because it is likely that PCBs will continue to be released from Upper Hudson River sediments.

Human Health Risk Assessment: Upper Hudson River, August 1999 (EPA, 1999d) and Responsiveness Summary, March 2000 (EPA, 2000e)

- EPA estimated that an adult who eats a half-pound meal per week of fish caught in the Upper Hudson River, over a 40 year period beginning in 1999, would have an increased risk of cancer that is 700 times greater than EPA's goal for protection of human health.

- The cancer risk for a young child (age 1 to 7) who eats less than one three-ounce fish meal per week for seven years is estimated to be 600 times greater than EPA's goal for protection of human health.

- An adult who eats one fish meal per week for seven years would be exposed to PCBs at a level 65 times greater than EPA's level of concern for non-cancer health effects.

Ecological Risk Assessment, August 1999 (EPA, 1999e) and Ecological Risk Assessment Addendum: Future Risks in the Lower Hudson River, December 1999 (EPA, 1999b)[2]

- PCB contamination in water and sediments in the Hudson River generally exceed ecological risk standards.

- PCB contamination in the Hudson River threatens the survival, growth, and reproduction of fish as well as mammals that feed on insect, plants, or fish from the river.

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[2] As noted in the introduction to this section, peer reviewers raised concerns about the adequacy of the ecological risk assessment reports. EPA is currently preparing a responsiveness summary that may revise these conclusions.

- Significant risks were estimated for all species included in the ecological risk assessment, including largemouth bass, striped bass, shortnose sturgeon, mallard duck, tree swallow, bald eagle, belted kingfisher, great blue heron, little brown bat, mink, river otter, and raccoon.

- Fragile populations of threatened and endangered species (e.g., shortnose sturgeon, bald eagle) are particularly susceptible to PCB risks.

Human Health Risk Assessment: Mid-Hudson River, December 1999 (EPA, 1999b)

- An adult who eats one meal per week of fish caught in the mid-Hudson has an estimated cancer risk that is more than 100 times greater than EPA's goal for protection of human health.

- An adult who eats one meal per week of fish caught in the mid-Hudson is exposed to PCBs at a level that is 30 times higher than EPA's level of concern for non-cancer health effects.

- A young child who eats less than one three-ounce meal per week of fish caught in the mid-Hudson has an increased cancer risk that is 100 times greater than EPA's goal for protection, and an estimated exposure level that is ten times higher than EPA's level of concern for non-cancer health hazards.

Revised Baseline Modeling Report, January 2000 (EPA, 2000f)

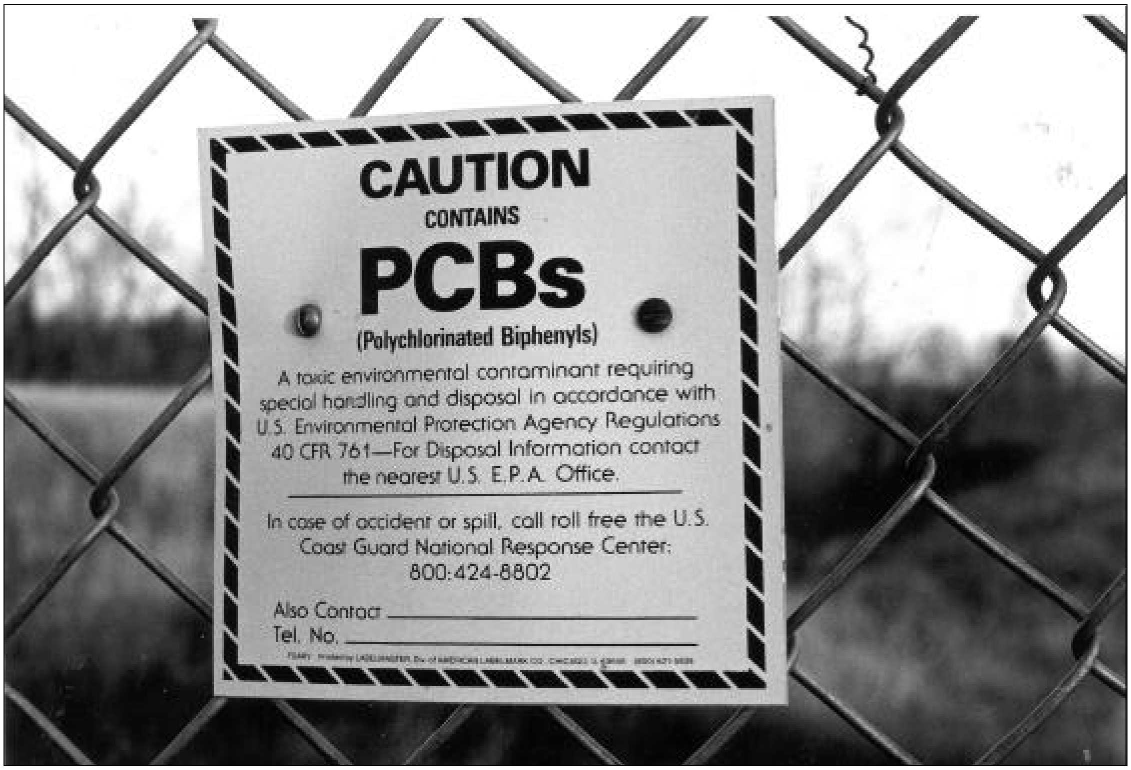
- Under normal (i.e., non-flood) conditions, sediment contamination is the dominant source of PCBs to the river, not upstream sources (e.g., new PCB inputs from GE's Hudson Falls plant site).

- Sediment contamination is expected to be the dominant source of PCBs to the river for 20 to 30 years.

- PCB concentrations in surface sediment are expected to decline by seven to nine percent per year for the next 20 years.

- Although surface sediment concentrations are expected to decline in general, erosion in some locations is expected to expose higher subsurface concentrations after 40 or 50 years.

- A 100-year flood would result in only small additional increases in sediment erosion above what might be expected for typical annual peak flows.



PCBs break down very slowly in the environment and concentrate thousands of times as they pass up the food chain.

2. FURTHER PROGRESS IN ENVIRONMENTAL DREDGING

Advances in Dredging demonstrated the use of environmental dredging with brief summaries of 24 contaminated sediment cleanup projects. Subject to data availability, each project summary identified the site characteristics (e.g., type of water body, water depth, sediment type, contaminants of concern), dredging equipment, cleanup goals, and dredging results (e.g., sediment resuspension measurements, post-cleanup contamination levels). The 24 projects were selected based on the availability of performance data, and a diversity of site characteristics and dredge types. As noted in *Advances in Dredging,* the 24 projects were only examples of many sediment cleanup projects that had been performed by 1997.

Since Scenic Hudson prepared *Advances in Dredging*, interest in contaminated sediment sites and potential contaminated sediment remedies has grown. The following factors contributed to the growing interest in contaminated sediment cleanups:

- In the Great Lakes Region, cleanups have been proposed or implemented in the recent years for several of the 43 Areas of Concern identified under the Great Lakes Water Quality Agreement. Because of the Great Lakes Water Quality Agreement and the importance of the lakes to the region's economy, there is a well developed institutional infrastructure involved in Great Lakes contaminated sediment issues.

- Media attention to contaminated sediment issues has grown as remedies have been investigated or proposed for several large, high-profile sites such as the Lower Fox River, the Hudson River, New Bedford Harbor, and the Grand Calumet Harbor/Indiana Harbor Ship Canal.

- Publications by EPA and other agencies such as the EPA's Clean Water Action Plan (EPA, 1998d), Contaminated Sediment Management Strategy (EPA, 1998b), and survey of the incidence and severity of contaminated sediments (EPA, 1997a).

One consequence of the growing attention to contaminated sediment is that information about contaminated sediment sites and remedy plans has become much more available. Appendix A identifies some of the useful contaminated sediment information resources that have become available in recent years.

Included in the recent contaminated sediment research are reports that have compiled and analyzed data on various sediment remediation projects. For example, the IJC (1997) summarized the progress in cleaning up Great Lakes AOCs and analyzed barriers to remediation. EPA (1998c) compiled remedy and cost information for contaminated sediments in the U.S. portions of the Great Lakes. GE and its consultants (GE et al., 1999) compiled a large database of contaminated sediment sites in the U.S. Scenic Hudson compiled information from these and other sources to prepare an up-to-date overview of contaminated sediment cleanup projects.

Exhibit 3 presents information about the selected remedies and implementation status for 101 contaminated sediment projects at 88 sites. There are more remedies than sites because some sites are being addressed in phases. For example, the Fox River is included three times in Exhibit 3, for two demonstration projects and a forthcoming river-wide cleanup plan. The exhibit includes 89 projects that are complete, on-going, or planned (i.e., a remedy has been proposed or selected but not yet implemented), as well as 12 potential projects under investigation. In addition, Exhibit 3 identifies key contaminants of concern, sediment removal or in-situ remedies (e.g., dredging, dry excavation, capping, no action), sediment disposal and/or treatment remedies (e.g., off-site disposal, on-site treatment), sediment volume, and information sources.[3]

Based on information in Exhibit 3 and other information sources, the following sections describe the current state of four aspects of contaminated sediment cleanups:

- Removal;
- Handling, dewatering, and water treatment;
- Sediment treatment; and
- Disposal.

Exhibit 3 includes sites with in-situ capping or "no action" remedies. Because this report focuses on ex-situ remedies, the current state of capping and "no action" are not analyzed.

2.1 Contaminated Sediment Removal

Based on an EPA (1995) analysis of Superfund remedies for 29 PCB-contaminated sediment sites and other expert opinion, *Advances in Dredging* concluded that ex-situ remedies (i.e., involving dredging and dry excavation) are preferred to in-situ remedies including no action. This conclusion is supported by the larger and broader sample of remedies included in Exhibit 3. Of 89 complete, on-going, or planned projects, 88 percent involve sediment removal and 12 percent involve in-situ management as primary components of their remedies.[4] Two-thirds of the 66 removal remedies for which removal methods are known involve dredging, 27 percent involve dry excavation, and six percent involve wet excavation. Dry excavation tends to be selected, and apparently preferred to dredging, for contaminated sediments in streams, ponds, shallow nearshore areas, or other sites that are easily dewatered.

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[3] Because Exhibit 3 was prepared primarily from previously published sources and many of the projects were on-going, planned, or under investigation, some of the information may now be out of date.

[4] Some remedies include in-situ and ex-situ management for sediments in different areas. For example, many remedies include sediment removal for hot spots and no action for areas of lesser contamination. Results presented in this section are based on the primary remedies for each site.

Exhibit 3
Summary of Contaminated Sediment Sites

Site Name	Primary Contaminants of Concern	Sediment Removal or In-Situ Management	Sediment Treatment/Disposal	Sediment Volume (yd^3)	Status	Data Sources
Black River (USX/KOBE)	PAHs; Cadmium	Hydraulic and Mechanical Dredging	On-site Disposal	60,000	Complete	d;f
Buffalo Color - Area D	PAHs; Metals; Organics	Dredging	On-site Disposal	35,000	Complete	d
Buffalo River	PCBs; PAHs; Organics; Metals	Hydraulic, Mechanical, Pneumatic Dredging	CDF	10,200	Complete	f
Collingwood Harbor	PCBs	Pneumatic Dredging	CDF	8,000	Complete	g
Columbus McKinnon	PCBs	Dredging	Off-site Disposal	2,349	Complete	d
Commencement Bay - Sitcum Waterway	Metals; PAHs	Hydraulic and Mechanical Dredging (navigational)	CDF	2,830,000	Complete	f
Formosa Plastics	Ethylene Dichloride	Hydraulic and Mechanical Dredging	Stabilization; Off-site Disposal	7,500	Complete	f
Fox River - Deposit N Demo	PCBs	Hydraulic Dredging	Off-site Disposal	8,190	Complete	e
Frontier Pendleton	Metals; Organics	Dredging	nd	56,000	Complete	d
Gould (Portland)	Organics; Metals	Hydraulic Dredging	On-site Disposal	11,000	Complete	f
Grasse River (ALCOA) - Pilot	PCBs	Hydraulic Dredging	On-site Disposal	3,500	Complete	d;f
Lavaca Bay	Mercury	Hydraulic Dredging	CDF	90,000	Complete	f
Lower Rouge River	Zinc	Mechanical Wet Dredging	CDF	34,500	Complete	d
LTV Steel	PCBs; Oil	Hydraulic Dredging	Off-site Disposal	116,000	Complete	d;f
Marathon Battery	Cadmium	Hydraulic and Mechanical Dredging; Dry Excavation	Off-site Disposal	100,200	Complete	f
New Bedford Harbor - Phase 1	PCBs	Hydraulic Dredging	CDF	14,000	Complete	f
Niagara Mohawk - Cherry Farm	PAHs	Hydraulic Dredging	On-site Disposal	50,000	Complete	d;f
North Avenue Dam/Milwaukee River	PCBs; PAHs; Metals	Mechanical Wet Dredging; No Action	nd	8,000	Complete	d
North Hollywood Dump	Organics; Metals	Hydraulic Dredging	On-site Disposal	40,000	Complete	f
Petit Flume	Phenol	Hydraulic Dredging	Off-site Disposal	2,000	Complete	d;f
Poineer Lake	PAHs; Organics	Hydraulic Dredging	Off-site Disposal	6,600	Complete	f
River Raisin - Ford Outfall	PCBs	Mechanical Wet Dredging	Stabilization; On-site Disposal	28,500	Complete	d;f
Sheboygan River/Harbor - Pilot	PCBs; Metals	Mechandical Dredging; Wet Excavation; Cap	On-site CTF	3,800	Complete	d;f
Shiasawssee River (pre-ROD)	PCBs	Mechanical Wet Dredging	Off-site Disposal	1,805	Complete	d;f
St. Lawrence River - GM	PCBs	Hydraulic Dredging; Cap	On- and Off-site Disposal	13,800	Complete	d;f
United Heckathorn	DDT	Mechanical Wet Dredging	Off-site Disposal	108,000	Complete	f
Waukegan Harbor	PCBs; PAHs	Hydraulic Dredging	Thermal Desorption; On-site Disposal	50,000	Complete	d;f
Wolf Creek (unnamed tributary)	PCBs; Lead	Dredging	Off-site Disposal	13,000	Complete	d
Wycoff Co. - Eagle Harbor #2	PAHs; Mercury	Mechanical Wet Dredging	Stabilization; CDF; Off-site Disposal	3,000	Complete	f
Baird & McGuire	Dioxin; Organics; Metals	Wet Excavation	Incineration	1,500	Complete	f
Bayou Bonfouca	PAHs	Wet Excavation	Incineration	169,000	Complete	f
Lapiri Landfill (Sediments)	Organics; Metals	Wet and Dry Excavation	Thermal Desorption; On-site Disposal	163,500	Complete	f
Loring Air Force Base	PCBs; PAHs; Lead; DDT; Chlordane	Wet and Dry Excavation	On-site Disposal	162,000	Complete	f
Bloody Run Creek	Dioxin; Organics	Unknown Removal	nd	27,000	Complete	d
Creekside Golf Course	Dioxin; Phenol	Unknown Removal	Off-site Disposal	1,300	Complete	d
Iroquois Gas and Westwood Pharmaceutical	PAHs; Organics	Unknown Removal	nd	11,000	Complete	d

Exhibit 3 (continued)
Summary of Contaminated Sediment Sites

Site Name	Primary Contaminants of Concern	Sediment Removal or In-Situ Management	Sediment Treatment/Disposal	Sediment Volume (yd^3)	Status	Data Sources
Monguagon Creek	PAHs; PCBs; Metals; Organics	Unknown Removal	nd	21,128	Complete	d
Niagara Transformer	PCBs	Unknown Removal	Off-site Disposal	11,500	Complete	d
Union Road	Lead	Unknown Removal; Cap	On-site Disposal	5,600	Complete	d
102nd Street Embayment	PCBs; Organics	Dry Excavation	On-site Disposal	28,500	Complete	d;f
Black and Bergholtz Creeks (Love Canal)	Dioxin; Organics	Dry Excavation	Incineration; Off-site Disposal	17,200	Complete	d;f
Gill Creek - DuPont	PCBs; Organics	Dry Excavation	Stabilization; Off-site Disposal	8,020	Complete	d;f
Gill Creek - Olin	Mercury; HCH; PAHs	Dry Excavation	On-site Disposal	6,850	Complete	d;f
Housatonic River - Hot Spot 1	PCBs	Dry Excavation	Off-site Disposal	6,000	Complete	f
Mallinckrodt Baker	DDT	Dry Excavation	Off-site Disposal	4,000	Complete	f
National Zinc	Metals	Dry Excavation	Stabilization; Off-site Disposal	6,000	Complete	f
Natural Gas Compressor Station	PCBs	Dry Excavation	Off-site Disposal	75,000	Complete	f
Newburgh Lake	PCBs	Dry Excavation; Hydraulic and Mechanical Dredging	Off-site Disposal	588,000	Complete	d;f
Ottowa River (Tributary)	PCBs	Dry Excavation	Stabilization; Off-site Disposal	10,000	Complete	d;f
Queensbury - Nearshore	PCBs	Dry Excavation	Off-site Disposal	5,000	Complete	f
Ruck Pond	PCBs	Dry Excavation	Off-site Disposal	7,730	Complete	d
Tennessee Products - Phase 1	Coal Tar	Dry Excavation	Off-site Disposal	21,400	Complete	f
Town Branch Creek	PCBs	Dry Excavation	Off-site Disposal	17,000	Complete	f
Upper Rouge River	PCBs	Dry Excavation	Off-site Disposal	7,000	Complete	d;f
Willow Run Creek	PCBs; Metals	Dry Excavation	On-site Disposal	450,000	Complete	d;f
Convair Lagoon	PCBs	Cap	na	na	Complete	f
Hamilton Harbor	PCBs; PAHs	Cap; In-situ treatment	na	na	Complete	g
Wycoff Co. - Eagle Harbor #1	PAHs; Mercury	Cap	na	na	Complete	f
James River	Kepone	No Action	na	na	Complete	f
Sangamo - Weston	PCBs	No Action	na	na	Complete	f
St. Mary's River	Metals; PAHs; PCBs	No Action	na	na	Complete	d
Ashtabula Fields Brook Site	PCBs; Organics; Metals	Dredging	Off-site Treatment and Disposal	14,000	On-going	d;f
Cumberland Bay	PCBs	Hydraulic Dredging	Off-site Disposal	150,000	Complete	b;k
Fox River - SNU 56/57 Demo	PCBs	Hydraulic Dredging	Off-site Disposal	29,000	On-going	e
Manistique Harbor	PCBs	Hydraulic Dredging	Off-site Disposal	130,000	Complete	d
Menominee River	Arsenic; PCBs; PAHs; Organics	Dredging	nd	10,000	On-going	d;f
Newton Creek/Hog Island Inlet	PAHs	Unknown Removal	On-site Treatment and Disposal	2,400	On-going	d
Nyanza Chemical Waste Dump	Mercury; Metals; Organics	Unknown Removal	On-site Disposal	17,330	On-going	f
Pine River - Hot Spot	DDT; PBB; Organics	Dry Excavation	Off-site Disposal	21,500	On-going	f;j
Sullivan's Ledge	PCBs	Unknown Removal; Cap	On-site Disposal	5,200	On-going	f
Dupont Newport Plant	Metals; Organics	Dry Excavation	Off-site Disposal	1,500	On-going	f
Kalamazoo River (Bryant Mill Pond)	PCBs	Dry Excavation	On-site Disposal	165,000	On-going	d;f

Exhibit 3 (continued)
Summary of Contaminated Sediment Sites

Site Name	Primary Contaminants of Concern	Sediment Removal or In-Situ Management	Sediment Treatment/Disposal	Sediment Volume (yd^3)	Status	Data Sources
Ottowa River (Aquablok Demo)	PCBs; PAHs; Metals	Cap	na	na	On-going	f
Ashtabula River and Harbor	PCBs	Mechanical Wet Dredging	CDF	1,000,000	Planned	d
Commencement Bay - Hylebos Waterway	Metals; PCBs; PAHs	Dredging	CDF	508,000	Planned	f
Grand Calumet River/Indiana Harbor	PAHs; PCBs; Metals	Hydraulic and Mechanical Dredging	CDF	4,500,000	Planned	i;d;f
New Bedford Harbor - Phase 2	PCBs	Hydraulic Dredging	CDF	500,000	Planned	a
Pine River - St. Louis Impoundment	DDT; PBB; Organics	Dredging	Off-site Disposal	260,000	Planned	d;f
Randle Reef (Hamilton Harbor)	PAHs	Dredging	nd	30,000	Planned	g
Saganaw River	PCBs; Dioxin; Metals	Dredging	CDF	320,000	Planned	d;f
Sheboygan River/Harbor - Full	PCBs; Metals	Dredging	Off-site Disposal	118,200	Planned	f
St. Lawrence River - Reynolds Metal	PCBs	Dredging	On- and Off-site Disposal	77,000	Planned	d;f
Trenton Channel (Black Lagoon)	PCBs; PAHs; Mercury	Dredging	CDF	20,625	Planned	d;f
Silver Bow Creek	Metals	Unknown Removal	Off-site Disposal	nd	Planned	f
Vineland Chemical	Arsenic	Unknown Removal	On-site Treatment and Disposal	70,000	Planned	f
McCormick and Baxter - Portland	PAHs	Cap	na	na	Planned	f
McCormick and Baxter - Stockton	Dioxin/Furan; PAHs	Cap	na	na	Planned	f
Montrose Chemical	DDT; PCBs	Cap	na	na	Planned	f
Pine Street Canal (Burlington)	PAHs; Organics; Metals	Cap	na	na	Planned	f
Black River (S. Branch)	PCBs; Metals	nd	nd	6,500	Investigation	d
Fox River - River	PCBs	nd	nd	10,900,000	Investigation	d
Grasse River (ALCOA) - Full	PCBs	nd	nd	nd	Investigation	f
Housatonic River - River Sediment	PCBs	nd	nd	nd	Investigation	f
Hudson River	PCBs	nd	nd	nd	Investigation	
Kalamazoo River (River Sediments)	PCBs	nd	nd	11,000,000	Investigation	c;g
Little Menomonee River	Creosote; PAHs	nd	nd	15,000	Investigation	d
Manitowoc River Basin	PCBs	nd	nd	210,000	Investigation	d
Passaic River (Diamond Alkalii)	Dioxin/furan; PAHs; PCBs; Metals	nd	nd	nd	Investigation	f
Queensbury - Deep Water	PCBs	nd	nd	nd	Investigation	h
Shiawassee River (Post-ROD)	PCBs	nd	nd	nd	Investigation	d;f
St. Louis River	Metals; Organics	nd	nd	nd	Investigation	d

na -- Not applicable
nd -- No data available
CDF -- Confined disposal facility
CTF -- Confined treatment facility

Sources:
a Dickerson, 2000
b Dolata, 2000
c Eberhardt, 2000
d EPA, 1998c
e Fitzpatrick, 2000
f GE et al., 1999
g IJC, 1997
h Moreau, 2000
i Kirschner, 2000
j Cieniawski, 2000
k Sevenson Environmental Services, 2000

In most dry excavation projects, sheet piling or other hydraulic barriers are used to dewater contaminated sediment before removal with conventional earthmoving equipment (e.g., backhoes, bulldozers). In some cases, stream channels have been temporarily or permanently rerouted to expose contaminated streambeds. In at least one cleanup (i.e., the Queensbury Project on the Hudson River), the water level at the contaminated sediment site was lowered by controlling the flow from upstream dams. Ability to dewater the site is an important factor in selecting dry excavation. Among complete and on-going projects in Exhibit 3, dry excavation has been used to remove more than 1.4 million cubic yards from 18 sites. The median sediment volume removed in the dry excavation projects is 10,000 cubic yards, and the average sediment volume removed is approximately 76,000 cubic yards. The largest dry excavation cleanup occurred at Newburgh Lake, Michigan, where almost 590,000 cubic yards of PCB-contaminated sediment were removed.[5]


Source: Hahnenberg (1999)

Although dry excavation is common, contaminated sediments usually are removed by conventional dredging or wet excavation. Among the sites included in Exhibit 3, dredging or wet excavation has been used to remove more than 1.7 million cubic yards of contaminated sediment during 37 complete or ongoing projects.[6] The largest of these projects involved wet excavation. For example, 169,000 cubic yards of creosote-contaminated marsh sediments were removed from Bayou Bonfouca, Louisiana, using a computerized, custom-built, barge-mounted dredge (Palermo et al., 1998b). Most sediment cleanups with hydraulic or mechanical dredges have been smaller than 100,000 cubic yards. However, five dredging projects over 100,000 cubic yards have been completed (i.e., LTV Steel, Indiana; United Heckathorn, California; Manistique Harbor, Michigan; Cumberland Bay, New York; Marathon Battery; New York). In addition, seven hydraulic and/or mechanical contaminated sediment projects currently in planning, not including the Hudson River, are expected to produce from 118,000 to 4.5 million cubic yards.

The dredging projects included in Exhibit 3 generally were conducted with conventional hydraulic and mechanical dredges. Among the complete, on-going, and planned dredging projects for which the dredge type is known, hydraulic and mechanical dredges were selected for 51 percent and 33 percent of the projects, respectively. Wet dredging equipment was selected for

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[5] Hydraulic and mechanical dredges were used for portions of the Newburgh Lake cleanup.

[6] This total does not include 2.8 million cubic yards of contaminated sediment removed in the Commencement Bay, Sitcum Waterway navigational dredging project.

11 percent of the projects, and pneumatic dredges were selected for four percent of the projects.[7] *Advances in Dredging* described several innovative hydraulic and pneumatic dredges specifically designed for contaminated sediment cleanups. With the exception of a small number of demonstration projects, these innovative dredges have not been utilized for contaminated sediment cleanups in the U.S. Unavailability may be one reason these dredges have not been used, because most of these dredges were developed overseas. In addition, conventional dredges have advantages (e.g., relatively low cost, relatively high sediment production rates) over innovative dredges, as well as a growing track record of success.

As mentioned above, the Hudson River PCB site is not the only very large contaminated sediment site for which remedial options are under investigation. The Lower Fox River in Wisconsin and the Kalamazoo River in Michigan each contain approximately 11 million cubic yards of PCB-contaminated sediment. These two sites are responsible for about 85 percent of the PCB loadings to Lake Michigan from tributaries. In addition, investigations are underway for approximately 210,000 cubic yards of PCB-contaminated sediment in the Manitowoc River Basin in Wisconsin, PCBs in 8.5 miles of the Grasse River in New York, dioxin and other contaminants in 6 miles of the Passaic River in New Jersey, and PCBs in 8 miles of the South Branch of the Shiawassee River in Michigan.

2.2 Contaminated Sediment Handling, Dewatering, and Water Treatment

In most contaminated sediment cleanups, especially cleanups involving dredging or wet excavation, the water content of the sediment or dredge slurry needs to be reduced before the sediment can be disposed. If the water removed from the sediment carries contaminants, it must be treated. Thus, contaminated sediment cleanup plans, especially for large cleanups, usually include land-based facilities for sediment dewatering and water treatment. The facilities also may serve as staging areas where dried sediment is loaded onto trucks, rail cars, or barges for transportation to disposal facilities. At some sites, the facilities also include sediment treatment technologies (see Section 2.3). Dewatering and water treatment often are unnecessary in dry excavation cleanups.

When sediment dewatering and water treatment are needed, sediments are brought from the removal sites to sediment dewatering and water treatment facilities in several ways, depending on several site-specific factors such as the sediment removal method used, the amount of sediment and water generated, the water content of the sediment or sediment slurry, and the distance between the facility and the dredging location. For example, hydraulic and pneumatic dredges produce sediment slurries that can be pumped through a pipeline to the treatment location. Slurry pipelines are somewhat flexible and usually are floated on the water surface from the dredge to shore. As described in Section 3.2, slurry pipelines used at two remediation demonstration projects on the Lower Fox River were overpacked with a secondary pipeline (e.g., an 8-inch slurry pipeline was enclosed within a 12-inch secondary containment pipeline) to minimize potential leakage. None of the information sources reviewed for either *Advances in*

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[7] Cleanup projects that involved more than one type of dredge were counted more than once in these percentages.

Dredging or this report have identified incidents of pipeline leakage or failure in contaminated sediment cleanups.

Barges are sometimes used to transport contaminated sediment from dredging locations to dewatering and water treatment facilities. Barges typically are used with mechanical dredges, but have been used at least once at a hydraulic dredging site. Specifically, the on-going cleanup at Manistique Harbor (see Section 3.2) used barges in conjunction with hydraulic dredges because dredging occurred over a large area in locations away from the on-shore sediment dewatering and water treatment facility.

Sediment dewatering usually is accomplished with settling basins and mechanical equipment such as belt filter presses. In some cases, chemicals (e.g., polymers) are used to enhance dewatering. In addition, screens and other mechanical devices are often used to remove large debris or to separate sediment particles by size. See, for example, the Manistique Harbor case study in Section 3.2, which includes a step-by-step description of the sediment dewatering and particle separation process. Detailed descriptions of all of the most common sediment dewatering and particle separation techniques and equipment are available in EPA's Assessment and Remediation of Contaminated Sediment (ARCS) Remediation Guidance Document (EPA, 1994).

Methods of treating water generated by contaminated sediment cleanups vary, and are chosen based on site-specific factors such as contaminants and treatment effluent standards. Water treatment systems at PCB-contaminated sediment sites use conventional treatment technologies such as sand and carbon filters. The case studies in Section 3.2 provide examples of water treatment systems used in PCB-contaminated sediment cleanup projects.

2.3 Contaminated Sediment Treatment

Various treatment methods are available to immobilize sediment pollutants or decontaminate sediment by removing or destroying the pollutants. Most contaminated sediment cleanups performed to date, however, have not included sediment treatment beyond dewatering. Among the projects in Exhibit 3 for which treatment/disposal remedies are known, about 25 percent include treatment. The use of treatment technologies probably has been limited primarily by cost and technical feasibility issues (e.g., capacity of commercially-available treatment systems), particularly for large projects. In addition, due to high costs, treatment may be deemed unnecessary or not cost-effective if landfilling or other disposal options are determined to be adequately protective.

Although the use of contaminated sediment treatment is limited, there has been substantial progress in the 1990s to develop, demonstrate, and commercialize new technologies. EPA has published results for at least ten bench- and pilot-scale technology demonstrations performed under the ARCS program (see Appendix A), and contamination concerns associated with navigational dredging projects have led USACE and others to evaluate sediment treatment technologies for potential large-scale applications. For example, at least six treatment technologies have been pilot-tested as potential remedies for contaminated sediment generated by navigational dredging in the New York/New Jersey Harbor (Stern et al., 1998; Hall et al., 1998).

Technical and cost information about treatment technologies for PCBs and other pollutants have been compiled by several sources, some of which are identified in Appendix A. For example, EPA maintains several databases with information about technology demonstration projects. A search of one of these databases, EPA's Remediation and Characterization Innovative Technologies (REACHIT) database (http://www.epareachit.org), for ex-situ treatment of PCBs in saturated sediments identified 23 technologies offered by 21 vendors. EPA (1994) and Tuttle and Lester (1998) summarize many established and emerging contaminated sediment treatment technologies. Both of these sources include technology descriptions, performance information, and available cost information.

General treatment options for PCB-contaminated sediment include incineration, alternative thermal destruction (e.g., pyrolysis), vitrification, chemical treatment (e.g., dechlorination, gas-phase chemical reduction), thermal desorption, solvent extraction, stabilization (e.g., with cement or fly ash), and bioremediation. Some of these technologies have proven to be very effective. For example, the ECO-LOGIC gas-phase chemical reduction process achieved PCB destruction efficiency of 99.9999 percent in a test at Bay City, Michigan (Tuttle and Lester, 1998), and already is in commercial use in Australia and Japan (Arnold, 2000). A pilot test of the Westinghouse vitrification process using New York/New Jersey Harbor sediment achieved 100 percent destruction of PCBs (Stern et al., 1998). Costs of the potential treatment technologies vary and are influenced by the amount and type of material treated, the quantity of material, initial contaminant concentrations, contaminant reduction goals, and other factors. In general, however, the contaminated sediment treatment costs range from approximately $30 per cubic yard for soil washing to several hundred dollars per cubic yard for thermal destruction (EPA, 1994). Some technologies produce potentially marketable residuals (e.g., slag glass from vitrification) that may help to off-set treatment costs.

Treatment technologies used in complete and on-going sediment cleanups in Exhibit 3 include stabilization (e.g., adding cement or fly ash to immobilize the sediment), incineration, thermal desorption, and ex-situ bioremediation.

2.4 Contaminated Sediment Disposal

The primary disposal options for dredged or excavated contaminated sediment include upland landfills, aquatic or semi-aquatic confined disposal facilities or containment cells, or beneficial use (e.g., as fill material). Because most (i.e., about 75 percent) of the contaminated sediment cleanups listed in Exhibit 3 do not included treatment, the sediments generally have been placed in upland landfills. Among the cleanup projects where disposal information is available, about 19 percent include disposal in confined disposal facilities (CDFs) or similar structures. About 81 percent of the projects include upland disposal, including about 50 percent with off-site disposal, about 29 percent with on-site disposal, and about 3 percent with off-site and on-site disposal. Most off-site landfilling occurred at existing commercial landfills, and most on-site landfills were built as part of the cleanup projects.

In the U.S., options for upland landfilling include Resource Conservation and Recovery Act (RCRA) non-hazardous solid waste landfills, RCRA hazardous waste landfills, and Toxic Substances Control Act (TSCA) toxic waste landfills. PCB-contaminated sediments with 50 ppm or higher must receive TSCA-compliant treatment or disposal. There are currently nine commercially-permitted TSCA landfills in the U.S. (EPA, 2000d). Sediment contaminated with less than 50 ppm PCBs may be managed in solid waste landfills. Because transportation and disposal fees for solid waste landfills are much lower than for TSCA landfills, it is common for sediments to be separated by level of contamination and disposed of in different locations. For example, sediment from Manistique Harbor contaminated above 50 ppm PCBs was placed in TSCA landfills in Utah and near Detroit, Michigan. Sediment contaminated below 50 ppm PCB was placed in a solid waste landfill nearby in Munising, Michigan. This approach helps to minimize the cost of the cleanup.

The Ft. Edward Yacht Basin is not accessible to large tour boats because sediment contamination interferes with maintenance dredging.

3. RESULTS OF CONTAMINATED SEDIMENT CLEANUPS

The preceding section showed that a large majority of contaminated sediment cleanup decisions include removal by dredging or excavation. Dozens of contaminated sediment dredging or excavation cleanups have been successfully performed in the U.S., and several more large cleanups are being planned. These facts attest to the feasibility and effectiveness of removing contaminated sediment. Nevertheless, press materials, Internet sites, and reports by some of the parties responsible for contaminated sediment (e.g., GE, the Fox River Group of Industries) claim that contaminated sediment cleanup activities increase contamination problems.

For stakeholders in the Hudson River PCBs site, experiences at other sites are the best source of information about the methods and outcomes of contaminated sediment cleanups. Section 3.1 presents the results of eleven cleanups in terms of post-cleanup contaminant concentrations in sediment and fish. Section 3.2 provides information about cleanup methods and outcomes for four contaminated sediment cleanup projects, including the Deposit N and Sediment Management Unit (SMU) 56/57 dredging demonstration projects on the Lower Fox River, Wisconsin; Manistique Harbor, Michigan; and Cumberland Bay, New York.

3.1 Monitoring Results

Because contaminant resuspension has been the primary concern about dredging PCB contamination from the Upper Hudson River, the dredging results included in the 24 cleanup project summaries in *Advances in Dredging* focused on sediment resuspension monitoring. Data on sediment contamination before and after dredging were presented too, when available. These types of results are not readily accessible for most contaminated sediment cleanups.

Since *Advances in Dredging*, GE has referred to sediment and fish monitoring results as evidence that contaminated sediment dredging makes matters worse. For example, the Spring 2000 issue of GE's newsletter (GE, 2000b) concludes, based on no specific evidence, that "Elsewhere, PCB levels in fish and sediment have increased – not decreased – after dredging." In addition, GE's newsletter presents partial sediment concentration results for three sites (i.e., Manistique Harbor, St. Lawrence River, River Raisin) as evidence that dredging is unsuccessful.

This section presents pre- and post-dredging results for eleven sites, including sediment contamination results for eight sites and fish contamination data for nine sites.[8] These results were compiled from various previously-published sources (e.g., FRG, 1999) identified from a literature search, an Internet search, and personal communications with various experts. Sites identified from these sources were included in this analysis if sediment and/or fish contaminant data were available.

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[8] The Wisconsin Department of Natural Resources is preparing a report that will present monitoring results for approximately 20 sites. The report will be released with the Remedial Investigation/Feasibility study for the Lower Fox River site near the end of 2000 (Fitzpatrick, 2000a).

Black and Bergholtz Creeks, New York

Between the late 1970s and late 1980s, a series of remedies was implemented to address dioxin contamination in and around the Love Canal site in Niagara Falls, New York. Among Love Canal's impacts was contamination of sediment and wildlife in the downstream creeks and rivers, including Bergholtz Creek, Black Creek, Cayuga Creek, the Little River, and the Niagara River. Remedies addressing the impacted creeks and rivers included initial landfill encapsulation in 1979, final landfill closure in 1984, storm drain cleaning and plugging in 1986, and dry excavation of contaminated sediments from Black and Bergholtz Creeks in 1989 (Skinner, 1993).

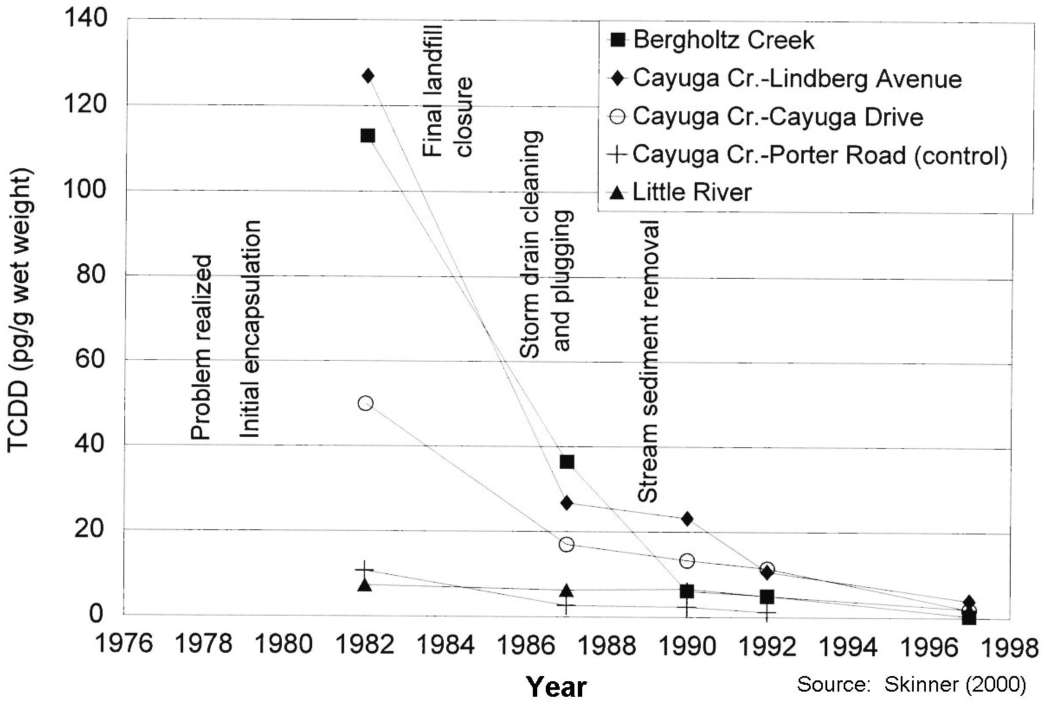
Dioxin concentrations (measured as 2,3,7,8-TCDD) in fish were monitored throughout the remedial period at locations in Bergholtz and Cayuga Creeks and the Little River. Exhibit 4 summarizes the results of the monitoring program and shows that each of the remedies was followed by a substantial reduction in dioxin contamination in fish. Some of the post-dredging reductions in fish contamination probably are attributable to continued benefits of prior remedial actions. However, the stream sediment removal appears to have reduced dioxin contamination by the greatest amount and most rapidly at the Bergholtz Creek monitoring station, the closest station downstream. For example, dioxin concentrations in fish at the Bergholtz Creek monitoring station were about 35 pg/g (wet weight) before dredging (1985) and 5 pg/g after dredging (1990). Dioxin contamination in fish at the control station (Cayuga Creek - Porter Road) declined very little between 1987 and 1990, which suggests that natural attenuation cannot account for the large declines seen downstream from the cleanup site.

Black River, Ohio

In 1989 and 1990, 49,700 cubic yards of sediment contaminated with PAHs, metals, and oil and grease were dredged from the Black River adjacent to the former USS/KOBE Steel coking facility. Dredging was performed with a watertight clamshell dredge. The cleanup target of the project was to remove all sediment in the contaminated area down to bedrock. Although there were no specific contaminant or biological goals, the project was undertaken to eliminate liver tumors in brown bullhead associated with PAH exposure (IJC, 1997).

Concentrations of PAHs measured in sediment from 1980 to 1997 are presented in Exhibit 5. The very large declines in PAH concentrations in sediment are attributable to at least three factors: the end of PAH discharges following closure of the coking plant in 1982, natural attenuation, and dredging of contaminated sediment. The share of each these factors to the river's recovery cannot be determined from the available data.

Exhibit 4
Changes in 2,3,7,8-TCDD Concentrations in Whole Young Cyprinid Fish Following Remediation of Love Canal



Source: Skinner (2000)

Exhibit 5
PAH Concentrations (ppm) in Sediment of the Black River Before and After Dredging (1989 and 1990)

PAH	**1980**[a]	**1984**	**1992**	**1997**
Phenanthrene	390	52	2.6	0.89
Fluoranthrene	220	33	3.7	1.86
Benzo(a)anthracene	51	11	1.6	1.02
Benzo(a)pyrene	43	8.8	1.7	0.88

[a] PAH discharges ended in 1982

Data sources: IJC (undated(a)); Ohio EPA (1999)

Observations of liver tumors in brown bullhead reveal more than the sediment data about the impact of dredging at the site. As shown in Exhibit 6, dredging appears to have increased the incidence of cancer and other liver impacts in brown bullhead for approximately three years following the completion of the project. Site conditions and equipment choices are likely to have contributed to the magnitude of the short-term impact. Shallow bedrock at the dredging site is likely to have complicated the removal, particularly because a mechanical dredge was used instead of a hydraulic dredge. In the fourth year after dredging, however, there was a precipitous decline in both cancerous and non-cancerous tumors, especially in the youngest age group (i.e., three years) studied (EPA, 1999c). No cancers were observed, and 85 percent of the fish analyzed had healthy livers. The recovery reportedly continued through 1997.[9] Based on these trends, Ohio EPA (1999) concluded that fish tumor frequencies increased following sediment dredging, but that "remedial dredging has been effective in reducing the long-tem impacts of the coking operations on the river." GE (1997) described this short-term impact without also describing either the large improvement in fish health in the fourth year or the post-dredging decline in sediment contamination.

Exhibit 6
Incidence of Liver Impacts in Brown Bullhead Collected from the Black River Before and After Dredging (1989 and 1990)

Incidence of Liver Tumors	1982	1987	1992	1993	1994
Cancer	31%	7%	27%	41%	0%
Non-cancer neoplasm	25%	14%	19%	20%	0%
Altered hepatocytes	21%	34%	8%	5%	15%
Normal	23%	45%	46%	34%	85%

Data sources: IJC (undated(a)); Ohio EPA (1999)

Grasse River, New York

As described in *Advances in Dredging*, Alcoa, Inc. performed a small, pilot dredging project in 1995 at a site on the Grasse River. Hydraulic and mechanical dredging removed about 3,000 cubic yards from the one-acre site. Boulders and debris present at the site were removed with a backhoe. According to GE (2000a), dredging reduced average PCB concentrations in surface sediment 86 percent, from 518 ppm before dredging to 75 ppm after dredging. Maximum surface sediment PCB concentrations were reduced 85 percent, from 1,780 ppm to 260 ppm. GE did not include results for all sediment depths, and complete data were not obtained from Alcoa in time for inclusion in this report.

PCBs were monitored in resident fish before and after dredging. Monitoring results were requested from Alcoa, but were not provided in time for this report. GE (2000a) presented a summary of the monitoring data, but did not included important details (e.g., sample sizes, whether the summary is based on average or maximum concentrations). The GE summary shows PCB concentrations in resident fish to be approximately 11 ppm before dredging. During 1995, just after the project, GE reports that the resident fish PCB concentration rose to more than 40 ppm. In 1996 and 1997, the PCB concentrations fell back to levels (i.e., approximately 12 to 14 ppm) just above the pre-dredging concentration. In 1998, three years after dredging, the PCB concentrations in resident fish declined to roughly 4 ppm, which is less than half of the pre-dredging concentration. Thus, based on these limited and unconfirmed results, it appears that

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[9] Ohio EPA (1999) refers to results of a 1997 fish study by Write State University and Ohio EPA. However, the results are not presented.

dredging caused a temporary (i.e., three year) increase in PCB concentrations in resident fish that was followed by a dramatic decline below pre-dredging contamination levels.

Lake Jarnsjon, Sweden

Lake Jarnsjon is located on the Eman River in Sweden. In 1994, the entire 62-acre lake was dredged to remove PCB contamination that originated from a papermill. Dredging is estimated to have removed 97 percent of the PCB mass from the lake and, as shown in Exhibit 7, reduced sediment concentrations by more than 90 percent (FRG, 1999). Pre- and post-dredging PCB concentrations in water and fish were measured in the lake and at upstream and downstream stations on the Eman River. Exhibit 8 shows that post-dredging PCB concentrations in fish in Lake Jarnsjon were 56 percent lower than pre-dredging concentrations. Reductions in fish contamination at the upstream background station were 33 to 36 percent. These findings show that the cleanup significantly reduced PCB contamination in the sediment and fish. FRG (1999) noted that post-cleanup fish-tissue PCB concentrations at the lake were still higher than anywhere else in the river system. This is correct, however, dredging would not be expected to reduce contamination below background (i.e., upstream) levels, and the only downstream sampling location was about 50 miles downstream where concentrations should be substantially lower than source concentrations.

Exhibit 7
PCB Concentrations in Sediment Before and After Dreding at Lake Jarnsjon, Sweeden (1994)

	Concentration (mg/kg)		Percent Reduction
	1991	1996	
Maximum	30.7	2.4	92%
Minimum	0.4	0.01	98%

Data compiled by FRG (1999)

Exhibit 8
PCB Concentrations in Fish Tissue and Surface Water Before and After Dreding at Lake Jarnsjon, Sweeden (1994)

	Fish Tissue			Surface Water (ng/L)		
	Concentration (mg/kg lipid)		Percent Reduction	Concentration (ng/L)		Percent Reduction
Monitoring Location	1991	1996		1991	1996	
35 km upstream (background)	1.4	0.9	36%	0.7	0.2	71%
10 km upstream (background)	9.1	6.1	33%	1.2	0.9	25%
Lake Jarnsjon (dredging site)	36	16	56%	8.6	2.7	69%
20 km downstream	--	--	--	5.1	2.3	55%
80 km downstream	6.7	5.2	22%	1.3	1.1	15%

Data compiled by FRG (1999)

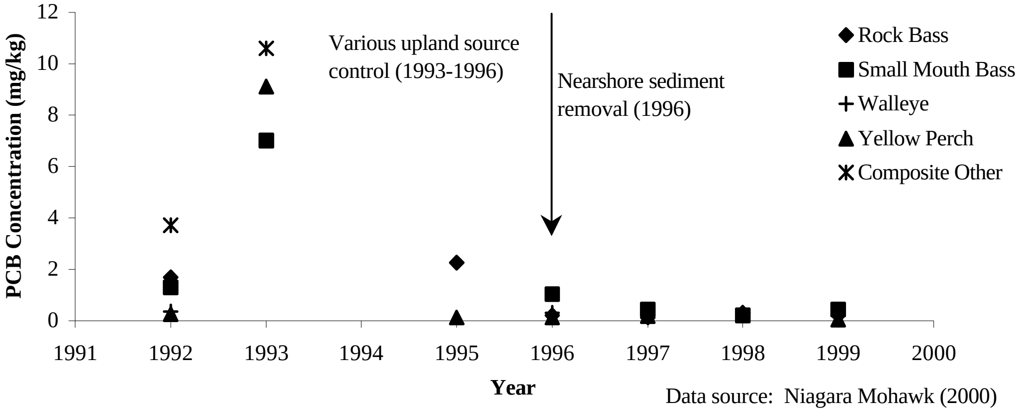
Queensbury, New York

Between 1993 and 1996, the Niagara Mohawk Corporation completed the first phase of a PCB cleanup on the Hudson River at Queensbury, New York. The site includes contaminated soil on the riverbank and nearshore sediments extending to a depth of 25 feet. The site is located on a portion of the river known as the Sherman Island Pool, which is impounded between two hydroelectric dams (Moreau, 2000). The GE Hudson Falls plant is located at the downstream end of the Sherman Island Pool. Pre-cleanup PCB concentrations in sediment at the Queensbury site ranged from non-detect to 12,000 ppm (Scenic Hudson, 1997a).

The first phase of the cleanup included removal of on-shore contamination between 1993 and 1996, and dry excavation of a portion of the nearshore sediments in 1996. The sediment cleanup area was dewatered by controlling flows across the upstream and downstream hydroelectric dams. The second phase of the cleanup to address deep-water sediment contamination is currently under investigation.

Exhibit 9 presents the results of fish contamination monitoring at the site and at upstream and downstream locations from 1993 to 1999. Exhibit 9 also includes fish contamination data collected at the site in 1992 as part of a project that was not focused on the Queensbury site. The 1992 data were collected at a different time of year than the 1993 to 1999 data and may be based on larger fish. According to the New York State Department of Environmental Conservation (DEC), the pre-cleanup fish contamination levels at the site are best represented by the 1993 data (Sloan, 2000).

Exhibit 9
Average PCB Concentrations in Fish Collected at the Queensbury Site



Data source: Niagara Mohawk (2000)

Fish contamination at the Queensbury site was lower following remediation. For example, average PCB concentrations in yellow perch declined from 9.11 ppm in 1993, to 1.4 ppm in 1995, and 0.04 ppm in 1999. PCB concentrations in small mouth bass declined from 7.02 ppm in 1993, 1.04 ppm in 1996, and 0.43 in 1999 (Niagara Mohawk, 2000). Remediation of the sediments and the riverbank soils probably both contributed to the declines in fish contamination. DEC expects that remediation of the deepwater sediment contamination in the second phase of the cleanup would reduce fish contamination further (Sloan, 2000).

River Raisin, Michigan

Approximately 27,000 cubic yards of PCB-contaminated sediment were removed from the Raisin River in 1997 in an area adjacent to a Ford Motor Company facility. Sediment contamination data from primary sources were not available for this report. According to GE (2000a), however, dredging reduced the maximum concentrations at the site by more than 99 percent, from 29,000 ppm[10] before dredging to 20 ppm after dredging. Average sediment PCB concentrations were reduced by more than 99 percent, from 6,510 ppm before dredging to 9.7 ppm after dredging.[11,12]

Ruck Pond, Wisconsin

In 1994, 7,730 cubic yards of PCB-contaminated sediment were removed from Ruck Pond, a mill impoundment on Cedar Creek, Wisconsin. The cleanup was conducted by dewatering the pond, allowing the sediment to partially dry, and removing the sediment with conventional excavation equipment. Fill dirt used to access the pond was spread over portions of the site before re-inundation. The cleanup is estimated to have removed 782 pounds of PCBs, or 96 percent of the PCB mass. Average sediment PCB concentrations were reduced 82 percent from 474 to 84 ppm, and maximum sediment PCB concentrations were reduced 99 percent from 150,000 ppm to 280 ppm (EPA, 1998c; GE et al., 1999).

The Wisconsin Department of Natural Resources conducted caged-fish studies to monitor the effect of the cleanup on fish contamination. Caged fish were placed in the pond and at upstream and downstream locations for 28-day periods[13] immediately before the cleanup and approximately one year later. Average PCB concentrations from the caged fish studies are presented in Exhibit 10. Post-cleanup fish contamination was approximately 83 percent lower than pre-cleanup fish contamination at Ruck Pond.[14] Smaller declines in fish contamination observed at the upstream and downstream locations may be due to a system-wide natural recovery (e.g., due to continuing delivery of PCBs from sediment to the water column) and/or

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[10] EPA (1998c) reported the maximum PCB concentration at the site before dredging to be 49,000 ppm.

[11] Average and maximum PCB concentrations in the surface sediment layer before dredging were 4,130 and 28,000 ppm, respectively (GE, 2000a).

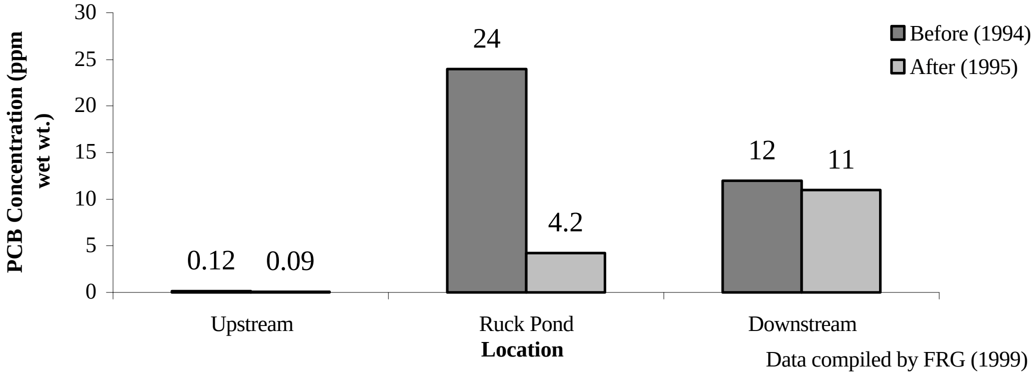
[12] Michigan Department of Environmental Quality and U.S. EPA personnel had difficulty colleting post-cleanup sediment samples at the site because the site had been dredged to bedrock. At most sampling locations, there was not enough sediment present to collect samples (Cieniawski, 2000).

[13] Two cages in Ruck Pond were not recovered until 29 and 37 days (FRG, 1999).

[14] Measured on a lipid basis, the post-cleanup fish contamination was approximately 90 percent lower than pre-cleanup fish contamination at Ruck Pond (FRG, 1999).

uncertainty in the data. It is apparent, however, that the remedy had a significant benefit at Ruck Pond and did not adversely affect conditions downstream. Moreover, additional testing at Ruck Pond in 1997 showed further declines in fish contamination; average PCB concentrations ranged from 0.35 to 3.1 ppm (FRG, 1999).

Exhibit 10
PCB Contamination in Fish Before and After Sediment Remediation at Ruck Pond, Wisconsin (1994)



Data compiled by FRG (1999)

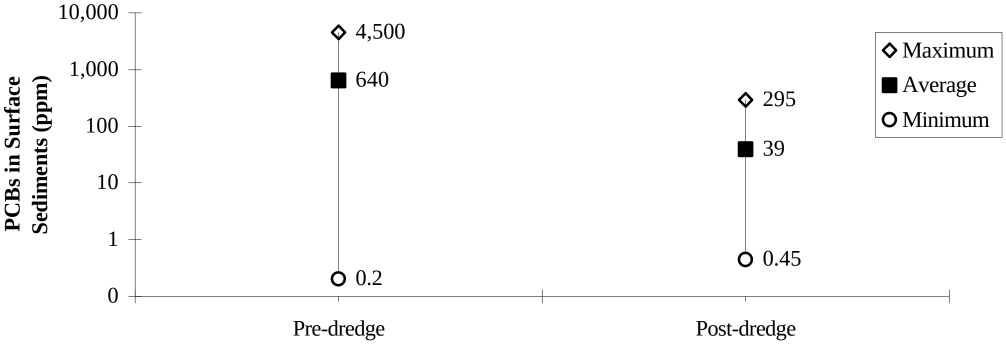
Sheboygan River, Wisconsin

Between 1989 and 1991, a modified clamshell dredge was used to clean up 17 PCB-contaminated sediment deposits in the Sheboygan River. The cleanup removed an estimated 95 percent of the PCB mass from the deposits. Complete cleanup results data from primary sources could not obtained for this report. However, GE (2000a) reported sediment results data for two of the deposits. Specifically, GE reported surface concentration data for one deposit, and surface and subsurface concentration data for another deposit. The basis used by GE to select which data were presented could not be determined.

Despite the use of a mechanical dredge, PCB concentrations in sediment were reduced substantially in both locations. Results for the first location are presented in Exhibit 11. At this location, average surface sediment PCB concentrations were reduced by 94 percent, from 640 ppm before dredging to 39 ppm after dredging, and maximum PCB concentrations were reduced by 93 percent, from 4,500 ppm before dredging to 295 after dredging.

At the second location, maximum PCB concentrations for all sediment depths (i.e., including both surface and subsurface sediment) were reduced by 90 percent, from 1,400 ppm before dredging to 136 ppm after dredging. GE did not report the reduction in average PCB concentration for all sediment depths at this deposit, but did report that the average and maximum post-dredging PCB concentrations in surface sediments were 5 and 8.2 ppm, respectively.

Exhibit 11
PCB Concentrations in Surface Sediment at the Sheboygan River Site Before and After Mechanical Dredging



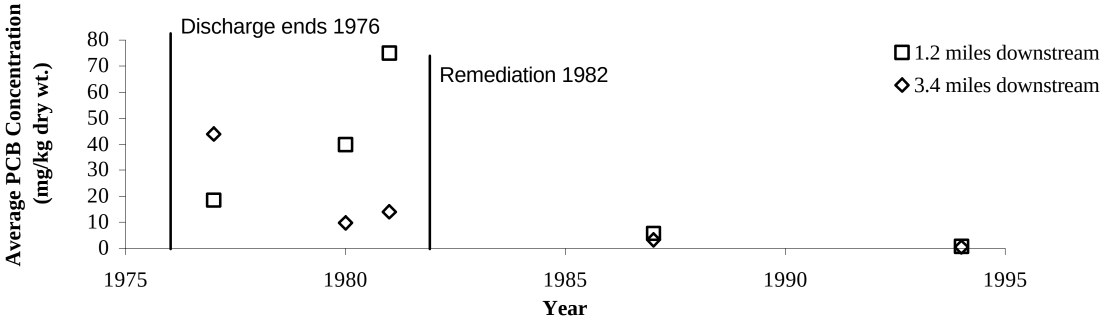
GE (2000a) also presented PCB concentrations in small mouth bass in the Sheboygan River during and after remediation. Pre-dredging fish contamination data apparently were unavailable. During remediation, average smallmouth bass PCB concentrations just downstream from the site were just under 5 ppm in 1990 and just over 7 ppm in 1991. In the first three years following remediation (i.e., 1992 to 1994) PCB concentrations in downstream fish were between 5 and 6 ppm. From 1995 to 1998, the PCB concentrations have ranged between approximately 3 and 4 ppm. The lowest reported average concentration (about 3 ppm) and maximum concentration (about 4 ppm) both occurred in 1998. GE also reported smallmouth bass PCB concentrations for the same time period at the dredging locations. These data are highly variable and no trend is apparent.

South Branch of the Shiawassee River, Michigan

In 1982, 1,085 cubic yards of PCB-contaminated sediment were dredged from the South Branch of the Shiawassee River in Michigan. PCB concentrations in sediment before and after remediation are shown in Exhibit 12, and PCB concentrations in white perch are shown in Exhibit 13. Both exhibits include data collected at monitoring stations 1.2 miles and 3.4 miles downstream. The monitoring results from the station closest to the site (i.e., 1.2 miles downstream) are more indicative of source conditions and the impact of remediation.

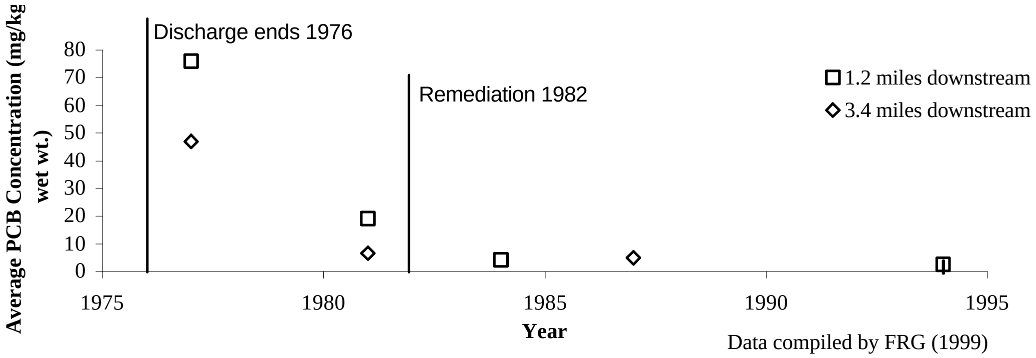
PCB concentrations measured in white perch and sediment downstream from the dredging site before and after dredging indicate that the cleanup, along with PCB attenuation following the discontinuation of discharges in 1976, contributed to a striking recovery in the river. Trends in average PCB concentrations before and after dredging in sediment and fish are presented in Exhibit 12 and Exhibit 13, respectively. As shown in Exhibit 13, average PCB concentrations in white perch collected 1.2 miles downstream from the dredging site decreased from 19 ppm (wet weight) in 1981 (i.e., the year before dredging) to 4.2 ppm in 1984 and 2.6 ppm in 1994 (FRG, 1999). Exactly how much of the post-dredging PCB reductions are attributable to dredging is unclear. However, it is clear that remediation did not make matters worse by increasing fish contamination.

Exhibit 12
Trends in Average PCB Concentrations in Sediment Before and After Sediment Remediation in the South Branch of the Shiawassee River



Data compiled by FRG (1999); does not include data collected in 1974 before discharges ended (i.e., 530 mg/kg 1.2 miles downstream and 97 mg/kg 3.4 miles downstream)

Exhibit 13
Trends in Average PCB Concentrations in Fish Before and After Sediment Remediation in the South Branch of the Shiawassee River



Data compiled by FRG (1999)

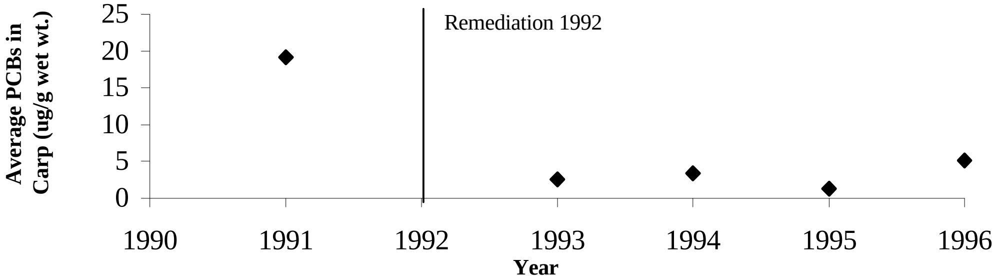
St. Lawrence River - General Motors, New York

As described in *Advances in Dredging*, General Motors dredged 13,000 cubic yards of PCB-contaminated sediment in 1995 from a cove on the St. Lawrence River adjacent to the GM Central Foundry Division Superfund site. The dredging site was isolated from the river with sheet piling, and dredging was performed with a hydraulic dredge supplemented with a backhoe for debris removal. Debris and uneven bedrock beneath the sediment prevented the complete removal of sediment, and the project goal of 1 ppm PCBs in sediment was not met in a portion of the site. Maximum PCB concentrations were reduced by almost 99 percent from 8,800 ppm before dredging to less than 100 ppm after dredging. Average PCB concentrations were reduced from about 200 ppm to 9.2 ppm (Hartnett, 1996; GE, 2000b). A multi-layer cap consisting of sand, activated carbon, and gravel was placed over 1.7 acres of the 10 acre project area.

Waukegan Harbor, Illinois

As described in *Advances in Dredging*, about 38,300 cubic yards of PCB-contaminated sediments in Waukegan Harbor were remediated in 1992. The remedy included hydraulic dredging of all sediment with more than 50 ppm PCBs, on-site thermal extraction of at least 97 percent of the PCBs, and disposal of treated sediment in a containment cell constructed in the "Slip #3" portion of the site (IJC, undated(b)). In 1997, the State of Illinois lifted a fishing advisory for the harbor citing decreases in PCB concentrations in fish attributable to cleanup (GLC, 2000). Data to document PCB trends in Waukegan Harbor fish are limited. Exhibit 14 presents data for carp, which have been presented previously (e.g., IJC, 1997; Hahnenberg, 1999) as evidence of the harbor's recovery. Although Exhibit 14 suggests a significant decline in fish contamination after remediation at Waukegan Harbor, the pre-dredging sample size is only one fish. Thus, the apparent decline cannot be statistically confirmed.

Exhibit 14
PCB Concentrations in Carp at Waukegan Harbor
Before and After Dredging (1992)



Data compiled by Hahnenberg (1999)

Summary of Results

The results presented in this section provide specific evidence that contaminated sediment cleanups can reduce contamination in sediment and fish. Results vary from site-to-site, and some studies are subject to research limitations (e.g., small sample sizes). Viewed collectively, however, the studies show consistently that dredging had beneficial results and did not make matters worse as GE claims. In general, contaminant reductions at the study sites exceed reductions at control sites, and the greatest contaminant reductions are seen at monitoring locations closest to the cleanup areas. Short-term (i.e., three-year) adverse impacts on fish contamination was suggested only for two site, the Black and Grasse Rivers, where a mechanical dredges were used and where challenges were posed by bedrock and/or debris. Clear benefits were observed at these sites by the fourth years after the cleanups.

Post-cleanup contaminant reductions at most of the sites are at least partially attributable to gradual background attenuation of contaminants (e.g., due to diffusion from contaminated sediments or microbial decomposition) and, in some cases, to land-based or other source control actions before the sediment cleanup. In addition, the contaminant reductions in fish at some sites are at least partly hidden by contamination originating from other sites nearby. For these reasons, it is difficult or impossible to precisely determine the percentage reductions in sediment and fish contamination at these particular sites that are attributable only to sediment removals. However, at sites such as Ruck Pond, Black and Bergholtz Creeks, and Lake Jarnsjon, contaminant reductions at cleanup locations greatly exceed contaminant reductions at control locations. Moreover, it should be noted that although background reductions in sediment contamination are beneficial when associated with chemical or bacterial decomposition, they are not necessarily beneficial when due to contaminant loss (e.g., to downstream waters or into the food chain).

3.2 Case Studies

This section presents case studies for four contaminated sediment cleanup projects. Unlike the dredging project summaries in *Advances in Dredging*, which focused on dredging methods and sediment resuspension results, these case studies include information about sediment handling, disposal, and other aspects of the cleanups. The case studies were selected to include a range of ex-situ cleanup methods that might be relevant to the Hudson River PCBs site. In addition, the two Lower Fox River sites are included because of the overall similarity of the Fox River and Hudson River sites and the likelihood that demonstrations on the Lower Fox River will be considered to be relevant examples for the Hudson River. The level of detail varies among the case studies because of information availability from primary sources.

Lower Fox River, Wisconsin

The Lower Fox River flows a distance of 39 miles from Lake Winnebago to Green Bay, Wisconsin. Sediment contamination is widespread throughout the river. The primary contaminants of concern in the Lower Fox River are PCBs, which were used in the manufacture and recycling of carbonless copy paper. An estimated 418,000 to 825,000 pounds of PCBs were released to the river beginning in 1954 (WDNR, 1998). Although industrial PCB use ended in 1970, contamination remains in 35 sediment deposits above the De Pere Dam, containing an estimated 8,800 pounds of PCBs, and in areas downstream of the dam, containing an estimated 44,000 to 88,000 pounds of PCBs. (Fitzpatrick, 1998) The sediment releases an estimated 620 pounds of PCBs to Green Bay each year (Velleux and Endicott, 1994).

A river-wide cleanup investigation is underway under the direction of the Wisconsin Department of Natural Resources (WDNR), and a final Remedial Investigation/Feasibility Study is expected in November 2000. Meanwhile, pilot dredging projects have been undertaken in two locations, Deposit N at Kimberley, Wisconsin and SMU 56/57 at Green Bay, Wisconsin.

Deposit N

WDNR conducted a dredging demonstration project at Deposit N in 1998 and 1999. Deposit N was located along the south bank of the Fox River adjacent to Kimberley, Wisconsin, and just upstream from the Cedars Dam. The deposit covered three acres and was one of the most highly-contaminated of the River's sediment deposits (EPA, 1999f). In 1998, before dredging, PCB concentrations in sediment at Deposit N averaged 16 ppm with a maximum of 180 ppm (Foth & Van Dyke, 2000). Average and maximum PCB concentrations at Deposit N were measured at least six times between 1989 and 1998. Average concentrations ranged from 16 ppm to 130 ppm, and maximum concentrations ranged from 61 to 186 ppm (Foth & Van Dyke, 2000). The pre-dredging concentration varied widely because the distribution of PCBs at the site were highly heterogeneous (Fitzpatrick, 2000a).

Deposit N contained 11,000 cubic yards of sediment, of which 7,070 cubic yards were targeted for removal (Foth & Van Dyke, 2000). The sediment deposit averaged about two feet thick and was underlain by bedrock. Water depth at the deposit site averages approximately eight feet. The cleanup plan included goals for an average remaining sediment thickness of three inches with no thickness more than six inches in the western portion of the site, and an average remaining sediment thickness of six inches or less in the eastern portion of the site. This goal was intended, "to capture the bulk of the contamination efficiently and cost effectively without exceptional efforts to try and remove the thin layer of residual sediment laying on top of the fractured bedrock surface" (Foth & Van Dyke, 2000).

The dredging demonstration project was performed with a barge-mounted, eight-inch diameter cutterhead dredge in a swing ladder configuration. Sediment slurry was pumped to an on-shore dewatering system through an eight-inch HDPE pipe, which was overpacked inside an 18-inch HDPE pipe as secondary containment in the event of a pipeline leak (Foth & Van Dyke, 2000).

The sediment dewatering system for the Deposit N project is illustrated in Exhibit 14. The slurry pumped to shore from the dredge site (1) was discharged to a shaker screen (2) for removal of coarse material (e.g., rocks, debris). The slurry was then passed through hydrocyclones (not shown) to remove coarse-grained material.[15] Next, a thickening polymer was added (3) to the slurry to facilitate settling (4). Thickened sediment from the bottom of the settling tanks was pumped to two 220 cubic food capacity filter presses (5) for further dewatering. The filter cake, which was typically 60 percent solids by weight, was tested for contaminants and solids content prior to disposal (7). Water removed from the slurry and sediment in the treatment process was pumped through bag filters, to sand filters, and then to liquid-phase carbon adsorbers (6), and the water treatment effluent was tested for PCBs and several other water quality parameters before discharge to the river. During the cleanup, the treatment system operated 24 hours per day, seven days per week.

Features of the treatment site included surface water and erosion control structures and measures, a security fence, and a multi-layer liner in areas where sediment and water treatment equipment were located. The liner included geotextile fabric, a 60 mil HDPE liner, six inches of sand, six inches of gravel, and four inches of bituminous concrete. In addition, a public

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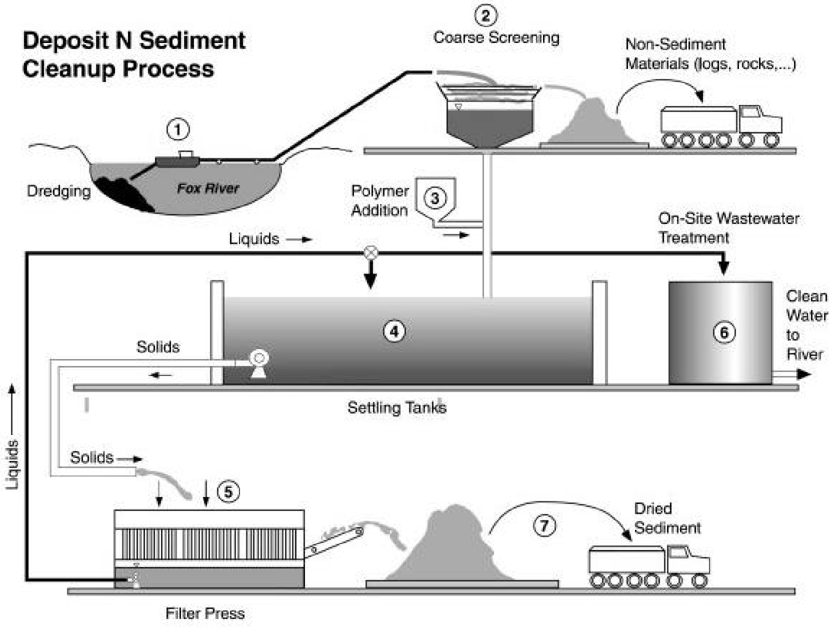
[15] PCBs tend to adsorb to fine, organic sediment particles rather than coarse (e.g., sandy) sediment particles. Separation of fine- and coarse-grained sediment helps to concentrate the contamination and reduce overall disposal or treatment costs.

observation platform was constructed within view of the treatment area. The site was surrounded by four real-time air quality monitors (Foth & Van Dyke, 2000).

Exhibit 14
Sediment Remediation Process for the Lower Fox River
Deposit N Project



Source: Foth & Van Dyke (2000)

Sediment contaminated with more than 50 ppm PCBs was transported by truck to an existing TSCA landfill. Sediment with less than 50 ppm PCBs was trucked to a local landfill. All truckloads were covered, and tailgates were sealed to prevent spillage. Trucks and the paved loading area were power washed after each loading. The water generated by cleaning was pumped to the treatment system (Foth & Van Dyke, 2000).

Because the State of Wisconsin does not own land adjacent to Deposit N, it was necessary for the state to negotiate access agreements with three landowners, including a private family, Inter Lake Papers, and the U.S. Army Corp of Engineers (and their Lessee, Friends of the Fox). The access agreements identified allowable activities, restoration activities, and other conditions requested by the property owners (WDNR, 1999).

Water quality downstream from Deposit N was of particular concern to Inter Lake Papers which withdraws 20 million gallons per day (MGD) water from the river immediately downstream from the site for production of food-grade paper. To mitigate potential sediment and contaminant resuspension, the deposit was surrounded during the first dredging season by a perimeter barrier constructed of 80 mil HDPE anchored to the river bottom and connected to the river bank.[16] In addition, a silt curtain was placed downstream from the dredging area within the perimeter barrier, and a deflector barrier was installed outside the perimeter barrier as an extra measure of protection for the Inter Lake Papers water withdrawal. The deflector barrier extended from 20 feet upstream to 200 feet downstream of the intake. Sediment resuspension and river turbidity were monitored with six turbidity meters at various locations. The monitors were equipped to telemetrically relay turbidity readings to an on-shore computer (WDNR, 1999).

The first dredging season began on November 26, 1998 and continued to late December when the project was suspended because of winter weather. Dredging at Deposit N was completed from August 20 to October 14, 1999. Because dredging at Deposit N was completed ahead of schedule, the cleanup was expanded to Deposit O on the opposite shore of the river. Dredging at Deposit O occurred from October 15 to November 9 (Foth & Van Dyke, 2000).

Upon completion of the project, 7,160 cubic yards of sediment had been removed from Deposit N, an amount slightly above the targeted removal of 7,070 cubic yards. A total of 111 pounds of PCBs were removed from Deposit N, which was about 78 percent of the pre-dredging PCB mass. At Deposit O, an additional 1,030 cubic yards of sediment were removed containing an estimated 6 pounds of PCBs. Average PCB concentrations in sediment at Deposit N were reduced to 14 ppm from pre-dredging levels of 16 to 130 ppm. Maximum PCB concentrations were reduced to 130 ppm from pre-dredging levels of 61 to 186 ppm. Although the project was complicated by shallow bedrock, the dredging contractor met the residual sediment depth goals (e.g., an average of three inches with no more than six inches in the western portion of the site, and an average of six inches or less in the eastern portion of the site).

The final report for the Deposit N project (Foth & Van Dyke, 2000) concludes that sediment resuspension and transport during dredging was insignificant and had no impact on Lake Paper's 20 MGD water withdrawal immediately downstream from the site. Turbidity monitoring showed that average turbidity levels downstream from the site were approximately two to four nephelometric turbidity units (NTU) above background levels, a difference which is within the range of the turbidity meter accuracy and natural variations in turbidity in the river.

A further evaluation of the effectiveness of the Deposit N project was prepared by the Fox River Remediation Advisory Team (FRRAT, 2000), which included independent experts from the University of Wisconsin-Madison and the U.S. Geological Survey. The FRRAT used a mass-balance approach to determine the fate of PCBs during the first season of Deposit N project. The evaluation concluded that dredging removed 89 percent of the PCB mass from the portion of the site dredged. Approximately 37.8 pounds of PCBs were removed from the site, 5.7 pounds of PCBs remained undredged, 4 pounds of PCBs were lost downstream, and 0.0004 pounds of PCBs were returned to the river through the water treatment system. The FRRAT concluded that environmental dredging was an effective mechanism for removal of contaminated sediments from the site, and that shore-side processing was an effective means of concentrating and permanently removing contaminated sediments from the river.

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[16] Based on low levels of sediment resuspension during the first dredging season, the perimeter barrier was not used during the second dredging season.

In addition the FRRAT determined that the mass balance approach is the most scientifically defensible measure for assessing the effectiveness of the dredging operation (FRRAT, 2000). The concentration-based approach favored by FRG, which simply compares before and after surface sediment concentrations, was described by the FRRAT as misleading because it does not account for the quantity of PCBs permanently removed from the river. Although average surface sediment PCB concentrations in the portion of the site dredged during the first season declined by 33 percent, 89 percent of the PCB mass was removed. The post-dredging PCB mass (5.7 pounds) is approximately half of the annual load of PCBs (about 8.8 to 11.1 pounds per year) from the area to the river before dredging. Thus, the FRG approach does not show how the cleanup will reduce PCB loading to the river from the deposit in future years.

Another notable finding of the FRRAT was that monitoring of total suspended solids (TSS) did not completely describe downstream transport of PCBs during dredging (FRRAT, 2000). Because PCBs have low solubility and tend to remain adsorbed to suspended solids, TSS is commonly monitored as an indicator of contaminant loss during environmental dredging projects. Monitoring during the Deposit N project included measurement of dissolved PCBs, as well as PCBs adsorbed to suspended particulates. The majority of PCB detected was associated with TSS, and there was little or no measurable difference between TSS concentrations upstream and downstream from the dredging site. However, about 25 percent of the downstream PCBs were dissolved, and dissolved PCB concentrations were not necessarily correlated with TSS concentrations. This finding suggest that monitoring plans for future dredging projects should include measurement of both dissolved and particulate PCBs.

Sediment Management Unit 56/57

SMU 56/57 is located at the Fort James Turning Basin at Green Bay, Wisconsin, which contains the highest concentrations of PCBs in the Lower Fox River (up to 710 ppm). SMU 56/57 encompasses an area of nine acres and is part of a larger contiguous area of sediment contamination. In 1997, the Fox River Group (FRG) of responsible parties[17] and State of Wisconsin signed an agreement to conduct a dredging demonstration project at SMU 56/57. FRG and WDNR are jointly responsibility for the project.

The agreement between the FRG and Wisconsin did not include specific cleanup goals (e.g., cleanup target concentrations, sediment quantities). However, 0.25 ppm was used as a tentative cleanup target. Based on that target, the volume of sediment expected to be dredged was estimated to be 80,000 cubic yards (Fitzpatrick, 2000b). Dredging was expected to last two months and be complete in the late fall of 1999. As described further below, delays and equipment problems prevented completion of the project before winter weather ended the dredging season.

The SMU 56/57 demonstration project was conducted with dredging, dewatering, and disposal equipment and methods similar to those use for the Deposit N demonstration project.

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[17] The Fox River Group includes Appleton Papers, Inc., Fort James Corporation, NCR Corporation, P.H. Glatfelter Company, Riverside Paper Corporation, U.S. Paper Mills Corp., and Wisconsin Tissue Mills, Inc.

Sediment was removed with hydraulic dredges and transported to the on-shore treatment system through a 12-inch pipeline sealed within a 16-inch pipeline. The slurry pipeline discharged to two, one-acre settling ponds. Settling of the sediment in the ponds was hastened by adding aluminum sulfates. Settled sediment from the ponds was pumped to filter presses for further dewatering, and water from the ponds was passed through sand and carbon filters before being returned to the river (Culhane, 1999b). A new landfill was built to hold the dried sediment. The landfill was lined with layers of clay, a 60-mil layer of HDPE, sand, five feet of clay, a second layer of HDPE, and finally a second layer of sand with a leachate collection system (Culhane, 1999b). The project included an extensive water, sediment, and air monitoring program.

The project was initiated with a cutterhead dredge that produced a sediment slurry with about five percent solids, which was lower than expected and too low for efficient operation of the dewatering system. In early September, the cutterhead dredge was replaced with a horizontal auger dredge that achieved the necessary slurry density (i.e., about 15 percent solids), but removed fewer cubic yards per day. The second dredge was then replaced with a larger horizontal auger dredge with an expected capacity of 200 cubic yards of sediment per hour (Culhane, 1999a). Also contributing to the delays were higher pH levels than anticipated in the water, which interfered with the sand and carbon filtration system (Culhane, 1999a), and the presence of debris[18] in the sediment. When dredging was suspended for the winter, 29,000 cubic yards of sediment had been removed from the site (Culhane, 2000a).

After the end of the 1999 dredging season, a controversy arose about whether the SMU 56/57 demonstration project would be completed. In early spring 2000, the FRG proposed not to complete the project and to cap the site instead. In addition to the technical problems and delays, the proposed change was driven by interim sediment sampling following the end of the 1999 dredging season. Surface sediment concentrations were above pre-dredging concentrations over most of the site where dredging was begun. At one sampling location, the surface sediment PCB concentration increased from 3.5 ppm before the project to 280 ppm at the end of the 1999 dredging season (Culhane, 2000a).

FRG and WDNR, partners in the SMU 56/57 project, had opposing interpretations of these results. FRG regarded the results as evidence of the failure of dredging as a remedy in general. WDNR blamed the results on failure to complete the project. WDNR noted that the concentration increases were primarily in portions of the site where sediment was not dredged down to the targeted depth.[19] The dredge cut part way into the contaminated sediment deposits in these areas leaving elevated subsurface concentrations exposed. Dredging decreased surface sediment concentrations, however, in three of the four locations where the targeted depth was reached with a second "cleanup pass" of the dredge (Fitzpatrick, 2000b).

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[18] Debris was less problematic at SMU 56/57 than at Deposit N where the sediment was underlain by bedrock (Hahnenberg, 2000b).

[19] At sites where the contamination is not underlain by bedrock, dredging depth targets can be set at depths just below the lowest depth of contamination above the cleanup level. Under-dredging (i.e., not meeting the dredging depth target) can result in residual concentrations above the cleanup target concentration. Over-dredging results in unnecessary handling and processing of sediment contaminated below the cleanup target concentration.

As WDNR and FRG negotiated during the winter and spring, other stakeholders weighed in on the situation, its consequences, and potential solutions. The EPA, the Wisconsin Justice Department, the U.S. Fish and Wildlife Service (FWS), environmentalists, and the Science and Technical Advisory Committee of the Lower Fox River and Green Bay Remedial Action Plan all agreed with WDNR's interpretation of the sediment sampling results and favored completion of the dredging project.

A letter from the Science and Technical Advisory Committee of the Lower Fox River and Green Bay Remedial Action Plan to WDNR, FRG, and EPA stated that, "We find it completely unacceptable for the demonstration project to remain unfinished." Further, the committee, which is composed of independent scientists and engineers, concluded that, "Based on the available data we concur with [WDNR's] conclusion that where properly performed to the necessary sediment depth, dredging has been demonstrated at site 56/57 to be a viable option for removal of PCB contaminated sediments."(Culhane, 2000b).

The Wisconsin Justice Department sent a letter to the FRG warning that the companies might be subject to additional liability for damage to natural resources unless the project was completed (Culhane, 2000a). According to the Justice Department, "It is evident from the data that by leaving the sediment restoration project at [SMU] 56/57 unfinished, the FRG has left the river in a vulnerable and more damaged state."

The FWS, in a letter to EPA, characterized the high concentrations of PCBs in the areas where dredging was begun but not completed as an imminent and substantial endangerment to public health and the environment, and associated natural resources. FWS urged EPA to issue a unilateral administrative order under the Superfund law for immediate resumption of dredging in the areas were dredging was begun but not completed. Further, FWS recommended that dredging in additional areas should be initiated only if the dredging could be completed within a single season, and that day-to-day management of the project should be under EPA authority. Finally, FWS recommended that temporary capping may be needed if dredging is not completed within a season (Hartwig, 2000).

The Clean Water Action Council, the key environmental group involved in the Fox River site, also called on EPA to step in to complete the project. A press release issued by the group in March 2000 alleged that the FRG, which has always opposed dredging remedies for the Fox River, deliberately designed the project to fail "to portray dredging as a dangerous cleanup option for the Fox River, to build support for their 'natural recovery' do-nothing option." Although the Clean Water Action Council "supports, dredging, removal, and detoxification treatment of PCB hotspot sediments," it opposed the SMU 56/57 project from its inception because of doubts about FRG's commitment to successful dredging (CWAC, 2000). The subcontractor hired to perform the dredging, dewatering, and water treatment for the demonstration project also charged that the demonstration project, "was designed to fail from its inception" (Four Seasons Environmental, 2000).

The EPA, which also agreed with WDNR's interpretation of the sediment sampling results, joined the negotiations between WDNR and FRG. In May 2000, EPA announced an agreement with one of the FRG companies to continue the project (EPA, 2000c). Specifically, Fort James Corp., which owns the property adjacent to the SMU 56/57 site, agreed to a two-phase cleanup involving 71,500 cubic yards of contaminated sediment. The agreement included a cleanup goal of one ppm in the dredging area, and a post-dredging, six-inch sand cap at the edges of the dredging area and in any other areas with residual PCB concentrations between one and ten ppm. Dredging resumed on August 26, 2000, and was expected to be complete by the end of October (EPA, 2000b).

Manistique Harbor, Michigan

Manistique Harbor is located at the mouth of the Manistique River on the north shore of Lake Michigan along Michigan's Upper Peninsula. Sediments in the lower 1.7 miles of the Manistique River and Harbor are contaminated with PCBs from several sources, including past discharges from a paper mill, a transformer manufacturer, and other industries. EPA estimated that before the on-going cleanup, sediments of the harbor contained about 16,600 pounds of PCBs and released about 110 pounds of PCBs per year to Lake Michigan (EPA, undated(a)). Much of the contamination is contained in undecomposed and erodible woodchips, sawdust, and wood pulp that remain in many areas of the harbor from saw mills that operated along the river until the 1930s. Because of the PCB contamination, Manistique Harbor is one of the 43 Great Lakes Areas of Concern (AOCs) and is on the National Priorities List of Superfund sites.

PCB contamination is concentrated in three areas of the river/harbor identified as Areas B, C, and D.[20] As shown in Exhibit 15, Area B is in the northern portion of the site, upstream from the U.S. Route 2 Bridge. Area C is downstream from the U.S. Route 2 bridge near the mouth of the river. Area D, the largest of the four areas, covers 16 acres and is in the lower harbor within the harbor breakwater. Prior to remediation, the maximum PCB concentration measured in sediment at the site was 2,510 ppm (at Area B), and the site-wide average concentration was 30.2 ppm. During the cleanup, however, contamination up to 10,000 ppm was found in Area D (Hahnenberg, 2000d).

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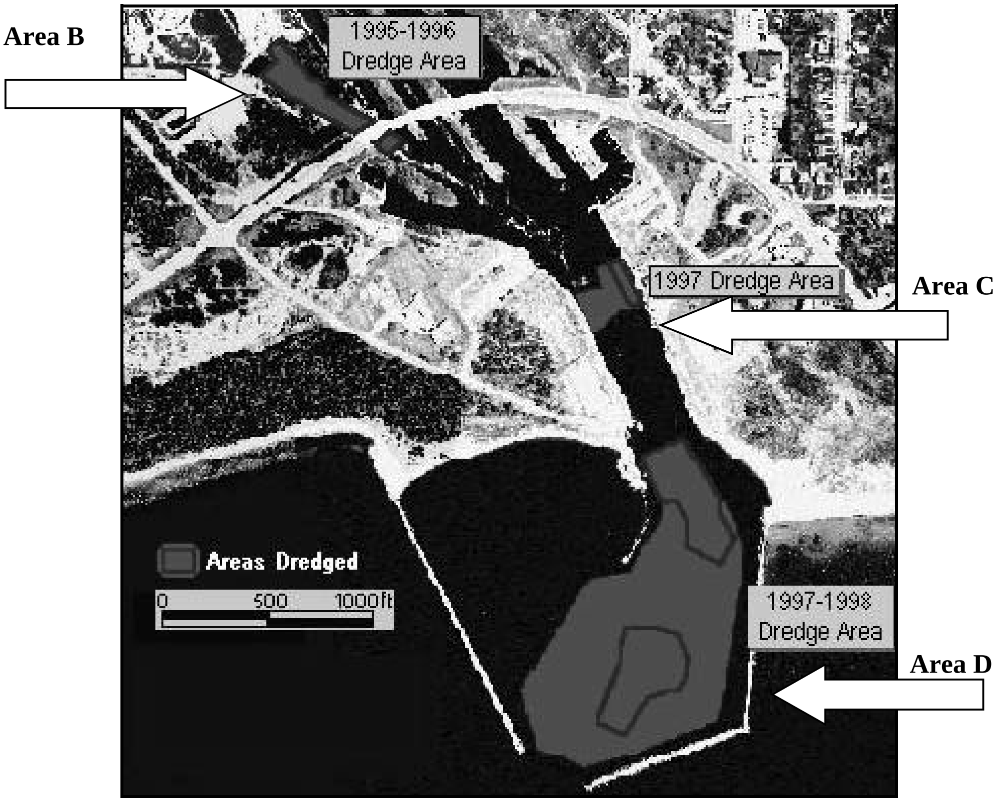
[20] A fourth suspected area of contamination, Area A, was found to have low levels of contamination (Hahnenberg, 2000b).

Exhibit 15
Manistique Harbor, Michigan



Source: EPA, undated(c)

The first remedial action at Manistique Harbor occurred in 1993 when a weighted plastic cap was placed over Area C as an emergency measure (EPA, undated(b)). Area C was considered an immediate risk because it contained highly contaminated material (i.e., PCBs up to 400 ppm) and was located in an area highly susceptible to erosion (e.g., in the case of a flood).

In 1995, EPA announced a site-wide remedy that included capping of the lower harbor sediments at Area D and sediment dredging in the relatively protected Area B, also referred to as the North Bay. No action was selected for Area A where sediment contamination was below the site-wide action level of 10 ppm.

Dredging at Area B, which was described in *Advances in Dredging*, began in the fall of 1995 and was completed in 1996 after a break for winter weather. Before dredging, the North Bay was isolated from the harbor with a coffer dam and silt curtains. In 1995, a diver-assisted plain suction dredge was used to remove fine, unconsolidated sediment from the northern portion of North Bay. In 1996, a horizontal auger dredge was used to remove coarse sediment and wood chips from areas of the North Bay upstream and downstream of the barriers, including areas near the Route 2 Bridge in the river channel. In all, 17,000 cubic yards of contaminated material were dredged from Area B. A layer of gravel was placed in the North Bay after dredging to improve the riverbed habitat for fish and other aquatic species (EPA, 1997b).

Before the cleanup began, a sediment dewatering and water treatment system was constructed adjacent to the North Bay. Sediment particles of sand size and larger were removed by a series of equipment including a debris screening box, shaker screens, and a rotary screen. The slurry still containing fine sediment particles was then pumped to four settling tanks to which a polymer was added to facilitate settling. Solids from the settling tanks were passed through a belt filter press for further dewatering. All solids were dried and shipped off site for disposal. Sediments containing 50 ppm or greater PCBs were disposed of in TSCA-compliant landfills in Utah and Michigan. Sediments containing less than 50 ppm PCBs were disposed of in a non-hazardous waste landfill in Munising, Michigan (EPA, 1998c). All water generated in the treatment system was passed through a series of filters before discharge to the river. First, the water was passed through a sand and anthracite coal filter. Next, the water was passed through a diatomaceous earth filter to remove clay and bacteria. Then, the water was passed through activated carbon filters. After filtration, the water was pumped to two 1 million gallon storage lagoons where samples were collected and analyzed to confirm water quality before discharge to the harbor.

Based on the successful completion of dredging at Area B, EPA proposed in 1996 to amend the site-wide remedy to include dredging at Areas C and D. EPA signed an agreement with the responsible parties in which EPA absolved the responsible parties from future liability for the site in exchange for $6.4 million and "in-kind" services to carry out the dredging remedy at Areas C and D. The amount of the agreement was based on the estimated cost of capping Areas C and D and maintaining the caps for 30 years.

To enable the expanded scope of dredging, several modifications were made to the dredging equipment and the sediment dewatering and water treatment system. For example, a 15-foot horizontal auger dredge was ordered to replace the 4-foot dredge used at Area B. With the larger dredge, potential sediment production rates increased from 50 - 100 cubic yards per day to 500 - 1,000 cubic yards per day. The capacity of the water treatment system was increased from 1,200 to 2,000 gallons per minute, and a hydrocyclone was added to enhance separation of coarse grained sediments from the slurry. In addition, hopper barges were acquired to transport slurry from dredging locations to the sediment dewatering and water treatment system (Hahnenberg, 1997). At the sediment dewatering and water treatment facility, sediment was pumped off the barges in a slurry. Sediment that accumulated over time in the bottom of the barges was removed with a clamshell dredge (Hahnenberg, 2000a).

Source: Hahnenberg (1999)

Dredging at Areas C and D was expected to generate 102,000 cubic yards of sediment and be complete in the fall of 1998. Area C was dredged in the summer of 1997 after removal of the plastic cap placed over the area in 1993. Less than 1,000 cubic yards were removed from Area C containing PCBs up to 400 ppm (EPA, undated(b)). Dredging at Area D began after completion of dredging at Area C, and continued in 1998, 1999, and 2000. By the end of 1999, approximately 97,000 cubic yards of sediment had been removed from Area D, including 41,000 cubic yards in 1997, 31,000 cubic yards in 1998, and roughly 25,000 cubic yards in 1999. Dredging in Area D was nearly complete at the end of the 1999 season (Hahnenberg, 2000a).

Dredging at Area D was complicated by expected and unexpected factors. The presence of shallow bedrock beneath the sediment, which was expected, prevented over-dredging of the contaminated sediment layer. In addition, the harbor was found to contain a large amount of slab wood remaining from lumbering in the late 1800s and rock debris blasted from the harbor by the Army Corps of Engineers to facilitate navigation. Also, because Area D was more contaminated than expected and consisted of fairly homogenous fine-grain sediment, overall sediment disposal cost were higher than expected (i.e., more dewatered sediment than expected had to be disposed of in a TSCA landfill). These factors slowed cleanup and added to its total cost (Hahnenberg, 2000d). The final cleanup cost was $44 million (EPA, 2000a).

EPA announced the completion of cleanup dredging at Manistique Harbor in August 2000. In all, an estimated 130,000 cubic yards of contaminated sediment were removed (EPA, 2000a). Because the cleanup was completed recently, EPA has not published result data. Based on EPA's most recent testing during the cleanup (i.e., from the 1999 season), however, average PCB concentrations in Area D were about 14 to 18 ppm, and the highest concentration detected was 2,072 ppm (Hahnenberg, 2000d). The testing also showed that contamination in Area D was much higher then initially thought. Although, EPA reported pre-cleanup average and maximum PCB concentrations 30.2 ppm and 810 ppm, respectively, testing in 1999 found contamination as high as 10,000 ppm.

The Fox River Group (2000) tested sediment in Manistique Harbor before and during the cleanup. The FRG study compares before and during results for surface sediments (i.e., zero to three inches in depth) only. Between 1993 and 1999, the median PCB concentrations in the dredged portion of Area D decreased from 7.5 to 4.9 ppm, mean PCB concentrations decreased from 19 to 13 ppm. These decreases were not statistically significant. The maximum PCB concentration detected in 1999 (94 ppm) was slightly higher than the maximum PCB concentration detected in 1993 (90 ppm).[21] The FRG results are not directly comparable to the EPA results because FRG analyzed only the top sediment layer, and samples were not necessarily collected at the same times or locations.

FRG also presented 1999 post-cleanup sediment testing for Area B. The average and maximum surface sediment concentrations were 4.9 and 15 ppm, respectively. The maximum

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[21] These results exclude "border samples" collected at locations that could not be clearly identified as dredged or undredged. A 1999 boarder sample had PCBs at 390 ppm.

concentration detected at all depths was 620 ppm. According to EPA, the maximum pre-dredging concentration at Area B was 2,510 ppm.

Cumberland Bay, **New York**

Cumberland Bay is located at Plattsburgh, New York, on the western shore of Lake Champlain. About 34-acres of Cumberland Bay were contaminated with PCBs, dioxins, furans, and other contaminants in a sludge bed of sediment, wood pulp, wood chip debris, and fine organic matter (Sevenson Environmental Services, undated). PCB concentrations in the sludge bed generally ranged from about 10 ppm to 70 ppm, but a maximum concentration of 1,850 ppm was detected in one location (Dolata, 1999). The goals of the Cumberland Bay cleanup project were to remove all visible sludge and to attain residual sediment PCB concentrations of 1 ppm or lower.

The cleanup at Cumberland Bay included hydraulic dredging of approximately 150,000 cubic yards of sediment, sludge, and debris from the bay, and excavation of 38,000 cubic yards of sediment from the shoreline (Sevenson Environmental Services, undated). Dredging began in June 1999. Two horizontal auger hydraulic dredges with a combined capacity of 4,000 gallons per minute were used simultaneously in different portions of the site.

Dredge slurry was pumped from each of the two dredge platforms to a treatment plant that included shakers and desanders for initial particle separation, a 400,000-gallon sludge slurry storage tank, and eight plate-and-frame filter presses with a combined capacity of 1,760 cubic feet. Dewatered sediment was shipped to landfills for disposal. Sediment containing PCB concentrations 50 ppm or greater was disposed of in a hazardous waste landfill, and all other sediment was disposed of in an industrial non-hazardous waste landfill.

Water separated from the dredged solids was treated to drinking water standards and returned to Lake Champlain. The water treatment system had a capacity of 2,000 gallons per minute and included secondary settling, pH neutralization, oxygenation, sand filtration, and carbon filtration. About 160 million gallons of water were treated during the project (Sevenson Environmental Services, undated).

To mitigate potential sediment resuspension, silt curtains were placed around work zones within the site and around the perimeter of the site (Dolata, 1999). In addition, 1,000 feet of steel sheet piling was installed in water up to 30-feet deep to enclose the most contaminated area (Sevenson Environmental Services, undated).

PCB and sediment resuspension during dredging were monitored at various locations in and around the site. Within each of the two work zones, real-time turbidity sensors were placed on the dredge head and 50 feet behind the dredge. Turbidity measurements were displayed on a computer screen on the dredge platform to aid the dredge operators in controlling sediment resuspension. The New York State Department of Environmental Conservation required immediate action to reduce sediment resuspension if total suspended solids (TSS) measured 50 feet behind either dredge exceeded background concentrations by 25 mg/l or more for 15 minutes. Additional turbidity monitors were placed upstream and downstream of the dredges outside the perimeter of the work zone silt curtains. Real-time data from these sensors were displayed and recorded by a computer at an on-shore control station. The computer was programed to sound an alarm if any single TSS reading exceeded background concentrations by 5 mg/l or more. In the event of an alarm, water quality samples were taken for PCB analysis. DEC rules for the project required the TSS target to be lowered if PCB concentrations in the water samples (either filtered or unfiltered) were above the New York State Ambient Water Quality Criterion (Dolata, 2000b).

The project was initially expected to take two years, but was nearly complete in one. When winter weather ended the 1999 dredging season, the project was approximately 96 percent complete with about 142,000 cubic yards of sediment having been dredged (Dolata, 2000b). During the winter, however, an additional sludge deposit was found in a portion of the site between Wilcox Dock and a nearby breakwater. The sludge was located under a rock-hard crust layer and was nearly two-feet thick in places (Meyers, 2000). Dredging in 2000 included removal of the newly discovered sludge with a diver-assisted plain suction dredge, and further dredging in some areas dredged in 1999. Dredging was expected to be complete by September 22, 2000 (Dolata, 2000a).

Suspended sediment monitoring during the first season showed TSS consistently equal to background concentrations at the site perimeter and workzone perimeter stations. Although TSS was frequently measured above background behind the dredge, PCBs never exceeded the shutdown threshold and dredging never had to be suspended. A public beach located a few hundred yards away from the site was able to remain open during the summer while dredging was underway (Trieste, 2000). PCB concentrations in fish were monitored and post-dredging sediment concentrations were measured, but data are not yet available.

4. DREDGING DECISION FACTORS

Because *Advances in Dredging* focused on dredging and not other elements of contaminated sediment cleanups (e.g., disposal), it did not propose a specific remedy for the Hudson River PCBs site and made no conclusions about the overall benefits, impacts, or feasibility of a cleanup. Instead, it examined general feasibility of contaminated sediment dredging as a component of a cleanup plan in the Upper Hudson River based on available technologies, experiences elsewhere, and eight dredging "decision factors:"

- Sediment resuspension;
- Sediment characteristics;
- Water depth and site access;
- Water current;
- Depth of contaminated sediment and dredge accuracy;
- Production rate and sediment density;
- Dredge availability; and
- Cost.

This section briefly summarizes and updates the conclusions from *Advances in Dredging* about each decision factor. In addition, this report discusses two new decision factors:

- Sediment dewatering and water treatment; and
- Sediment treatment/disposal.

Although *Advances in Dredging* focused only on the dredging component of contaminated sediment cleanups, dredging options cannot be selected independent of these additional components of cleanups (Miller, 1996).

4.1 Sediment Resuspension

Advances in Dredging presented quantitative sediment resuspension data from several cleanups to clarify the capabilities and relative performance of various dredges. The data show that hydraulic and pneumatic dredges generally resuspend less sediment than mechanical dredges, and resuspension by all types of dredges can be minimized with certain operational techniques (e.g., carefully controlling dredge speed). Although several specialty dredges have been developed to control sediment resuspension, properly operated conventional dredges (e.g., cutterhead and horizontal auger dredges) can remove contaminated sediment with little or no resuspension. Data presented in Section 2.1 of this report show that conventional dredges have been used for almost all sediment cleanups in the U.S. In general, contaminated sediment resuspension has not been a significant impediment in environmental dredging projects.

Major contaminated sediment dredging projects now usually include downstream water quality monitoring during dredging (see, for example, the case studies in Section 3.2). Based on data collected during the Deposit N project, the Fox River Remediation Advisory Team recommends that monitoring include measurements of dissolved contaminants, as well as contaminants associated with suspended solids (FRRAT, 2000).

4.2 Sediment Characteristics

Advances in Dredging reported that sediment particle size and density can affect dredge performance and efficiency. These factors should be considered when selecting dredges, designing sediment dewatering and water treatment systems, and planing other aspects of remedial activities. Rocks and large debris, if present, can interfere with dredge operation and delay cleanup progress, especially when hydraulic dredges are used. Some specialty hydraulic dredges (e.g., the Amphibex dredge, Eddy Pump) are able to handle debris better than conventional hydraulic dredges. A combination of hydraulic and mechanical dredging was used for some cleanups (e.g., the GM site on the St. Lawrence River, Marathon Battery) where debris interfered with hydraulic dredging.

Most of the contaminated sediment in the Upper Hudson River is in the Thompson Island Pool where the sediments are generally silts and sands without large amounts of debris. However, gravel and debris are likely to be present in some areas. To remediate sediment contamination in areas of the Hudson River with large amounts of debris, mechanical dredging could be used alone or in combination with hydraulic dredging. If feasible, shallow areas with debris could be temporarily dewatered to facilitate sediment removal and mitigate potential impacts of wet mechanical dredging.

4.3 Water Depth and Site Access

All dredges have maximum depths of operation, and most have minimum depth requirements. *Advances in Dredging* identified minimum and maximum dredging depths for 17 dredge types. These data have not been updated. Because sediment hot spots in the Upper Hudson are located along the shore in shallow areas, dredging equipment able to operate in shallow waters or from shore would be needed. Shoreline access is likely to be unavailable in some locations. Water depth and site access restrictions will have to be evaluated separately for each of any locations EPA proposes to remediate.

It may be feasible to temporarily dewater shallow hot spot areas with sheet piling, as has been done at several sites (e.g., Housatonic River, the GM St. Lawrence River site). This approach is unlikely to be feasible, however, where water depth is more than 10 feet or where there is significant groundwater discharge (Hahnenberg, 2000d). The feasibility of this approach would have to be evaluated for specific hot spot locations.

4.4 Water Current

As described in *Advances in Dredging*, rapid water current can interfere with dredge positioning, heighten contaminated sediment resuspension, or preclude the use of silt curtains or other physical barriers. Based on the results of hydrodynamic modeling conducted by EPA for the Hudson River PCBs Reassessment, the hot spots are almost exclusively located in quiescent areas where currents would be under 2.5 feet per second during a 100-year flood. Because currents in these areas would be substantially lower during normal conditions, *Advances in Dredging* concluded that water current would not be a major obstacle to remediation. Moreover, based on remedial activities at other sites (e.g., Manistique Harbor, Cumberland Bay, Lower Fox River), remedial activity on the Upper Hudson River would be likely to occur in the summer and fall months when the river's currents tend to be lowest.

4.5 Depth of Contaminated Sediment and Dredge Accuracy

Advances in Dredging described how dredge accuracy, in both the depth and area of sediment removal, can be a significant factor affecting the cost of contaminated sediment cleanups. Efficient environmental dredging minimizes the amount of uncontaminated sediment removed along with contaminated sediment. Based on reported depth accuracies of available dredges (i.e., about one foot or less for most dredges) and the depth of sediment contamination (i.e., 95 percent in the upper two feet (Malcolm Pirnie, 1986)) in the Thompson Island Pool portion of the Hudson River PCBs site, *Advances in Dredging* predicted that dredge accuracy would not be a decisive factor in selecting dredges for the Hudson River PCBs site.

Environmental dredging projects at sites where contaminated sediment is underlain by uncontaminated sediment sometimes include dredging depth goals that are intended to slightly overdredge (i.e., dredge below) the contaminated sediment layer. Overdredging is not possible at sites where the contaminated sediment is underlain by bedrock, and it is difficult or impossible to remove all sediment down to bedrock with the frequently-used conventional dredges (i.e., cutterhead, horizontal auger, clamshell). Some cleanups at sites with shallow bedrock have included a goal of dredging all sediment down to bedrock. A more realistic and achievable approach was used for the Deposit N demonstration project on the Lower Fox River (see Section 3.2), where the dredging goals specified maximum residual depths of sediment above the bedrock. This approach was intended to balance contaminant mass removal with dredging efficiency and project cost (Foth & Van Dyke, 2000).

PCB hot spots in the Upper Hudson River tend to be underlain by clean sediment. However, there are bedrock outcrops in some locations (Tomchuk, 2000) which might complicate, but not prevent, dredging if located beneath or adjacent to a PCB hotspot. The presence of bedrock at a hot spot location should be taken into account when selecting cleanup approaches, equipment, and goals.

4.6 Sediment Density and Removal Rate

The cost and schedule of environmental dredging projects are largely dependent on the amount of sediment to be removed and the rate of removal. The rate of removal is affected by several elements of a remedial design and implementation, such as the choice of wet dredging or dry excavation; the types, number, and sizes of dredges used; the dredge operation speed; and the capacity of sediment dewatering and water treatment systems. Uncontrollable factors also affect the sediment removal rate. For example, dredging has to be suspended during the winter in northern areas, and inclement weather can delay dredging in other seasons. The presence of debris or bedrock also can cause difficulties and delays.

GE claims that environmental dredging in the Upper Hudson River would take 20 years to complete during which boating, fishing, and other recreation would be disrupted (GE, 2000b). Any such estimate of the duration and impacts of the cleanup are unsupportable, however, without details (e.g. how much sediment would be dredged, how sediment would be dredged) about the remedial scenarios EPA has not yet identified. Moreover, GE did not provide any evidence (e.g., from experiences at other contaminated sediment cleanup sites) that dredging would disrupt navigation or other uses. In fact, sediment contamination in the Upper Hudson, the New York/New Jersey Harbor, and in many other locations interferes with and elevates the cost of navigational channel maintenance.

4.7 Dredge Availability

Advances in Dredging reported that the use of specialized contaminated sediment dredges in the U.S. has been hindered by unavailability. But because of the scale and significance of the Hudson River PCBs site, Scenic Hudson recommended that efforts should be made to acquire superior technologies that are not readily available.

Since *Advances in Dredging*, the availability of specialty dredges has not increased, and they have not been used in full-scale contaminated sediment cleanups in the U.S. Scenic Hudson continues to support the use of innovative remedial technologies. However, conventional dredges are suitable for environmental dredging.

4.8 Cost

Advances in Dredging summarized key factors that contribute to the costs of contaminated sediment dredging, such as transportation of the dredge to and from the site, fuel, and maintenance. Dredging costs are only a part of the overall cost of contaminated sediment cleanups. Sediment dewatering, water treatment, and sediment treatment/disposal may contribute more to cleanup costs than dredging. The costs incurred from these activities are affected by site-specific factors such as the amount of sediment, the site location, and disposal options. EPA (1994), which *Advances in Dredging* cited as a source of useful information for estimating contaminated sediment dredging costs, also contains information for estimating other remedy components, including dewatering, treatment, and disposal.

Data from complete and on-going sediment cleanups show a very wide range in costs. Based on data compiled by EPA (1998c), the estimated costs of 11 current and on-going contaminated sediment cleanups with dredging ranged from $1 million to $44 million.[22] The costs of seven dry excavation projects ranged from $550,000 to $11.8 million. Cleanup costs expressed as dollars per cubic yard of sediment remediated ranged from $29 to $1,371 for dredging cleanups, and $30 to $1,247 for dry excavation cleanups. The median unit cleanup costs were $222 per cubic yard for dredging cleanups and $550 per cubic yard for dry excavation cleanups. Data compiled by Cushing (1999) also showed that dredging cleanups are more economical than dry or wet excavation cleanups. Specifically, the median cost of 19 dredging cleanups was $273 per cubic yard, and the median cost of 15 dry or wet excavation cleanups was $425 per cubic yard.

4.9 Sediment Dewatering and Water Treatment

Dredge selection for contaminated sediment cleanups can be affected by the need to process and dispose of sediment after it is removed. For example, a mechanical dredge was used for the Black River site in Ohio because the available disposal site was not capable of handling hydraulically dredged sediment. The feasibility of hydraulic dredging was enhanced at the LTV Steel site by the availability of existing surplus wastewater treatment capacity at the LTV facility (Miller, 1996).

If the remedial plan for the Hudson River PCBs site includes hydraulic dredging, a sediment dewatering and water treatment facility will have to be constructed somewhere on shore. The facility would contain low-technology equipment (e.g., settling tanks, belt filter presses) and processes (e.g., water filtration) commonly used in large-scale by various industries such as mining/mineral processing and municipal wastewater treatment. At a minimum, the facility would include settling basins or impoundments, debris separation and sediment particle sizing equipment, presses or other dewatering equipment, a water filtration system, a stockpiling area for dewatered sediment, and a truck or rail loading area. The facility probably would be similar to the facilities described in Section 3.2. Although the amount of sediment removed from the Upper Hudson could be significantly greater than the amount removed at these sites, the area of the sediment dewatering and water treatment facility would not necessarily be proportionally larger. The size of the facility would depend on the rate at which sediment would be generated and the throughput of water and sediment at the facility, not just the amount of sediment to be dredged.

Dredged sediment probably would be brought to the sediment dewatering and treatment facility by a temporary floating pipeline, barge, and/or truck. Temporary pipelines are the most economical means of transportation (EPA, 1994) and are most likely to be used with hydraulic dredges. Hydraulic dredge discharge pipelines are commonly used in navigational dredging in lengths ranging from less than 3 kilometers (1.8 miles) to more than 15 kilometers (9.3 miles), and much longer distances are theoretically possible (EPA, 1994). Barges are more likely to be used if the remedy includes dredging sites far from the facility, or if a mechanical dredge or wet

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[22] The estimated cleanup cost for Manistique Harbor in EPA (1998c) was updated with a more recent cost estimate (EPA, 2000a).

excavation equipment is used at any area of the site. Trucks are unlikely to be used to transport wet sediment unless excavation is performed from shore.

Based on experience at other contaminated sediment dredging sites, as well as practical limitations, it is unlikely that sediment would be transported, as GE has suggested, via a fixed pipeline on the river bank or a new haul road constructed along shore. Therefore, it is unlikely that "the forested and residential character of the Upper Hudson and its shoreline would be dramatically altered for decades by the pipeline and by the network of haul roads that would have to be built..." (GE, 1997).

4.10 Sediment Treatment/Disposal

General options for contaminated sediment treatment and disposal are described briefly in Section 2. EPA's feasibility study for the Upper Hudson River is likely to analyze several treatment and/or disposal options that could be used in conjunction with dredging. EPA will probably analyze the feasibility of constructing a new landfill somewhere near the Upper Hudson River or sending the sediment to existing landfills. Factors affecting the selection of a disposal option include (not necessarily in order of significance) the amount of sediment to be remediated, PCB concentrations in dewatered sediment, landfill construction and maintenance costs, transportation costs, site availability, protection of human health and the environment, and community acceptance.

Although new landfill construction near the Upper Hudson River would be logical and consistent with cleanup decisions elsewhere in the country, EPA is unlikely to include it in a cleanup plan for the Hudson River PCBs site because of local opposition. Therefore, it is reasonable to expect the cleanup plan to include sediment disposal in existing landfills. Examples of existing landfills that might be considered are a TSCA-permitted landfill at Model City, New York, for sediments with more than 50 ppm PCBs, and regional solid waste landfills for sediments with less than 50 ppm PCBs.

EPA's feasibility study for the Hudson River PCBs site probably will include at least one remedial scenario that includes treatment. Treatment could increase the overall effectiveness of the cleanup and possibly even prevent the need for landfilling. It would substantially increase the cost, however, and depending on the amount of sediment generated, cleanup targets, and other factors, treatment might not be technically feasible or cost-effective relative to disposal without treatment.

GE predicts that dredging PCB-contaminated sediment in the Upper Hudson River would require the construction of a new landfill to hold 1.3 million cubic yards of contaminated sediment (GE, 1997). GE's prediction represents only one of the treatment/disposal options EPA is likely to consider, and a worst-case estimate of the amount of sediment that would be generated. In addition to protection of the environment, the Superfund law requires EPA's remedy decision to consider technical feasibility, cost, community acceptance, and other criteria. Thus, it is unlikely that EPA will propose the extreme scenario GE so often describes.

5. SUMMARY AND CONCLUSION

In December 2000, EPA is scheduled to release its Proposed Plan for the Hudson River PCBs Superfund site. Because EPA has determined that PCB contamination poses unacceptable risks to human health and the environment, the Proposed Plan is likely to recommend dredging and/or excavation of PCB-contaminated sediments from some or all of the 40 “hot spots” in the Upper Hudson River. Because the possibility of dredging contaminated sediments has in the past raised concerns about remobilizing contamination from the riverbed, Scenic Hudson investigated the equipment and methods used to clean up contaminated sediment and their track record of performance. Scenic Hudson presented its findings in the 1997 report *Advances in Dredging* (Scenic Hudson, 1997b).

This report updates *Advances in Dredging* by presenting an expanded analysis of contaminated sediment cleanup decisions at other sites, the results of post-cleanup monitoring at nine sites, and detailed case studies describing remedial methods and outcomes at four sites. Unlike *Advances in Dredging,* which focused on concerns about contaminated sediment resuspension, this report addresses issues associated with the processing (e.g., transportation, dewatering, treatment) and disposal of contaminated sediment. In addition, this report evaluates the effectiveness of dredging and excavation cleanups in terms of contaminant reductions in sediment and fish. The report also summarizes recent findings of EPA’s Hudson River PCBs Reassessment. Findings of the report are summarized below and support the report’s conclusions.

Recent EPA findings suggest that the Upper Hudson River should be cleaned up.

EPA will not make conclusions about the need for and feasibility of cleaning up the Hudson River PCBs site until December 2000. However, Hudson River PCBs Reassessment reports released by EPA after *Advances in Dredging* contain numerous findings and conclusions that indicate the need for a cleanup. For example, reasonably conservative cancer risk estimates for eating fish from the Upper Hudson are 700 times higher than EPA’s cancer risk goal and seventimes higher than the highest risk allowed under the Superfund law. Potential ecological risks include threats to the survival, growth, and reproduction of a wide range of fish, bird, and mammal species, including threatened and endangered species. Human health and ecological risks are expected to persist for many years unless the contaminated sediment is remediated. In addition, EPA’s recent Reassessment findings contradict three of GE’s key arguments against the need for a cleanup: (1) that natural bacteria are eliminating PCBs from the sediment, (2) that deposition of clean sediment is isolating the hot spots as sources of PCBs to the river, and (3) that upstream sources (i.e., GE’s Hudson Falls plant), not the hot spots, are the main source of PCBs downstream.

Dredging is still the preferred remedy for sediment contamination at other sites.

Based on information compiled from several sources (e.g., EPA, 1998c; GE et al., 1999), Scenic Hudson analyzed remedies selected for 89 contaminated sediment cleanups. The analysis shows that dredging or excavation has been used in almost 90 percent of the complete, on-going, and planned projects. At least 72 percent of the removal remedies involved dredging or wet excavation. Considering only the complete and on-going projects included in the analysis, dredging and wet excavation have been used to remove at least 1.7 million cubic yards[23] of contaminated sediment in the U.S.

Advances in Dredging described several innovative dredges designed specifically for handling contaminated sediment. With a small number of exceptions, innovative dredges have not been used for contaminated sediment cleanups in the U.S. Availability continues to be a barrier to the use of innovative dredges, and experience has shown that properly-operated conventional dredges can meet the requirements of contaminated sediment cleanups.

Dry excavation has been used to clean up many contaminated sediment sites. Dry excavation is suitable for shallow-water sites that can be drained (e.g., sheet piling, stream diversion) to facilitate the cleanup. Dry excavation has been used to remove at least 1.4 million cubic yards of contaminated sediment from sites in the U.S.

Several large-scale contaminated sediment cleanups have been performed with dredging and/or excavation.

Because the Hudson River PCBs site is one of the largest contaminated sediment sites in the country, it could be among the largest contaminated sediment dredging projects if EPA proposes a dredging cleanup. Until EPA identifies a cleanup target concentration and a planned extent of remediation, it is meaningless to estimate the amount of sediment that would be generated. However, it almost certainly would be less than the 1.3 million cubicyards that GE (1997) estimated based on the assumption that 270 acres comprising the full area of all 40 hot spots would be dredged to a depth of three feet.

The Upper Hudson River is not the only contaminated sediment site where a large-scale cleanup is being considered. Dredging already has been selected for 500,000 cubic yards of PCB-contaminated sediment at New Bedford Harbor, Massachusetts. USX Corporation has agreed to dredge 687,000 cubic yards of sediment contaminated with PCBs and other pollutants from the Grand Calumet River, and a much larger volume of sediment may be removed from the Grand Calumet River/Indiana Harbor in a separate initiative. A cleanup of approximately one million cubic yards of contaminated sediment has been proposed for the Ashtabula River in Ohio. In Michigan, a cleanup as been planned for more than 300,000 cubic yards of contaminated sediment in the Saginaw River and Harbor. As shown in Exhibit 3, cleanups involving more than 100,000 cubic yards of sediment have been completed or are underway at several sites, including two sites in New York (Marathon Battery and Cumberland Bay). Thus, a decision to perform contaminated sediment dredging on the Upper Hudson River would not be unprecedented, nor would the methods of remediation.

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[23] This total does not include 2.8 million cubic yards of contaminated sediment removed in the Commencement Bay, Sitcum Waterway navigational dredging project.

Contaminated sediment resuspension can be controlled.

The Deposit N demonstration project on the Lower Fox River in Wisconsin (see Section 3.2) is a good example of the ability to control contaminated sediment resuspension during environmental dredging. The dredging site was located immediately upstream from a 20 million gallon per day intake for water used in the manufacture of food-grade paper. Environmental dredging with a hydraulic cutterhead dredge minimized sediment resuspension, and silt curtains were used to further protect the river and the downstream water withdrawal. Sediment resuspension rates were monitored with sensors that relayed real-time data to an on-shore computer. Throughout the project, downstream turbidity remained equal to or only slightly higher than upstream turbidity, and the paper mill reported no degradation of water quality in their river water intake at any time (Foth & Van Dyke, 2000). A mass balance based evaluation of contaminant loss during the first year of the Deposit N project indicated that about 4 pounds of PCBs were lost downstream during dredging. However, this amount of loss is less than half of the 8.8 to 11.1 pounds of PCBs that the area would have released per year to the river without dredging.

Monitoring data show reductions in sediment and fish contamination following sediment cleanups.

Post-cleanup monitoring data presented in Section 3.1 consistently show beneficial results of sediment cleanups, including contaminant mass reductions and reductions in sediment and fish contamination. For example, average PCB concentrations in white perch in the South Branch of the Shiawassee River decreased from 19 ppm in theyear before dredging to 4.2 ppm two years after dredging. Average PCB concentrations in Hudson River fish at the Niagara Mohawk Queensbury site ranged from about 7 to 11 ppm at the start of remedial activities and have been below 1 ppm since the end of the cleanup. Near the Love Canal site, dioxin concentrations in fish decreased from about 35 parts per trillion two years before a stream sediment cleanup to about 5 parts per trillion one year after the cleanup. In only one case (i.e., the Black River, Ohio) was there a short-term (three-year) increase in fish impacts apparently associated with exposure to contamination during the cleanup. However, fish hatched after the cleanup were essentially unimpacted by sediment contamination and there was a precipitous drop in fish impacts beginning in the fourth year after dredging.

Some of these decreases were partially attributable to background attenuation or other remedial activities. But at sites where outcomes at cleanup sites can be compared to outcomes at background locations, larger benefits are seen at the cleanup sites. At Lake Jarnsjon, Sweden, for example, dredging removed 97 percent of the PCB mass and reduced fish tissue PCB concentrations by 56 percent. PCB concentration in fish at two upstream background locations decreased by 33 and 36 percent. At the Ruck Pond site, where a dry excavation cleanup removed 96 percent of the PCB mass, PCB concentrations in fish decreased 83 percent from 24 ppm before dredging to about 4 ppm after dredging. At a control location upstream from Ruck Pond, PCB concentrations decreased 25 percent from 0.12 ppm to 0.09 ppm.

At some sites, especially where bedrock or debris complicated dredging, reductions in PCB contamination have fallen short of cleanup goals in portions of the sites. GE's characterization of some of these cleanups as "unsuccessful" (e.g., GE, 2000b) ignores important beneficial outcomes. For example, a cleanup goal of 10 ppm was met in only about 30 percent of the Raisin River site. However, the cleanup reduced maximum PCB concentrations at the site from about 49,000 ppm before dredging to about 20 to 110 ppm after dredging. At the St. Lawrence River General Motors site, almost 20 percent of the site had to be capped after dredging because the cleanup goal of 1 ppm was not met in that portion of the site. But average PCB concentrations at the site were reduced from about 86 to 99 percent, and maximum PCB concentrations were reduced from 8,800 ppm before dredging to less than 100 ppm after dredging.

Options for large-scale sediment dewatering, water treatment, and sediment disposal are well developed.

Options for sediment dewatering, water treatment, and sediment treatment/disposal are just as important as dredging options in selecting contaminated sediment cleanups. All of these components of contaminated sediment cleanups must be evaluated together in choosing a cleanup plan for a particular site.

In contaminated sediment dredging projects, sediment and water are transported from dredging sites to on-shore processing or disposal facilities either by floating pipeline or barge. Both of these options are routine in navigational dredging projects that move millions of cubic yards of sediment every year. Sediment dewatering and water treatment facilities for contaminated sediment cleanup projects, such as those described in the case studies in this report, involve low-technology equipment and methods that are commonly used in large-scale applications in various industries (e.g., mining, industrial wastewater treatment).

Although there has been progress in the 1990s to develop and commercialize technologies for treating contaminated sediments, the use of available technologies remains limited. About a quarter of the contaminated sediment cleanups analyzed for this report included some form of ex-situ treatment (e.g., stabilization, thermal desorption). Cost and technical feasibility issues are barriers to contaminated sediment treatment. Disposal without treatment has been considered sufficiently protective of human health and the environment at a majority of contaminated sediment sites.

Dredged contaminated sediments usually are disposed of in upland landfills (i.e., as opposed to in-water disposal facilities or other disposal options). Upland landfilling was selected for 88 percent of the complete and on-going contaminated sediment cleanups identified for this report (see Exhibit 3). Off-site landfilling (i.e., sending dewatered sediment to existing landfills) was selected for 55 percent of the projects, and on-site landfilling (usually involving the construction of a new landfill) was selected for 33 percent of the projects. In large-scale contaminated sediment cleanups, sediment with low levels of contamination is sometimes separated from sediment with high levels of contamination to minimize overall disposal costs.

There are many potential options for cleaning up the Hudson River PCBs site.

The technologies available for dredging, processing, and disposing of contaminated sediment enable a wide range of potential cleanup scenarios for the Hudson River PCBs site. This report documents beneficial outcomes of ex-situ cleanup options involving dredging or excavation. In-situ capping is not evaluated in this report, but also is an option likely to be evaluated for the Hudson River PCBs site. Remedial guidance documents (e.g., Palermo et al., 1998a) and other sources have defined the site conditions suitable for capping (e.g., sheltered areas with calm waters, minimal navigational disturbance, and without upwelling of groundwater), and capping has been used at a number of sites. However, underwater caps are susceptible to damage by gradual erosion, burrowing organisms, rooted plants, ice scour, boat scour (also anchorage or trawling), or flooding, and usually must be monitored and maintained for decades.

In addition to remedy technology variables, EPA has flexibility in defining the scope of a potential cleanup (e.g., based on a choice of target cleanup levels or which hot spots to remediate). Thus, GE's predictions about the nature and scale of the cleanup (e.g., the construction of a 1.3 million cubic yard landfill on the river bank) are unfounded. Under Superfund remedy selection guidelines,[24] EPA must develop and review a range of remedial scenarios. If EPA determines that a cleanup is needed, it will propose to implement an option that it considers feasible based on detailed review in the Feasibility Study.

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[24] A description of the EPA process and criteria for evaluating and selecting Superfund remedies can be found at http://www.epa.gov/oerrpage/superfund/resources/remedy/rods/index.htm

Most of the Hudson's "hot spots" are along the banks of this quiet stretch of the river known as the Thompson Island Pool.

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ACRONYMS AND UNIT ABBREVIATIONS

AOC	Area of Concern
ARCS	Assessment and Remediation of Contaminated Sediments
CDF	Confined Disposal Facility
CTF	Confined Treatment Facility
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
CWAC	Clean Water Action Council
EEDP	Environmental Effects of Dredging Program
EPA	Environmental Protection Agency
FRG	Fox River Group
FWS	U.S. Fish and Wildlife Service
GE	General Electric Company
HDPE	High density polyethylene
IJC	International Joint Commission
MDEQ	Michigan Department of Environmental Quality
NYSDEC	New York State Department of Environmental Conservation
PAH	Polycyclic Aromatic Hydrocarbon
PBB	Polybrominated Biphenyl
PCB	Polychlorinated Biphenyl
PRP	Potentially Responsible Party
RCRA	Resource Conservation and Recovery Act
ROD	Record of Decision
SARA	Superfund Amendments and Reauthorization Act
SMU	Sediment Management Unit
TSCA	Toxic Substances Control Act
TSS	Total Suspended Solids, a measure of turbidity
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
WDNR	Wisconsin Department of Natural Resources

mg/kg	miligrams per kilogram (parts per million)
Fg/kg	microgram per kilogram (parts per billion)
pg/g	picograms per gram (parts per trillion)
MGD	million gallons per day
mil	unit of thickness equaling 1/1000 inch
NTU	nephelometric turbidity units, a measure of turbidity
ppm	parts per million
ppb	parts per billion (1,000 ppb = 1 ppm)
ppt	parts per trillion (1,000 ppt = 1 ppb)
yd^3	cubic yard

GLOSSARY

Aqueous	Pertaining to, similar to, or dissolved in water.
Benthic	Of or pertaining to the bottom of a lake, sea, or river.
Bioaccumulation	A process by which certain substances accumulate in the tissues of organisms as they pass up successive levels of the foodchain.
Bioremediation	The destruction or detoxification of contaminants by natural or introduced microorganisms.
Bioturbation	The gradual mixing of soil or sediment by the action of organisms, especially burrowing organisms.
Congener	A member of a kind, class, or group. Used with respect to PCBs, congeners are any of 209 types of PCB that differ in the number and position of chlorine atoms bound to the biphenyl molecule.
Containment	Remediation methods in which contaminants or contaminated materials are isolated with covers, liners, or other surrounding physical barriers.
Estuary	An arm of the sea where ocean tides meet river currents.
Hydraulic	Involving, moved, or operated by a fluid under pressure.
Ex-situ	Removed from the original place.
Hydrophobic	Incapable of or tending not to dissolve in water.
In-situ	In the original place.
Pneumatic	Involving, moved, or operated by air or other gases.
Porewater	Water absorbed in the minute pore spaces between sediment particles.
Riparian	On or of a river bank.
Slurry	A mixture of a liquid and fine solid particles.
Turbidity	The condition of sediment or other particles suspended or stirred up in a liquid.

APPENDIX A
SEDIMENT REMEDIATION INFORMATION RESOURCES ON THE INTERNET

Contaminated Sediment Remediation (General)

Lake Michigan Forum
“A Citizen’s Guide to Cleaning Up Contaminated Sediment”
http://www.lkmichiganforum.org/lakewideproblems/sediments/index.html

U.S. Army Corps of Engineers
Center for Contaminated Sediments
http://www.wes.army.mil/el/dots/ccs/index.html

Environment Canada
Contaminated Sediment Remediation
http://www.cciw.ca/green-lane/cuf/cat-sediment.html

Great Lakes Commission
Contaminated Sediments
http://www.glc.org/projects/dredging/sediment/sediment.html

U.S. Environmental Protection Agency
Assessment and Remediation of Contaminated Sediment (ARCS) Program Publications
http://www.epa.gov/glnpo/arcs/arcsguide.html

U.S. Environmental Protection Agency
Remediation and Characterization Innovative Technologies (REACH IT) Database
http://www.epareachit.org/index3.html

U.S. Environmental Protection Agency
Hazardous Waste Clean Up Information (CLU-IN)
http://clu-in.org/

South and Southwest Region Hazardous Substance Research Center
Sediments Research Web – A Resource for Researchers and Practitioners
http://maven.gtri.gatech.edu/sediments/

U.S. Environmental Protection Agency
Technical Information [resources for contaminated sediment]
http://www.epa.gov/region5superfund/sediments/techinfo.htm

Contaminated Sediment Dredging

U.S. Army Corps of Engineers
Environmental Effects of Dredging and Disposal (E2-D2) Literature Database
http://www.wes.army.mil/el/e2d2/

Contaminated Sediment Treatment/Disposal

U.S. Environmental Protection Agency
Alternative Treatment Technology Information Center (ATTIC)
http://www.epa.gov/bbsnrmrl/attic/index.html

Remedy Decision Resources

International Joint Commission
Great Lakes Water Quality Board – Reports
http://www.ijc.org/boards/wqb/

U.S. Environmental Protection Agency
Superfund Remedy Selection Guidance
http://www.epa.gov/oerrpage/superfund/resources/remedy/rods/index.htm

PCBs

International POPs Elimination Network
Your Information and Action Resource for PCBs
http://www.ipen.org/pcb_workinggroup.htm

U.S. Environmental Protection Agency
The PCB Homepage at EPA
http://www.epa.gov/opptintr/pcb/

Hudson River PCBs Site

U.S. Environmental Protection Agency
http://www.epa.gov/hudson/
http://www.epa.gov/r02earth/superfnd/hudson/hudson.htm

Other Contaminated Sediment Sites

Grand Calumet River
Grand Calumet Task Force
http://www.grandcal.org/

Grand Calumet River
Indiana Department of Environmental Management
http://www.state.in.us/idem/nwro/grandcal.html

Manistique River/Harbor
U.S. Environmental Protection Agency
http://www.epa.gov/r5water/fields/FIELDSITE/MANISTIQ/PAGES/HOME.HTM

Fox River
U.S. Environmental Protection Agency
http://www.epa.gov/reg5oopa/foxriver/

Fox River
Wisconsin Department of Natural Resources
http://www.dnr.state.wi.us/org/water/wm/lowerfox/

Various
U.S. Environmental Protection Agency, Great Lakes National Program Office
http://www.epa.gov/glnpo/sediments.html

Various
U.S. Environmental Protection Agency
Realizing Remediation
http://www.epa.gov/glnpo/sediment/realizing/realcover.html

Scenic Hudson

http://www.scenichudson.org

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