SCENIC HUDSON INC

ADVANCES IN DREDGING CONTAMINATED SEDIMENT

New Technologies and Experience Relevant to The Hudson River PCBs Site

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Joshua Cleland

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ABOUT SCENIC HUDSON

Thirty-three years ago, Scenic Hudson was organized around the single issue of saving Storm King Mountain from scarring excavation and the intrusion of the world's largest "pumped storage" power plant. After an 18-year court battle, the landmark Scenic Hudson Decision granted citizens, for the first time, legal standing in environmental disputes; established environmental law as a new specialty; and set forth language that was used by Congress in drafting the National Environmental Policy Act (NEPA). Today, Scenic Hudson is a multi-faceted organization working to protect the Hudson River Valley's water, land, air, historic, and recreational resources. Our unique agenda combines environmental and public health advocacy with open space protection, and draws its strength from the support and active participation of Hudson Valley citizens.

This report was prepared by Scenic Hudson's Environmental Associate, Josh Cleland, with the guidance of Scenic Hudson's Environmental Director, Cara Lee.

Joshua Cleland has been an Environmental Associate at Scenic Hudson since November 1994. At Scenic Hudson, he is involved in a variety of local and state issues involving toxic chemicals in the environment. At present, he is responsible for Scenic Hudson's Technical Assistance Grant from the EPA, which enables Scenic Hudson to contract top technical experts to critique the EPA studies and decision documents for the Hudson River PCBs site. Prior to joining Scenic Hudson, Mr. Cleland was a Senior Associate at ICF Incorporated, and environmental consulting firm, where he worked on risk and economic analyses in support of EPA hazardous waste rulemakings. He holds a Master's degree in natural resource economics and policy from the Duke University School of Forestry and Environmental Studies, and a Bachelor's degree in biology from the University of Michigan.

Cara Lee has served as the Environmental Director of Scenic Hudson since 1984. She is responsible for the initiation and management of projects on a wide range of environmental issues in the Hudson River Corridor. Ms. Lee serves as a member of the Hudson River Estuary Management Advisory Committee and Chairs the Hudson River Improvement Fund of the Hudson River Foundation. In 1991, she was a recipient of the EPA's Environmental Quality Award. Prior to coming to Scenic Hudson, Ms. Lee was a researcher and writer for the Connecticut Natural Heritage Program and The Nature Conservancy. Ms. Lee is a graduate of Kirkland/Hamilton College and received her Master's in Environmental Studies from Yale University's School of Forestry and Environmental Studies.

Chip Porter

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- Mr. Ian Orchard, Remediation Technologies Program, Environment Canada; and
- Dr. Michael R. Palermo, Research Civil Engineer, U.S. Army Corps of Engineers, Waterways Experiment Station.

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FOREWORD

Scenic Hudson is pleased to provide this report on dredging methods and technologies as they relate to PCB contamination in the upper Hudson River. This report was written by Joshua Cleland, Scenic Hudson's Environmental Associate, and funded with a grant form the Hudson River Foundation. The report presents objective information on the evolution of contaminated sediment dredging over the last decade. This report documents the feasibility and effectiveness of modern dredging technologies deemed suitable for use on the Hudson River. Scenic Hudson's findings counter the common assumption that dredging would only "stir up" PCBs and worsen contamination downstream. Our research shows that resuspension of contamination has proven highly controllable in settings similar to the Hudson.

The notion that dredging is a "dirty" or unreliable way to clean up the Hudson has been promoted since the 1970's by General Electric, which asserts that dredging is unnecessary since layers of clean sediment now isolate PCBs from the Hudson's ecosystem, and buried PCBs are being broken down naturally in place. These scenarios do not portray the true fate of Hudson River PCBs. In reality, the upper Hudson River sediments will continue to be a significant source of PCB contamination to the River's foodweb until they are physically removed from the system.

Consequences of PCBs

Today, many Hudson Valley residents are unaware that commercial fishing on the River was once a rich regional tradition and boon to the economy -- a $40 million per year industry. This unique way of life has been wiped out by PCB contamination. Similarly, the economic value of the Hudson's recreational fisheries remains untapped as long as almost every species of fish is polluted with unacceptable levels of PCB contamination.

The economic impact of PCB contamination will soon be felt in another way. For the Port of New York to stay economically competitive, berth and channel depths must be maintained. Contamination is driving up the cost of harbor restoration astronomically. Upriver PCB contamination remains the single biggest source of PCBs to New York Harbor. Rehabilitation and long-term maintenance of New York Harbor and portions of the New York State Canal System will be seriously crippled if upstream sources of contamination are not eliminated in the near future.

Recent research indicates that PCBs in the Hudson are costing us far more than dollars. Studies on PCBs as hormone disrupters and their impact on neurological functions have revealed chilling new evidence of the dynamic role PCBs play in human health and development. PCBs now appear responsible for reduced intelligence, emotional instability, as well as abnormal brain function in children exposed in utero.

New Hudson River wildlife studies also reveal PCB-linked reproductive failure and abnormalities in birds and fish.

Time for Change

In 1984, when the U.S. Environmental Protection Agency opted for a "no-action" decision regarding the Hudson River PCBs cleanup, uncertainty about dredging feasibility was cited as a primary reason. However, as the USEPA moves toward a new decision, a cleanup is feasible. With this report, Scenic Hudson addresses such concerns and dispels outdated ideas about dredging. We summarize progress and experience achieved elsewhere to illustrate the feasibility of remedial dredging.

This report will assist natural resource managers, decision-makers, elected officials and citizens in reframing the discussion about clean-up options for the Hudson. We believe it provides a valuable means for sorting fact from fiction about clean-up choices and will aid people in the Hudson Valley in asserting their support for a cleaner, safer Hudson River. For two decades, convenient excuses have sandbagged cleanup proposals. During this time, similar contaminated waterways have been discovered and restored around the country. The Hudson is long overdue for the equal treatment it deserves.

Cara Lee, Environmental Director, Scenic Hudson
April 1997

EXECUTIVE SUMMARY

PCB contamination is the Hudson River's most pressing toxics issue. Two General Electric plants at Hudson Falls and Fort Edward, New York discharged PCBs to the Hudson for nearly 30 years. Hundreds of thousands of pounds of PCBs remain in the sediments, particularly in 40 hot spots in the upper Hudson River above Troy, NY. As a result, PCB concentrations in fish exceed the Food and Drug Administration's safety limit of two parts per million (ppm) for nearly 200 miles downriver.

In an ongoing study of the Hudson River PCBs Superfund site, the U.S. Environmental Protection Agency (USEPA) is evaluating cleanup options for the hot spots. This report focuses on one of the options: contaminated sediment dredging. The findings dispel outdated beliefs and misconceptions about the feasibility of dredging in the Hudson and provide concrete evidence and experience of successful remedial dredging. The key findings are:

- The uncertainty that characterized EPA's 1984 "no action" decision about the Hudson River sediments has been replaced by extensive literature and governmental guidance on contaminated sediment remediation. This includes information on the capabilities of and appropriate operating procedures for available dredges, methods for selecting contaminated sediment remedies, and methods for estimating the outcomes of dredging and the alternatives.
- Several available dredges are capable of cleanups with virtually no resuspension of contaminated sediments. Impacts are limited to the immediate area of dredging.
- There is a growing body of literature documenting successful remedial dredging projects. Dredging is now the preferred remedy at PCB-contaminated sediment sites. It has been included in 23 of 25 cleanup decisions at Superfund sites with PCB-contaminated sediment since 1984.

ABOUT PCBs

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. As endocrine disruptors, neurotoxins, and suspected carcinogens, PCBs cause a wide array of adverse health effects in humans and wildlife. These include, for example, liver damage, skin irritations, and reproductive, neurological, and developmental effects (e.g., subtle effects on intelligence and behavior). PCBs break down very slowly in the environment, and concentrate thousands of times as they pass up the food chain. PCBs also pass from mother to child through the umbilical cord and breast milk.

ADVANCES IN DREDGING

Contaminated sediment remediation is a relatively recent undertaking in the U.S., stimulated by the Superfund Law of 1980. At the time of the USEPA's 1984 "no action" decision for the Hudson River, there had been no large cleanups of contaminated sediment in the U.S. The available dredges were built to clear navigational channels and ports. Sediment resuspension and environmental impact were not significant concerns.

Once it became apparent that unmodified pre-Superfund dredges and dredging methods had limited or uncertain applicability for contaminated sediment sites, government agencies and private interests began investigating alternative dredges and methods. The USEPA and U.S. Army Corps of Engineers have cooperated in the Assessment and Remediation of Contaminated Sediment (ARCS) program. This work has included testing of several innovative dredges, analyzing dredging methods and mitigation techniques, and developing remedy selection and impact assessment guidance.

The dredges now available include several conventional dredges, initially developed for navigational projects, and the newer specialty dredges *designed specifically* to remove contaminated sediment. The design and operation of some conventional dredges have also been modified for use on contaminated sediment. This report describes more than 20 dredges, including their capabilities, limitations, and performance history.

SITE CLEANUPS

A review of the contaminated sediment literature shows that contaminated sediment has been removed successfully from hundreds of sites around the world, including a rapidly growing number in the U.S. many of which are rivers. Examples of dredged rivers discussed in the scientific literature include: Aji River (Japan), Black River (OH), Buffalo River (NY), Cape Fear River (NC), Duwamish River Waterway (WA), Grasse River (NY), Hori River (Japan), Hudson River (NY), James River (VA), Mill River (CT), Oyabe River (Japan), Shiawassee River (MI), St. Johns River (FL), St. Lawrence River (NY), and Welland River (Canada). *Since 1984, the USEPA included dredging in 23 of 25 Superfund decisions at sites with PCB contaminated sediments.*

This report summarizes 24 dredging projects documented from previously-published sources, government reports, and interviews with project managers. The purpose of the site cleanup summaries is to illustrate recent advances in contaminated sediment cleanups and to assemble practical findings from past experience. The summaries document the advantages and disadvantages of various dredges and dredging techniques used under diverse site conditions. Quantitative performance data (e.g., water column turbidity, sediment production rates) are included when available, as well as relevant site data such as sediment types and contaminants, water depth, and background turbidity. *The site cleanup descriptions include cases in which contaminated sediments were removed with little or no significant sediment resuspension.*

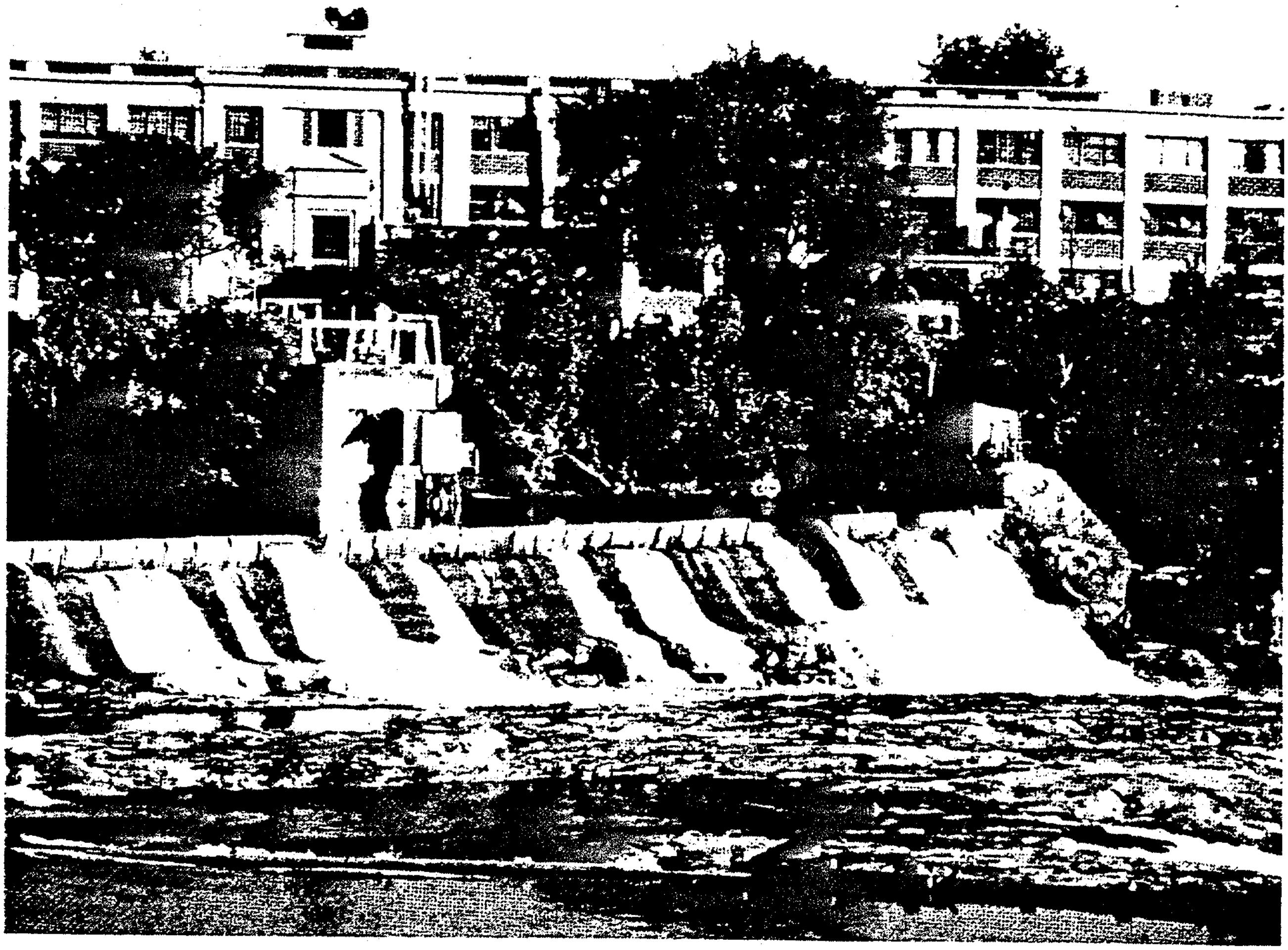
DREDGE SELECTION

Experience demonstrates that there is no single best dredge for all contaminated sediment remediation projects. For each project, a dredge is selected based on site characteristics, dredge features, and the goals and constraints of the cleanup. Previously-published literature identifies selection criteria for contaminated sediment cleanups. Scenic Hudson's report summarizes the following selection factors:

- Resuspension of contaminated sediment;
- 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 appropriate, these factors are discussed in relation to conditions in the upper Hudson River. As a practical matter, a dredge cannot be specified independent of the other aspects of a cleanup, such as sediment handling, treatment, and disposal. Accordingly, this report provides information useful in evaluating appropriate dredges for the Hudson River PCBs, but does not propose a specific remedy.

Within the next two years, the USEPA will make a new cleanup decision for the contaminated Hudson River sediments. In developing and evaluating remedial alternatives, the USEPA will have a broader array of options than were available in 1984, and better information on the short-term and long-term implications of these actions for human health and the environment. As the best developed and most proven method relieving contaminated sediment impacts, dredging will be indispensable element of the most promising solutions.



General Electric's plant at Hudson Falls, New York discharged PCBs for nearly 30 years ending in 1977. PCBs in the ground beneath the plant continue to seep into the river.

1. INTRODUCTION

The Hudson River is the Nation's largest Superfund site, extending nearly two hundred miles from Hudson Falls, NY to the southern tip of Manhattan. Polychlorinated biphenyls (PCBs) released to the river over a period of more than 30 years contaminate the sediments. Bioaccumulation of the PCBs in the foodchain causes fish to be contaminated above the Food and Drug Administration (FDA) safe limit, and New York State has restricted or banned commercial and recreational fishing on the Hudson since 1976. During these 20 years, State and Federal agencies and dozens of citizens groups have searched for a permanent solution to PCB contamination. All initiatives have ended in political deadlock.

This report addresses one of the central issues in the stalemate over cleaning up the Hudson River PCBs -- contaminated sediment dredging. Advocates and opponents have long debated:

- Is contaminated sediment dredging feasible?
- Does dredging impact the environment?
- How does dredging compare with the alternatives, including no action?

For more than a decade, the debate on these questions has been framed by the U.S. Environmental Protection Agency (USEPA) 1984 interim decision against dredging. The decision cited a lack of information to determine the feasibility and effectiveness of contaminated sediment dredging. Nevertheless, the USEPA suggested reconsidering the decision if new information became available. Such a reassessment by the USEPA is now underway.

General Electric (GE) steadfastly opposes any remediation of the Hudson River sediments and maintains that dredging would be a "horrible assault" on the river (GE, 1996). Moreover, GE characterizes the 1984 interim decision as a definitive determination. Missing from the Hudson River dredging debate is objective information on how contaminated sediment dredging has developed since 1984 and how the questions above were answered at other contaminated sediment sites.

Scenic Hudson never has been on the sidelines of Hudson River PCBs debate. We have long advocated a cleanup of PCB "hot spots" in the upper Hudson River. With this report, however, we are careful not to draw conclusions where more information (e.g., from the USEPA's reassessment) will be needed. We do not propose a specific remedy, for example, because we did not analyze sediment handling, treatment, or disposal technologies. From an engineering perspective, it is not realistic to select a preferred removal (i.e., dredging) technology independent of these other components.

The goal of this report is to provide current information that will be useful in evaluating and selecting a remedy for the Hudson River PCBs site. The report includes 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 are included for perspective.

This report is for the public, decision makers, and others with an interest in the Hudson River PCBs site. It is intended to summarize, in non-technical language, the current state of contaminated sediment dredging technology and its applicability to the Hudson River PCBs site. This information is provided to replace outdated perceptions and to build support for the best option for restoring the Hudson River.

1.1 The Hudson River

From its headwater at Lake Tear of The Clouds in the Adirondack Mountains, the Hudson River flows 315 miles south through New York State to its mouth at New York Harbor. The Hudson and its tributaries drain a watershed of 13,390 square miles, mostly in New York, but also small parts of Vermont, Massachusetts, Connecticut, and New Jersey. The Hudson River and its drainage basin are shown in Exhibit 1.

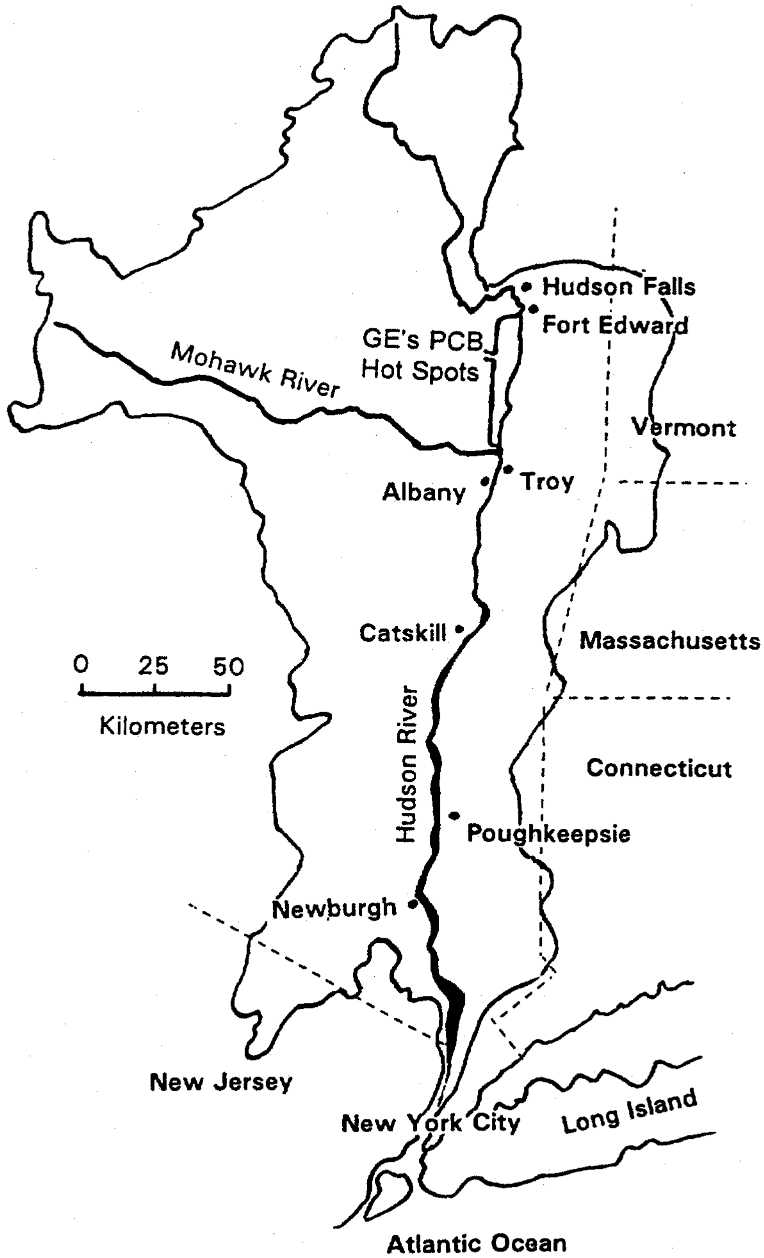
The southernmost 153 miles of the Hudson River is an estuary, where freshwater mixes with saltwater from the ocean and tides ebb and flow twice daily. The maximum tidal range is 4.7 feet at the city of Troy. The saltwater gradient typically reaches about 60 miles north of New York City to Newburgh. The Hudson Estuary is a particularly rich ecosystem, with a mix of freshwater and marine species and freshwater and brackish tidal marshes. The Hudson is the only major East Coast estuary where all native fish species are still found. The average depth of the Hudson Estuary is 27 feet, and its maximum depth is more than 200 feet (USEPA, 1991a). A navigational channel is maintained at 32 feet from the Battery to Albany and 14 feet from Albany to Troy.

The Hudson Estuary ends at the Federal Dam at Troy. The 150-mile half of the Hudson north of Troy is commonly called the "upper" Hudson River. The upper Hudson is more shallow and generally more narrow than the lower Hudson River. Water flow is heavily influenced by a number of tributaries (e.g., the Sacandaga River, the Batten Kill, Fish Creek, and the Hoosic River) several dams, riparian wetlands, and regulation of Great Sacandaga Lake (USEPA, 1991a). Flows are fairly steady through most of the year with a large peak in the spring months.

1.2 History of PCB Contamination in the Hudson River

The Hudson River is contaminated with PCBs released from two General Electric capacitor plants located at Hudson Falls and Fort Edward, New York. GE began legally discharging PCBs from Fort Edward plant in 1947 and from the Hudson Falls plant in

Exhibit 1
The Hudson River Basin



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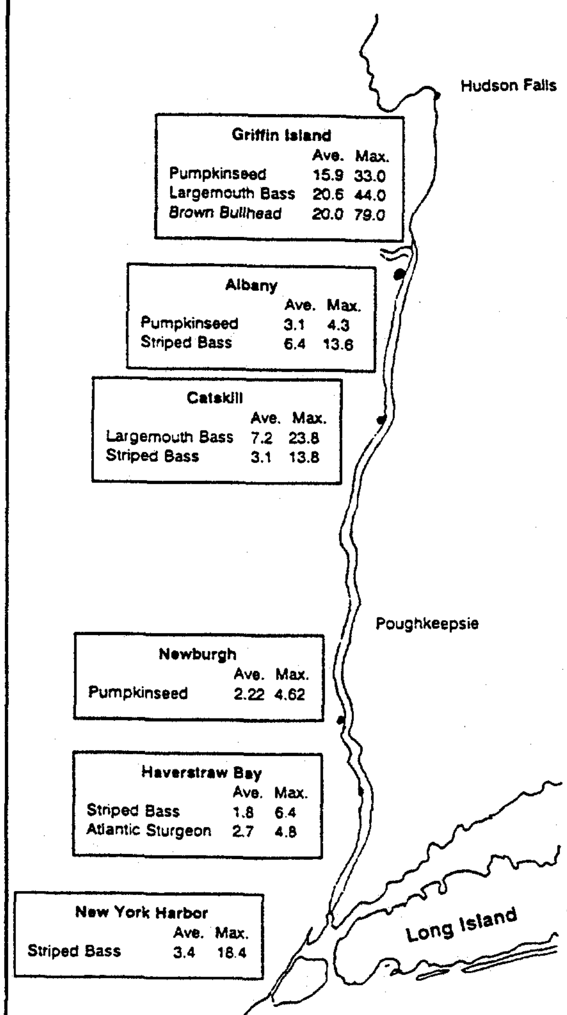
1952 (Sanders, 1989). Intentional discharges ended in 1977, following a 1976 agreement with the State of New York and passage of the Toxic Substances Control Act (TSCA). The total amount of PCBs discharged from the facilities is unknown. Estimates of permitted discharges range from 500,000 to 1.3 million pounds[1] of PCBs.

Until 1973, much of the PCB released by the GE plants accumulated in sediments behind the Fort Edward Dam. When the dam was removed in 1973, contaminated sediment was redistributed downstream. The transported sediment formed approximately 40 "hot spots," primarily in depositional zones, in a 40 mile stretch of the upper Hudson River. Appendix A shows the locations of the PCB hot spots. In addition to the hot spots, there are sediment "remnant deposits" that remained in place after the Fort Edward Dam was dismantled. Removal of the dam lowered the water level in the river exposing the remnant sediment deposits in the river.

Exhibit 2
1994 PCB Concentrations in Hudson River Sportfish (parts per million)



Source: NYS DEC 1994 Data

The New York State Department of Environmental Conservation (DEC) and other agencies have studied PCB concentrations in Hudson River fish since the 1970s. Health advisories and commercial fishing bans have been in place continuously since 1976. Currently, there is an "eat none" health advisory for women of childbearing age and children for all fish species from the Hudson River. For others, the health advisories vary by location and fish species, but generally limit consumption to one meal per week or per month. Exhibit 2 shows 1994 fish contamination data for several species at several locations. There is a steady gradual decrease in PCB concentrations

[1] Purchase records indicate that GE used over 133 million pounds of PCBs at the two plant sites. The upper estimate of PCBs released to the Hudson River (i.e., 1.3 million pounds) is based on a plant manager's estimate in 1976 that less than one percent of the PCBs used at the plant were released to the river (Sanders, 1989).

moving downriver from the GE plants and sediment hot spots. The downward trend reverses only at New York Harbor.

In addition to the sediment contamination from historical discharges to the river, there is substantial contamination at GE's Fort Edward and Hudson Falls plant sites in the form of non-aqueous phase liquid (NAPL) (i.e., essentially undiluted PCB oil) in the ground. DEC estimates that 1.5 million pounds of PCBs remain beneath the Hudson Falls site and approximately 600,000 pounds remain beneath the Fort Edward site. GE is currently remediating these sites under consent orders with the DEC. (Note that these sites are not included in the federal Hudson River PCBs Superfund site.)

In 1994, contractors working for GE discovered nearly pure PCBs seeping into the river from contaminated ground beneath the Hudson Falls site. The visible seeps are located in the riverbed at Bakers Falls, adjacent to the site, and in underwater tunnels in a long-abandoned paper mill between the Hudson Falls plant and the falls. Fish and water column monitoring data suggest that the rate of PCB releases from the ground beneath Hudson Falls plant increased in the early 1990s. The total amount of PCBs that entered the river from the seeps is unknown.

1.3 Cleanup Efforts

The Federal Government and New York State have jurisdiction over the Hudson River PCB contamination. The two plant sites are listed on the New York State Registry of Inactive Hazardous Waste Sites. A series of DEC consent orders have directed cleanup activities at the plant sites, including eliminating further PCB releases from the seepages discovered in 1994.

The Federal jurisdiction comes under the Comprehensive Environmental Response Compensation Liability Recovery Act (CERCLA), also called the Superfund law. Superfund became law in 1980 and was updated in 1986 with the Superfund Amendment and Reauthorization Act (SARA).

The Hudson River PCBs Superfund site covers approximately 200 miles of the Hudson River from the GE plant sites to the mouth of the Hudson River at New York City. The focus of the site, however, is the 40 mile reach of the upper Hudson River from the GE plant sites to the Federal Dam at Troy, New York. This portion of the site includes the contaminated sediment hot spots and the riverbank remnant deposits.

A 1984 USEPA Record of Decision (ROD) determined that no action would be taken to remediate the contaminated sediments in the river, citing doubts about the dredging. However, the USEPA said that a reassessment would be conducted if "techniques for dredging of contaminated sediments from an environment such as this one are further developed." The ROD called for capping the exposed remnant deposits. The caps are now in place and GE is required to monitor their effectiveness.

In 1989, the USEPA initiated a reassessment of the Hudson River PCB Superfund site. Exhibit 3 identifies the circumstances that prompted the reassessment, including USEPA policies, technological advances in contaminated sediment remediation, and a request from New York State. The reassessment is still underway and remedy selection is expected in late 1998.

Exhibit 3
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."* (USEPA, 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 (NYDEC) requested a reassessment of the No Action Decision."* (USEPA, 1991)

2. CONTAMINATED SEDIMENT REMEDIATION

Contaminated sediment remediation is accomplished by reducing the toxicity, mobility, or availability of the contaminant(s). A number of options are available for each approach to remediation. No matter which approach is taken, another critical management decision is necessary: whether to first remove sediments or to manage them in place. This section describes the factors that bear upon this decision, including the impacts of and alternatives to dredging.

This report does not discuss technologies for managing excavated contaminated sediments. There are many options and extensive literature on their advantages and disadvantages. For example, treatment technologies potentially applicable to the Hudson River PCBs site are identified in a report prepared by the Hudson River Sloop Clearwater (Hirschhorn, 1994), and Environment Canada's SEDTEC database contains detailed information on approximately 90 treatment technologies for contaminated sediments. In addition, USEPA (1994a) and Averett et al. (1990) contain detailed information on methods for managing contaminated sediments. As discussed in Section 5, sediment cleanup plans must include removal technologies that are compatible with the treatment and disposal technologies and *vice versa*.

2.1 Historical Context of Dredging

Contaminated sediment cleanups lag years behind efforts to control air and water pollution. Congress created laws to control air and water pollution in the early 1970s, but it was not until after Superfund became law in 1980 that we began to understand the extent and significance of sediment contamination. Even today, basic research is needed to develop sediment quality criteria and methods of assessing and controlling pollution.

Long before the passage of Superfund, there was a large and thriving industry for removing sediments from rivers, lakes, and coastal waters. For decades, Federal law has mandated the U.S. Army Corps of Engineers (USACE) to dredge ports and rivers around the country for maintenance of navigational channels. The total amount of sediment dredged for navigational purposes is very large; in 1988 the USACE estimated that it dredged 250-300 million cubic yards per year for navigational maintenance (Engler, 1988). This does not include dredging by private interests.

> **"Conventional dredges were designed to obtain high output, but little attention was paid to the environmental impact. As a result, these dredges produce more turbidity compared with those special-purpose dredges that were designed specifically to reduce sediment resuspension."** (Herbich, 1992)

The dredging technologies and practices available in the U.S. before Superfund were geared toward removing large volumes of sediments, not for handling contamination. Sediment resuspension and environmental impacts of dredging were not of concern to dredge designers or users (Herbich, 1992). The predominant dredges of the time were mechanical bucket and hopper dredges that stirred up sediment and spilled it as it was lifted through the water column and deposited into collection barges. These dredges could create large visible plumes of suspended sediment.

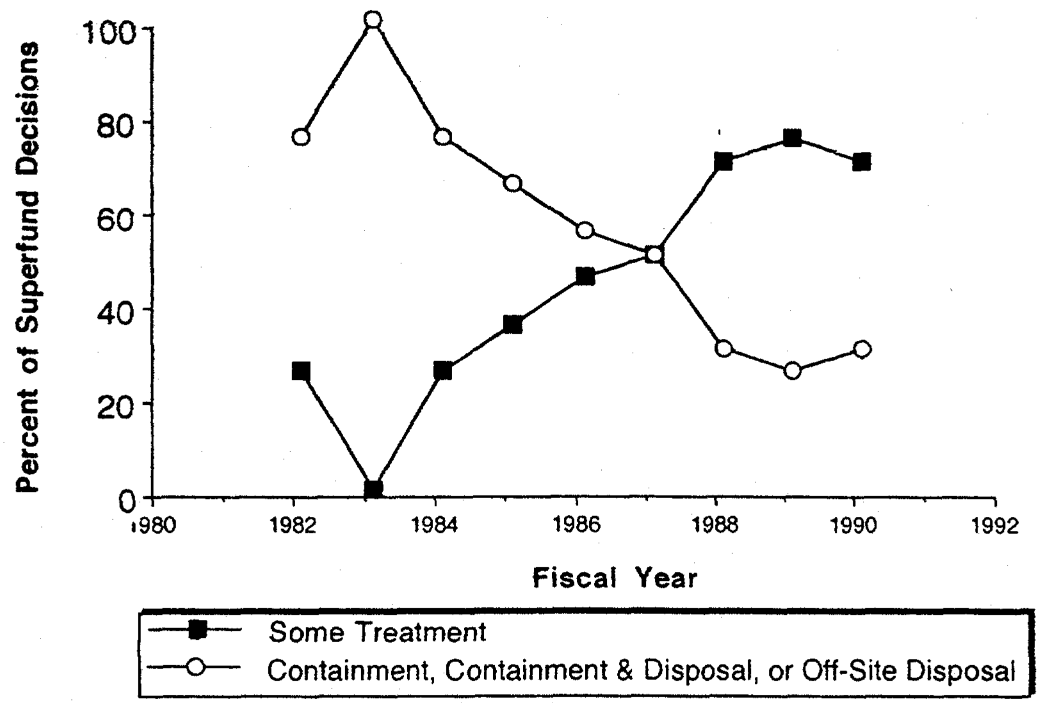
With the passage of Superfund in 1980, the Federal government committed to an unprecedented nationwide cleanup of contaminated sites. Superfund was unprecedented, but not just in scale: no major environmental statute before Superfund addressed contaminants already released to the environment. Earlier laws such as the Water Pollution Control Act, Clean Air Act, Resource Conservation and Recovery Act regulated waste management and ongoing or new releases of contaminants to the environment.

Because Superfund addressed existing contamination, USEPA and parties responsible for Superfund sites faced a baffling array of novel technical issues. For example, prioritization of cleanups and goal-setting gave rise to new human health and ecological risk assessment methods. Site remediation studies added to the need for consistent and reliable methods for detecting minute quantities of contaminants in environmental media (e.g., soil, groundwater). Such technical issues were barriers to Superfund implementation, particularly in the first half of the 1980s.

Among the most important challenges to the Superfund program was the limited technology available for remediating contaminated environmental media (e.g., groundwater, air, soil). As Exhibit 4 demonstrates, early Superfund remedies were dominated by containment (i.e., landfilling or capping wastes in place). Containment limits the mobility of contaminants, but does not provide the same level of long-term environmental protection as remedies that treat contaminants before disposal. Throughout the 1980s, the use of treatment remedies grew rapidly as a boom of private research and development and government sponsored research programs produced dozens of new remedial technologies.

The research and development boom in environmental remediation has been slower to develop for contaminated sediment than other environmental media. Most of the new technologies were designed for contaminated soil and groundwater, which are the most commonly contaminated media at Superfund sites (Exhibit 5). Progress in developing sediment remediation is also slowed by technical barriers (e.g., the lack of consistent chemical testing methods) and the ambiguous regulatory jurisdictions. In particular, more than ten Federal laws define the USEPA's responsibilities with regard to contaminated sediments, and the USACE has considerable jurisdiction as well. The Federal, as well as state, authorities for contaminated sediment management are fragmented and duplicative (USEPA, 1994c).

Exhibit 4
Treatment Versus Disposal in Superfund Cleanups

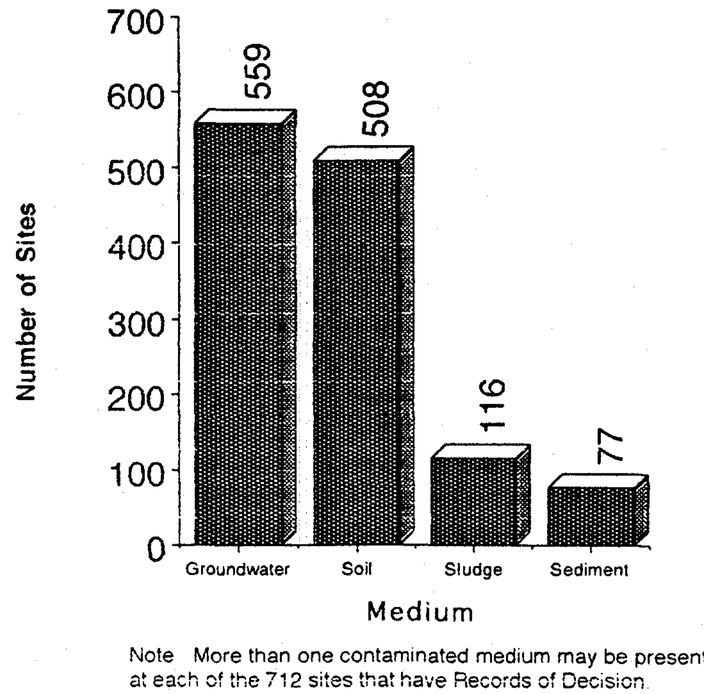


Source: USEPA, 1991b

Gradually, there has been increased recognition of the significance of contaminated sediments nationwide. One eighth to one quarter of all Superfund sites involve contaminated sediments (Wall, 1991 cited in Thibodeaux, 1994), including some of the largest sites. There are 34 Great Lakes Areas of Concern (AOCs) with contaminated sediment problems. And despite improvements in water quality under the Clean Water Act, there are more than 1,200 State advisories against consuming fish related to historical sediment pollution (USEPA, 1994c). Sediment contamination has become a critical factor in navigational dredging projects. For example, contamination in New York Harbor has stalled maintenance dredging. These contaminated areas have persistent ecological, human health, and economic impacts that no longer can be ignored.

Since the mid-1980s, a number of new programs have been initiated to advance the assessment and remediation of contaminated sediments. In 1989, the USEPA established a steering committee to develop a management strategy to coordinate efforts to assess, prevent, and remediate contaminated sediments (USEPA, 1995c). Efforts are underway to prioritize sediment contaminants of concern and their sources and develop sediment quality criteria.

Exhibit 5
Contaminated Media at Superfund Sites Where Remedies Have Been Selected



Source: USEPA, 1993, based on Records of Decision for fiscal years 1982-1991.

The Army Corps of Engineers has been very active in this field of research. In particular, the Corps developed sediment assessment methods and investigated a number of technical issues under its Environmental Effects of Dredging Program (EEDP) and the Improvement of Operations and Maintenance Techniques Research Program (Zappi and Hayes, 1991). The USEPA and the USACE have cooperated on a number of projects including site-specific feasibility studies and pilot tests under the Assessment and Remediation of Contaminated Sediment (ARCS) Program.

2.2 Environmental Dredging

The use of many conventional dredges and dredging techniques for contaminated sediment cleanups is limited by the potential resuspension of contaminants into the water column and dispersal of contaminants from relatively stable deposits. Consequently, the rule of thumb developed in the early days of Superfund was that sediment dredging may cause more harm than good and should be limited to use at sites with exceptionally severe contaminant impacts. This thinking underlies the 1984 "no action" decision for the sediment hot spots of the Hudson River PCBs site.

Once it became apparent that unmodified pre-Superfund dredges and dredging methods had limited or uncertain applicability for contaminated sediment sites, the USEPA, the USACE, and private interests began investigating alternative dredges. For example, the USACE reviewed dredging technologies and conducted field tests under the Environmental Effects of Dredging Program and other programs (Zappi and Hayes, 1991). The USEPA 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). The USEPA and the USACE cooperated on dredging field tests for the New Bedford Harbor Superfund site, where full scale remediation of PCB hot spots is complete and further dredging is planned.

> **"Dredging technology exists that is capable of greatly reducing turbidity and resuspension in connection with dredging of bottom sediments in most applications."** (National Academy of Science, 1989)

Innovative dredging technologies investigated by the USACE, the USEPA, and Environment Canada include several dredges specifically designed to minimize contaminated sediment resuspension. Some of these dredges use shields, acoustic sensors, turbidity monitors, and even underwater cameras to monitor or control sediment resuspension. Innovative dredges also include conventional dredges with substantial design (e.g., watertight bucket dredges) or operational modifications to reduce sediment loss.

Many of the innovative dredges were actually invented before Superfund brought attention to contaminated sediments in the U.S. In fact, most of the innovative dredges were developed in other countries, especially Japan and the Netherlands, which remain ahead of the U.S. in contaminated sediment remediation. Experimentation with these technologies by the USEPA, the USACE, and Environment Canada, as well as academic research into dredging overseas, has increased the availability of concrete performance data and advanced acceptance of the technologies. However, "environmental dredging" as it has come to be called (e.g., USEPA, 1994a; Palermo et al., 1992) continues to be slowed in the U.S. by the Jones Act, which prohibits the importation of foreign-built ship hulls and dredges (Zappi and Hayes, 1991).

The literature on contaminated sediment management documents advances in dredging technology over the past 15 years. Dredging is now the preferred remedy for PCB-contaminated sediments at Superfund sites. In work related to the Manistique Harbor Area of Concern (USEPA, 1995d), an interagency task force including the USEPA, the USACE, and the National Oceanic and Atmospheric Administration (NOAA) reviewed the 30 Superfund decisions for 29 sites with PCB-contaminated sediment. Among these sites, dredging or dredging followed by capping was selected for 23 sites, capping only was selected for one site, and "no-action" was selected for one site. At the time of the analysis, remedies had not been selected for four sites. Appendix B (from USEPA, 1995d) presents information on the remedies at the 29 sites.

"In a review of 30 Superfund actions at 29 different sites with PCB-contaminated sediments, a strong trend emerged. Capping alone was chosen as the remedy for only one site (Hudson River PCBs [remnant deposits]); at this site, the sediments are not underwater...The sites for which dredging has been chosen and/or implemented far outnumber the sites for which capping of PCB-contaminated sediments has been chosen and/or implemented. Dredging alone is also preferred over a remedy of capping and dredging combined." (USEPA, 1995d)

2.3 Concerns About Dredging

When the USEPA cited doubts about the efficacy of dredging the Hudson River in the 1984 ROD, the primary concern was the release of PCBs to water, air, and, fish (USEPA, 1984). Like all remedial technologies, dredging is not 100 percent effective and some fraction of the contaminant is not recovered. Contaminated sediment that escapes the dredge may be either left in place or resuspended into the water column. Additional environmental issues include physical impacts to the river bottom habitat and the effects of dredging-related turbidity on aquatic organisms.

2.3.1 Sediment Resuspension

PCBs and other hydrophobic contaminants in contaminated sediment are, for the most part, bound to fine sediment particles, especially natural organic carbon particles (van Oostrum and Vroege, 1994). A fraction of the contaminant is dissolved[2] in the porewater between the sediment particles. In addition, there may be colloidal PCB droplets in the sediment pore space.

During any dredging, some fraction of the sediment and associated porewater escapes the dredge and is resuspended into the water column. In a river, most resuspended contamination moves downstream. Some contaminated sediment will resettle into the riverbed or on the riverbank. Some contamination may be washed out to sea, and some will enter the foodchain. Although PCBs tend to remain bound to sediments, they may desorb and dissolve into the water. The dissolved PCBs and colloidal PCBs can become airborne above the water surface. At some very

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2 The proportions of dissolved and particulate-bound contaminant depends on a number of properties of the sediment, the water, and the contaminant. Higher-chlorinated PCB congeners tend to be less soluble than lower-chlorinated PCB congeners.

contaminated sites, such as New Bedford Harbor, Massachusetts where PCB concentrations were as high as 100,000 ppm, a visible film of PCB oil has been seen on the water surface. The mobility and fate of the PCBs depends on the composition of PCB congeners. Higher chlorinated congeners are more hydrophobic, less volatile, and thus less mobile than lower chlorinated congeners. Sediment type and other environmental factors influences the mobility of PCBs, too.

The fate of the resuspended contaminants is the greatest concern. In particular, contaminated sediment resuspension may increase PCB concentrations in the water column and possibly the air near the site of dredging during dredging. The inadvertent release of contamination, to all media collectively, is referred to as contaminant loss. Methods for estimating contaminant loss from contaminated sediment is an area of active research (e.g., Young et al., 1996). A recent report from the USEPA's ARCS program (USEPA, 1996f) summarizes current methods for estimating contaminant loss from dredging, capping, and no action.

Since most of the PCB remains bound to sediment particles upon resuspension, the effectiveness of dredging is usually measured in terms of the increase in total suspended solids (TSS) concentrations in the water during dredging. Later in this report, TSS monitoring data from several dredging projects are provided as measures of contaminated sediment resuspension with various dredges operated under various conditions.

Contaminant loss may increase toxics exposure to organisms in the time and area of dredging. Mobilized contaminants quickly diffuse in the environment away from the point of dredging, but the process of bioaccumulation acts to concentrate the available contaminant in the food web. To minimize contaminant loss, it is important that dredging operations resuspend as little sediment as possible. Dredging equipment must be selected and operated with dredging efficiency as a goal, and mitigation equipment (e.g., with silt curtains or oil absorbent booms or pads) should be used where appropriate. Technologies and operational methods used to minimize and mitigate contaminated sediment resuspension are described in Sections 3.3 through 3.5.

2.3.2 Other Potential Impacts

In addition to contaminant mobilization, dredging and sediment resuspension have the potential to impact aquatic biota physically. High turbidity itself can be a hazard to fish. By limiting light penetration or smothering leaves, turbidity can interfere with primary productivity by phytoplankton and submerged aquatic vegetation. Stationary or slow moving organisms are more susceptible to these impacts than mobile organisms. Even with the least efficient dredges, these impacts are temporary and confined to a limited area. Silt curtains or other barriers (described in Section 3.4) can be used to mitigate these impacts is some situations. It is noteworthy that the suspended sediment concentrations generated by most dredges are similar to those resulting from storms and other natural disturbances.

Because dredging necessarily removes the surface layer of sediment, rooted aquatic plants, invertebrates, and other organisms in the sediment are disturbed or destroyed. The removal of bottom sediment also may affect habitat quality by altering sediment properties (e.g., grain size, nutrient concentrations) and bottom topography. The dredged site recovers gradually as organisms from adjacent unaffected areas recolonize.

West (1987) monitored the natural recovery of a 26-acre dredging area at South Creek, North Carolina. The study area was covered with phosphate slurry released from a pipeline rupture in February 1986. Between February and April 1986, the slurry and underlying sediments (to a depth of one half to four feet) were dredged. Recovery of the benthic macroinvertebrate community in the dredged area and in an unaffected control area were monitored from May 1986 to May 1987. Although the slurry spill and dredging significantly disturbed the benthic habitat, by the end of the monitoring period "predominant grain size, porewater content, and total organic content of the dredge site approximated those of the control site." In addition, the total faunal densities and species richness of the benthic community at all water depths were not significantly different from the control site by the end of the first year.

2.4 Alternatives to Dredging

Alternatives to dredging include capping contaminated sediments with clean sediment or other materials, *in situ* (i.e., in place) treatment of contaminants, and no action.

2.4.1 Capping

Capping involves constructing a physical barrier on the sediment to reduce contaminant exposure and loss. Typically cap materials are clean sediment, gravel, soil, textiles, or membranes. Caps may be made of a combination of materials in layers. The primary purpose of a cap is to stop contaminated sediment and porewater from releasing contaminants to the overlying water. Other benefits include providing additional sediments to adsorb contaminants, reducing contaminant releases associated with burrowing organisms (bioturbation), and creating anaerobic (i.e., low oxygen) conditions favorable to the decay of some contaminants (Thibideaux et al., 1994). There are at least 26 capping sites in the world (Thibideaux et al., 1994), including several sites in the U.S. (e.g., Sheboygan Falls (WI), Puget Sound) (Averett and Francinques, 1994; Stivers and Sullivan, 1994).

Caps may be constructed of a variety of materials including clean sediment, clay, gravel or cobbles, activated carbon, synthetic liners, or cement. Capping, like dredging, requires site-specific engineering, and local conditions like navigational use may limit or preclude its applicability. Capping is most effective in sheltered areas with calm waters, minimal navigational disturbance, and without upwelling of groundwater (Averett, 1994).

Capping is most effective in sheltered areas with calm waters, minimal navigational disturbance, and without upwelling of groundwater.
(Averett, 1994)

An advantage of capping is that contaminated sediment is not removed, transported, or subjected to the cost and difficulty of treatment or off-site disposal. Turbidity and sediment resuspension are issues of concern when the cap is put in place. There are a variety of techniques for constructing a cap (Palermo, 1994), but most involve either dumping from a ship or release through an underwater diffuser or pipeline. Dumping cap material on a contaminated area can resuspend sediment, especially when fine-grained sediments are capped with heavier materials (Thibideaux et al., 1994). A related concern is the release of contaminated porewater as fine grained contaminated sediments settle under the weight of the cap. Additional issues of cap placement are uniformity and entirety of coverage of the contaminated area (Palermo, 1994).

Because capping does not destroy or remove sediment contaminants, the questionable long-term integrity of caps is a significant potential limitation. Long-term threats to caps include gradual erosion, burrowing organisms, ice scour, boat scour (also anchorage or trawling), flooding, and slow diffusion of contaminated porewater through the cap. Since long-term field data on cap effectiveness are lacking, the effectiveness of caps are evaluated with models and professional judgement (Palermo and Miller, 1995).

Capping unavoidably impacts the extent and quality of benthic habitat. In the short-term, capping smothers bottom-dwelling organisms and their habitat. Depending on the cap material (e.g., concrete versus clean sediment), organisms from adjacent unaffected areas may or may not recolonize the area. In addition, turbidity from cap placement can cause temporary and localized impacts. The magnitude of these impacts depends on the materials used in the cap, placement, method, and site conditions.

Cost-effectiveness has been identified as an advantage of capping over dredging (Thibodeaux et al., 1994). However, site-specific factors (e.g., amount of contamination, cap or dredge specifications) and a lack of long-term data preclude a definitive conclusion on this matter. While the initial capital costs (e.g., for constructing the cap itself) may be less than those for dredging, post-construction monitoring and maintenance costs may erode the short-term cost advantage. For example, a review team for the Manistique River and Harbor Area of Concern determined that costs (i.e., net present value over 30 years) for dredging and capping options were similar and differences were within the error of the calculations (USEPA, 1995d). This analysis did not reflect costs beyond 30 years, even though PCBs were expected to leak at some poin in the distant future. In 1984, the USEPA estimated that the costs of capping (not including maintenance) the Hudson River PCBs site would be comparable to the costs dredging (USEPA, 1984).

Capping has the potential to interfere with navigation. For example, capping at the Manistique River and Harbor Area of Concern would have eliminated commercial navigation because the harbor would be too shallow after installation of a cap (USEPA, 1995d). This may be an issue of concern for the Hudson River PCBs site.

Since capping involves the filling of contaminated waterbodies, it decreases water depth and may alter the hydraulic patterns. Possible results include altered water velocity, meander patterns, erosion and depositional patterns, and habitat distribution. Recreational navigation may need to be restricted in some circumstances to protect cap material.

> **"Potential long-term risks to humans and wildlife are lower with dredging than with capping...Given enough time, it is reasonable to anticipate significant damage and disruption to a cap, with resulting release of PCBs, even if the cap is armored."**
> (USEPA, 1994)

Comparisons between the effectiveness of dredging and capping in terms of controlling contaminant exposures is complicated by the variability of specific remedies, site-specific factors, and limited data on the long-term effectiveness of caps. However, for the Manistique River and Harbor Area of Concern, Palermo and Miller (1995) concluded that capping was more effective than dredging during implementation and for the first 100 years. But they also concluded that dredging was more effective than capping in the long term (i.e., beyond 100 years) and that, "overall, there is a much greater level of confidence in the performance of [the dredging] alternative than the capping/stabilization alternative."

2.4.2 *In situ* Remediation

In situ remediation involves chemical or biological additions to the sediment to immobilize or destroy contaminants. Examples include *in situ* enhanced bioremediation, in which natural or genetically engineered bacteria are added to the sediment to detoxify contaminants, and *in situ* solidification, in which cement or other materials are mixed with sediment to immobilize contaminants. Both of these methods are experimental, and most management agencies do not yet consider them to be viable (Marcus, 1991).

For a number of reasons, *in situ* treatment may not be able to match the effectiveness of treatment *ex situ*. *Ex situ* processing enables more thorough mixing of contaminated material and chemical or physical treatment agents. In addition, excavation can be followed by confirmatory sampling to verify that the full extent of subsurface contamination has been reached. Another potential limitation of *in situ* treatment is resuspension of contaminated sediments as the necessary additions (e.g., nutrients, oxygen, microbes, cement) are injected and mixed into the sediment.

Although there have been no large-scale cleanups using enhanced bioremediation, there have been pilot tests (with mixed results) in Canada, The Netherlands, and the U.S. (Averett and Francinques, 1994). General Electric experimented with *in situ* bioremediation of PCB-contaminated sediments in the Hudson River (Mondello et al., undated). Additions of nutrients and hydrogen peroxide (for oxygen) were found to stimulate PCB degradation by native microbes. However, the biodegradation affected lower-chlorinated PCB congeners selectively, and the added microbes apparently did not enhance the process (Mondello et al., undated).

The USEPA reviewed research on *in situ* bioremediation for the Hudson River PCBs Phase I Reassessment in 1991 and concluded:

- Effective remediation of Hudson River PCBs would require both aerobic and anaerobic microbial action in sequence.

- Conditions needed of optimum aerobic action include, microbes that can grow on biphenyl or chlorobiphenyl compounds, above-ambient sediment temperatures, aeration, and sufficient PCB bioavailability.

- Anaerobic microbial action would require the absence of sulfates or other inhibitors, PCB concentrations above 50 parts per million (ppm), nutrients, supplemental carbon, and above-ambient sediment temperatures (USEPA, 1991a).

It is unlikely that conditions suitable for effective *in situ* bioremediation could be maintained on a large scale. Moreover, this approach apparently would not be feasible for sediments with less than 50 ppm of PCBs.

Methods for *in situ* stabilization are better developed than methods for *in situ* treatment. *In situ* stabilization has been tested in the U.S. and Japan. However, application has been limited because contaminants are neither removed nor destroyed, and benthic organisms are adversely affected (Averett and Francinques, 1994). Compared with other remedies, *in situ* stabilization has little or no prospect for habitat restoration in the treated area.

2.4.3 No Action

"No action" is defined as no intervention to remove, isolate, or detoxify environmental contaminants. No action is a misnomer because it is usually necessary t monitor the hazard posed by the site, and to institute and enforce site access or resour use restrictions to protect public health (Marcus, 1991).

Because no action usually involves some activity, it is not without cost. Howeve it costs less (excluding natural resource damages and other impact costs) than remedial options, at least in the short-run. Initial low cost is not the only reason that no action i considered for contaminated sediments. It may be an acceptable option at sites where the contaminants are located in a stable zone of natural sediment deposition, on the assumption that gradual burial will reduce potential risk exposures. In addition, no action is an acceptable option for contaminants that are not persistent due to rapid natural biological or chemical degradation (Herbich, 1992). Although the contaminate sediment hot spots in the upper Hudson River are fairly stable, they remain a significar source of PCBs to the water column - at least a pound per day (USEPA, 1997). Dechlorination occurs only where PCB concentrations exceed 30 ppm and has reduced the PCB mass in the Hudson less than 10 percent (USEPA, 1997). As the *status quo* for the Hudson River PCBs site, no action is not protective of human health and the environment.

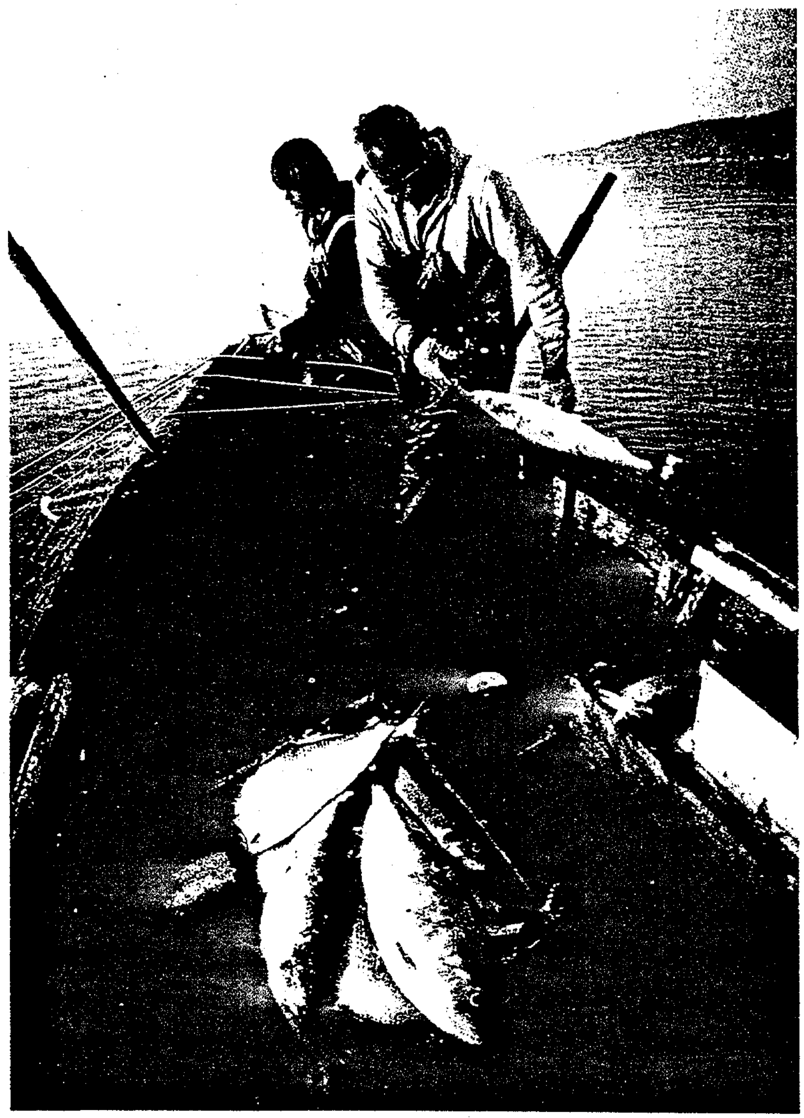
Although natural sediment deposition may gradually cover contaminated sedime with a clean layer (assuming the source of contamination has stopped), this process alo does not isolate contaminants from the ecosystem. Contaminated and uncontaminated layers of sediment near the surface are gradually mixed by organisms that live in and o the sediment. This process is called bioturbation. In addition, buried PCBs can reach the water column as contaminated pore water seeps from the sediment and as sediment are stirred by storm erosion, scouring by boats, ice, and debris. These processes facilita direct contaminant exposure to organisms at the bottom of the food chain. As they are passed up the food chain, PCBs and other bioaccumulating contaminants are concentrated to many times their level in the sediment.

Measures such as fences, warning signs, or deed restrictions are often used to mitigate risks at sites where no action is taken. Among the limitations of these method are that they are difficult to enforce, do not address ecological risks, and may involve long-term costs or economic impacts (e.g., for monitoring, maintenance, enforcement).

> **"...sufficient data to support a no-action alternative as the permanent recommended alternative [for the Hudson River PCBs site] are not available at this time."** (USEPA, 1984)

Because access to the Hudson River can not be restricted, human health risks currently are mitigated by fishing restrictions, including closure of the commercial striped bass fishery, and health advisories for all sportfish. These measures do not address ecological risks and do not effectively control human health risks, particularly for low-income subsistence fishermen and their families (Barclay, 1993; NYSDOH, 1994).

One of the reasons that the USEPA is reassessing the 1984 no action decision for the Hudson's contaminated sediments is that the no action alternative is inconsistent with the USEPA's statutory preference for remedies that "permanently and significantly reduce the volume, toxicity or mobility of the hazardous substance involved." The 1984 decision predates this preference, which was created in 1986 by the Superfund Amendments and Reauthorization Act (SARA). Even in 1984, the USEPA did not consider the no action alternative to be a solution to the PCB problem. In fact, no action was selected as an interim measure only, not a permanent remedy, because "...sufficient data to support a no-action alternative as the permanent recommended alternative are not available at this time." (USEPA, 1984)



Ted Spiegel

Twenty years of fishing bans have nearly wiped out the Hudson's commercial fishermen, ending a way of life handed down for generations.

3. DREDGING TECHNOLOGIES AND RELATED SEDIMENT CONTROLS

This section describes dredges available for contaminated sediment remediation, including conventional and specialty dredges. The dredges are grouped in two categories, mechanical and hydraulic dredges. This section also describes equipment and approaches to mitigate sediment resuspension.

Contaminated sediment resuspension is given special emphasis in this report because it is an issue of particular interest for the Hudson River PCBs site. The dredge technology descriptions in this section highlight design features for controlling sediment resuspension. Many of the technology descriptions include previously-published information on sediment resuspension.

3.1 Mechanical Dredges

Mechanical dredges are related to the familiar earth moving equipment (e.g., backhoes) used at construction sites on land. They scoop up sediments batch by batch and load them into a barge, truck, or directly into a land-based containment area. Mechanical dredges are mounted on vessels or, if the dredging area is close to shore, operated from the water's edge. Several available mechanical dredges are listed in Exhibit 6.

> **"In the case of clamshell dredges, the watertight buckets appear to be quite useful since they reduce turbidity by about 30 to 70 percent."**
> (Herbich, 1992)

Advantages of mechanical dredges are availability, ability to remove large debris, and ability to remove sediment at near *in-situ* density (USEPA, 1994a). Although careful operation can minimize sediment resuspension (Havis, 1988), mechanical dredges have the potential to resuspend sediments as the bucket contacts, handles, and lifts away from the sediment surface with each scoop. Sediment may be spilled or flushed into the water column as the bucket is lifted to and above the water surface and deposited in a barge.

Some conventional mechanical dredges have been redesigned to minimize sediment resuspension. Exhibit 7 shows two modified bucket dredges, which are described further in Section 4. Such modified mechanical dredges have been demonstrated at several sites (e.g., USEPA, 1994; Zappi and Hayes, 1991; Orchard, 1996), and are capable of reducing turbidity by 30 to 70 percent or more over conventional bucket dredges (Herbich, 1992; Orchard, 1996).

Exhibit 6
Mechanical Dredges

- Backhoe
- Bucket ladder
- Clamshell
- Closed-bucket clamshell
- Dipper
- Dragline
- Orange-peel

Source: Averett et al., 1990

3.2 Hydraulic and Pneumatic Dredges

Hydraulic dredges use strong pumps to collect sediment through a piping system, much the way a vacuum cleaner uses air suction to remove dust from a carpet. Because water is collected with the sediment, hydraulic dredges generate sediment slurries with sediment density lower than *in situ* sediment. Hydraulic dredges generally include some form of dredge head that mechanically loosens sediment and directs it to the hydraulic intake. Several hydraulic dredges are designed specifically for removing large volumes of contaminated sediments with minimal resuspension.

Hydraulic dredges are commonly used for navigational and contaminated sediment dredging. The USACE and other dredgers use hydraulic dredges to remove millions of cubic yards of sediment from navigational channels in the U.S. each year (Zappi and Hayes, 1991).

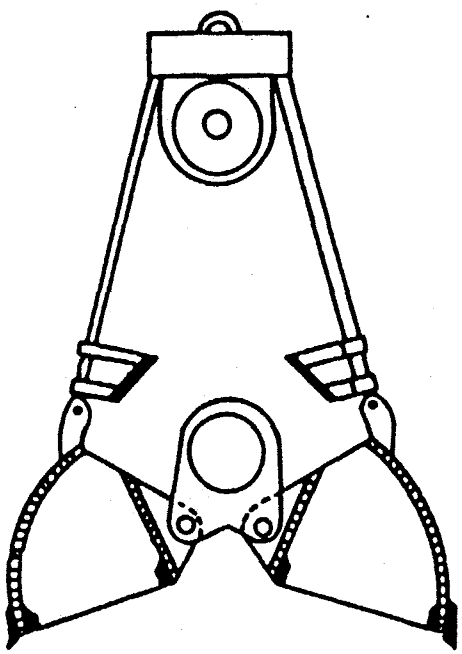
"[hydraulic dredges] provide an economical means for removing large quantities of contaminated sediments." (Zappi and Hayes, 1991)

Pneumatic dredges are a subcategory of hydraulic dredges (USEPA, 1994a). Unlike conventional hydraulic dredges which use continuous suction pumps, pneumatic dredges use an alternating cycle of negative and positive air pressure in a submerged chamber to impel sediment toward the surface (Exhibit 8).

Pneumatic dredges are able to remove sediments at higher densities than hydraulic dredges and disturb the sediment very little. These features make pneumatic dredges well suited to contaminated sediment dredging. However, pneumatic

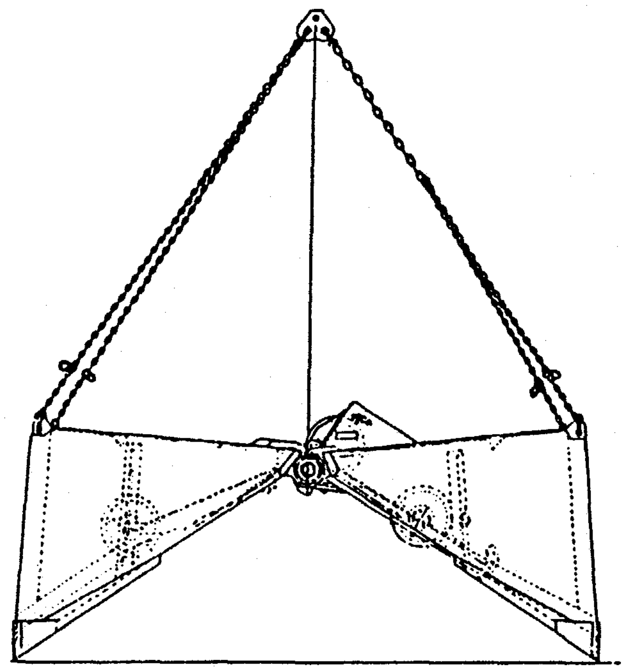
Exhibit 7
Modified Bucket Dredges

Enclosed Bucket



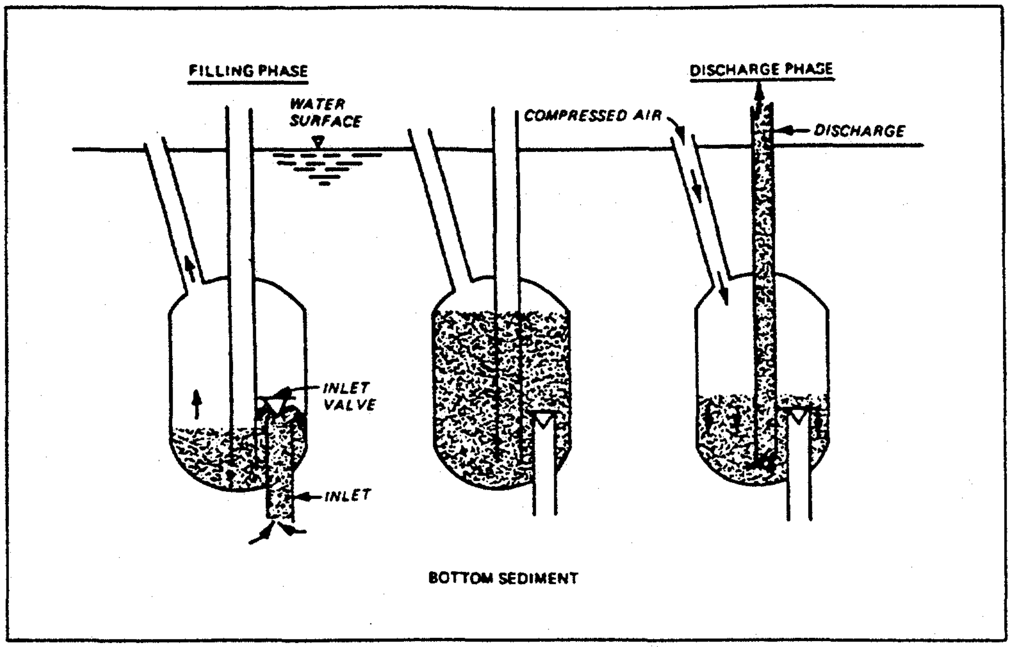
Source: Herbich and Brahme (1991).

Cable Arm Bucket



Source: Cable Arm, Inc.

Exhibit 8
Operation of a Pneumatic Pump



Source: Zappi and Hayes, 1991 after Herbich and Brahme, 1991

dredges are not widely available in the U.S. and their operational costs may be higher than those of conventional mechanical and hydraulic dredges (Zappi and Hayes, 1991).

3.3 Descriptions of Hydraulic and Pneumatic Dredges

This section provides brief descriptions of hydraulic and pneumatic dredges, including several that may be applicable to the Hudson River PCBs site:

Airlift Dredge

The Airlift dredge uses compressed air and a rotating cutterhead to dislodge sediment. Because the compressed air expands as it rises through the dredge pipe, it creates a current that carries water and sediment upward. The dredge is supported by a crane on a barge or on land. The Airlift dredge is able to handle a wide range of sediment types, but performance diminishes in water depths of less than 20 feet (Averett et al., 1990). An Airlift dredge evaluated by

Environment Canada removed 4,050 cubic yards of sediment at a rate of approximately 60 cubic yards per hour and a content of 30.7 percent solids (Orchard, 1996).

Amphibex Dredge

The Amphibex dredge is a combination hydraulic and mechanical dredge. It resembles a backhoe, but has a hydraulic intake for removing silts to fine sands. The bucket is used as needed to remove debris, such as large rocks, garbage, and tree limbs. The dredge is self-propelled and stationed by spuds and side stabilizing arms, providing great flexibility in positioning and maneuverability. At Scarborough Bluffs, Ontario, the Amphibex dredge was used to remove 47,250 cubic yards of sediment in waters as shallow as 19.5 inches. It was used to remove 13,500 cubic yards of sediment from the Welland River in October 1995. (Orchard, 1996)

Bucket Wheel Dredge

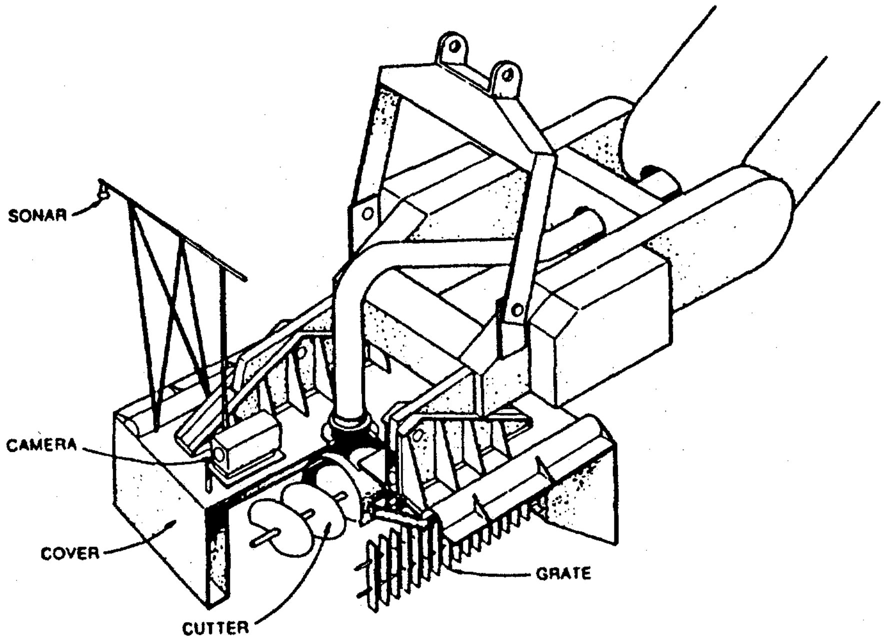
The bucket wheel dredge is a conventional hydraulic dredge developed to improve the efficiency of navigational dredging projects. A hybrid of a mechanical and hydraulic dredge, scoops on a rotating wheel collect and feed sediment to a hydraulic suction pipe. Advantages of this dredge include an ability to remove consolidated material and to control the production rate and solids content of the of the sediment slurry (by controlling the wheel rotation speed). The bucket wheel dredge resuspends more sediment than most hydraulic and pneumatic dredges because of the highly mechanical action of the cutter and the lack of turbidity barriers.

Clean-Up Dredge

The Clean-up dredge (Exhibit 9) was developed in Japan specifically for remediation of highly contaminated sediments. It uses a shielded auger to dislodge sediment as it swings back and forth. A cover and movable wing contain resuspended sediment and gas bubbles. Sonar and underwater television may be used to guide the dredge head (Averett et al., 1990). The Clean-up dredge is suitable for soft mud or sand at depths between 1.5 and 23 meters (Herbich, 1989). It has been used extensively overseas (2.2 million cubic meters removed by 1980), and has been used for PCB-contaminated sediments (Herbich, 1989). There is essentially no sediment resuspension from the Clean-up dredge. Herbich (1989) reports sediment resuspension of 1.1 to 7.0 mg/l at the suction head.[3]

[3] For comparison, background suspended sediment concentrations in the upper Hudson River generally are below 10 mg/l and may rise to 50 mg/l or more during large storms.

Exhibit 9
Clean-Up Dredge



Source: Zappi and Hayes, 1991

Cutterhead Dredge

Cutterhead dredges have been used for decades (Hayes et al., 1988). A rotating cutterhead at the end of the suction pipe loosens the sediment and a centrifugal pump draws the loosened sediment and water through a pipeline. The sediment slurry typically is less than 10 to 20 percent solids by weight. The cutterhead dredge is mounted on a barge and swung back and forth in an arc by two cables controlled by winches (Exhibit 10, bottom). The dredge is held in position by spuds in the rear of the barge. Although the cutterhead dredge was not developed for contaminated sediment dredging, there are now a number of operational and equipment modifications (e.g., shrouds covering the cutterhead that capture resuspended sediment) available for contaminated sediment cleanups.

Cutterhead dredges are the most common type of dredge because of their efficiency and ability to dredge all types of material including clay, silt, sand,

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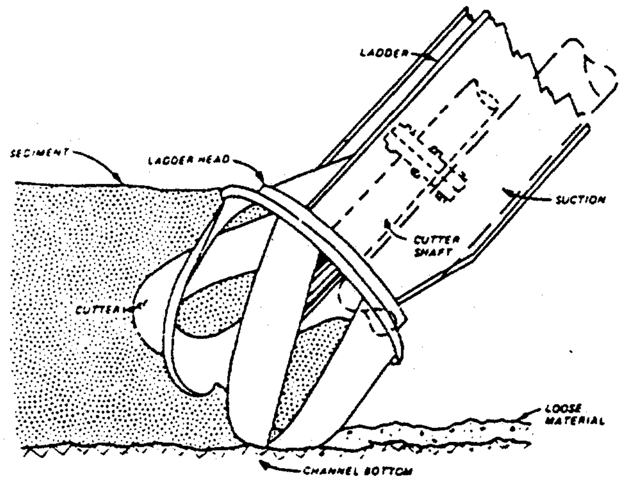
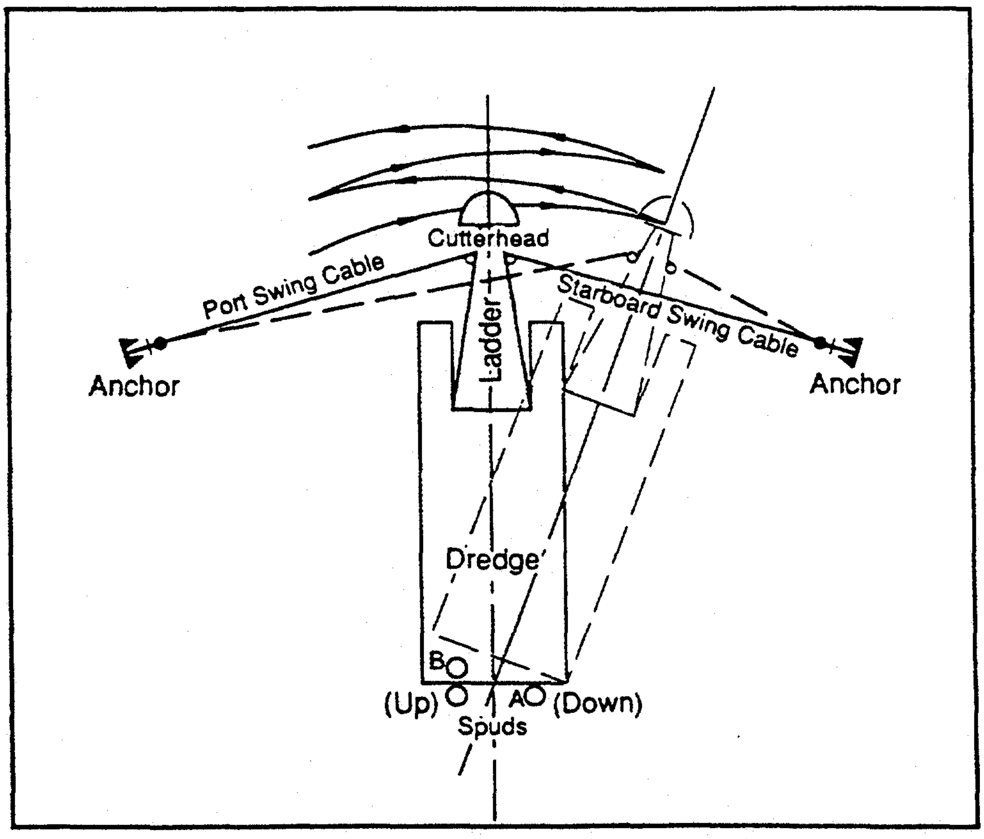
Exhibit 10
Cutterhead Dredge



Conventional (Open Basket) Dredgehead

Source: Zappi and Hayes (1991)



Sources: Zappi and Hayes, 1991; USEPA, 1990

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compacted deposits, gravel, and rock (Averett et al., 1990). However, their mobility is limited in waters with strong wave action or currents (Breerwood, 1994).

Sediment resuspension from the cutterhead dredge is strongly influenced by the design and the method of operation. For example, there must be enough hydraulic suction to collect the sediment dislodged by the cutterhead (Havis, 1988). Modifications to the configuration and operation contributed to the low rates of sediment resuspension from cutterhead dredging at the New Bedford Harbor Superfund site (Otis, 1994). McLellan et al. (1989) cited in Averett et al. (1990) found that suspended solids concentrations in cutterhead plumes during field tests ranged from 1.8 to 2.5 times background concentrations. Havis (1988) concluded that the cutterhead dredge is "a logical selection for controlling sediment resuspension while maintaining efficient production."

Delta Dredge

The Delta dredge is a small portable hydraulic dredge with two counter-rotating reversible cutterheads (Ewusi-Wilson et al., 1995). It is capable of shallow removals with minimal sediment disturbance or resuspension (Averett et al., 1990).

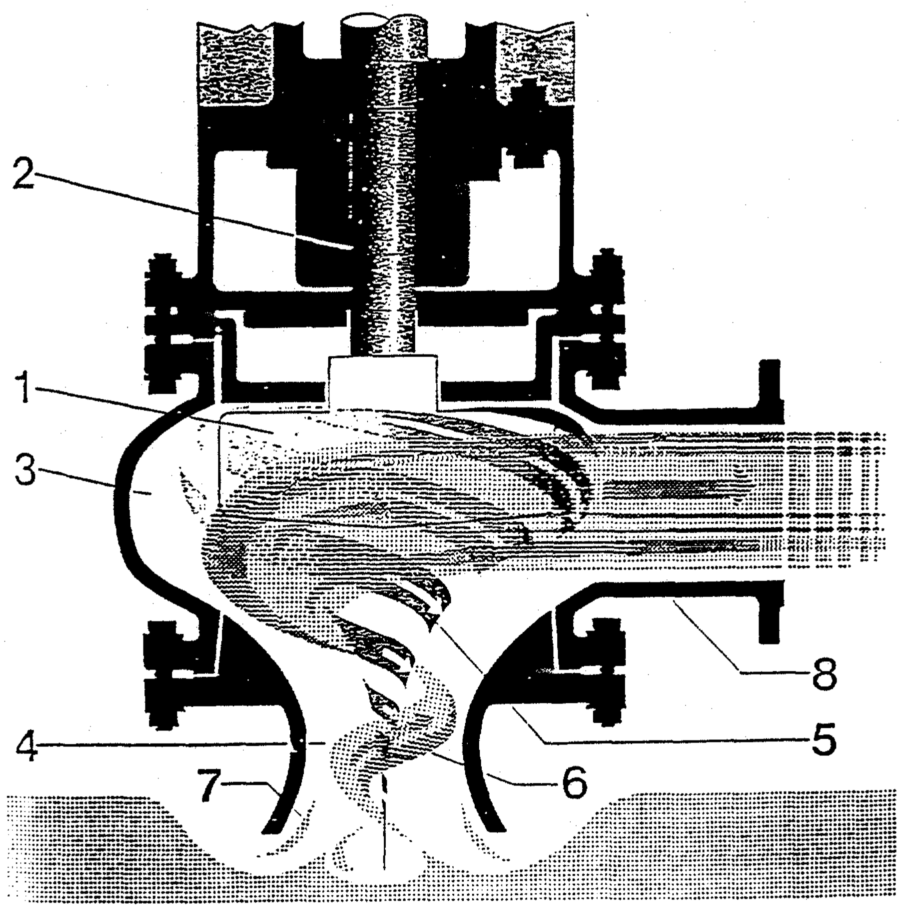
Dustpan Dredge

The Dustpan dredge has a wide dredge head with water jets to loosen sediment. It is designed for work in shallow water and for relatively high production rates (Averett et al., 1990). It is extremely efficient for removing sand, but is not effective for clay or hard-packed material (Breerwood, 1994). In addition, some features (e.g., water jets, trashbars, digging teeth) are not suitable for dredging contaminated sediments (Herbich, 1992). A modified Dustpan dredge, which was engineered to reduce sediment resuspension, was used to remove kepone-contaminated sediment from the James River, Virginia. Resuspension from the Dustpan dredge is similar to or slightly greater than resuspension from the cutterhead dredge (Averett et al., 1990).

Eddy Pump

The Eddy Pump is a unique hydraulic dredge, which uses a swirling hydraulic eddy current to withdraw contaminated sediments. The Eddy Pump is illustrated in Exhibit 11. Advantages of the Eddy Pump include low weight and energy requirements, high production rates, and high slurry densities (Averett et al., 1990). There is little or no sediment resuspension because there is no moving cutterhead and the intake nozzle is completely imbedded in the sediment. When the pump operates, the surface of the sediment collapses downward to the

Exhibit 11
The Eddy Pump



The Eddy Pump consists of an energy-generating rotor (1) attached to the end of a drive shaft (2) and placed within a volute (3). As the rotor begins to spin, it sets into motion the fluid present within the volute and the adjoining intake chamber (4). At normal operating speeds, this spinning fluid is forced down into the hollow center of the intake chamber, where it creates a high speed, swirling synchronized column of fluid (5), which agitates the material (6) to be pumped (e.g., sludge, sand, clay, or silt). This swirling column of fluid creates a peripheral "eddy" effect (7), which causes the agitated material to travel by reverse flow up along the sites of the intake chamber into the volute. Here the material, under pressure from below, is forced into the discharge pipe (8). (Courtesy of Xetex Corporation) imbedded nozzle; its action resembles a straw in a milkshake. At least one company operates Eddy Pump dredges in the U.S.

Hand-Held Hydraulic Dredges

Hand-held dredges are useful for areas too shallow for navigation or areas with small volumes of highly-contaminated sediment. The dredges can be operated from a boat, on shore, or by wading or diving operators. These dredges are readily available, maneuverable, and because there is no moving cutterhead, they have low sediment resuspension rates.
Production rates are limited to 250 yd^3/hour. Because they do not perform well in high water currents, they should be used with containment barriers of in calm waters (Ewusi-Wilson, et al., 1995).

Hand-held dredges have been used at at least two PCB-contaminated sediment sites: the South Branch of the Shiawassee River in Michigan and the Duwamish River Waterway in Seattle, Washington. (Averett et al., 1990).

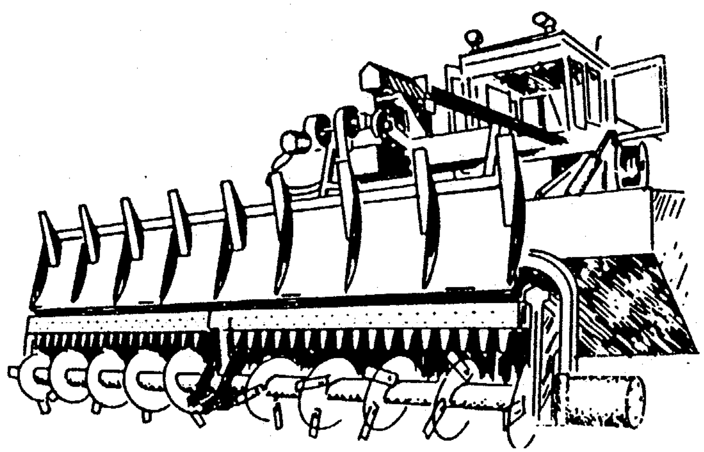
Hopper/Dragarm Dredge

The hopper dredge is a ship modified to collect, hold, transport, and dump sediments. Hopper dredges were developed for navigational dredging in deep harbors and rough-water shipping lanes (Ewusi-Wilson et al., 1995). Sediment is pumped into the hopper (i.e., the ship's hold) by a hydraulic dragarm dredge head mounted on the ship's side. When the hopper is full, the ship travels to a disposal site where it drops sediments from a door on the hull. In some applications, water is allowed to overflow from the hopper into the water surface (Havis, 1988). This practice is inappropriate for contaminated sediment dredging projects. Hopper dredges are very maneuverable, but precise control of the dredge head is difficult (Breerwood, 1994) and the dumping disposal method is inappropriate for heavily contaminated sediments.

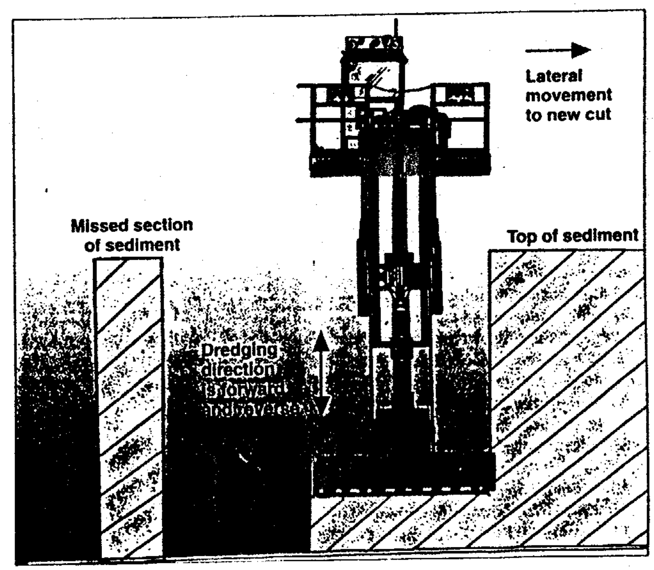
Horizontal Auger Dredge

The horizontal auger dredge includes a spiral auger and cutter knives to loosen sediment. The cutterhead can be contained within a retractable mud shield to control turbidity. The horizontal auger dredge can operate in depths from 2 to 15 feet. There are at least 500 in use. (Averett et al., 1990). Exhibit 12 shows two varieties of the horizontal auger dredge. The dredge on the lower right has a telescoping cutterhead.

Exhibit 12
Horizontal Auger dredge



Horizontal Auger Dredge



Sources: Seagren, 1994; USEPA, 1994a

Matchbox Dredge

The Matchbox dredge (Exhibit 13) was developed in The Netherlands specifically for the remediation of highly-contaminated sediments at depths to 85 feet (Herbich, 1989). It can remove fine-grained sediment at near *in situ* density with very little resuspension. The hydraulic intake is enclosed within a housing with valved openings on each end, resembling a matchbox. The shroud is designed to reduce water inflow and collect gas bubbles escaping from the sediment. A computer is used to maintain optimal dredging efficiency (Hayes et al., 1988). In the U.S., the Matchbox dredge has been tested at New Bedford Harbor, Massachusetts and Calumet Harbor, Illinois. Although the dredge generates little turbidity, it is said to be susceptible to clogging with debris (Averett et al., 1994).

Plain Suction Head Dredge

The plain suction head dredge is a hydraulic suction pipe with no auxiliary mechanical or hydraulic equipment for dislodging sediment. It can be maneuvered by cables and winches or by divers (i.e., diver-assisted

dredging). Since there is no mechanical cutterhead, the plain suction dredge is not effective on consolidated material. It is well suited, however, to removing unconsolidated material, including sand and gravel. The plain suction head dredge can remove 1,000 to 10,000 yd^3/hour of sediment at 10 to 15 percent solids by weight and with virtually no resuspension. A diver-assisted plain suction head dredge was used to remove 10,000 yd^3 of PCB-contaminated sediment, without resuspension, from the Manistique River and Harbor Superfund site, Michigan (USEPA, 1996c).

The portable hydraulic dredge is a smaller version of the plain suction head dredge. It is easily moved, and is effective in shallow water. Its production rates vary from 50 to 500 yd^3/hour with 10 to 40 percent solids by weight (Ewusi-Wilson et al., 1995).

Pneuma Pump

The Pneuma Pump is a pneumatic dredge developed in Italy and used extensively in Europe (Averett et al., 1990). The Pneuma Pump uses a cycle of controlled air pressure in a chamber to draw in sediment and then force it upward through a dredge pipe. It is capable of removing sediment at high density with little or no resuspension.

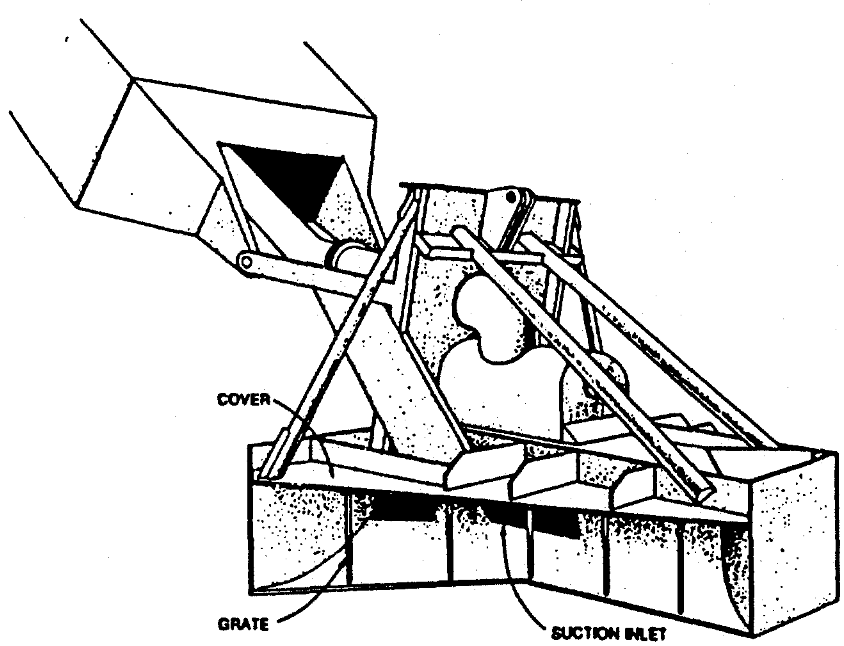
The Pneuma Pump performs best on loosely consolidated silt or clay at depths from 12 feet to more than 100 feet (Herbich, 1989). A cutterhead generally is not used with the Pneuma Pump, but can be added if needed. Advantages of the

Pneuma Pump are continuous and uniform flow, ability to remove sediments at up to 80 percent *in situ* density, and no disturbance of the sediment (Herbich, 1992). Production rates can be as high as 2,600 yd^3/hr (Averett et al., 1990).

Oozer Pump

The Oozer Pump (Exhibit 14) is similar to the Pneuma Pump, but uses two cylinders instead of three and adds a centrifugal vacuum for added efficiency. Five acoustic sensors measure the density of sediment layers and an underwater television camera aids the operator. Also, cutterheads can be added to loosen sediment, and a gas scrubber is available to collect toxic gasses. The Oozer Pump can operate at depths up to 18 meters (Herbich, 1989). Sediment can be removed at 30 to 80 percent *in situ* density at up to 800 yd^3/hour (Ewusi-Wilson et al., 1995). Ikalainen (1987) cited in Averett et al. (1990) reported that about 1 million cubic meters of contaminated sediments were remediated with Oozer Pumps between 1974 and 1984. In one study, total suspended solids were within the background concentration (6 mg/l) within 3 meters from the dredge head (Herbich, 1989).

Exhibit 13
Matchbox Dredge



Source: Zappi and Hayes, 1991

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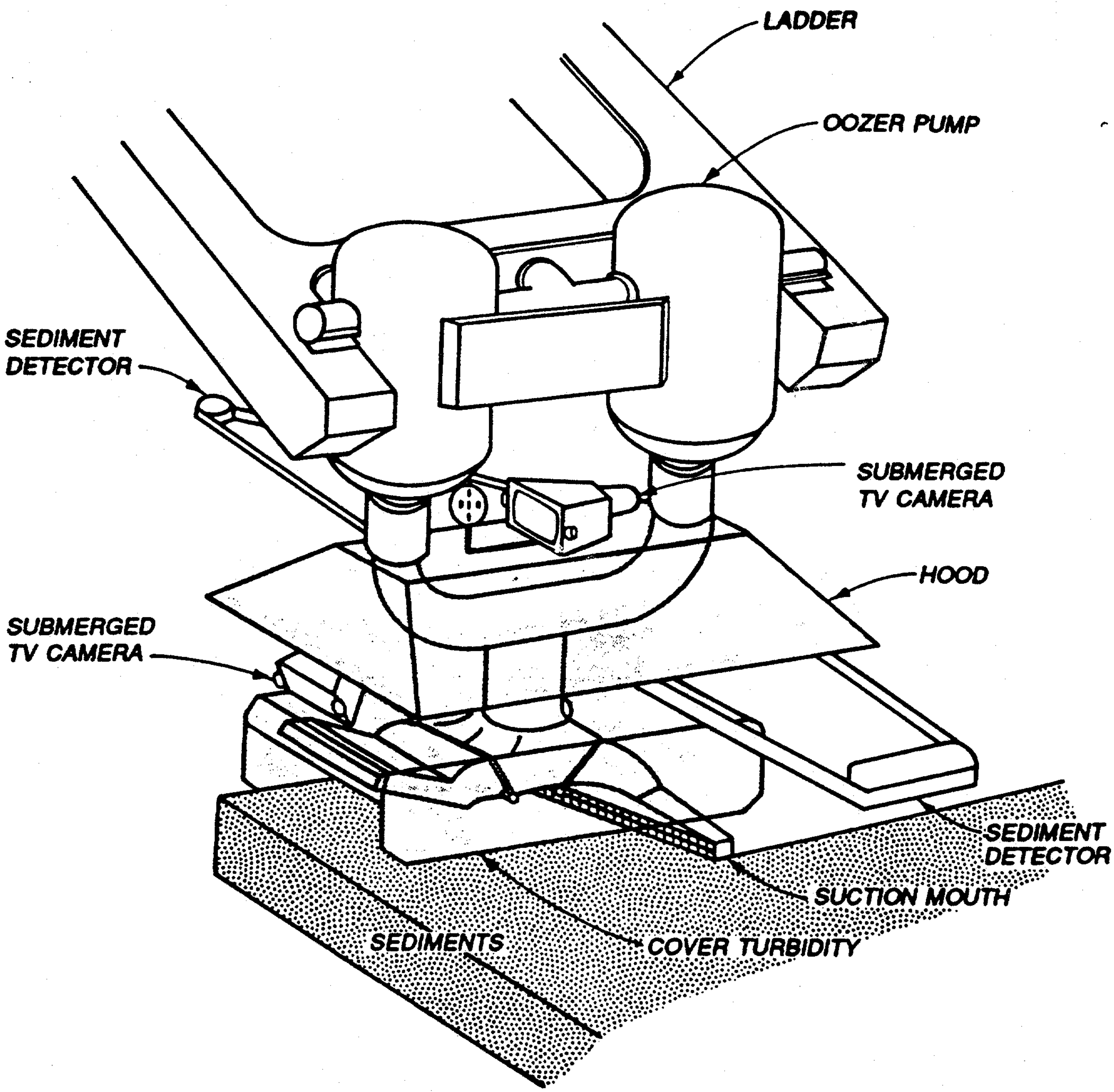
Exhibit 14
Oozer Dredge



Source: Zappi and Hayes, 1991

Refresher System

The Refresher System (Exhibit 15) is a modified cutterhead dredge that includes a helical cutting head, a gas collection system, and a flexible cover that is adjusted to the bottom contour with hydraulic controls. It is capable of operating in shallow or deep (up to 115 feet) water and produces less turbidity than a conventional cutterhead dredge (Averett et al., 1990; Herbich, 1989). In one study, total suspended solids concentrations ranged from 4 to 23 mg/l at a distance of 10 feet from the dredge head (Herbich, 1989).

Waterless Dredge

The Waterless dredge is able to remove sediment at relatively high density because it uses a submerged pump and a half-cylindrical shroud to cut water inflow. The shroud also contains resuspended sediment (Herbich, 1989). The Waterless dredge has been used successfully to remove lagoon sludge (at 30 to 50 percent solids by weight) and lead-contaminated sediment in the Mill River, Connecticut (Averett et al., 1990).

Wide Sweeper Cutterless Dredge

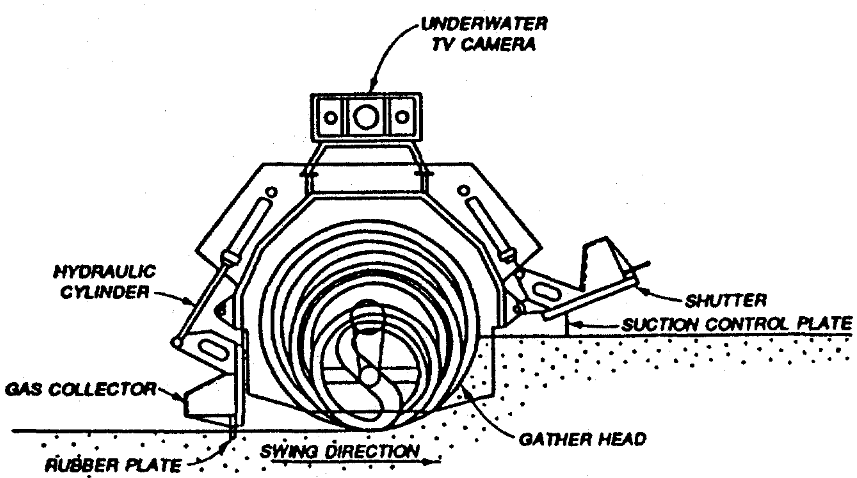
The Wide Sweeper cutterless dredge is designed to remove contaminated sediments without resuspension. It features a hydraulically articulated shroud, acoustic sensors to gauge sediment characteristics, two pumps (one submerged), and an underwater television camera to assist the operator (Herbich, 1989). Performance data are not available.

3.4 Physical Barriers

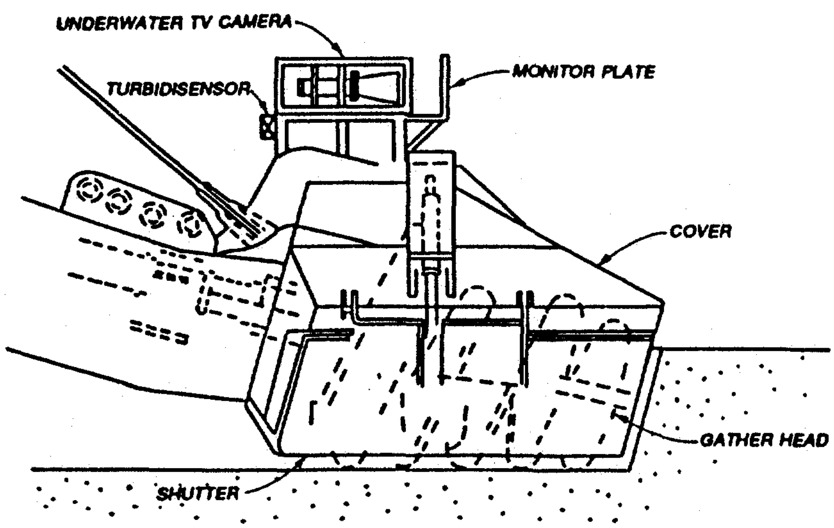
Various physical barriers can be used at dredging sites to mitigate sediment resuspension, contaminant loss, and/or turbidity impacts on nearby sensitive habitats. Exhibit 16 lists the available physical barriers. Silt curtains (which are impermeable) and silt screens (which allow some water to pass through) are suspended vertically in the water and are configured to trap resuspended sediments or limit current at the dredging site. Silt curtains may also minimize contaminant desorption from suspended sediments (van Oostrum and Vroege, 1994). Typical silt curtain configurations are shown in Exhibit 17.

Many factors contribute to the effectiveness or ineffectiveness of physical barriers, including water current, water depth, wind, tides, wakes, waves, and floating ice or debris (USEPA, 1994a). Silt curtains and screens work best in calm water with currents less than 50 cm/s (1.64 ft/s) and 21 feet in depth or less. Turbidity outside of a properly deployed silt curtain in calm water may be 80 to 90 percent less than the turbidity inside the curtain (Palermo et al., 1988). At New Bedford Harbor, Massachusetts, silt curtains

Exhibit 15
Refresher Dredge



a. FRONT VIEW



b. SIDE VIEW

Source: Zappi and Hayes, 1991

Exhibit 16
Physical Barriers for Sediment Control

- Caissons
- Dikes
- Oil booms
- Pneumatic barriers
- Sediment traps
- Sheet piling
- Silt curtains
- Silt screens

Source: Averett et al., 1990

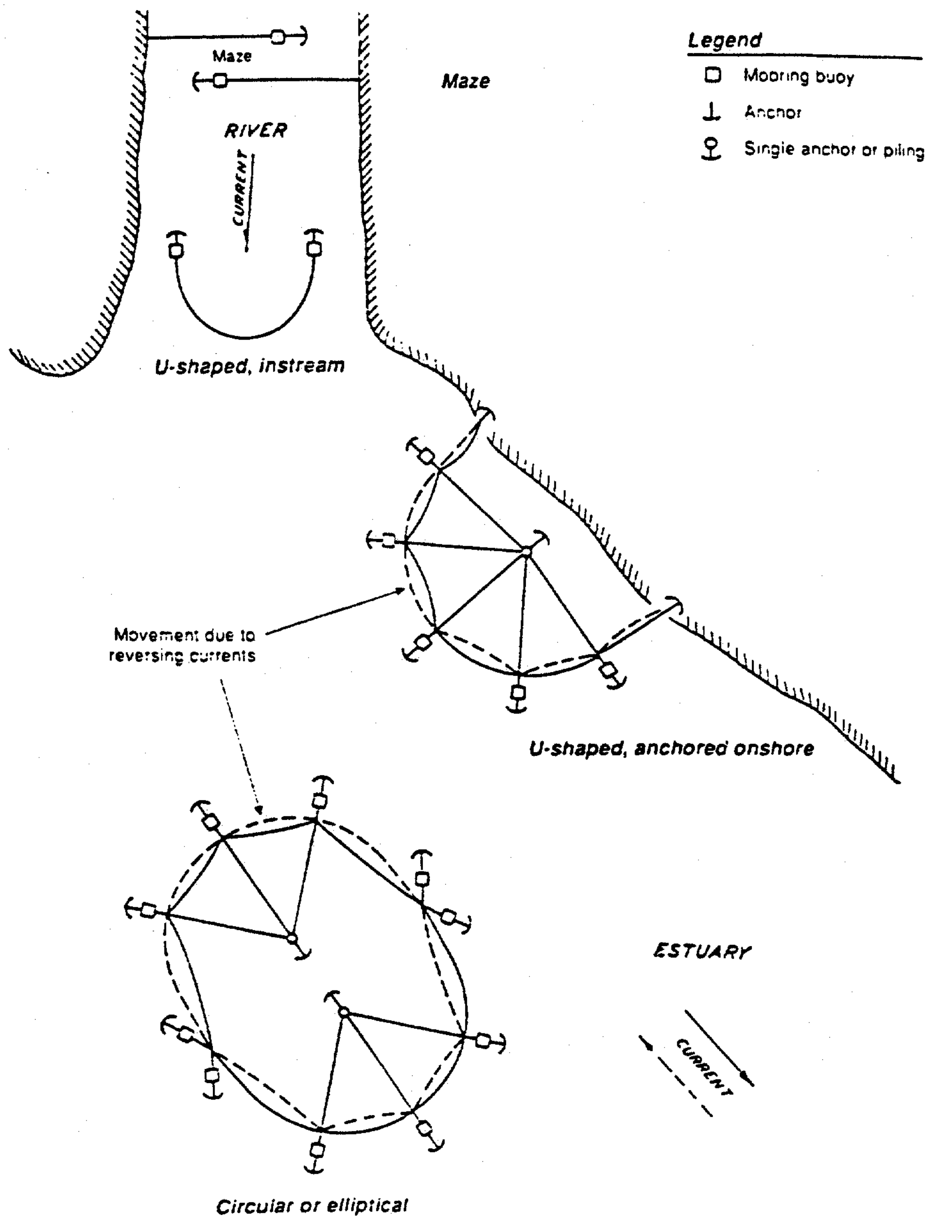
were not used after they were damaged in a storm (Dickerson, 1995). Silt curtains were not effective in Dokai Bay, Japan (Zappi and Hayes, 1991). However, they were effective at the Sheboygan River in Michigan, as well as Halifax Harbor and the Welland River in Canada (USEPA, 1994a).

In addition, a silt screen used to control surface turbidity (from a conventional bucket dredge) at a construction site in Sydney Harbor, Australia was effective in currents under 1 knot (1.69 feet per second) and withstood waves from passing ferries (Zappi and Hayes, 1991). Similarly, a silt curtain reduced by five times the suspended solids concentrations associated with a mechanical dredge used at Hollandsche IJssel, The Netherlands (Zappi and Hayes, 1991). Experimentation with new barrier designs for the Manistique River/Harbor Superfund site produced silt curtains and coffer dams that withstood seiche (i.e., a tide-like phenomenon on large lakes) currents of 4 feet per second (Hahnenberg, 1996).

Hard barriers (e.g., sheet pilings) serve the same functions as silt curtains, but they are more sturdy, and therefore more effective. Steel sheet pilings were used successfully at the GM Central Foundry Division Site on the St. Lawrence River (Hartnett, 1996). The disadvantage of hard barriers is that they are not as easily installed, moved, or removed as silt curtains or screens. In most cases, they also are much more expensive.

Oil booms and floating absorbent mats may be used to contain and recover oils or other hydrophobic contaminants including PCBs that are sometimes released from very highly-contaminated sediments (USEPA, 1994a).

Exhibit 17
Configurations For Silt Screens



Source: Barnard, 1978

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3.5 Operational Techniques to Control Resuspension

Techniques used to operate dredging equipment significantly affect sediment resuspension (e.g., Herbich, 1992; Pelletier et al., 1994). Field tests and full-scale cleanups (e.g., at New Bedford Harbor, Massachusetts and Manistique River/Harbor, Michigan) have contributed to a growing base of information on dredging methods to reduce contaminant loss. An effective means of minimizing sediment resuspension is to select a highly experienced dredge operator with first-hand knowledge of these techniques. In addition, sophisticated instrumentation (e.g., production sensors, sonar, underwater cameras) can provide dredge operators with important real-time data for optimal dredging efficiency.

Averett et al. (1990) described several operational methods to minimize sediment resuspension, including the following examples:

Dredging Speed -- Sediment may be resuspended by the mechanical action of a dredge as it impacts or moves through the sediment. Because the potential for resuspension generally rises with the speed or energy of the dredge's motion, resuspension can be minimized by advancing the dredge slowly. However, other variables such as dredge design and sediment type also influence the optimal rate of dredging.

In addition, sediment resuspension is mitigated by careful operation of moving parts (e.g., augers, cutterheads) that loosen sediment. A skilled dredge operator will match rate at which these moving parts dislodge sediments to the capacity of the hydraulic intake (Averett et al., 1990).

Depth of Cut -- Sediment resuspension is minimized with moderate depth cuts (Averett et al., 1990). If the cut is too deep, the sediment can overwhelm the capacity of the dredge head. If the cut is too shallow, dredges with moving cutterheads may dislodge the sediments with too much energy, like an electric mixer half-way out of the batter. Most dredges are accurate to a depth of about 1 foot. With favorable site conditions and with care, accuracies of 0.5 feet or better may be possible (Palermo, 1996).

Positioning -- Precise positioning and advancement of the dredge (e.g., to avoid dredging outside the area of contamination) increases the efficiency of dredging projects. Perhaps the best way to ensure careful positioning is to select an experienced dredge operator. As described in Section 4, dredge operators at the Pickering Nuclear Generating Station and Hamilton Harbour in Ontario, Canada, improved their performance as they gained experience with the equipment.

The dredge operator's positioning of the dredge can be aided by sensors and other equipment. For example, colored range poles were used to guide the dredge at the New Bedford Harbor site in Massachusetts (Averett et al., 1990), and an underwater camera and depth transducer aided dredge positioning at the Pickering Nuclear Generating Station (Orchard, 1996). Emerging electronic technologies (e.g., the global positioning system) make possible precise and perhaps automated positioning.

New York State health advisories for Hudson River anglers generally recommend no more than one meal per week or per month depending on species and location. An "Eat None" advisory applies to women of childbearing age and children under 15 for all fish from the Hudson River.

4. SITE CLEANUP DESCRIPTIONS

This section describes actual contaminated sediment dredging projects. It is by no means a complete list of projects: hundreds of sites have been dredged worldwide. The sites described in this section were selected based on the availability of dredge performance data and for a diversity of site characteristics. Information on sediment types and contaminants, water depth, resuspension, sediment production rates, and difficulties encountered are documented when available. Sediment resuspension is generally reported in total suspended solids (TSS) concentrations in the water column near the dredge. For reference, the background TSS concentration in the upper Hudson River is typically below 10 mg/l, but increases exponentially during high flow periods as a result of sediment runoff and resuspension. Peak TSS concentrations during annual high flows in the upper Hudson above Snook Kill and Moses Kill are about 50 mg/l. Below these tributaries, peak TSS concentrations during annual high flows are about 100 mg/l (Bopp, 1996). The site descriptions are in alphabetical order by site name.

Aji River, Osaka, Japan
- Pneuma Pump
  -- little or no resuspension
- Watertight Bucket Dredge
  -- resuspension near dredge and riverbed

Source: Zappi and Hayes, 1991

In 1979, the City of Osaka tested a Pneuma Pump and a watertight bucket dredge. Sediment at the dredging site was soft clay at a depth of about 30 to 40 feet. For both dredges, TSS was measured at various depths at 50, 100, and 150 meters distant from the dredge. Background suspended sediment concentrations were not provided.

Pneuma Pump. At a distance of 50 meters, suspended solids concentrations ranged from 6 to 14 mg/l (at all depths). At 150 meters, concentrations ranged from 4 to 14 mg/l. Similar results were reported for the Pneuma Pump used at Chofu Port and Kokura Port.

Watertight Bucket. Suspended solids concentration were apparently most affected closest to the dredge and closest to the riverbed. At a distance of 50 meters, suspended solids concentrations ranged from 13 to 80 mg/l (all depths included). At 150 meters, concentrations ranged from 12 to 25 mg/l.

Calumet Harbor, Illinois
- Cutterhead Dredge
  - -- low resuspension
  - -- resuspension all near bottom
- Matchbox Dredge
  - -- slightly higher resuspension
  - -- clogging
  - -- additional instrumentation needed

Source: Hayes et al., 1988

In 1985, the USACE field tested a conventional 12-inch cutterhead dredge and a Matchbox dredge at Calumet Harbor, Illinois. The water was 26 feet deep at the dredging site, and background suspended solids concentrations ranged from 2 to 5 mg/l with an average of 4 mg/l. The sediment type was silty loam.

Cutterhead Dredge: TSS measured near the cutterhead ranged from 7 to 17 mg/l above background. Sediment resuspension was largely confined to within half a meter above the riverbed, where the maximum plume area was 1.2 acres.

Matchbox Dredge: TSS measured near the Matchbox dredge during operation ranged from 12 to 27 mg/l above background. There was no suspended solids plume at 5 and 50 percent of the depth. At 80 percent of the depth (about 5 feet above the riverbed) the sediment plume (TSS > 10 mg/l) covered 0.4 acres. At 95 percent of the depth (within 1.6 feet above the riverbed), the maximum extent of the plume was 2.9 acres (Hayes et al., 1988). Clogging of the intake and an inexperienced operator may have interfered with the performance of the Matchbox dredge.

The USACE investigators (Hayes et al., 1988) concluded from the Calumet Harbor field test that resuspension from both dredges was quite low, and that one dredge could not be recommended over the other. They recommended additional instrumentation and controls to enhance the performance of the matchbox dredge in future trials.

Cape Fear River, North Carolina
- Pneuma Pump
  - -- no sediment plume
  - -- crane suspension not ideal

Source: Zappi and Hayes, 1991

In 1978, a Pneuma Pump was used to remove contaminated silty clay from the Cape Fear River. Water depths at the site ranged from about 26 to 30 feet, and the background suspended sediment concentration measured at the surface was 5.4 mg/l. The Pneuma Pump generated "no apparent suspended material buildup" with only "limited and intermittent" resuspension (Zappi and Hayes, 1991). It was found that operation of the dredge head suspended from a crane was not ideal for pump performance or excavation rates.

Chiba Port, Japan
- Hopper/Draghead Dredge
  - -- low resuspension with occasional spikes

Source: Zappi and Hayes, 1991

In 1979, a front-open draghead fitted on a hopper dredge was used to remove clayey silt at a depth of about 42 feet in Chiba Port. Suspended solids concentrations at the draghead were generally less than 10 mg/l. However, significant resuspension occurred when lifting the draghead from the sediment or when the dredge was moving at a high velocity. Similar dredges tested at Nagoya Port, Mikawa Port, and Kinuura Port yielded similar or less effective results. The front-open draghead can cause spikes of high resuspension, but the resuspension is limited to the immediate area of the draghead.

Collingwood Harbour, Ontario, Canada
- Pneuma Pump
  - -- production 183 yd^3/hr
  - -- TSS and TOC within guidelines

Source: Faldi and Gahring. 1994; Orchard, 1996

In November and December 1992, Environment Canada used a Pneuma Pump to remove sediments from two slip areas contaminated with zinc, lead, and debris from ship building. The slips were 13.5 to 20.7 feet deep, and the sediments were 26 percent sand, 64 percent silt and 10 percent clay. The Pneuma Pump produced 183 cubic yards of sediment per hour, which were transported 0.75 mile through a 6 inch pipeline to an impoundment. Resuspension rates are unavailable, but Faldi and Gahring (1994) report that turbidity and total organic carbon (TOC) measurements were well within Environment Canada's operational standards. The Pneuma Pump was able to operate among an assortment of different sized debris (Orchard, 1996). The Pneuma Pump was selected for further dredging in Collingwood Harbour in December 1993.

Cresta Reservoir, California
- Eddy Pump
  - -- essentially no resuspension
  - -- high slurry density

Source: Creek and Sagraves, 1995

In 1994, an Eddy Pump was used to dredge about 10,500 cubic yards of uncontaminated sediment from the Cresta Reservoir, an impoundment of the North Feather River near Sacramento, California. The Eddy Pump produced a high density slurry, typically 70 percent, but up to 90 percent, solids by weight. The sediment type was medium-grained sand with less than 10 percent silt and clay. The peak production rate during the project was about 310 cubic yards per hour.

TSS concentrations were monitored approximately 40 feet downstream from the dredge, near the dredge nozzle, and at an upstream background monitoring station. At the downstream station, TSS concentrations ranged from 1 to 9 mg/l, compared with

Hamilton Harbor, Ontario, Canada
- Modified Cable Arm Bucket Dredge
  - -- low resuspension
  - -- overfilling and operator experience affect performance

Source: Pelletier et al., 1994; Orchard, 1996

In 1992, Environment Canada conducted a pilot test of a modified cable arm bucket dredge at Hamilton Harbor, Ontario, Canada. Approximately 200 cubic yards of predominantly clay sediment contaminated with heavy metals and polycyclic aromatic hydrocarbons (PAHs) were dredged. The dredging area was a boat slip partially confined with silt curtains.

Among the design modifications to the dredge were vents to decant water overlying the sediment, rubber seals to reduce impact on the sediment and leakage during lifting, and an epoxy coating to reduce contaminant adhesion. In addition, the pear shaped bucket produced a level cut (instead of the "pot hole" cut of conventional bucket dredges) and minimal turbulence as the bucket is lifted through the water column.

Total suspended solids concentrations during dredging were generally less than 25 mg/l above background concentrations. Pulses of higher turbidity were caused by occasional overfilling of the bucket and disturbance from an unrelated tug boat near the dredging area. Resuspension occurred less frequently as the dredge operator gained experience. Pelletier et al. (1994) also describe demonstrations of the modified cable arm bucket, with similar results, at Toronto Harbor and the Pickering Nuclear Generating Station (see below).

Grays Harbor, Washington
- Hopper/Dragarm Dredge
  - -- little resuspension from dredge head
  - -- hopper overflow unacceptable for contaminated sediment

Sources: Havis, 1988; Zappi and Hayes, 1991

In 1983 and 1984, fine-grained sediments were dredged from Grays Harbor using a hopper/dragarm dredge and a variety of dredge heads (Zappi and Hayes, 1991). Overflow from the hopper produced a sediment plume (700 mg/l suspended solids) that would be unsuitable for contaminated sediment dredging. However, there was very little resuspension when there was no hopper overflow. Suspended sediment concentrations were negligible near the water surface and 40 to 50 mg/l near the bottom (Havis, 1988). Background concentrations are not available.

Hori River, Japan
- Watertight Bucket Dredge
  -- resuspension highest near riverbed

Source: Zappi and Hayes, 1991

A watertight bucket dredge was used at the Hori River, Japan in 1973. Background suspended sediment concentrations at the site ranged from 5 to 12 mg/l. Resuspension 23 feet downstream from the bucket during dredging ranged from 20 mg/l at a depth of 8 feet, to 105 mg/l at a depth of 1.6 feet.

James River, Virginia
- Modified Dustpan Dredge
  -- small plumes
  -- clogging

Source: Zappi and Hayes, 1991

The USACE tested a modified Dustpan dredge at the James River in 1982. The kepone-contaminated sediment was silty-clay at a depth of about 23 feet. Background suspended solids concentrations at the site ranged from 53 to 90 mg/l, and the daily average suspended solids concentrations during dredging ranged from 35 to 101 mg/l. The maximum resuspension rates observed were about 300 mg/l. The dredge created small plumes and clogged repeatedly.

Locations Unreported
- Clean-up Dredge
  -- resuspension indistinguishable from background

Sources: Zappi and Hayes, 1991; Sago, 1984; Sago 1976

Sago (1984) cited by Zappi and Hayes (1991) reported that Clean-up dredges had been used at 45 locations by 1981. Results for one field test are reported by Sago (1976) are presented in Zappi and Hayes (1991). Sediment at the dredging site was silty clay, and background suspended sediment concentrations ranged from 5 to 9 mg/l. During six days of dredging, suspended sediment concentrations within 10 feet of the dredge head ranged from 1.1 to 7.0 mg/l, indistinguishable from background concentrations. Resuspension from the Clean-up dredge occurs only during starting and stopping of the pump and changes in swing direction.

Manistique River/Harbor, Michigan • Plain Suction Head Dredge -- diver-assisted dredging -- no resuspension above background • Horizontal Auger Dredge -- telescoping cutterhead -- virtually no resuspension -- cutter handled woody debris Sources: Hahnenberg, 1996; USEPA, 1996c; USEPA, 1996d; USEPA, 1996e

PCB-contaminated sediment were removed from the Manistique River/Harbor site in Michigan during the summers of 1995 and 1996, and further dredging is planned for the summer of 1997. To date, the cleanup has occurred in the North Bay portion of the site. A plain suction head dredge was used to remove unconsolidated sediment from a finger of the North Bay area isolated by a cofferdam and silt curtain. A horizontal auger dredge was used to remove woodchips and heavy sediment from areas of the North Bay upstream and downstream of the barriers, including areas near the Route 2 Bridge in the river channel. Future dredging will take place in two areas of the river channel and the harbor.

Plain Suction Head Dredge: In the first season of dredging (i.e., 1995), a diver-assisted plain suction head dredge was used to remove 10,000 cubic yards of PCB-contaminated sediment from the North Bay portion of the site. A cofferdam and silt barriers with floating booms were used to mitigate sediment resuspension during debris removal and dredging. Average currents at the site were approximately 1 foot per second. However, the current and water level in the dredging area were affected by seiches, tide-like waves that occur on large lakes. During one seiche, the barriers withstood maximum current of approximately 4 feet per second.

The sediment was unconsolidated material with maximum PCB concentrations of 810 ppm. Visual observations, surface water analysis and other measurements showed that there was no sediment resuspension (Hahnenberg, 1996). Diver-assisted dredging continued in the 1996 season for an additional 6,500 cubic yards of sediment.

Horizontal Auger Dredge: Beginning in 1996, a floating horizontal auger dredge with a telescoping cutterhead was used for further dredging in the North Bay area. Two-thousand cubic yards of heavy sediment and woodchips were removed from portions of the North Bay upstream from the cofferdam and areas downstream from the sediment barriers. The horizontal auger dredge was selected because it is capable of removing the consolidated sediments present in this area. PCB concentrations in this area were as high as 2,510 ppm.

Turbidity was monitored several times per day during dredging. The turbidity action level was never exceeded. The horizontal auger dredge reportedly "chewed through" decaying woody debris in the sediment without difficulty or excess turbidity (Hahnenberg, 1996).

In addition to dredging hot spots in the North Bay, the Manistique cleanup decision called for capping a large area of contamination in the River/Harbor. However, in 1996 the USEPA proposed dredging these sediments instead, based on performance of the dredges and lower than expected disposal costs for the dredged sediments. Disposal savings were made possible by sediment separation methods, which sorted the highly contaminated materials into 3 percent of the volume. The USEPA concluded that dredging cost about the same as capping and provided greater environmental protection. Dredging in the River/Harbor is expected to begin in 1997.

New Bedford Harbor, Massachusetts

- Cutterhead Dredge
  - -- least resuspension
  - -- selected for full-scale cleanup
- Matchbox Dredge
  - -- background TSS within 150 meters
  - -- clogged by debris
- Horizontal Auger Dredge
  - -- less effective than others at this site
  - -- problems with anchoring, positioning, and mudshield

Sources: Dickerson, 1995; Zappi and Hayes, 1991; Averett et al., 1990; USACE, 1990

The USEPA in Cooperation with the USACE dredged contaminated sediment hot spots from the New Bedford Harbor in 1994 and 1995. The site included organic silts and clays contaminated with PCBs at concentrations up to 100,000 ppm and heavy metals. The depth to the sediment at this tidal estuary ranged from 1 to 6 feet. The average current was just over 1 foot per second.

Hot spot remediation was preceded by a pilot project in 1988 and 1989 in which the USEPA and the USACE compared the performance of three dredges: a horizontal auger dredge, a Matchbox dredge, and a cutterhead dredge. The USACE concluded from the pilot test that all three dredges were able to effectively remove the contaminated sediment without creating sediment plumes (USACE, 1990). The cutterhead dredge was recommended for full-scale hot spot dredging based on low sediment resuspension rates and several other operational advantages. Specific observations for each dredge included the following:

Horizontal Auger Dredge: The daily average suspended solids concentrations 200 feet downstream from the horizontal auger dredge ranged from 12 to 20 mg/l. The dredge generated high suspended solids (daily averages from 985 to 2,226 mg/l) at the dredge head. It was substantially less effective than the cutterhead and Matchbox dredges also tested at this site. Effectiveness was limited by problems with positioning, anchoring, and the mudshield. Positioning difficulties were attributed to the shallow water and high winds in this windy and tidal coastal harbor (USACE, 1990; Zappi and Hayes, 1991).

Matchbox Dredge: During dredging, the daily average (for two days) suspended solids concentrations 200 feet from the dredge ranged from 8 to 30 mg/l. Concentrations were considerably higher at the dredge head, ranging from 73 to 609 mg/l over 7 daily averages. Concentrations were generally at background levels within about 500 feet of the dredge. Clogging with debris limited the performance of the dredge (USACE, 1990; Zappi and Hayes, 1991).

Cutterhead Dredge: During the pilot test, the cutterhead dredge resuspended less sediment than the other dredges. The average suspended solids concentration 1 to 3 feet from the dredge head averaged 80 mg/l (Averett et al., 1990). Background concentrations were generally less than 10 mg/l (USACE, 1990).

Full-scale hot spot dredging of 10,000 cubic yards of contaminated sediment began in April 1994, using the cutterhead dredge. High PCB concentrations in the sediment produced a film of PCB oil on the water surface during the first three days of dredging (Otis, 1994). Although the PCB oil was contained by oil booms and silt curtains that were installed before dredging, it was necessary to modify the dredging equipment and procedures to prevent oil releases. For example, a shroud was added to the cutterhead to capture oils released from the sediment, and the swing speed of the cutterhead was reduced. These and other modifications were successful and dredging continued. By the time the hot spot dredging was 50 percent complete, total contaminant loss was 10 percent of the project goal (Dickerson, 1995). Hot spot dredging was completed on September 6, 1995.

In October 1996, the USEPA announced plans for a Phase II dredging project in upper and lower New Bedford Harbor to remove non-hot spot contaminated sediment. The project involves removal of 450,000 cubic yards of PCB-contaminated sediment spread over 170 acres. In the upper harbor, sediments contaminated above 10 ppm will be removed, while in the lower harbor and in saltmarshes, sediment contaminated above 50 ppm will be removed. The project will use a cutterhead dredge, possibly supplemented with a clamshell bucket dredge in deep water and salt marsh areas (USEPA, 1996a)

Osaka Bay, Japan
- Oozer Dredge
  - -- essentially no resuspension

Source: Zappi and Hayes, 1991

Fine-grained sediments with organic contaminants were dredged from Osaka Bay with an Oozer dredge. The water depth at the dredging site was about 50 feet, and background suspended solids concentrations ranged from 9 to 10 mg/l. During dredging, there was essentially no significant resuspension above background. At a distance of 50 feet from the dredge, suspended sediment concentrations ranged from 9 to 12 mg/l. At 328 feet from the dredge, concentrations ranged from 7 to 14 mg/l. The primary determinant of resuspension was the swing speed of the dredge.

Pickering Nuclear Generating Station, Ontario, Canada
- Cable Arm Bucket Dredge
  - -- Water velocity 4.9 feet/second
  - -- Precise excavation
  - -- Less than 10 mg/l excess TSS

Source: Orchard, 1996; Pelletier et al., 1994

In May 1993, a cable arm environmental bucket dredge was used to remove 200 cubic yards of sediment and organic debris (e.g., tree branches, dead fish) from the cooling water intake channel of the Pickering Nuclear Generating Station. The bucket had a maximum capacity of 4.3 cubic yards, and was equipped with an underwater camera, a depth transducer, a bucket closure confirmation system, and air-operated dewatering vents. Water current at the dredging site was 4.9 feet per second.

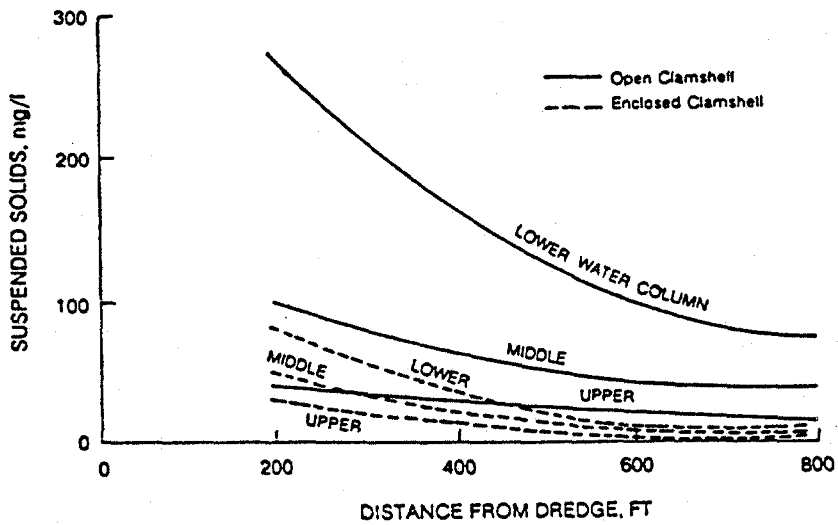
Since the reactor could not be shut down during dredging, it was necessary to maintain low levels of turbidity in the influent through out the project. A project limit was set at 22 mg/l TSS, corresponding to 10 mg/l above ambient turbidity. The operator's inexperience with the cable arm bucket dredge and the depth transducer caused exceedences at the start of the project. However, as the project proceeded, the operator met the turbidity limits while removing the sediment at a rate of approximately 31 cubic yards per hour.

St. Johns River, Florida
- Watertight Bucket Dredge
  - -- resuspended sediment plume
  - -- out-performs conventional bucket dredge

Sources: Zappi and Hayes, 1991; Hayes, 1986

A watertight bucket dredge was tested in the St. Johns River in 1982. Suspended sediment concentrations double the background level encompassed an area of 9.25 acres at 50 percent water depth, 0.47 acres at 75 percent water depth, and 24.8 acres at the sediment surface. (Zappi and Hayes, 1991) The performance of the watertight bucket dredge was compared to that of a conventional bucket dredge. Results are presented in Exhibit 18. The watertight bucket significantly reduces sediment resuspension.

Exhibit 18
Performance of Watertight Bucket Dredge Versus Conventional Bucket Dredge



Source: Hayes, 1986

> **St. Lawrence River, New York**
> - Horizontal Hydraulic Dredge
>   - -- site isolated with sheet piling
>   - -- unable to remove all contamination
>   - -- followed by partial capping
> - Backhoe
>   - -- used to remove large debris
>
> Source: Hartnett, 1996

A horizontal hydraulic dredge and a barge-mounted backhoe were used to remove PCB-contaminated sediments and debris from a cove on the St. Lawrence River adjacent to the GM Central Foundry Division Superfund site. The hydraulic dredge was similar to a horizontal auger dredge, but utilized a batter bar instead of an auger to dislodge sediment. The backhoe, which was used to remove large debris, had holes in the bucket for drainage. Both dredges were used throughout the cleanup project. Near the end of the project, the hydraulic dredge was operated as a plain suction dredge without the batter bar.

Sediment at the site included sand clay and silt, generally 1.5 feet deep and underlain by uneven bedrock. PCB concentrations in the sediment before dredging were as high as 8,800 ppm with an average of about 200 ppm. A total of 13,000 cubic yards of sediment were removed.

The 10 acre contaminated area was isolated from the St. Lawrence River with steel sheet piling. Preventing sediment resuspension within the cove was not a primary objective of the project because of the sheet piling. However, PCB concentrations were monitored outside the sheet piling to confirm its effectiveness. Typically, the PCB concentrations were 300 parts per trillion, with an overall maximum of about 0.5 ppm. The project action level of 2 ppm was never exceeded.

The project goal of 1 ppm PCB left in the sediment after dredging was not met in much of the contaminated area. Uneven bedrock substrate and resuspension within the sheet piling contributed to the difficulty reaching the contaminant reduction goal. Peak concentrations after dredging were less than 100 ppm. A multi-layer cap consisting of sand, activated carbon, and gravel was placed over 1.7 acres of the 10 acre project area.

T-Bay and M-Bay, Japan
- Refresher System
  - -- very little resuspension
  - -- performance related to dredging speed

Sources: Zappi and Hayes, 1991 citing Kaneko, Watari, and Aritomi, 1984

A Refresher dredge was used to remove contaminated silt from T-Bay in 1976-1977 and contaminated silt, clay, and colloidal material from M-Bay in 1980-1981.

At T-Bay water depth ranged from 7 to 9 feet and background suspended solids concentrations ranged from 1 to 6 mg/l. During dredging, suspended solids ranged from approximately 3 to 5 mg/l at depths of 1.6 to 6.6 feet. At 16 feet in depth, suspended solids concentrations were 5 to 6 mg/l. With a dredge head swing speed of 16 feet per minute, the plume area was 16.7 square yards. The plume was 21 square yards with a swing speed of 32 feet per minute.

Water depth at M-Bay ranged from 46 to 49 feet, and the background suspended solids concentration ranged from 6 to 9 mg/l. During dredging, suspended sediment concentrations were below background at 3 and 23 feet depth and 3 feet from the bottom. With a dredge head swing speed of 13 feet per minute, the suspended solids concentration was 4.2 mg/l. At both sites, resuspension increased four to five times with a doubling of the dredge head swing speed.

Waukegan Harbor, Illinois
- Cutterhead Dredges
  - -- two cutterhead sizes used
  - -- silt curtains successful in harbor
  - -- turbidity always less than half of goal

Sources: USEPA, 1989; Schmitt, 1996

In 1991 and 1992, cutterhead dredges were used to remove approximately 38,300 yd^3 of sediment from the Waukegan Harbor Superfund site. The contaminants included PCBs (up to 17,000 ppm), other organics, and a variety of metals. Sediments included clay and sand. The average depth of Waukegan Harbor is 20 feet.

Two areas of the site were dredged. The first area, Slip 3, was isolated from the Harbor with a cutoff wall before 6,300 cubic yards of highly-contaminated sediments were removed with an 8 inch cutterhead dredge. In a second area of the upper Harbor, a 10 inch cutterhead dredge was used to remove an additional 32,000 cubic yards of sediment in January and February 1992. Before dredging, silt curtains were installed and the area was raked to remove large debris.

Turbidity was measured daily during dredging in the upper Harbor. Samples were collected inside the silt curtain, just outside the silt curtain, and 500 feet outside the silt curtain. Background turbidity was not reported, but the action level for the project was 50 NTU. Inside the silt curtain, and at a depth of 20 feet, the average daily turbidity ranged from 3.21 to 23.5 NTU, with an average 12.3 NTU. Outside the silt curtain, turbidity ranged from 2.07 to 16.34 NTU, with an average of 8.5 NTU. At a distance of 500 feet, turbidity ranged from 2.61 to 12.75 NTU, with an average of 8.24. At all times and locations, turbidity remained well below the project action level.

Welland River, Ontario, Canada
- Horizontal Auger Dredge
  - -- no sustained sediment plumes
  - -- frequent debris blockage

Source: Miles and Marr, 1994; Orchard, 1996

In 1991, sediments contaminated with several metals, phosphorus, oil, and grease were removed from the Welland River using a modified horizontal auger dredge. Modifications included a removable vibrating shroud enclosing the auger, front screens, and real-time backscatter turbidity sensors. In the dredging area, the width of the Welland River is about 130 to 200 feet, with a maximum depth of about 13 feet. Average flows range from 501 to 869 cubic feet per second. The flow is reversed daily by downstream structures.

During dredging, there were no sustained plumes of resuspended material. With the shroud in place, average turbidity at the dredge head was 18.5 FTU. Without the should the average turbidity was 17.6 FTU. Operation without screens produced the lowest turbidity (average 5.4 FTU), but there was frequent blockage by debris. The background turbidity at the site was 5 FTU. Silt curtains used in conjunction with the dredge performed well.

5. SELECTING A DREDGE FOR CONTAMINATED SEDIMENT REMEDIATION

There is no single best dredge for all contaminated sediment remediation projects. For each project, a dredge should be selected based on site characteristics, sediment characteristics, dredge features, and the goals and constraints of the cleanup. As a practical matter, a dredge cannot be selected independently from the other components of a cleanup, which include sediment handling, treatment, and disposal. For example, the rate of sediment dredging, and therefore the optimal production rate of the dredge, can be constrained by the capacity of water treatment systems or the land area available for settling basins or disposal facilities.

Available sources provide useful information for selecting remedial technologies. Palermo (1991), the USEPA (1994a) and Averett et al. (1990) summarize dredge features and factors to consider when selecting a dredge. The USEPA (1994a) and Averett et al. (1990) provide similar information for the handling, treatment and disposal components of sediment cleanups. The USEPA (1994a) provides a step-wise approach to remedy selection, which starts with selection of a site for sediment handling, treatment and/or disposal.

A unique resource is Environment Canada's SEDTEC database on CD-ROM. The searchable database includes detailed data and diagrams on dozens of contaminated sediment removal and treatment technologies. The database includes technology descriptions and audits, case studies, cost and performance data, and manufacturer and vendor contacts.

This section identifies dredge features and site characteristics to evaluate when selecting a dredge for contaminated sediments. Selection factors related to sediment handling, treatment, and disposal technologies, which are not evaluated in this report, are not included.

5.1 Resuspension of Contaminated Sediment

Resuspension of contaminated sediment is the most common concern raised about dredging the Hudson River PCBs site. Because it is an important concern, sediment resuspension is given special emphasis throughout this report. For example, Sections 3 and 4 include quantitative resuspension data where available to clarify the capabilities and relative performance of various dredges. Several of the dredges, have been used to clean up contaminated sediment sites with little or no significant resuspension.

The USEPA, in a recent report from the ARCS program (USEPA, 1996f), provides methods for estimating contaminant losses from dredging, capping, and no action alternatives, as well as handling and treatment of excavated sediment. The report's analytical tools provide an objective framework for selecting a remedy and evaluating concerns about dredging-induced sediment resuspension (Miller, 1996).

5.2 Sediment Characteristics

Particle size and density can affect dredge performance and efficiency. The type of pump and other design features such as debris grates, mechanical cutters, and pipe diameter determine the types of sediment that can be handled by each dredge. For example, the Dustpan dredge and plain-suction dredgehead work best with soft sandy sediment (USEPA, 1994a), while many of the other dredges effectively handle smaller particles as well. The conventional cutterhead dredge, the Eddy Pump, and the Airlift dredge are able to handle virtually any sediment type.

The presence of gravel and debris or highly compacted sediment can limit dredge performance. Large debris can not be removed by hydraulic dredges. However, some hydraulic dredges (e.g., cutterhead, Eddy Pump) can handle gravel and smaller debris. For example, the Eddy Pump is able to pass gravel, cobbles, rags, vegetation, and woody debris (Harrison and Weinrib, undated). The Amphibex dredge is equipped with a hydraulic intake and backhoe for debris removal. Other hydraulic dredges have shields, grates, or even underwater video cameras to help dredge operators avoid difficulties with debris. In some instances (e.g., in the Saint Lawrence River), mechanical dredges have been used to remove large boulders and debris or loosen consolidated material prior to hydraulic dredging.

Since the Hudson River PCB hot spots tend to be located in depositional zones, the sediments are generally silts and sands. In some areas, there is likely to be gravel and debris including woodchips and other woody debris. A dredge with flexibility to handle small and large sediment, as well as small debris, would be most suitable. If any of the dredging areas have large debris, remediation could include mechanical debris removal followed by sediment dredging with a versatile, low-turbidity hydraulic dredge.

5.3 Water Depth and Site Access

Water depth can limit operation of the dredge or access to the dredging site. Because of mechanical and sometimes hydraulic design constraints, all dredges have a maximum depth of operation. Most dredges have a minimum depth requirement as well. The draft of the vessel on which the dredge is mounted can restrict the dredge to waters of a certain depth. Maximum and minimum dredging depths for some of the available dredge technologies are presented in Exhibit 19. Since the sediment hot spots in the upper Hudson River are located along shore, a dredge able to operate in shallow water (i.e., less than 10 feet) or from the shore would be necessary. Several of the dredges meet this requirement. The choice of a dredge for the Hudson River PCBs site

EXHIBIT 19
Operational Characteristics of Various Dredges[a]

Dredge Type	Minimum Dredging Depth[b] (feet)	Maximum Dredging Depth[b] (feet)	Production Rate (yd3/hr)[b]	Slurry Density (percent solids)[c]
Airlift	20	unlimited	60[d]	25-40
Backhoe	0[e]	23-80[f]	26-200	near *in situ*
Bucket Wheel	na	150[g]	30-600[g]	near *in situ*
Clamshell	0[e]	157	30-600	near *in situ*
Clean-up	3-16	13-80[h]	500-1,960	30-40
Cutterhead	3[g]-6	13-60[g]	25-5,000[g]	10-20
Dustpan	5[g]-16	52-62	25-15,000[g]	10-20
Eddy	3[i]	100[j]	310[j]	70[j]
Hand-Held	4[f,k]	1,000[f]	250[f]	na
Hopper	10-30	69	497-1,960	10-20
Horizontal Auger	2	16	60-160	10-40[l]
Matchbox	3-16	13-85[h]	24-80	5-15
Oozer	0[e]	160	330[h]-800[g]	25-80[l,m]
Plain Suction	5[g]	160[g]	1,000-10,000[g]	10-15[g]
Portable Hydraulic	2[g,k]	50[g]	50-500[g]	10-40[g]
Pneuma	0[e]-12[f]	150-500[f]	60-2,590[f]	25-80[l,m]
Refresher	3-16	13-115[h]	65[h]-1,300	30-40
Waterless	na	na	na	30[h]-50[f]

na Not available
a All data from USEPA (1994a) except where noted.
b Most values converted from meters (or cubic meters) and rounded.
c By weight unless noted
d Orchard, 1996
e Zero if operated from shore, otherwise limited by draft of vessel
f Averett et al., 1990
g Euwsi-Wilson et al., 1995
h Herbich, 1989
i Swing (1996) 3 feet if operated by cable suspension, less if suspended from a ladder.
j Harrison and Weinrib (undated)
k Depth for a barge mounted dredge, would be less if operated from shore.
l Palermo, 1991
m Percent *in situ* density

is not likely to be constrained by the maximum depth of operation of the available dredges.

Access to the cleanup site by the dredge can be limited by obstructions such as low bridges, dams, and power lines. Such obstructions should be identified and matched to the dimension of available dredges. Some dredges can be brought to the site over land to bypass obstacles.

5.4 Water Current

Rapid water current can interfere with dredge positioning or heighten sediment resuspension. The effects of current vary with the designs of dredge vessels and equipment. Physical barriers can reduce the current at the point of dredging. However, many physical barriers are themselves vulnerable to current. For example, silt curtains are most effective with currents less than 0.5 meter per second (1.64 feet per second). The interference of current in sediment cleanups may be minimized by dredging during periods of low flow.

Currents in the upper Hudson from Fort Edward to Troy typically range between 0.9 and 4.3 feet per second (Simpson, 1974 cited in USEPA, 1991). There is a strong seasonal pattern, with the highest currents generally in April and May when melting snow and rainfall produce a period of annual peak flows. In planning a cleanup for the upper Hudson River, it would be appropriate to limit dredging to the summer and fall months. If necessary, dredging could be temporarily suspended following storms or other high flow events.

At any given time, there is a great amount of spatial variability in currents in the upper Hudson River. In general, currents are lowest in the quiescent near-shore areas and embayments corresponding to sediment depositional zones. The current patterns are well depicted by a hydrodynamic model EPA (1996b) developed for the Hudson River PCB reassessment. The model makes detailed current estimates for the Thompson Island Pool portion of the Upper Hudson River during a 100-year flood event. The results show currents ranging from under one to over five feet per second, with high current areas often only meters away from low current areas. The sediment hot spots, which are shown in Appendix A, are almost exclusively located in quiescent areas where currents would be under 2.5 feet per second during a 100-year flood. Currents in these areas would be substantially lower during normal summer flows and should not constitute a major obstacle to successful dredging.

5.5 Depth of Contaminated Sediment and Dredge Accuracy

An efficient dredge removes no more sediment than necessary. For example, a dredge that removes ten inches of sediment in an area with contamination 1 inch deep produces 9 times as much sediment as necessary for remediation. Dredge accuracy, in both the depth and width of the cut, can be a significant factor to project cost, especially for large projects.

Despite the large size of the Hudson River PCBs site, dredge accuracy is not likely to be a critical selection factor. There is little difference between the accuracies of the available dredges. Most dredges are accurate to a depth of about 1 foot. With favorable site conditions and with care, accuracies of 0.5 feet or better may be possible (Palermo, 1996). The typical depth of contamination in the Thompson Island Pool is greater than the 1 foot or less accuracy of most dredges. Malcolm Pirnie (1986) used DEC data to estimate that 95 percent of the PCB contamination in the Thompson Island Pool is in the uppermost 2 feet of the sediment.

5.6 Production Rate and Sediment Density

The available dredges differ in sediment production rate (e.g., volume sediment removed per hour) and sediment density (i.e., the percentage solids in the water/sediment slurry). High production rates minimize the duration of the dredging project, and high sediment densities minimize the quantity of carriage water and the size of settling basins.

Production rate is a function of the dredge design (e.g., pump size, bucket capacity) and operation (e.g., rate of advancement of the dredge head). Exhibit 19 shows that most dredges have potential production rates ranging more than an order of magnitude. In some cases, this is because the dredges are available in several sizes (larger sizes have higher production rates).

It is not always advantageous to operate a dredge at its maximum production rate, because sediment resuspension is often related to dredging speed. At the New Bedford Harbor Superfund site, for example, the production rate was cut by about two-thirds shortly after the start of hot spot dredging to ensure acceptable performance (Otis, 1994). Optimal contaminated sediment dredging occurs at the maximum production rate that can be sustained without compromising other aspects of dredge performance.

The efficiency of a sediment cleanup is enhanced by a dredge capable of removing sediment at high density. Mechanical dredges are capable of removing sediment at or near *in situ* densities. Hydraulic dredges typically produce slurries much lower than *in situ* density. However, the pneumatic dredges and the Eddy Pump are capable of relatively high densities. Exhibit 19 compares the sediment densities produced by several of the available dredges.

Sediment production and density are not significant selection factors for sites with very small quantities of contaminated sediment. However, both will be significant considerations for the Hudson River PCBs site where there is a large amount of contamination. The production rate and slurry density of the dredge will strongly affect the duration of the project. The importance of sediment production rate and slurry density to project duration is illustrated by Exhibit 20, which is based on a hypothetical cleanup of 10,000 cubic yards of sediment. Since many factors influence the duration of an actual cleanup, Exhibit 20 should not be used to estimate the duration of a cleanup for the Hudson River.

Exhibit 20
Duration of a Hypothetical Dredging Project in Days
With Selected Production Rates and Slurry Densities[a]

Slurry Density[b]	Production Rate (yd^3/hr)		
	50	500	5,000
5%	500	50	5
10%	250	25	2.5
25%	100	10	1
50%	50	5	0.5
75%	33	3.3	0.3
90%	28	2.8	0.3
100%	25	2.5	0.3

a Assumes 8 hours dredging per day, and a total volume dredged of 10,000 cubic yards *in situ*.
b Relative to *in situ* density

5.7 Dredge Availability

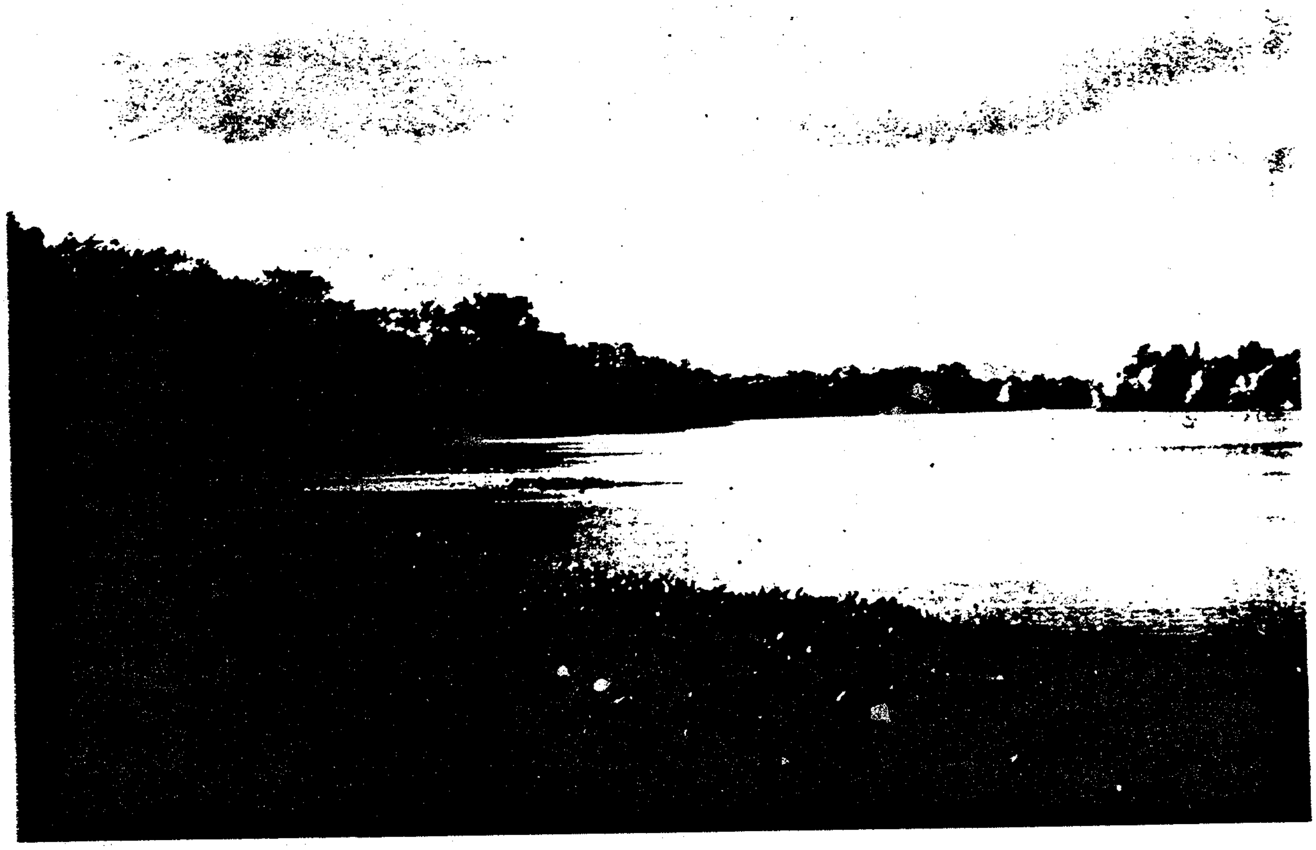
Use of specialized contaminated sediment dredges in the U.S. has been hindered by their relative unavailability. Conventional mechanical and hydraulic dredges are the most widely available and widely used dredges in the U.S. Specialty dredges, most of which were invented overseas, are less available because the Jones Act restricts the importation of foreign-made dredge vessels. Among the dredges listed in Exhibit 19 only the Clean-up, Refresher, and Oozer[4] dredges may be unavailable in the U.S. However, since the Jones Act prohibits the importation of foreign-built ship hulls, it may be legal

[4] Zappi and Hayes (1991) report that the Oozer dredge may be available from a firm in California. However, EPA (1994) indicate that the Oozer dredge is available in Japan only.

to import foreign-built dredge heads without dredging vessels (Zappi and Hayes, 1991). Given the scale and significance of the Hudson River PCBs site, present availability should not be used to screen candidate technologies. If the preferred technology is not readily available, efforts should be made to make it available.

5.8 Cost

Factors contributing to the cost of contaminated sediment dredging include transportation (for taking the dredge to and from the site), fuel, and maintenance and decontamination of the equipment. Other related costs include monitoring, health and safety equipment, and silt curtains or other mitigation (USEPA, 1994a). Generally speaking, the cost of a dredging project is related to its duration, and cost can be controlled by minimizing dredge "down time" and maximizing sediment production rates. Since dredging cost is highly project-specific, there is very little quantitative data in the dredging literature. The USEPA (1994a) includes useful information on estimating contaminated sediment remediation costs.



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

6. SUMMARY AND CONCLUSIONS

In the past 15 years, contaminated sediment dredging has advanced substantially. The passage of the Superfund law in 1980, as well as other developments in environmental science and policy, have expanded awareness of the extent and significance of contaminated sediment sites in the U.S. Along with this awareness there has been a growth in academic and governmental research to address contaminated sediment issues and a boom in private research and development on methods and equipment to remediate contaminated environmental media. Attention to contaminated sediments has lagged behind other environmental media because of an ambiguous overlay of mandates and jurisdictions, and resulting inconsistent technical and managerial approaches. However, concentrated efforts by the USACE and the USEPA in the late 1980s and early 1990s have made significant progress possible, as evidenced by coordinated work to remediate several Areas of Concern in the Great Lakes and major contaminated sediment Superfund sites.

The USEPA and USACE's contaminated sediment initiatives have included experimentation, and full-scale cleanups, with several dredging technologies. Dredges available for contaminated sediment remediation include modified or unmodified conventional dredges (i.e., developed for navigational dredging) and innovative dredges developed specifically for contaminated sediment remediation. Innovative dredges are used widely overseas where most were developed. A challenge remains in making innovative dredges more available in the U.S.

Along with progress in dredging technology, there have been advances in operating practices and instrumentation to control sediment resuspension, the primary concern about dredging safety. Advances in electronics have enabled the development of underwater and on-board instrumentation for guiding and positioning the dredge, as well as aiding the efficient operation of equipment. In addition, there is now considerable experience using silt curtains and other turbidity barriers, and the appropriate conditions and procedures for their use are well understood.

A growing number of contaminated sediment sites have been dredged, and over 20 cleanups are described in this report. In many cases contaminated sediments were removed with little or no significant sediment resuspension, and dredging impacts are almost always limited to the immediate area of the dredge. Documented performance by available dredges in various site conditions provide a useful database for evaluating potential contaminated sediment remedies at other sites.

The scientific literature on contaminated sediment remediation that has evolved since 1984 constitutes an important resource for the future management of the Hudson River PCBs site. For example, Environment Canada's SEDTEC database includes detailed information on more than 100 technologies for handling and remediating contaminated sediment, and recent guidance from the USEPA (e.g., USEPA, 1996f; USEPA, 1994a) detail the state-of-the-art assessment and remediation methods for contaminated sediments. Collectively, the technical expertise and practical experience of dredging experts at the USEPA, the USACE, and in academia, together with the extensive database on the site compiled for the USEPA reassessment, will replace the uncertainty and doubt about dredging apparent in the 1984 ROD.

Much work lies ahead for the USEPA in determining the specific remedy for the Hudson River sediments. In making that decision, the USEPA will have a broader array of options than were available in the 1980s, and better information on the short-term and long-term implications of these actions for human health and the environment.

The issue of dredging PCB-contaminated sediment from the Hudson River centers on three questions:

- Is contaminated sediment dredging feasible?
- Does dredging impact the environment?
- How does dredging compare with the alternatives, including no action?

The scientific literature has much more to offer on these questions than in 1984 when the USEPA last evaluated remedies for the Hudson River PCBs site.

Is contaminated sediment dredging feasible? Dredging is feasible for the Hudson River PCBs site. Millions of cubic yards of contaminated sediment have been removed from hundreds of sites around the world, including a rapidly growing number of sites in the U.S. These sites include many rivers. Examples of dredged rivers discussed in the scientific literature include: Aji River (Japan), Black River (OH), Buffalo River (NY), Cape Fear River (NC), Duwamish River Waterway (WA), Grasse River (NY), Hori River (Japan), Hudson River (NY), James River (VA), Mill River (CT), Oyabe River (Japan), Shiawassee River (MI), St. Johns River (FL), St. Lawrence River (NY), and Welland River (Canada). Since 1984, the USEPA included dredging in 23 of 25 Superfund decisions at sites with PCB contaminated sediments.

Does dredging impact the environment? Like nearly any means of environmental remediation, dredging has incidental environmental impacts. But these impacts are temporary, limited in area, and usually can be mitigated with selection of appropriate equipment and methods.

More than any other potential impact, remobilization of contaminants with resuspended sediment is the concern most often raised. Experience at sites remediated with innovative dredges contradicts the common perceptions. Several dredges are able to remove contaminated sediment with little or no significant resuspension. Successfully minimizing resuspension requires careful selection of a dredge or dredges suitable to site conditions and other goals, as well as selection of a dredge operator experienced with techniques to minimize resuspension. In addition, modern instrumentation, monitoring, and other mitigation equipment can ensure that impacts are minimized and confined to the immediate area of dredging.

The impact of dredge-induced contaminant losses can be evaluated with respect to (1) the present rate of contaminant losses with no action, (2) the human health and ecological risk posed by current conditions, and (3) the degree of additional risk that may be generated. For example, losses from dredging equivalent to losses that may occur under typical and high flow conditions without dredging may not be of significant environmental concern.

The most evident and unavoidable impact of dredging is removal of aquatic plants and other organisms associated with the dredged sediment. Habitat recovery after dredging can be artificially enhanced (e.g., by seeding aquatic plants or adding clean sediment), but is rarely necessary. Dredged areas are recolonized by organisms from surrounding or nearby unaffected areas. Indirect physical impacts associated with turbidity are virtually eliminated by selecting a dredge that controls contaminated sediment resuspension.

How does dredging compare with the alternatives, including no action? This question can only be answered on a site-by-site basis in consideration of site characteristics and project goals. However, dredging has a number of advantages over the alternatives, which include capping, *in situ* treatment, and no action. Because dredging removes contaminants from the environment, it provides superior long-term protection than capping or no action which are vulnerable to storms, ice and boat scouring, and other disturbances. *In situ* remediation is intended to immobilize or destroy contaminants, but the methods are not well developed and still involve a number of practical limitations. No action, as the *status quo* for the Hudson River PCBs site, does not adequately protect human health or the environment. Dredging or dredging followed by capping is the most commonly selected remedy for PCB-contaminated sediments at Superfund sites.

Recommendations

This report does not propose a specific remedy for the Hudson River PCBs site. In order to formulate a remedy, it would be necessary to evaluate PCB treatment and disposal options, which are not addressed in this report.[5] In addition, the USEPA has not yet released the Phase II reassessment reports, which will contain site-specific data useful for formulating detailed remedial options. However, we do endorse and recommend dredging as a component of the Hudson River PCBs remedy, based on

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[5] Contaminated sediment treatment and disposal methods are described and evaluated in EPA (1994a), Hirschhorn (1994) and Averett et al., (1990).

demonstrated technical feasibility and effectiveness. The additional recommendations below are consistent with our recommendation for dredging.

Do not rule out dredges based on initial inavailability -- Innovative dredges remain more difficult to obtain than the conventional dredges used for navigational maintenance. However, almost all types of dredges have been used somewhere in the U.S. Special efforts should be made to acquire the optimal dredge for the site regardless of its relative availability. For example, importation of a foreign-built dredge head or fabrication of a specialty dredge in the U.S. should be considered if the preferred dredge is not readily available from domestic companies. Extra efforts to obtain the best dredge are warranted by the unique size and significance of the site, as well as the USEPA's unprecedented level of effort on the reassessment.

Choose a dredge operator experienced in contaminated sediment removal -- Several sources cited in this report indicate that operator experience is an important factor in successful dredging. An experienced operator is familiar with the capabilities and limitations of the dredging equipment, and knows how to efficiently remove the contamination with minimal sediment resuspension. State of the art sensors, instrumentation, and positioning equipment can further enhance performance.

Evaluate combinations of dredges -- At the Marathon Battery and GM Central Foundry Division Superfund sites in New York State, two types of dredges were used. It may be advisable to use more than one type of dredge in the upper Hudson River as well. For example, a minimal resuspension dredge (e.g., Oozer dredge, Pneuma Pump) could be used for the most highly contaminated fine sediment areas, and a more versatile, high-production dredge could be used for less contaminated areas. In addition, a mechanical dredge could be used where needed to remove large debris. Pilot testing of various dredges would be useful for determining the suitability of candidates. For example, one or more of the innovative dredges (e.g., Pneuma Pump, Eddy Pump, cable arm bucket dredge) may exhibit suitable production, control contaminant loss, and meet other needs.

Optimize production rates without compromising environmental protection -- The duration of a dredging project is an important determinant of its cost (Hartnett, 1996, USEPA, 1994a), especially for large sites like the Hudson River PCBs site. Thus, the USEPA should be particularly mindful of the production rates and slurry densities of potential dredges. In addition, the USEPA should consider operating more than one dredge and other measures to speed the cleanup. However, worker safety and dredging effectiveness must be given top priority over project duration and cost.

Careful dredging is preferable to mitigation -- Silt curtains, sheet piling, or other physical barriers can successfully contain resuspended contaminated sediment. For example, sheet piling used at the GM Central Foundry Division site on the St. Lawrence

River confined resuspended sediment to the contaminated area. The conditions under which silt curtains and other mitigation equipment are ineffective are well understood.

Mitigation equipment is recommended at Hudson River dredging sites where conditions are suitable. However, it is better to prevent resuspension with careful operation of a specialty dredge than to confine resuspension to a limited area with sheet piling or other barriers. At the GM site, resuspension permitted within the sheet piling may have been a significant reason for difficulty obtaining the cleanup goal. Permitting resuspension within an isolated area is not recommended unless abundant large debris preclude hydraulic (or pneumatic) dredging.

Restoration of the Hudson River -- a gift to future generations.

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ACRONYMS AND UNIT ABBREVIATIONS

AOC	Area of Concern
ARCS	Assessment and Remediation of Contaminated Sediments
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
EEDP	Environmental Effects of Dredging Program
FDA	Food and Drug Administration
GE	General Electric Company
NOAA	National Oceanic and Atmospheric Administration
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
ROD	Record of Decision
SARA	Superfund Amendments and Reauthorization Act
TOC	Total Organic Carbon
TSS	Total Suspended Solids
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency

ft	foot
l	liter
m	meter
mg	milligram
NTU	nephelometric turbidity units
ppb	parts per billion
ppm	parts per million
s	second
yd	yard

GLOSSARY

Absorb	To take in or soak up into pore spaces or interstices.
Adhesion	The physical attraction or joining of two dissimilar substances.
Adsorb	To take up or assimilate by adherence to a surface.
Aerobic	Living or occurring in the presence of oxygen.
Anaerobic	Living or occurring in the absence of oxygen.
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 are 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.

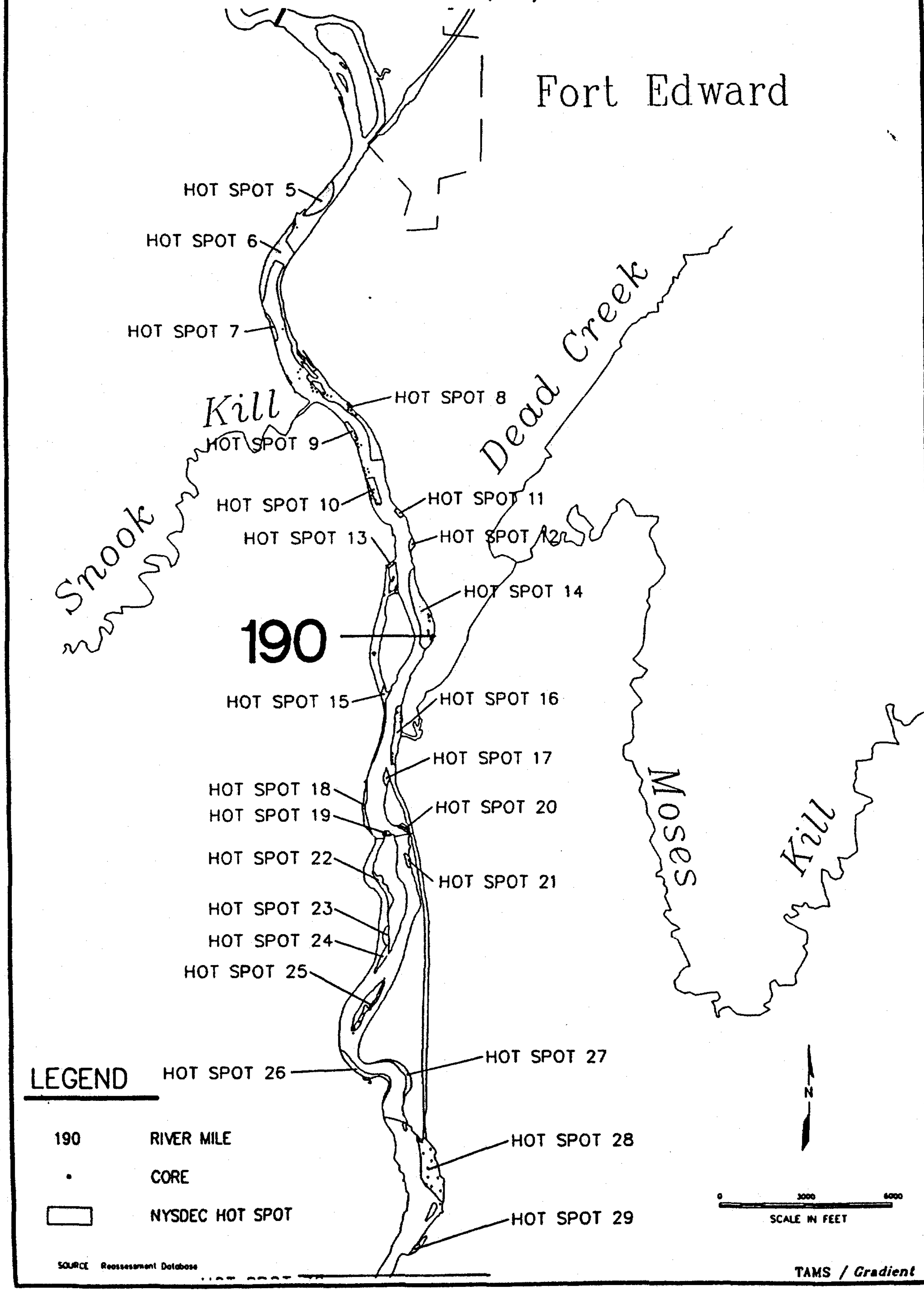
In situ	In the original place.
Macroinvertebrate	An invertebrate organism visible with the unaided eye.
Order of magnitude	An estimate of size or magnitude expressed as a power of ten (e.g., tens, hundreds, thousands etc.).
Phytoplankton	Minute floating aquatic plants.
Plume	An area of chemicals moving away form its source (e.g., a column of smoke, a cloud of turbidity in water).
Pneumatic	Involving, moved, or operated by air or other gasses.
Porewater	Water absorbed in the minute pore spaces between sediment particles.
Riparian	On or of a river bank.
Seiche	A tide-like phenomenon on large lakes.
Slurry	A mixture of a liquid and fine solid particles.
Transducer	Any device which converts input energy in one form to output energy in another form.
Turbidity	The condition of sediment or other particles suspended or stirred up in a liquid.

APPENDIX A

PCB Hot Spots in the Upper Hudson River

Source: USEPA, 1995a

Figure 2-17A
Phase 2 Low Resolution Sediment Coring
Locations (1994)

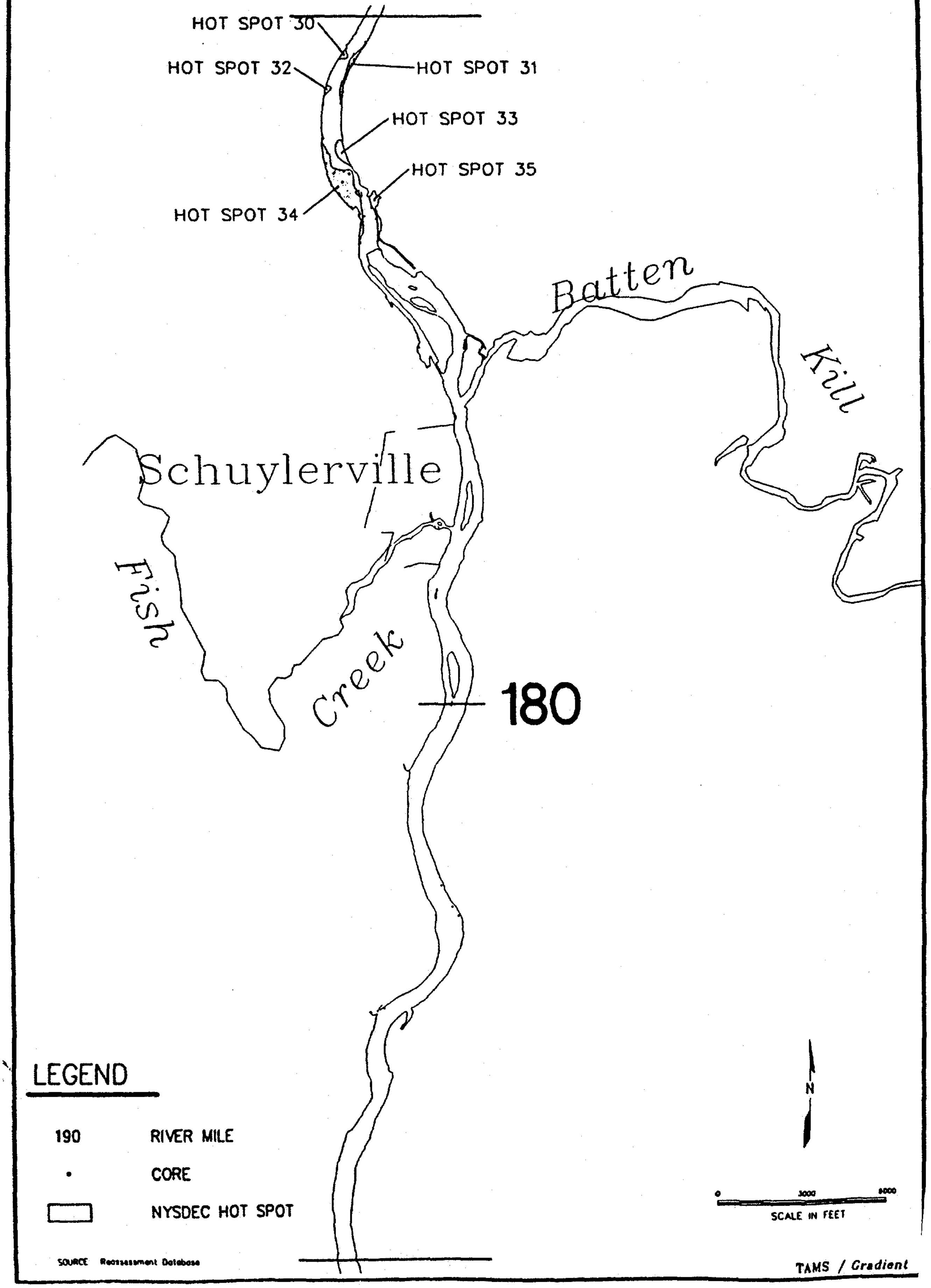


TAMS / *Gradient*

402798

File No.: 48 / Filename: FIG2-17b.dwg / Date: 8-15-95 / User: MC

Figure 2-17B
Phase 2 Low Resolution Sediment Coring Locations (1994)

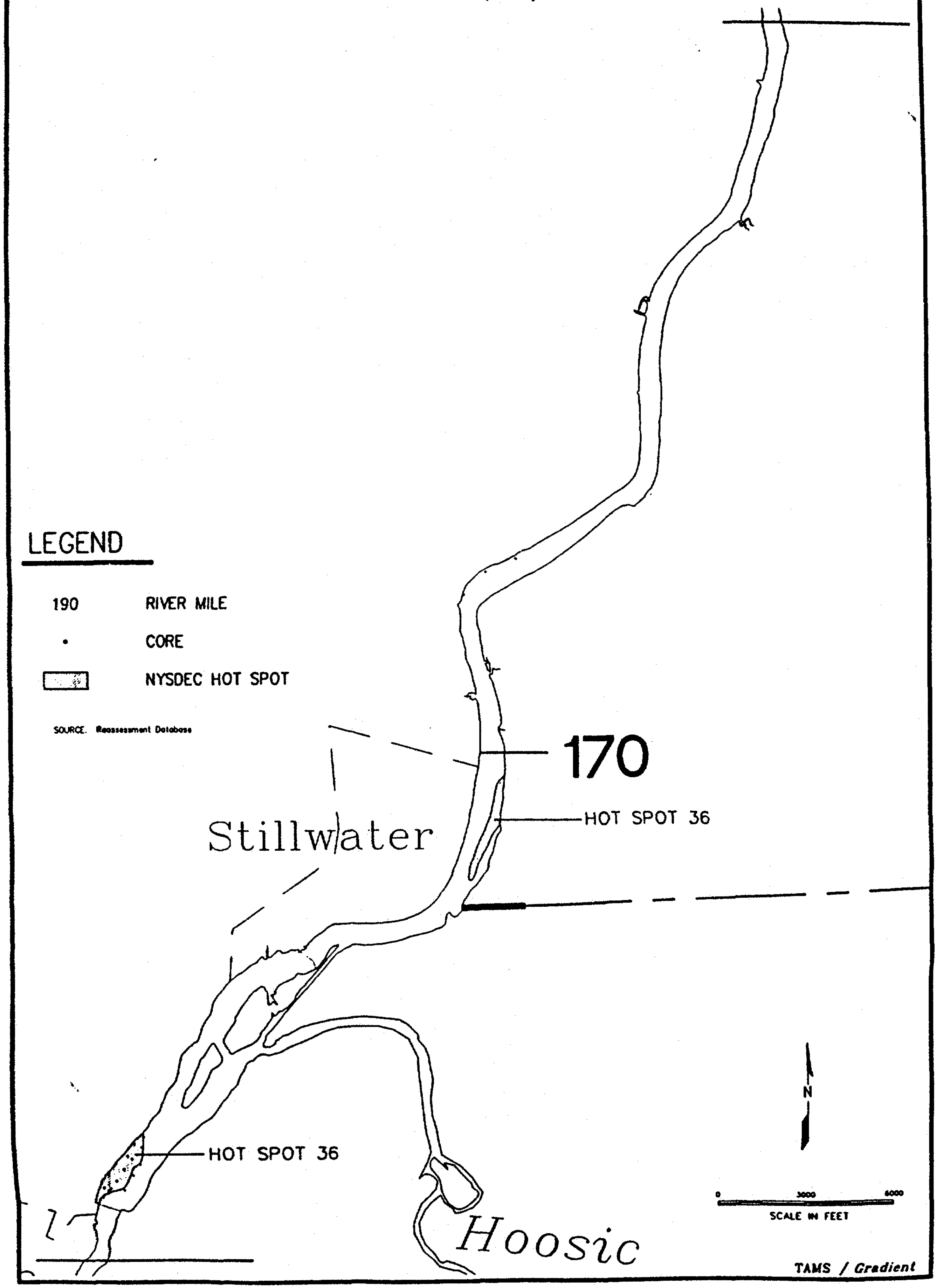


SOURCE: Reassessment Database

TAMS / *Gradient*

402799

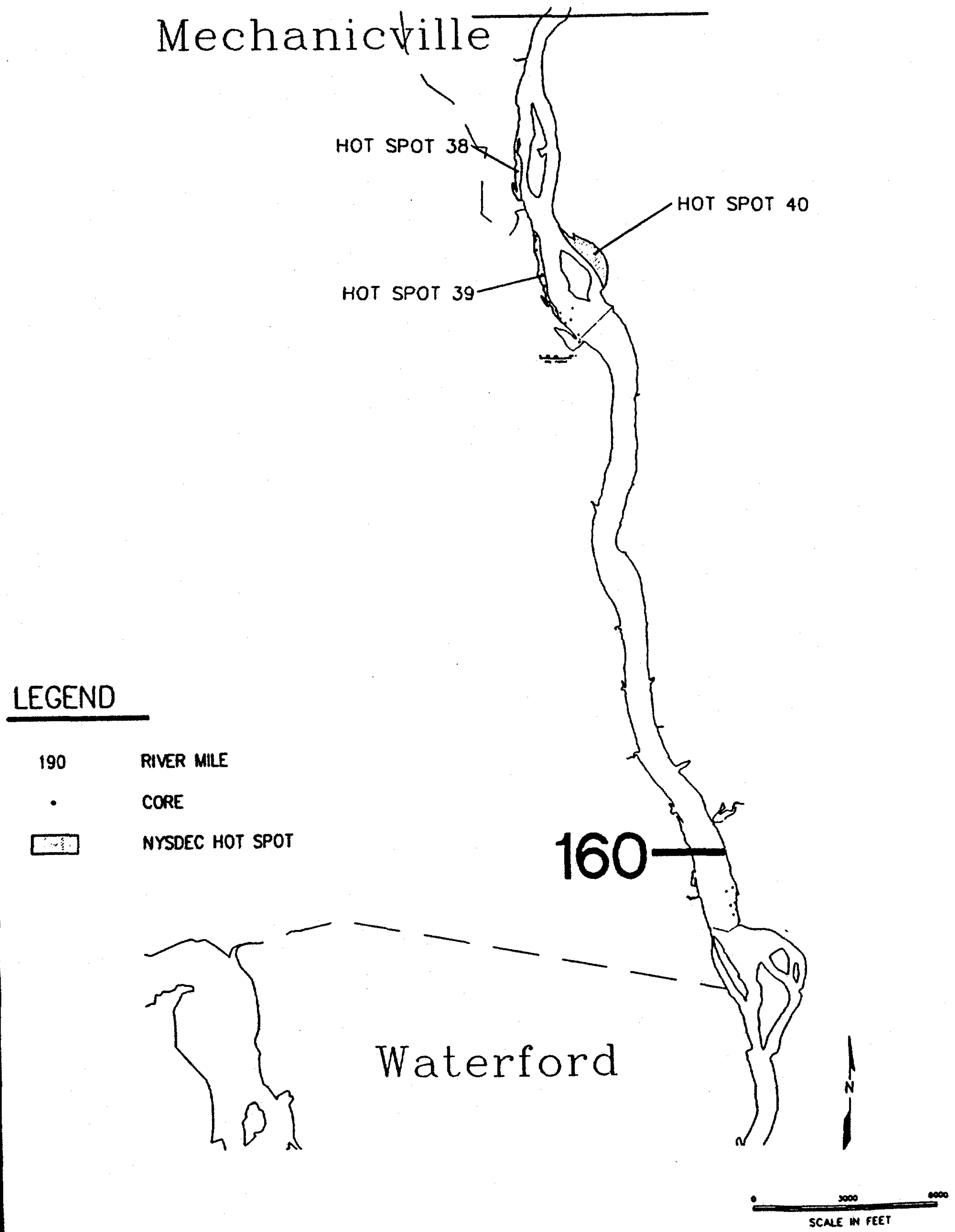
Figure 2-17C
Phase 2 Low Resolution Sediment Coring Locations (1994)



402800

File No.: 48 / Filename: FIG2-17d.dwg / Date: 8-15-95 / User: MC

Figure 2-17D
Phase 2 Low Resolution Sediment Coring Locations (1994)



SOURCE: Reassessment Database

TAMS / *Gradient*

APPENDIX B

PCB-Contaminated Sediment Remedies at Superfund Sites

Source: USEPA, 1995c

COMPARISON OF 29 SITES WITH PCBs IN SEDIMENTS

Site Name and Type Action	Concentration of Contamination	Volume of Contaminated Sediment	Remedy Chosen for PCBs	Action Levels ppm	Cost	Risk No. &/or Cleanup Goal	Threat to Human Health &/or Environment
General Motors: Central Foundry Division Massena, NY (Operable Unit #1) Remedial	up to 31,000 ppm	dredge 162,000 cu yds sediment & soil	Dredging and excavation of hot spots		$78 M	1 ppm	Human health and environment
			On-site treatment of dredged sediments by: biological treatment, or thermal destruction (not yet determined)	>10			
			On-site disposal of treatment residuals				
Reynolds Metals Company Study Area Massena, NY Removal ?		dredge 51,500 cu yds	Dredging of sediments	>1			Human health and environment
		treat 14,500 cu yds	Treatment by thermal desorption of dredged materials	>25			
			Disposal and capping of untreated sediments in Black Mud Pond	>1 and <25			
			Commercial incineration of contaminants condensed during thermal desorption				

Bolding indicates that remedy has been implemented

402803

Site Name and Type Action	Concentration of Contamination	Volume of Contaminated Sediment	Remedy Chosen for PCBs	Action Levels ppm	Cost	Risk No. &/or Cleanup Goal	Threat to Human Health &/or Environment
Hudson River PCBs, NY Remedial	50-500 ppm	1-1.5 M cu yds in river with 40 hot spots in 40-mile stretch	Interim remedy of no action in river (being reassessed - proposed plan due 12/95)		$3 M incineration of sediments estimated at $210 M		
		360,000 cu yds in five remnant deposits of sediment	**Interim Remedy: In-place containment (2 ft layer of soil & geobentonite clay mat) and bank stabilization of remnant deposits** (ABOVE WATER LEVEL)				
New Waterbury Ltd. New Waterbury, CT Removal	up to 6500 ppm		**Diverted portion of the Muddy River**		$550,000 approx.		
			Sediment excavated 7 ft. below existing river bed (deeper was not technically feasible)				
			Backfilled to original elevation of river bed. Contaminated sediment with up to 6500 ppm remains on river bottom				
New Bedford Harbor New Bedford, MA (Operable Unit #1) Remedial	up to 200,000 ppm	dredged 10,000 cu yds	**Dredged**	>4000	$14.4 M	10°	Human health and environment
			On-site incineration of sediment (Under review: on-site pilot treatability tests are being conducted, ROD amendment expected in 1997)	>4000			

Bolding indicates that remedy has been implemented

402804

Site Name and Type Action	Concentration of Contamination	Volume of Contaminated Sediment	Remedy Chosen for PCBs	Action Levels ppm	Cost	Risk No. &/or Cleanup Goal	Threat to Human Health &/or Environment
New Bedford Harbor (cont'd)			Proposed plan for Operable Unit #2 expected in Spring 1995. It will propose capping dredged sediments in disposal cells on shoreline				
Ottati & Goss/ Kingston Steel Drum Kingston, NH Remedial	14 ppm	5,000 cu yds sediments & soils	Excavation	>1	$8.6 M		Human health and environment
			Incineration to 1 ppm cleanup level				
S. Municipal Water Supply Well Peterborough, NH Remedial		dredged 1,170 cu yds	**Excavated/dredged**	>1	$7.4 M	2.9×10^{7}	Human health and environment
			Disposed off-site	>1			
Sangamo Weston/ Twelvemile Creek/ Lake Hartwell Pickens, SC (Operable Unit #2) Remedial	mean: 5-10 ppm in surficial sediments >50 ppm in 1 sample in deeper sediments	4.7 million cu yds	Institutional Controls: - Continuation of existing fish consumption advisory - Public education regarding advisory and other issues - Future monitoring of PCBs in aquatic biota and sediment - Regulation of sediment flushing event.		$30-50 M estimated costs of Engineering Controls such as capping or dredging		Human health and environment

402805

Bolding indicates that remedy has been implemented

Site Name and Type Action	Concentration of Contamination	Volume of Contaminated Sediment	Remedy Chosen for PCBs	Action Levels ppm	Cost	Risk No. &/or Cleanup Goal	Threat to Human Health &/or Environment
Harbor Island Seattle, WA Remedial	>50 ppm		Likely options: - Dredging and disposal or - Capping ROD due mid-1995				
Strandley-Manning Region 10 Remedial	<50 ppm generally up to 1100 ppm in one hot spot		Likely option: Dredging			1 ppm (10 ppm where dredging will cause erosion)	
			Off-site incineration	>300			
			Off-site disposal	<300 and >1 ppm			
Commencement Bay - Nearshore/Tide Flats Tacoma, WA (2 of 6 Operable Units) Remedial (2nd action)	<5 ppm generally never >50 ppm	remediate 1,181,000 cu yds	Natural recovery combined with containment measures, as needed: - Capping, or - Nearshore disposal, or - Confined aquatic disposal, or - Removal & upland disposal		$32.3 M	150 ppb 10^{5}	Human health and environment
Sullivan's Ledge New Bedford, MA (Operable Unit #2) Remedial (marsh/wetland)		5,200 cu yds sediment & soil	Excavation & dewatering		$2.8 M contingent remedy: $7.8 M	aquatic: 20 μg/Gc non-aqua: 15 ppm 10^{4} - 10^{6}	Environment
			Solidification/stabilization				
			On-site disposal				
			Contingency remedy: off-site incineration & on-site disposal				

Bolding indicates that remedy has been implemented

402806

Site Name and Type Action	Concentration of Contamination	Volume of Contaminated Sediment	Remedy Chosen for PCBs	Action Levels ppm	Cost	Risk No. &/or Cleanup Goal	Threat to Human Health &/or Environment
Hooker - 102nd St. Niagara Falls, NY **Remedial**		28,000 cu yds	**Dredging**		$30.1 M	42.4 ppb	Human health and environment
			Off-site incineration of hot spots				
			On-site disposal of "lesser contaminated sediment," and capping of landfill				
Middletown Airfield Dauphin County, PA (4 of 5 Operable Units) **Remedial**			Sampling sediments and comparing samples with existing data base		$1.3 M		Human health and environment
			Selection of future remedy based on results				
Paoli Rail Yard Paoli, PA **Remedial**			Excavation	>10	$28.3 M	1 ppm	Human health and environment
			On-site solidification/ stabilization	>1			
			On-site disposal and capping of landfill				
Carolina Transformer Fayetteville, NC **Remedial**	16,000 - 650,000 ppm		Excavation		$10.5 M	1 ppm	Human health and environment
			On-site treatment	>1			
			Solidification	>TCLP			

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Site Name and Type Action	Concentration of Contamination	Volume of Contaminated Sediment	Remedy Chosen for PCBs	Action Levels ppm	Cost	Risk No. &/or Cleanup Goal	Threat to Human Health &/or Environment
Smith's Farm Brooks, KY (Operable Unit #1, after amendment) Remedial	122 ppb - 363 ppm	5,200 cu yds	Excavation	10^{-5}	$22-25 M	2 ppm	Human health and environment
			On-site treatment (chemical treatment & solidification/ fixation)				
			On-site disposal				
Folkertsma Refuse Walker, MI Remedial	141 - 245 ppb	1,300 cu yds	Excavation & dewatering		$1.5 M	10^{-4} - 10^{-6}	Human health and environment
			On-site disposal & capping of landfill				
Sangamo Dump/ Crab Orchard National Wildlife Refuge, IL (Operable Unit #2) Remedial/Federal	1 - 120,000 ppm	38,400 cu yds. sediments & soil	Excavation	>5	$25 M	0.5 ppm 10^{-6}	Human health and environment
			Incineration and in-situ vitrification, if needed	>5			
			Stabilization/fixation of residues and non-incinerated sediments				
			On-site disposal & capping of landfill				
Re-Solve N. Dartmouth, MA Remedial	0.13 - 2.5 ppm	3,000 cu yds	Excavation	>1	$20 M	1 ppm	Human health and environment
			On-site treatment (mobile dechlorination & on-site incineration, if needed)				
			On-site disposal & capping of landfill				

Bolding indicates that remedy has been implemented

Site Name and Type Action	Concentration of Contamination	Volume of Contaminated Sediment	Remedy Chosen for PCBs	Action Levels ppm	Cost	Risk No. &/or Cleanup Goal	Threat to Human Health &/or Environment
Burnt Fly Bog Monmouth County, NJ Remedial	8.4 ppm	5,600 cu yds	Excavation		$6.1 M		Human health and environment
			Off-site disposal				
Millcreek Dump Millcreek, PA Remedial (was a wetland)	1.5 ppm		Excavation		$12 - 18 M	40 ppb	Environment
			Disposal & capping of landfill				
Fields Brook Ashtabula, OH Remedial	up to 518 ppm	52,000 cu yds	Excavation & dewatering	10^{-6}	$35.1 M		Human health and environment
		16,000 cu yds	Thermal treatment				
		36,000 cu yds	Solidification & on-site landfilling				
Outboard Marine Waukegan, IL Remedial	50 - 10,000+ ppm	300,000 lbs. of PCBs in sediments	Dredging of Slip 3 & chemical extraction or thermal treatment	>500 ppm	$19 M	50 ppm	Human health and environment
			Dredging of Crescent Ditch & chemical extraction or thermal treatment	>10,000 ppm			
			Placement in Slip 3 containment cell	>50 ppm			
Schmalz Dump Harrison, WI Remedial (marsh/wetland)		3,500 cu yds	Excavation to 1 ft. & dewatering		$2.1 M		Future threat to environment
			Off-site disposal				

Bolding indicates that remedy has been implemented

402809

Site Name and Type Action	Concentration of Contamination	Volume of Contaminated Sediment	Remedy Chosen for PCBs	Action Levels ppm	Cost	Risk No. &/or Cleanup Goal	Threat to Human Health &/or Environment
Martha C. Rose Chemicals, MO Remedial			**Excavated to bedrock or 4 ft. (whichever was less)**			<10 ppm	
Dayton Tire & Rubber Dayton, OH Removal			**Dredged**				
Eagle Harbor, WA Region 10 Removal	5-52 ppm		**Permanently capped 54 acres with sandy, silty sediments** **NOTE: PCBs under cap are Non-Detect (high levels of PAHs are under cap)**				
			Additional capping is expected as part of a remedial action				
Sheboygan River & Harbor Sheboygan, WI Remedial	upper river: up to 4,500 ppm	2,700 cu yds	**Dredged & stored for biodegradation pilot study**			0.025 ppm	Human health and environment
	upper river: up to 580 ppm	820 cu yds	**Capped 5 sediment deposits** - Alternative-Specific Remedial Investigation (Pilot Project)				
	upper river: 63-295 ppm		**Dredged as practicable, then capped 4 sediment deposits**				

402810

Bolding indicates that remedy has been implemented

Site Name and Type Action	Concentration of Contamination	Volume of Contaminated Sediment	Remedy Chosen for PCBs	Action Levels ppm	Cost	Risk No. &/or Cleanup Goal	Threat to Human Health &/or Environment
Sheboygan River & Harbor Sheboygan, WI *Time-Critical Removal*	**750 - 1,100 ppm**	**2,700 cu yds**	**Dredged and stored in a tank until ROD**			1-28 ppm avg.: 13 ppm	Human health and environment

Bolding indicates that remedy has been implemented

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