

i n t e g r a t i n g
SEDIMENT CLEANUP
and brownfield redevelopment

by

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A PUBLICATION OF THE

NORTHEAST-MIDWEST

INSTITUTE

TABLE OF CONTENTS

Summary	3
Sediment-Brownfield Connection	3
Nature of Sediment Contamination	4
Extent of the Problem	4
Sediment Cleanup Approaches	5
Dredging	5
Capping, Containment, and Treatment	6
Challenges of Sediment Remediation	7
Securing Funds for High Cleanup Costs	7
Determining Cleanup Standards and Guidelines	7
Coordinating Multiple Cleanup Authorities	8
Barriers to Linking Contaminated Sediment Cleanup and Brownfield Redevelopment	10
Case Studies: Integrating Sediment and Brownfield Remediation	11
Use of Voluntary Cleanup Agreements to Avoid Superfund Listing	11
Sediment Cleanup to Remove a Stigma at Brownfield Sites	14
Brownfield Cleanup to Spur Sediment Removal and Containment	15
Use of Brownfields as Sediment Repositories	18
Addressing Sediment through State Voluntary Cleanup Programs	19
Conclusions and Recommendations	20
Appendix: Innovative Treatment Technologies for Contaminated Sediment and Sludge	21
Endnotes	24

SUMMARY

The cleanup of contaminated sediment and redevelopment of brownfield sites appear to be complementary. In many cases contaminated sediment and brownfields are found in close proximity to one another, often along waterfront areas that are in high demand for residential and commercial redevelopment. Yet for many reasons, sediment and brownfield remediation are rarely linked.

As demonstrated by several case studies, a growing but still small number of communities are finding ways to jointly address contaminated sediment

and brownfield redevelopment. By recognizing and reinforcing the connections between these sites, federal, state, and local entities may achieve more efficient and cost-effective cleanup and redevelopment. These connections could be strengthened by clarifying the guidelines for addressing sediment contamination; creating mechanisms for coordinating sediment and brownfield programs; and developing information about the potential benefits of integrating sediment and brownfield cleanup.

SEDIMENT-BROWNFIELD CONNECTION

The essential difference between sediment contamination and brownfield contamination is that sediment lies under surface water. Contaminated sediment is soil, sand, organic matter, or minerals that accumulates at the bottom of a water body and contains toxic or hazardous materials that may adversely affect human health or the environment. Brownfields are abandoned, idled, or underused industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived contamination — on the land, in the groundwater, or in buildings.¹

In waterfront areas, the most obvious connection between contaminated sediment and brownfield sites is their close proximity. Historically, rivers afforded ideal locations for industrial facilities because they provided transportation corridors for raw materials and finished products. Through decades of largely unregulated discharges, these industrial sites and adjacent waterways became contaminated. In fact, an estimated 5 to 10 percent of the nearly 500,000 existing brownfields are located beside a waterway.

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NATURE OF SEDIMENT CONTAMINATION

Industrial facilities historically have contributed contaminants to surface waters through direct discharges from pipes. Over time, these contaminants settled into the sediment that lies beneath the water. Today, contaminants may leach into aqueous sediment through groundwater and subsurface plumes, in many cases from leaking underground storage tanks. Surface runoff from contaminated sites and overflows from sewage treatment plants also contribute to sediment contamination. In addition, particulate matter in the air that is deposited in surface waters can contaminate sediment.

Sediment contaminants include five types:

- Nutrients — phosphorus and nitrogen compounds
- Bulk Organics — oil and grease
- Halogenated Hydrocarbons or Persistent Organics — DDT and PCBs that resist decay
- Polycyclic Aromatic Hydrocarbons (PAHs) — a group of organic chemicals that includes several petroleum products and byproducts
- Metals — iron, manganese, lead, cadmium, zinc, mercury, and metalloids such as arsenic and selenium

EXTENT OF THE PROBLEM

Contaminated sediment causes numerous environmental, recreational, and economic impacts. The release of excess nutrients causes red tides, contaminates shellfish, kills wildlife, reduces biodiversity, destroys sea grass, and contributes to a host of other ecosystem problems. It also promotes the growth of algal blooms that reduce the oxygen available to fish and create sections in water bodies that are aesthetically unappealing for boating or swimming. Toxic contaminants in sediment can enter the

food chain, causing human health risks from fish consumption. Sediment contaminants also can decrease the reproduction of ducks and fish, affecting local economies that depend on tourist dollars from bird watching, hunting, and fishing.²

Most of the nation's contaminated sediment sites are found in California, Washington, and the eastern half of the United States along the coast and inland waterways. Many of these sites are concentrated in the Great Lakes and the harbors of Boston, Chicago, Detroit, Los Angeles, and Puget Sound.

To determine the severity of the contamination problem, the U.S. Environmental Protection Agency (EPA) in 1998 assembled the largest set of sediment chemistry and related biological data ever compiled into a national database called the National Sediment Inventory. The inventory includes approximately two million records, collected from 1980 through 1993 from more than 21,000 monitoring stations. The inventory identified approximately 2,400 river reaches (water body segments) in 50 states where adverse effects from contaminated sediment are probable. In a January 1998 report to Congress based on the inventory, EPA identified 96 watersheds that contain "areas of probable concern"

Areas of Probable Concern

EPA defines Areas of Probable Concern as those areas with at least ten Tier 1 sampling stations and a total number of Tier 1 and Tier 2 sampling stations that account for at least 75 percent of all sampling stations in the area. At Tier 1 stations, associated adverse effects from the contamination are probable. At Tier 2 stations, associated adverse effects are possible, but expected to be infrequent.

Source: EPA National Sediment Quality Survey, 1998

(APCs). (See box on previous page.) APCs are areas where further study of the effects and sources of sediment contamination is warranted. According to EPA, “A reasonable estimate of the national extent of contamination leading to adverse effects on aquatic life is between 6 and 12 percent of sediment underlying surface waters.”³

Frequently, disturbed sediment recontaminates water bodies. According to the International Joint Commission, the U.S.-Canadian partnership dedi-

cated to addressing problems in the nations’ shared surface waters, contaminants buried in the deep sediment (below 10 cm) can be transported back into the water column by two processes. The activity of benthic invertebrates — organisms living on or in the bottom of a water body — can recycle material from as deep as 40 cm to the more active surface layer, and major storms, internal waves, currents, and vessel traffic also can resuspend contaminated sediment.⁴

SEDIMENT CLEANUP APPROACHES

Sediment is assessed to compare the potential environmental and human health impacts of leaving contaminated sediment in place, undisturbed, versus some form of removal or control to prevent exposure. The selection of a remediation technique depends on whether the material is toxic, explosive, reactive, or otherwise dangerous to handle; how severely the contaminants are affecting the ecosystem; and whether the sediment will be transported downstream or remain in place. The cost and feasibility of alternative techniques must be considered, along with their potential to resuspend the toxics into the water column. Each technique has environmental benefits and consequences.

DREDGING

Dredging, one of the most common remediation methods, removes the contaminated sediment from the bottom of a water body. In some cases it is not physically possible to dredge an area; when dredging is feasi-

ble it generally is very expensive. Dredged material may require dewatering, which increases costs. The dredged site also may require air monitoring, dust suppression, and vapor monitoring. Excavation of ditches, streams, and creeks can require the potentially expensive temporary diversion of water. Dredging also incurs costs for transport, treatment, tipping fees, and liability.

The environmental impacts of dredging are widely debated. During the dredging process, contaminated sediment inevitably is resuspended in the water column to some degree. The effect of this suspension depends on the quantity and toxicity of the sediment that is released and the sensitivity of downstream aquatic life to it. Another environmental impact of dredging results from the disposal of dredged material. The safe disposal of sediment, whether it is contaminated or not, has become a challenge. Federal and state regulations increasingly restrict disposal of this material, particularly if it contains contaminated sediment.

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For example, New Jersey in 1997 banned dumping of all sediment off the state's coast.

Dredged material results not only from the removal of contaminated sediment, but also from dredging to make water channels longer and deeper for shipping and navigation. Harbors in particular require periodic dredging to remove accumulated silt. According to a joint report of Taxpayers for Common Sense and the National Wildlife Federation, "Port authorities are now engaged in a race to the bottom to accommodate megaships, which require channels that are at least 50 feet deep. More than a dozen ports are aiming toward that end, which will result in a huge overcapacity of deep draft ports and a mountain of dredge spoils, some of which are highly contaminated."⁵ A contentious debate continues over the economic demand for dredging waterways versus the environmental impacts of disturbing and disposing of dredged sediment.

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CAPPING, CONTAINMENT, AND TREATMENT

Other sediment management techniques include capping and containment. A section of a waterway may be capped if dredging is not required and the area is not affected by storms, subject to erosion or strong undercurrents, or contaminated with a large accumulation of hazardous chemicals in nonaqueous forms. The best caps are finely grained, organically rich, and able to bind with contaminant particles. Capped areas must be monitored periodically to ensure that toxic contaminants are not released. Containment techniques isolate a portion of a waterway by enclosing it within cofferdams, dikes, or other structures. Their environmental impact depends on the quantity of contaminated sediment that is released during construction of the containment structure.

A wide variety of techniques for treating or neutralizing sediment contaminants are being developed. These methods are described in the appendix to this report.

CHALLENGES OF SEDIMENT REMEDIATION

SECURING FUNDS FOR HIGH CLEANUP COSTS

Funding can be a barrier to the cleanup of both brownfield and sediment sites. Most municipalities do not have the capacity and resources to undertake sustained sediment site investigations and cleanups without state and federal assistance. They lack funds, as well as the statutory authority, to investigate common property resources such as aquifers and aqueous sediment.⁶ States also may need to devote their limited resources to more pressing environmental priorities.

Some federal programs provide funding for state and local efforts to address sediment contamination. For example, every state and Puerto Rico has a Clean Water State Revolving Loan Fund, which takes in contributions from the states and EPA and then issues low- or no-interest loans for water quality projects. Congress appropriated \$1.35 billion for the fund in fiscal 2001. The loans may be used for excavation, removal, and disposal of contaminated soil or sediment; phase I, II, and III assessments; construction of wetlands as a filtering mechanism; and excavation and disposal of underground storage tanks.

Several programs in the U.S. Army Corps of Engineers (USACE) can fund beneficial dredging projects. For example, in fiscal 2000 Congress appropriated \$11 million for environmental quality restoration; \$1 million for the beneficial use of dredged material; \$1 million for environmental dredging projects; and more than \$6 million for aquatic ecosystem restoration activities.⁷

According to an EPA study, the vast majority of assessment work at sites with sediment contamination was conducted through Superfund site investigations or with the assistance of USACE.⁸ In the Great Lakes, virtually all U.S. sediment remediation conducted before 1997 was funded as a result of enforcement actions taken against polluters, typically

industries or municipalities. Since then, states such as Michigan have taken steps to clean up contaminated sediment. The Clean Michigan Initiative (CMI), approved in a public referendum in November 1998, funds five programs focused on cleanup, pollution prevention, and redevelopment statewide. In its first two years, the program designated \$25 million for waterfront redevelopment and remediation of contaminated lake and river sediment.

Through CMI, the state initiated cleanup of contaminated sediment in designated lakes and rivers at five sites in the summer of 1999. Five additional sites were being remediated in 2000. The state proceeds with the site remediation while retaining the right to pursue cost recovery against identifiable potential responsible parties. According to Bill Creal of the Michigan Department of Environmental Quality, it will take from five to seven years to clean up a site with contaminated sediment and sort out the liability issues. Without the CMI funding, however, it might take 15 years to implement a management strategy.

DETERMINING CLEANUP STANDARDS AND GUIDELINES

Redevelopment of brownfield sites has been hindered by uncertainty about cleanup standards and guidelines, and similar uncertainty can stall sediment cleanup. Many states lack clear guidelines for determining the pollutant levels that cause adverse ecological and human health effects. Only nine states — California, Florida, Massachusetts, New Jersey, New York, South Carolina, Texas, Washington, and Wisconsin — have developed sediment quality guidelines. Moreover, in most cases it is impossible to quantify how much sediment needs to be cleaned up and to what standard in order to achieve specific social, environmental, and economic improvements.

Recognizing this uncertainty, the Federal Interagency Sedimentation Project is working to improve the data and methodology for assessing sediment contamination. The project coordinates the research of its members, including representatives from EPA, the U.S. Geological Survey, the U.S. Army Corps of Engineers (USACE), the U.S. Bureau of Land Management, the U.S. Department of Agriculture (including the Forest Service), and the Tennessee Valley Authority. For example, the Department of Agriculture is studying physical properties of sediment to determine both the degree to which sediment traps contaminants and the time frame for biodegradation, chemical degradation, and burial of contaminants.

EPA is developing a *User's Guide for Multi-Program Implementation of Sediment Quality Criteria in Aquatic Ecosystems* to assist those who use the sediment quality criteria generated by a variety of environmental programs. The guide will clarify how sediment quality criteria values can be used with the programs for Water Quality Standards, National Pollutant Discharge and Elimination System (NPDES) permitting, Superfund and RCRA investigations, and sediment assessment, prevention, and remediation. EPA also is developing technical information on a method used to derive sediment quality criteria known as the equilibrium partitioning approach. The draft guide and final technical document are expected to be released by 2001.

USACE's Center for Contaminated Sediments consolidates research and facilitates the sediment activities of USACE organizations, the U.S. Department of Defense, other federal and state agencies, academia, and the private sector. USACE also provides guidance on ecological and human health risks associated with upland disposal of dredged

material and is developing a method to rapidly screen sediment for dioxin. USACE is seeking more practical and cost-effective decontamination and detoxification approaches.

COORDINATING MULTIPLE CLEANUP AUTHORITIES

Jurisdictional issues make sediment cleanup projects more complicated than most brownfield redevelopment efforts. More than 60 federal programs can help reduce the amount of sediment entering the ecosystem, treat contaminated sediment, find beneficial uses for sediment, and identify parties who are responsible for legally and illegally dumping toxics into waterways. According to EPA's *Contaminated Sediment Strategy*, "Implementation of these programs by different EPA program offices under a wide range of statutory authorities has created inconsistencies in procedures for assessing the relative risks posed by contaminated sediment and has increased the potential for duplication in the areas of research, technology development, and field activities."⁹

At least nine EPA offices are working on aspects of the sediment issue. EPA and other federal agencies work under a variety of statutes, including the Resource Conservation and Recovery Act; Clean Air Act; Clean Water Act; and Marine Protection, Research, and Sanctuaries Act. According to EPA's

water office, these authorities enable the agency to compel responsible parties to clean up contaminated sites, recover costs for EPA's cleanups from responsible parties, and coordinate with natural resource trustees to seek restitution from responsible parties for natural resource damages.¹⁰

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The coordination of federal programs is complicated further by working with state and local programs, whose jurisdictions may overlap or conflict in areas that are contaminated by multiple sources or cross political boundaries. A National Research Council study concluded, "Federal leadership will be required on issues that span multiple jurisdictions or threaten federally protected species."¹¹ EPA is working to improve the coordination of research and regulatory activities among federal agencies, state agencies, international organizations, and private parties.

In addition, the Coastal America Partnership provides a forum for interagency collaborative action and a mechanism to facilitate regional action plans to protect, preserve, and restore the nation's coastal living resources. Established by a memorandum of understanding in 1992, the partnership includes federal agencies with statutory responsibilities for coastal resources or whose operational activities affect the coastal environment. Its

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primary goals are to build early project collaboration, enhance project benefits, leverage funding, facilitate technology transfer, and improve education and understanding among both the partners and the general public. The partnership focuses on regional activities that provide direct local and watershed action.

Coastal America also fosters collaboration among federal, state, and local agencies and private alliances to address coastal environmental problems. The partnership's interagency teams develop regional plans and strategies that provide frameworks for selecting projects and implementing programs. This planning process seeks to incorporate environmental objectives into regional economic development plans and encourage early identification of opportunities to restore the environment while advancing devel-

opment. More than 400 Coastal America projects are underway throughout U.S. coastal areas.

BARRIERS TO LINKING CONTAMINATED SEDIMENT CLEANUP & BROWNFIELD REDEVELOPMENT

Waterfront brownfield sites are ripe for cleanup and reuse due to growing demand for residential, recreational, and commercial development near fishable, swimmable, and aesthetically pleasing waterways. However, typically it is not possible to couple waterfront brownfield redevelopment and sediment remediation. Under normal circumstances, if contamination is confined to a brownfield and does not affect groundwater or aquifers, state voluntary cleanup programs do not require landowners to clean up the sediment on waterfront lots. (See box.) Innocent landowners do not bear responsibility for historic contamination of sediment by discharges and leaching from their sites. These landowners need only install controls such as fencing to prevent human exposure to contaminated sediment.

Even if state and local governments sought to hold waterfront landowners responsible for cleaning

up adjacent sediment contamination, it would be extremely difficult and costly to prove liability for the small share of sediment contamination that a waterfront property may have contributed. This is because sediment can be contaminated by numerous off-site sources through groundwater, discharges, subsurface plumes, and even the settling of particulate matter from the air.

Because areas of contaminated sediment are numerous and their remediation is expensive and complicated, states and municipalities usually avoid dealing with them unless the contamination causes imminent harm to people or wildlife. Municipalities often separate the issues of upland and aqueous contamination in order to expeditiously return upland sites to the tax rolls or convert them into waterfront parks and greenways.

Jurisdictional Issues that Complicate Linking Sediment and Brownfields

State Authority Over Surface Waters: Since most states claim authority over their surface waters, private cleanups account for only the landward soils unless contamination that is traceable to the property appears elsewhere during any later assessment for different reasons.

Limited Private Landowner Responsibility: Unless the state owns the waterfront property, voluntary cleanup programs for private landowners generally do not require sampling of aquatic sediment. Such sampling occurs only when there is evidence of groundwater contamination and the potential for subsurface flow into the water body.

Superfund Liability: Usually waterfront properties near Superfund waterway sites have offshore aqueous sediment evaluated through the Superfund program, creating a link between waterfront redevelopment and sediment cleanup. However, private landowners of waterfront sites may be reluctant to voluntarily assess their property because of possible liability as a potentially responsible party to the Superfund site contamination. Thus, a water body's proximity to a Superfund site actually may discourage waterfront redevelopment and sediment sampling.

Source: Brian Pietruszewski, *Application of Field-Based Characterization Tools in the Waterfront Voluntary Setting*, U.S. EPA, May - July, 1999.

CASE STUDIES: INTEGRATING SEDIMENT AND BROWNFIELD REMEDIATION

Because contaminated sediment and brownfields typically are cleaned up under different authorities by different agencies, opportunities to link these parallel efforts may be overlooked. Moreover, many indirect linkages may not be readily apparent. They include:

- The willingness of responsible parties to enter into voluntary cleanup agreements for both water bodies and brownfields in order to avoid the listing of a site on the Superfund National Priorities List.
- The potential for contaminated sediment cleanup to remove a stigma and perception of contamination at neighboring waterfront brownfield sites.
- The capacity for brownfield cleanup to spur sediment removal or containment to allow the use of surface waters for recreation or shipping.
- The opportunity to reuse some brownfield sites as repositories for dredged contaminated sediment.

USE OF VOLUNTARY CLEANUP AGREEMENTS TO AVOID SUPERFUND LISTING

As demonstrated by the case of a General Electric site on Connecticut's and Massachusetts' Housatonic River, the specter of listing a waterfront site on the Superfund National Priorities List (NPL) can provide a strong incentive for responsible parties to voluntarily clean up land, water, and sediment contamination. For more than two decades, residents, business owners, environmentalists, community activists, and public officials from Connecticut and Massachusetts have worked to initiate cleanup of the Housatonic River and its floodplain. After three years of intense negotiations, the parties have reached a settlement spurred by the desire of both the responsible party and the community to avoid listing the site under the federal Superfund program. The cleanup plan will restore the river area and redevelop the contaminated site into one of Massachusetts' largest center-city business complexes.

The contamination of the area's soil, groundwater, and sediment was well documented over the past twenty years by General Electric (GE), the Massachusetts Department of Environmental Protection (DEP), and the U.S. Environmental Protection Agency (EPA). However, area residents and businesses were divided over which strategies should be used to ensure that GE, the sole responsible party, would pay for the cleanup. Most of the residents and citizens wanted an expedited settlement without resorting to the Superfund program, which entails the stigma and procedural delays of a listing on the NPL. The recent agreement would allow treatment and remediation at the GE site under the supervision of EPA.

History of Contamination: Located in western Massachusetts and emptying into Long Island Sound, the Housatonic River is contaminated with PCBs, a potential human carcinogen. (See box.) The contamination can be traced directly to the Pittsfield GE site, which historically is the sole producer and major handler of PCBs in western Massachusetts. From the 1930s to 1977, GE used PCBs in its Pittsfield operations to produce electrical transformers, capacitors, and other equipment. GE disposed of PCB-laden material in wetlands, ravines, and the river and its riverbank until PCBs were banned in 1977.

Polychlorinated Biphenyls (PCBs)

For years, PCBs have been used as lubricants and coolants in electrical equipment because they are nonflammable and provide excellent insulation. These compounds usually appear as an oily liquid that can persist for decades or much longer in the environment. PCBs are a probable human carcinogen and pose special risks to pregnant women. They also are linked to problems with intellectual functions in children and affect the nervous, immune, and reproductive systems. PCB manufacturing was banned in 1977.

In the 1940s and 1950s, GE also offered free fill material to residents and businesses in Pittsfield. It was later discovered that this material was laden with very high concentrations of PCBs. The contaminated fill also was used in the oxbows created after the U.S. Army Corps of Engineers straightened a section of the Housatonic River.

The extent of the PCB contamination roughly coincides with the ten-year flood plain of the Housatonic River. The level of PCB contamination in Pittsfield and the Housatonic is so extensive that DEP required GE to remove soil from many residences in the 1990s under the Massachusetts Contingency Plan, which enables state regulators to categorize, determine oversight procedures, and set standards for site cleanup. DEP and EPA discovered PCB levels greater than 100,000 parts per million (ppm) in soil from the Housatonic's riverbank (the EPA considers 2 ppm to be a safe level for residential areas).

Surveys concluded that the level of PCBs at the site may adversely affect fish and stress bottom-dwelling organisms. PCBs tend to accumulate in fatty tissue and become more concentrated as they pass through the food chain. PCBs also may migrate downstream because they are readily absorbed in the fine sediment found in slow-moving sections of the river and behind the dams. Storms or other high flow events may cause resuspension of PCB-laden sediment and result in sediment transport and deposition further downstream.

Negotiations: The discovery of the PCB contamination in the city, the river, and the GE facility, and ensuing discussions about the cleanup strategy divided Pittsfield into several factions. Some groups in the town of 48,000 wanted to sue GE and put the site on the Superfund NPL, but others urged all parties

to negotiate a settlement in hopes that a cleanup could get started quickly.

Initially, GE cooperated with EPA and state officials in the investigation and remediation of the site pursuant to state laws and the federal Resource Conservation and Recovery Act (RCRA), which governs corrective action for contamination at operating facilities. However, progress under RCRA was slow and additional contaminated sites were being located while the parties negotiated.

In 1997, EPA Region 1 proposed the GE-Housatonic River site for NPL listing, in order to shift the site jurisdiction from RCRA to the Comprehensive Environmental Response Compensation and Liability Act (CERCLA), or Superfund, regime. CERCLA designation would allow EPA to spend Superfund money on cleanup and then bill GE for its costs. Some property owners supported the CERCLA listing as the most certain means of accomplishing the cleanup.

GE countered by suing EPA in April 1998, contending that EPA proposed the listing only to gain a bargaining advantage, not because the site met the criteria for listing under CERCLA. GE opposed the listing in part due to concern about the company's public image. The mayor of Pittsfield and some local business owners joined GE in opposing the listing, concerned about its stigma, and fearing it would cause property values to plummet. In addition, the mayor believed an NPL listing would further delay the start of cleanup activities because GE would fight the listing in court, and the mandatory provisions of Superfund cleanups can extend the duration of cleanup itself. In fact, a March 1997 General Accounting Office study found the time required for Superfund cleanups had increased from less than four years in the early 1980s to more than ten years.

All parties sought a workable plan that would restore the city and river, redevelop the GE facility, and avoid resorting to the Superfund program.

After three years of negotiations, in September 1998, the parties reached what they consider a satisfying conclusion.

Partnerships in Play: Negotiations continued among EPA Region 1 and GE, as well as numerous other parties, including representatives of Pittsfield, Connecticut, Massachusetts, the U.S. Fish and Wildlife Service, the U.S. Department of Justice, and the National Oceanic and Atmospheric Administration. All parties sought a workable plan that would restore the city and river, redevelop the GE facility, and avoid resorting to the Superfund program.

After three years of negotiations, in September 1998, the parties reached what they consider a satisfying conclusion when GE and EPA Region 1 agreed to a modified cleanup agreement. The negotiating parties agreed that the actions required in the settlement will protect humans from future risks, clean up the river and improve the natural resources, and create a refurbished facility that will benefit Pittsfield's economy. The parties decided to accelerate and expand the cleanup process in the river, the flood plain, and in the city while the agreement was scrutinized by the U.S. District Court and released for public comment. However, EPA still may add the facility to the NPL if necessary to obtain additional money and enforce GE's responsibilities to restore the site.

Consent Decree Provisions: The consent decree describes the actions that GE will take to remediate the sites and restore some of the natural environment. The decree covers 11 former oxbows of the river that were filled with GE waste; a PCB spill at GE Building 68; approximately eight miles of PCB-contaminated flood plain soils; river sediment; two landfills; and areas of contaminated soil in Pittsfield. GE has spent \$114 million so far on removing PCB oils from the plant, rebuilding a dam to prevent downstream PCB transport, installing the new groundwater and oil recovery systems, and removing contaminated soil from flood plain residential properties and the nearby schoolyard. The settlement is expected to cost GE an additional \$200 million to \$750 million.

Under the consent decree, GE will demolish antiquated vacant buildings, refurbish others, and clean up contamination at the site to create one of the state's largest new center-city business complexes on about 20 percent of the 250-acre site. This area will be turned over to the Pittsfield Economic Development Association (PEDA). Created by the Massachusetts Legislature in 1998, PEDA will plan for the cleanup, redevelopment, and marketing of the site. PEDA can issue revenue bonds to fund redevelop-

ment, refurbish the 100-year-old GE facility, and prepare it for new tenants.

The site can accommodate 700,000 to 1 million square feet of building space. The city plans to house prospective tenants at the demolition site by creating temporary office space, rent free, for up to six years. Because only one building on the 250-acre site was listed on the Superfund NPL, prospective tenants may use several state financial and tax incentives that support brownfield redevelopment. Already a large electric vehicle manufacturer, EV Worldwide, plans to occupy part of the site, bringing an expected 1,000 jobs over five years.

Negotiated Cleanup Standards and Remedies

The GE plant site will be cleaned up to allow for the commercial/industrial use of the property, with environmental restrictions and easements placed on all GE-owned properties to ensure that current uses will not change. As part of the agreement, GE must make the property at the site that it does not own safe for current use through a combination of cleanup and deed restrictions (with appropriate compensation to the property owners).

If a property owner proposes to EPA a legally permissible new use for the property, GE must clean up the site to the standard of the future use. For example, if a commercial property were to be converted to a recreational area, the cleanup standard would increase from 25 ppm to 10 ppm. At residential properties along the river, the sites will be cleaned up to 2 ppm, while nonresidential areas will be required to adhere to the standards listed above.

Soil from the 26-acre Silver Lake, which contains as much contamination as the entire river south of GE, will be removed and the lake will be capped. The shoreline will be cleaned and landscaped and some type of recreation area will be created at the lake. A landfill at the GE facility will be capped and an extensive groundwater monitoring system established to monitor the groundwater surrounding the landfill. A leachate collection system and liner will be installed. Dredged material from the first half-mile of the river will be stored in this area. An additional area may be used and will be designed in a similar manner.

GE will give the city more than \$10 million in direct economic aid, including \$1 million per year for ten years to offset lost tax revenues. GE will fund marketing studies to help the city attract new tenants and make the buildings handicapped accessible. The company's total cost will be between \$45 and \$50 million.

To mitigate the damage to wildlife, wetlands, and the Housatonic, GE must fund a \$15-million natural resource damage package that will restore, replace, or acquire the equivalent of areas that were contaminated by GE's operations. These measures include habitat enhancements such as herbaceous native grassland species, riparian communities, and wetland protection. In addition, GE will provide \$6 million in project work.

If PEDA succeeds in attracting new tenants and owners to the site, it will be required under the consent decree to contribute \$4 million for natural resource restoration. Thus, the consent decree directly links the success of the redevelopment with the restoration of the area's natural resources.

SEDIMENT CLEANUP TO REMOVE A STIGMA AT BROWNFIELD SITES

Waukegan Harbor, on Lake Michigan in the city of Waukegan, Illinois, illustrates the complexity of the sediment-brownfield relationship. For years, the harbor could not be dredged to better accommodate commercial shipping because it was heavily contaminated with PCBs. Without a harbor depth to support shipping boats at their full capacity, area industries suffered escalated shipping costs that discouraged the growth of shipping-dependent industries.

At the same time, historic sediment contamination created a perception of severe contamination

throughout the area, inhibiting private investment in developing vacant brownfield sites near the harbor.

Therefore, sediment remediation in Waukegan Harbor had the potential to support brownfield redevelopment in two ways: by allowing the dredging needed to revive the area's industrial base, and by restoring a positive perception of the area for redevelopment.

Harbor Significance: Overall, Waukegan Harbor is an area primarily focused and dependent on commercial and industrial uses, with sport fishing and recreational boat use also contributing to the economy. Located midway between Milwaukee and Chicago, the harbor is an important shipping port and also is designated as the only harbor of refuge for commercial vessels operating between the two cities. Almost all of the area's economic activity and municipal services depend in some manner on the harbor. The National Gypsum Company reports that harbor commerce supports 7,000 jobs with an annual payroll of \$25 million.¹²

According to a 1997 dredging case study report issued by the U.S. Department of Transportation's Maritime Administration (MARAD), the harbor desperately needs dredging to support shipping. Authorized to a depth of 23 feet, the harbor was last dredged in 1972 to 18 feet and has since silted in to 16 feet. The shallower depth requires many vessels to light load to up to 40 percent of capacity. Three of four industries participating in a 1994 survey reported having to alter normal shipping procedures in order to accommodate shallower water depths. For example, National Gypsum's ships have a capacity of 23,800 tons, but because of diminishing water depth they could load only 15,300 tons in 1998, 13,600 tons in 1999, and 11,500 tons in 2000. Light loading can increase annual shipping costs by hundreds of thousands of dollars.

Sediment remediation in Waukegan Harbor had the potential to support brownfield redevelopment in two ways: by allowing the dredging needed to revive the area's industrial base, and by restoring a positive perception of the area for redevelopment.

Contamination and Cleanup: In 1981, when Waukegan Harbor was designated an Area of Concern by the International Joint Commission, initial studies showed approximately 136,000 kilograms of PCBs in the harbor proper, with some of the most highly contaminated sites having concentrations as high as 500,000 mg/kg — 10,000 times the level subsequently deemed to be safe.¹³ Outboard Marine Corporation was identified as the primary source of PCBs.

In all, 453,600 kilograms of PCBs were removed from the harbor, leaving no sediment with PCB levels of more than 50 mg/kg — the level specified in the consent decree. Outboard Marine Corporation assumed the \$20-25 million cost of cleanup. With these environmental dredging measures taken, a plan was developed for renewing maintenance dredging efforts in the harbor, with implementation of the plan scheduled for 2002. As of May 2000, 300,000 cubic yards of sediment contaminated with low levels of residual PCBs had yet to be removed.

Area Redevelopment: By the mid-1990s, heavily contaminated sediment had been removed from the harbor. Cleanup of two nearby Superfund sites was nearly complete, and negotiations at a third Superfund site were proceeding. However, the stigma of contamination remained and potential developers and businesses feared liability for residual pollution. The perception was reinforced when the city of Waukegan purchased a former gas station to convert into a park, only to discover two leaking underground tanks that cost \$180,000 to clean up.¹⁴

To relieve the stigma, Illinois EPA (IEPA) launched a pilot under its 1996 brownfield initiative to conduct preliminary site assessments on the harbor waterfront. Working with local officials, IEPA selected sites that were primed for redevelopment. Today two of the sites, which were found to be mostly free of contamination, are being redeveloped into a theater and housing project. Additional sites are undergoing assessment, clearing the way for further development.

It is widely held that there would have been no interest in redeveloping the area at all if the sediment contamination had not been addressed. The cleanup of the harbor and neighboring sites, coupled with IEPA's brownfield initiative, helped stir interest in redeveloping the harbor area. Subsequently, the results of IEPA's site assessments are expanding the opportunities for brownfield redevelopment that the harbor cleanup began.

BROWNFIELD CLEANUP TO SPUR SEDIMENT REMOVAL AND CONTAINMENT

In some cases, redevelopment of a brownfield provides the impetus to clean up or contain contaminated sediment in adjacent surface waters. For example, the stagnant Malden River in Massachusetts will be restored through an ambitious redevelopment project known as TeleCom City. A lake in Hammond, Indiana, and a pond in Astoria, Oregon, were rehabilitated in conjunction with brownfield redevelopment, and became attractive amenities for the area. In Bay City, Michigan, redevelopment of a brownfield site for industrial use spurred the cleanup of sediment contamination near the mouth of the Saginaw River so that the waterway could be dredged for shipping use.

TeleCom City, Massachusetts: About five miles north of Boston, three cities abutting the Malden River in the Mystic Valley joined forces to transform a 207-acre brownfield into a state-of-the-art telecommunications research and development park called TeleCom City. As a result of the TeleCom City project, the heavily contaminated Malden River will be restored as well.

Currently, more than 70 percent of the TeleCom City site is covered by asphalt. Much of the site was built on former wetlands and tidal areas that were filled with foundry refuse from the Jupiter Steel Casting Company. Coal storage yards, lumber companies, leather tanning, coal gasification, metal finishing, and textile and chemical manufacturing operated on the site until the early twentieth century. The Malden River flowed through the site, providing an important transportation corridor for the businesses there.

As the industries and technologies changed over the last century, the Malden River became obsolete as a transportation corridor. It was dammed in the early 1960s, becoming a stagnant pond, 300 feet wide and a mile long, polluted by nonpoint sources and combined-sewer overflows. Pollutants from Allied Chemical and the former Monsanto Chemical Company contaminated the river's sediment, and oil, organic material, coal tars, and polyaromatic hydrocarbons have been found in the core samples. Toxins from upland locations continue to migrate into the river, resisting several efforts to correct the problem.

Chemical companies hit hard by environmental issues disappeared from the site by the 1970s. The Massachusetts Department of Environmental Protection (DEP) has listed nine sites in the 207-acre parcel as confirmed or potential hazardous waste sites — one of the highest concentrations of listed sites in the Commonwealth. Although some parcels were converted to industrial or public use through federally funded urban renewal programs, today more than 70 percent of the land is severely underutilized and 68 percent of the existing buildings are obsolete, physically deteriorated, or unsuitable for conversion or improvement.

Despite its contamination, the site was chosen for the TeleCom City project because it is uniquely suited to serve as the physical and technological focus for Massachusetts' telecommunications industry. The site's location is its greatest amenity, providing ready access to universities, business development, public transportation, and Logan Airport. Moreover, the site's riverfront setting could become an asset and focal point for the development.

The local governments joined with federal officials led by Senators Edward Kennedy and John Kerry, Congressman Edward Markey, and the Weld-Cellucci administration to develop an innovative plan to transform the blighted industrial land. According to TeleCom City's Master Plan, the project will be worth an estimated \$750 million when built out to a three-million-square-foot facility, housing hundreds of technology companies, generating an estimated \$450 million on-site payroll, and quintupling the area's current tax base from \$1.1 million to \$6 million. The virtual global technology park will be a self-contained research and development facility, combining a technology transfer and licensing consortium of regional universities and corporations, a product commercialization center, a

manufacturing center, and an advanced communications infrastructure.

The mayors of Malden, Medford, and Everett signed an agreement in March 1995 to create the

Mystic Valley Development Commission (MDVC), a joint economic development agency that oversees the TeleCom City project. Governor William Weld and the state legislature established MVDC the following year. MVDC acts as the area's central permitting authority and is responsible for zoning, regulatory, and tax requirements for TeleCom City. MVDC manages the local real estate taxation in the project area, dividing the tax revenues according to a land ownership formula.

The Master Plan calls for a substantial program of acquisition, clearance, and infrastructure development in partnership with Massachusetts and the New York developer Priotte, Lane, and Associates Ltd. To overcome fragmented ownership and liability constraints, the MVDC will obtain ownership control over the project area and establish a consistent set of zoning controls, which will allow for the comprehensive environmental testing of the area without the constraints of parcel boundaries. The MVDC has the power of eminent domain and will act as the area's

central permitting authority.

Because residents of the three cities have been cut off from the Malden River for such a long time, there is not a strong push to restore the river to its natural conditions. The cleanup will make the river safe enough for boating, but not fishing or swimming. The Master Plan calls for a 50- to 60-acre landscaped area for public access to the river by boardwalks and overlooks, and vegetation will be planted to deter direct contact with the river. The project abuts the 70-acre Mystic River Reservation, one of the largest open space systems in the northern metropolitan

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Boston region. In addition, Bike to the Sea, Inc., is constructing a ten-mile bicycle path to occupy the abandoned railroad track along the river's eastern boundary.

Hammond, Indiana: Hammond's George Lake is a shallow lake surrounded by industrial facilities, including the Bairstow site, a 97-acre former steel mill waste dump for slag (the residual material from smelting). The city of Hammond acquired the site for a lake restoration project, including a youth golf course, adult golf course, and wetlands restoration. Soon after, the city obtained an EPA grant for a \$200,000-Phase I and II site assessment.¹⁵

The site restoration involved capping 100 acres of slag field, with 46 acres completed to date and the remaining 54 underway. The first 46 acres were capped with about 60,000 cubic yards of bottom ash from the site. The ash, of the consistency of clay, forms an impervious surface to be covered with soil and grass for the golf course, which then will be outfitted with a drainage system to channel any surface water runoff.

The assessment included sediment sampling in the lake, which found minor elevated pH levels that were caused by groundwater and surface water runoff from the brownfield. The lake bottom is being dredged to increase the depth of the lake's south basin from two feet to ten feet, primarily to support fishing, eliminate the growth of invasive species that thrive in shallow water, and provide a place for fish to winter. This dredging will remove 200,000 to 300,000 cubic yards of sand and sediment that can be mixed with "new earth" from a Hammond Sanitary District lagoon and lime from a nearby BP/Amoco site for use as the cap on the remaining 54 acres of the Bairstow site. The sand and sediment also will be used on the golf courses. In addition, the city is reconstructing the shoreline with 12 new acres of wetland.

Thus, the Bairstow site redevelopment has cleaned up and enhanced George Lake, created ben-

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eficial uses for the lake sand and sediment, and created an attractive lake and wetland that provide an amenity for the recreation area. In fact, the rehabilitation of the once blighted area has convinced the owners of the adjacent BP/Amoco industrial site to invest in redeveloping their property.

Bairstow's redevelopment also illustrates the power of cooperation. EPA funded a large share of the project through brownfield and watershed restoration grants; the state department of natural resources provided \$1.5 million to deepen the lake; and both agencies are working with the state department of environmental management, the U.S. Fish and Wildlife Service, and BP/Amoco to complete the project.

Astoria, Oregon: The redevelopment of a brownfield site in Astoria, Oregon, is having a similar effect of rehabilitating a pond with contaminated sediment. The three-acre pond is located in the middle of a sixteen-acre site on the banks of the Columbia River. The site once housed a plywood mill that floated logs down the river and into the pond. Over time, the pond became contaminated with petroleum from the mill's activities.¹⁶

When the city of Astoria proposed redeveloping the site for residential use, the Oregon Department of Environmental Quality (DEQ) worked with the city to devise a cleanup plan. They found that the sediment was not highly contaminated, and cleaning it up would be prohibitively expensive. In addition, natural biological processes already at work would eventually remove the contamination. Therefore, DEQ agreed to leave the contaminated sediment in place if the city established institutional controls to prevent human and wildlife exposure. The institutional controls include deed restrictions on each housing lot that prohibit recreational use of the pond. To deter trespassing, the developer will grade the bank line and surround the pond with dense

native vegetation — an aesthetically appealing alternative to fencing.

In addition, mechanisms have been created to maintain the pond's depth because the Columbia River is subject to rising and falling tides of 11 feet. At low tide, the water drained from the pond, leaving a mud flat that exposed the contaminated sediment. To maintain the pond's depth and prevent contact with the sediment by humans and shore birds, a barrier was installed at the pond's 30 foot-wide opening to the river. The barrier was set at an elevation that allows daily water exchanges between the pond and the river to prevent stagnation, but also maintains a water depth that ensures the sediment is not exposed.

The developer could have simply filled in the pond, but now it provides an amenity and open space for the community. DEQ will regularly monitor the site's groundwater and pond sediment to determine to what degree the petroleum contaminants have broken down. The contaminants are expected to diminish to safe levels within 15 years, enabling the institutional barriers on use of the pond to be lifted.

Bay City, Michigan: In the Bay City area on the Saginaw River, a state waterfront development grant has indirectly spurred redevelopment of a brownfield site and cleanup and disposal of contaminated sediment.¹⁷

The state of Michigan provides waterfront development grants, redevelopment loans and grants, and Clean Michigan Initiative (CMI) funding to address environmental issues that discourage the redevelopment of contaminated sites. These funds are specific to upland areas, and generally contaminated sediment does not affect their use because dredging may not be required for waterfront redevelopment. Also, sediment already is being addressed by other programs — a natural resource damage settlement with the state and U.S. Fish and Wildlife Service has

provided money for federal and state efforts to dredge PCB "hot spots" in the river.

However, in the case of one waterfront development grant, a facility that handles aggregate needed to be relocated from the downtown area to an industrial area closer to the mouth of the Saginaw River.

The new site is a brownfield that formerly served as a bulk oil terminal. Because the relocated aggregate facility requires access to shipping, about a quarter-million cubic yards of contaminated sediment must be dredged from the boat slip and part of the river to give the facility access to the shipping channel. The sediment will be shipped to a certified facility for disposal. Thus, reuse of the brownfield led to dredging of the waterway and, finally, the cleanup of contaminated sediment.

In the Bay City area on the Saginaw River, a state waterfront development grant has indirectly spurred redevelopment of a brownfield site and cleanup and disposal of contaminated sediment.

USE OF BROWNFIELDS AS SEDIMENT REPOSITORIES

Occasionally brownfields with limited redevelopment potential can serve as repositories for contaminated sediment, providing both a beneficial reuse of the site and an urgently needed

repository for dredged material. According to the Ashtabula River Partnership, the site of a former sodium plant provides an ideal location for the contaminated sediment from the river.¹⁸

The brownfield is a decommissioned sodium plant that houses several old buildings and structures, some of which need to be torn down. The cleaned site is not well suited for redevelopment and is adjacent to the landfill where the sediment from the Fields Brook Superfund site is disposed. The draft comprehensive management plan-environmental impact statement for the Ashtabula River anticipated disposing the sediment in another landfill. However, a newly revised plan selected the sodium plant site as the sediment repository because it has no wetlands and will reduce by two-thirds the distance the sediment must be transported from the river to the site.

ADDRESSING SEDIMENT THROUGH STATE VOLUNTARY CLEANUP PROGRAMS

A few state brownfield and voluntary cleanup programs (VCPs) explicitly address sediment contamination or create opportunities for linking sediment remediation with brownfield redevelopment. In Maine, if responsible parties can be identified, they must clean up both the brownfield and the sediment that was contaminated by the brownfield's discharges. Maryland's voluntary cleanup program requires Phase I and II site assessments that include sampling of surface water and sediment samples from water bodies that are located on the contaminated property or affected by discharges from the property.

In 1991, Washington became the first state to adopt sediment quality criteria, including narrative standards and numeric biological and chemical effects criteria. The state developed a decision framework to use those criteria in deciding when to list a contaminated site, require cleanup, require source controls to protect sediment, and prohibit the disposal of dredged material in open waters.

Washington also has a program to search for the upstream property owners that are responsible for sediment contamination. Using core samples, it is possible to determine the historical source of contamination, although coring has its limits and works better in lakes and ponds than it does in flowing systems. Once the responsible parties are identified, negotiations determine their percentage of responsibility for the cost of the environmental assessment and cleanup. An assessment is not required by law, but

banks and insurance companies will not approve the sale or transfer of the property until an assessment and any necessary cleanup are complete.

In Michigan, brownfield redevelopment usually does not involve sediment. The state's liability scheme relieves new landowners of liability for contaminated property after they perform a baseline environmental assessment (BEA). Once owners or developers complete a BEA, they are not held responsible for historic contamination of sediment from the waterfront site. Moreover, the sediment itself generally is not part of the BEA.

However, the Clean Michigan Initiative (CMI) shows potential for integrating sediment cleanup with brownfield redevelopment, but clear connections have yet to be made. Approved by Michigan's voters in November 1998, CMI funds five programs focused on cleanup, pollution prevention, and redevelopment statewide. In its first two years, the initiative designated \$25 million for waterfront redevelopment and remediation of contaminated lake and river sediment. So far CMI has not spurred joint cleanup efforts by the Michigan Department of Environmental Quality's surface water quality division, which is responsible for sediment, and its environmental response division, which handles brownfields. However, the generous allocation of funding for both types of cleanup through a single state agency creates an unusual opportunity for collaboration.

CONCLUSIONS AND RECOMMENDATIONS

Sediment contamination is a vast and daunting problem, complicated by limited funds and incomplete guidelines for assessment and cleanup. Brownfield redevelopment may create new avenues to address sediment contamination. As the demand grows for residential, recreational, and commercial development near fishable, swimmable, and aesthetically pleasing waterways, opportunities may exist to leverage sediment cleanup with redevelopment at the numerous waterfront sites where contaminated sediment and brownfields coexist.

Anecdotal evidence suggests these opportunities already are available and need only be explored and cultivated to make a dent in the sediment contamination challenge. The following measures could reinforce the sediment-brownfield link.

Establish or clarify guidelines for addressing sediment contamination. Even when state and local governments respond to upland contamination, they may avoid concurrently addressing contaminated sediment because they lack guidelines for determining whether sediment should be removed, capped, contained, or left undisturbed. Many of them need criteria for assessing the risk of sediment contamination and the most cost-effective, environmentally sensitive method of addressing it, similar to the guidelines established by Washington state. This information would remove a significant barrier to concurrently remediating sediment and brownfields.

Create mechanisms for coordinating programs that address sediment and brownfields. As the Michigan Department of Environmental Quality illustrates, even well-funded programs in the same agency have difficulty collaborating on sites of mutual concern. The Clean Michigan Initiative is just one example of a state effort that could establish clear connections between its sediment and brownfield cleanup programs, producing more cost-effective and comprehensive cleanup at waterfront sites impaired by both types of contamination.

Develop information about the potential benefits of integrating sediment and brownfield remediation. Examples such as Waukegan Harbor and Astoria demonstrate the sometimes subtle connections between contaminated sediment and brownfields. The mere perception of a clean waterway and the amenity it provides to neighboring sites can dramatically enhance the desirability of brownfield sites for redevelopment. Moreover, projects that encompass both water and land contamination have access to a host of funding sources associated with sediment, surface water, natural resources, and contaminated sites. These benefits can be illustrated through the small but growing number of projects that include sediment and brownfield cleanup.

APPENDIX

Innovative Treatment Technologies for Contaminated Soil, Sediment, and Sludge

Technology	Description	Contaminants Treated	Overall Cost*	Time Requirements	Resource Requirements	Status
In Situ Treatments**						
Biodegradation	The use of microorganisms to decompose chemical compounds, which would otherwise persist for a long time in the environment.	Most effective on volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), fuels, explosives; less effective on inorganic compounds.	~\$100/cubic meter.	Average	Operation and maintenance (O&M) intensive	Available
Enhanced Bioremediation	The activity of naturally-occurring microbes is stimulated by circulation of water-based solutions through contaminated soils to enhance biological degradation. Nutrients, oxygen, or other amendments may be used to enhance treatment.	Effective in treating petroleum hydrocarbons, solvents, pesticides, wood preservatives, and other organic chemicals. Especially effective in treating low level residual contamination in conjunction with source removal.	\$30-100/cubic meter of soil.	May take several years (slower than average)	NA	Available
Bioventing	Adding oxygen to soil in the vadose zone (above the water table where pores and crevices are not saturated with water) to stimulate microbial activity for bioremediation.	Most effective on VOCs, SVOCs, and fuels; less effective on inorganic compounds.	\$10-\$70/cubic meter.	Slower than average	Neither operation and maintenance intensive nor capital intensive	Available
Land Treatment	Contaminated surface soil is treated in place by tilling to achieve aeration, and if necessary, by addition of amendments. Periodic tilling to aerate the waste enhances the biological activity.	Most successful in treating petroleum hydrocarbons and other less volatile, biodegradable contaminants. Diesel fuel, No. 2 and No. 6 fuel oils, JP-5, oily sludge, wood-preserving wastes (PCP, PAHs, and creosote), coke wastes, and certain pesticides have been treated successfully.	\$30-\$70/cubic meter.	Average to slower than average	NA	Available
Natural Attenuation	Natural processes — such as dilution, dispersion, volatilization, biodegradation, adsorption, and chemical reactions with soil materials — are allowed to reduce contaminant concentrations to acceptable level.	Can be used to treat VOCs, SVOCs, and fuels on a site-specific basis, depending on degree of contamination, geology, and treatment of residual contaminants (e.g., heavy metals).	Usually low, though there are costs for modeling, containment, sampling and sample analysis (potentially extensive).	Usually very slow	Usually neither O&M nor capital intensive	Available, though little guidance exists on use
Phytoremediation	Use of plants to remove, transfer, stabilize, and destroy contaminants in soil and sediment.	May be applicable for the remediation of metals, pesticides, solvents, explosives, crude oil, polychlorinated aromatic hydrocarbons (PAHs), and landfill leachates.	Expected to be low.	Slower than average	NA	Under testing in SITE program
Electrokinetic Separation	Use of electrochemical and electrokinetic processes to desorb, and then remove, metals and polar organics.	Target contaminants are heavy metals, anions, and polar organics.	Little available information; indications of \$50/cubic meter and up.	NA	NA	Few trials in the United States; more in Europe
Soil Flushing	Use of chemical amendments and fluid pumping to mobilize and recover contaminants. May also use surfactants to decrease surface tension of contaminants (NAPLs) or cosolvents to increase solubility of NAPLs.	Target contaminant group is inorganics, including radioactive contaminants. Can be used to treat VOCs, SVOCs, fuels, and pesticides, but may be less cost-effective than alternatives.	Varies widely depending on amendment; \$25-\$250/cubic meter reported.	Short to medium term	Operation and maintenance intensive	Pilot

<i>Technology</i>	<i>Description</i>	<i>Contaminants Treated</i>	<i>Overall Cost*</i>	<i>Time Requirements</i>	<i>Resource Requirements</i>	<i>Status</i>
Soil Vapor Extraction (SVE)	Physical separation of contaminants by creating a vacuum in soil. SVE is the most frequently used innovative treatment. May be used in situ or ex situ.	Target contaminant groups are VOCs and some fuels.	\$10-\$50/cubic meter, plus possible costs of water treatment and off-gas treatment.	Average	Operation and maintenance intensive	Available
Thermally Enhanced Soil Vapor Extraction	SVE can be enhanced by application of heat (generated by steam, hot air, radio waves, microwaves, or electrical resistance) to increase contaminant volatility	Target contaminant group is SVOCs.	\$30-\$130/cubic meter	Faster than average	O&M and capital intensive	Available
Fracturing	Cracks are developed by fracturing beneath the surface in low permeability and over-consolidated sediments to open new passageways that increase the effectiveness of many in-situ processes and that enhance extraction efficiencies. Common techniques include pneumatic fracturing, blast-enhanced fracturing and Lasagna™ process.	Fracturing is applicable to the complete range of contaminant groups with no particular target group.	\$9-\$13/metric ton for pneumatic fracturing. Cost for Lasagna™ is \$180-\$200/metric ton for 1-year treatment; \$110-\$130/metric ton for 3-year treatment.	Varies	NA	Limited availability
Solidification/Stabilization/Containment	This umbrella covers a wide range of techniques to decrease the mobility of contaminants in water. Techniques include removal of water, enhanced sorption with reactive barriers, precipitation/ coprecipitation, lime addition, removal of contaminants through passive/reactive barriers, use of poz-zolonic (cement-like) barriers to decrease soil permeability and bond with contaminants, and the use of low-permeability barriers (slurry walls, sheet pile walls, grout walls) to prevent contaminant transport. May be used in situ or ex situ.	Target contaminant group is generally inorganics, including radionuclides.	Wide variability depending on technique and contaminant; reported costs from \$25/cubic meter to >\$300/cubic meter.	Faster than average	Capital intensive	Available
Vitrification	Combining contaminated soil with amendments needed to form a glass when melted, and melting. Glass is impermeable and relatively stable. Can be used in situ or ex situ.	Most effective on inorganic contaminants; effective on VOCs, SVOCs, and fuels.	More expensive than average.	Faster than average	Both O&M and capital intensive. Requires large amounts of energy.	Pilot
Ex Situ Treatments						
Solar Detoxification	Destroying contaminants by photochemical and thermal reactions using the ultraviolet energy in sunlight.	Target contaminant group is VOCs, SVOCs, solvents, pesticides, and dyes. The process also may remove some heavy metals from water.	NA	Field trials were rapid (e.g., four months)	NA	Pilot
Composting	Contaminated soil is excavated and mixed with bulking agents and organic amendments such as wood chips, hay, manure, and vegetative wastes.	Biodegradable organic compounds, explosives, and PAHs.	Variable depending on technique and contaminant. \$190-\$290/cubic yard reported.	NA	NA	Available
Chemical Oxidation or Thermal Reduction	Use of chemicals that oxidize or reduce (add or remove oxygen from, respectively) contaminants in order to destroy them.	Target contaminant group for chemical redox is inorganics. The technology can be used but may be less effective against nonhalogenated VOCs and SVOCs, fuel hydrocarbons, and pesticides.	\$190-\$660/cubic meter.	Faster than average	Neither O&M nor capital intensive	Available

Technology	Description	Contaminants Treated	Overall Cost*	Time Requirements	Resource Requirements	Status
Substitution (dehalogenation)	Use of organic chemical reactions to convert contaminants into less toxic compounds, typically by replacing halogen.	Target contaminant groups are halogenated SVOCs and pesticides. Dehalogenation is one of the few processes that has been successfully field tested in treating PCBs.	\$220-\$550/metric ton (exclusive of excavation, refilling, residue disposal, or analytical costs).	Inadequate data	O&M and capital intensive to inadequate data	Few full-scale tests
Landfarming	Contaminated soil, sediment, or sludge is excavated, applied into lined beds, and periodically turned over or tilled to aerate the waste.	Most successful in treating petroleum hydrocarbons.	Pretreatment costs \$25,000-\$50,000; \$100K - \$500K for pilot or field test; <\$75/cubic yard to prepare bed.	NA	NA	Available
Fungal Degradation	The use of white rot fungus to biodegrade specific contaminants, including lignin (e.g. Kraft pulping wastes). Can also be used in situ.	Can remediate predominant conventional explosives: TNT, RDX, and HMX. White rot fungus has the potential to degrade and mineralize other recalcitrant materials, such as DDT, PAH, PCB, and PCP2-4. Laboratory testing on lignin, certain PAHs, DDT, TCDD, and PCBs.	Estimated at \$98/cubic meter.	Slower than average	Operation and maintenance intensive	Pilot
Slurry Phase Biological Treatment	An aqueous slurry is created by combining soil, sediment, or sludge with water and other additives. The slurry is mixed to keep solids suspended and microorganisms in contact with the soil contaminants.	Successfully used to treat explosives, petroleum hydrocarbons, petrochemicals, solvents, pesticides, wood preservatives, and other organic chemicals.	\$130-\$200/cubic meter for slurry treatment; \$160-\$210/cubic meter when off-gas treatment is added.	Can be fast	NA	Available
Soil Vapor Extraction	A vacuum is applied to a network of above-ground piping to encourage volatilization of organics from the excavated media. The process includes a system for handling off-gases.	VOCs.	\$10-\$50/cubic meter, plus pilot testing.	12-36 months for a typical site	Neither O&M nor capital intensive	Available
Solvent Extraction	Use of solvents to separate or remove organic contaminants from wastes, soils, sludges, and sediments.	Primarily used for organic contaminants such as PCBs, VOCs, halogenated solvents, and petroleum wastes.	\$110-\$440/metric ton.	Longer than average	Both O&M and capital intensive	Available
High Temperature Thermal Desorption	Removal of VOCs and SVOCs from soil by transfer to gas phase. Vaporized contaminants are captured and destroyed.	Most effective on SVOCs, PAHs, PCBs, and pesticides.	\$45-\$330/metric ton.	Faster than average	Both O&M and capital intensive	Available
Low Temperature Thermal Desorption	Same as above.	Most effective on nonhalogenated VOCs and fuels.	\$45-\$330/metric ton.	Faster than average	Both O&M and capital intensive	Available
Hot Gas Decontamination	Raising the temperature of contaminated equipment or material for a specified period of time. The gas effluent from the material is treated in an afterburner system to destroy all volatilized contaminants.	Applicable to process equipment requiring decontamination for reuse; also to explosive items, such as mines and shells (after removal of explosives), or scrap material contaminated with explosives.	Varies with the amount and type of material being treated.	Faster than average	Both O&M and capital intensive	Available
Incineration	Burning contaminated media to destroy hazardous waste.	Effective on explosives and hazardous wastes, particularly chlorinated hydrocarbons, PCBs, and dioxins.	\$220-\$1,110/metric ton for off-site incinerators; \$1,650-\$6,600 for soils contaminated with PCBs or dioxins.	Faster than average	Both O&M and capital intensive	Available

<i>Technology</i>	<i>Description</i>	<i>Contaminants Treated</i>	<i>Overall Cost*</i>	<i>Time Requirements</i>	<i>Resource Requirements</i>	<i>Status</i>
Open Burn/ Open Detonation	Explosives or munitions are destroyed by self-sustained combustion ignited by an external source.	Explosives, VOCs, SVOCs, fuels, and inorganic contaminants.	NA	Less than average	Both O&M and capital intensive	Available
Chemical Extraction	Waste-contaminated soil and extractant are mixed, dissolving the contaminants. Contaminants and extractant are separated for treatment and further use.	Effective in treating organic contaminants such as PCBs, VOCs, halogenated solvents, and petroleum wastes. Also applicable for the separation of the organic contaminants in paint wastes, synthetic rubber process wastes, coal tar wastes, drilling muds, wood-treating wastes, separation sludges, pesticide/insecticide wastes, and oily waste.	\$110-\$440/metric ton.	NA	NA	Available
Pyrolysis	Chemical decomposition is induced in organic materials by heat in the absence of oxygen. Organic materials are transformed into gaseous components and a solid residue (coke) containing fixed carbon and ash.	Target contaminant groups are SVOCs and pesticides. The process is applicable for the separation of organics from refinery wastes, coal tar wastes, wood-treating wastes, creosote-contaminated soils, hydrocarbon-contaminated soils, mixed (radioactive and hazardous) wastes, synthetic rubber processing wastes, and paint waste.	~\$300/metric ton.	Faster than average	Both O&M and capital intensive	Limited availability
Vitrification	(see in situ treatments, above)					

Source: Gorte, Julie Fox. *Marketing Brownfield Cleanup Technologies*, Northeast-Midwest Institute, February 1999.

*Cost figures exclude costs of testing, assessment, and monitoring, except where noted.

**In situ refers to wastes being treated on-site. Ex situ refers to wastes being taken off-site and treated.

ENDNOTES

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⁹ U.S. Environmental Protection Agency, Office of Science and Technology, *Contaminated Sediment Strategy - Chapters 1-4*, September 1998, p. 15, www.epa.gov/OST/cs/manage/strat1-4.html.

¹⁰ U.S. Environmental Protection Agency, Office of Water, *Contaminated Sediment Management Strategy*, EPA-823-R-08-001, April 1998, p. 57.

¹¹ The National Academies, National Research Council, *National Strategy Needed to Protect Coastal Areas From Dangerous Levels of Nitrogen and Phosphorus*, April 2000, p. 4.

¹² Information on Waukegan Harbor throughout this section is drawn from an internal memo by Jessica Taverna, Northeast-Midwest Institute, September 2000.

¹³ "Areas of Concern" are defined by the U.S.-Canada Great Lakes Water Quality Agreement (Annex 2 of the 1987 Protocol) as "geographic areas that fail to meet the general or specific objectives of the agreement where such failure has caused or is likely to cause impairment of beneficial use of the area's ability to support aquatic life." The U.S. and Canadian governments have identified 43 such areas; 26 in U.S. waters, 17 in Canadian water (five are shared between U.S. and Canada on connecting river systems).

¹⁴ Information on area redevelopment was drawn from personal communication with Greg Michaud, former RAP coordinator, currently of Johnson Depp and Quisenberry, September 19, 2000.

¹⁵ Information on Hammond was drawn from personal communication with Milan Kruszynski, City of Hammond Department of Environmental Management, September 19, 2000.

¹⁶ Information on Astoria was drawn from personal communication with Paul Benoit, Community Development Director, City of Astoria, October 18, 2000.

¹⁷ Information on Bay City was drawn from personal communication with Rhonda Klann, Michigan Department of Environmental Quality, October 13, 2000.