Sierra Club
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Healthy Harbors, Restored Rivers

A Community Guide to Cleaning Up Our Waterways

SIERRA CLUB GREAT LAKES PROGRAM

June 2001

Healthy Harbors, Restored Rivers

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about the sierra club

The Sierra Club is a non-profit, member-supported, public interest organization that promotes conservation of the natural environment by influencing public policy decisions—legislative, administrative, legal, and electoral. The Club celebrated its centennial in 1992 and has over 700,000 members.

Statement of Purpose: to explore, enjoy, and protect the wild places of the earth, to practice and promote the responsible use of the earth's ecosystems and resources; to educate and enlist humanity to protect and restore the quality of the natural and human environment; and to use all lawful means to carry out these objectives.

The Sierra Club's Great Lakes Ecoregion Program works to turn back specific threats to the region. Based in Madison, Wisconsin, the Program has coordinated efforts for over twenty-five years to protect the Great Lakes from air, water, and land pollution. Regional activists employ an ecosystem approach to address environmental problems in the Great Lakes Basin.

Acknowledgements
This booklet reflects the hard work and ideas from organizations around the Great Lakes Basin and beyond. It is based on *A Citizen's Guide: Cleaning Up Contaminated Sediment*, released by the Lake Michigan Federation in 1989. It also draws heavily from two Scenic Hudson publications: *Advances in Dredging Contaminated Sediment* and *Results of Contaminated Sediment Cleanups Relevant to the Hudson River.* Geoffrey Tichenor provided countless hours of editorial and general support services. Special thanks go to Emily Green for her guidance, support, and overarching contributions, Scott Cieniawski from US EPA Great Lakes National Program Office and Josh Cleland from ICF Incorporated for their expertise and review. Additional thanks go to Robert Paulson from Wisconsin Department of Natural Resources and Jan Miller from the Army Corps of Engineers for their technical help, Amy Shenot for editorial help and moral support, Bill Feyerherm for computer wrangling, Sandy Welander for research support, Erin Burg for her bibliographical skills and loose ends management, and Lindsay Riesch for review. And thanks (as always) to Judy Hofrichter and Eric Uram.

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Additional copies are available. Please contact the Sierra Club's Midwest office at 214 N. Henry St. Suite 203, Madison, Wisconsin, 53703.

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getting started

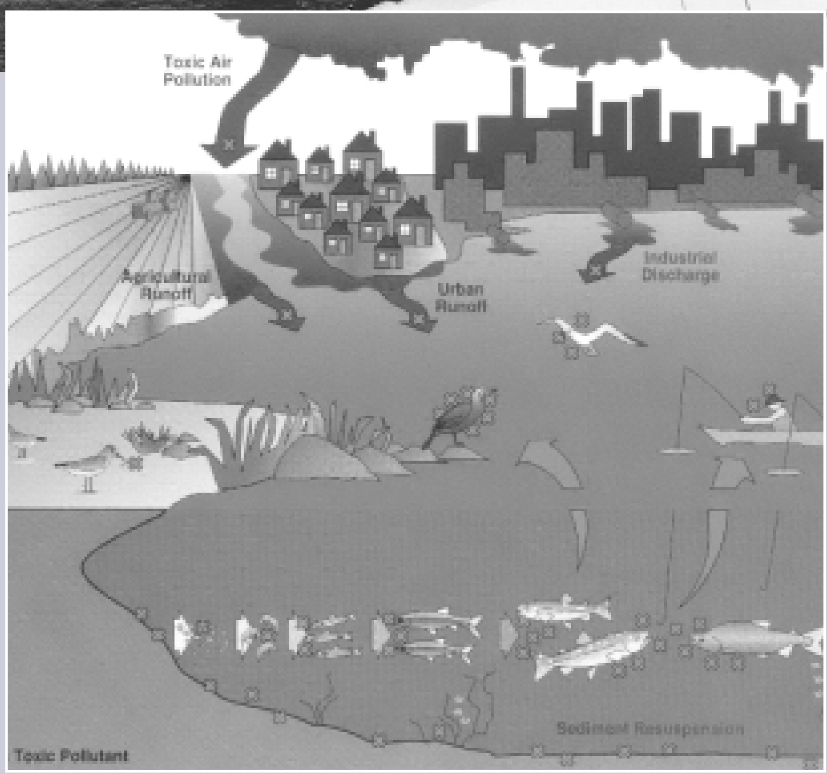
MICHIGAN TRAVEL BUREAU

The Great Lakes are the crown jewels of the Midwest and a natural treasure of worldwide importance. Their crystalline waters support a wealth of life, including species found nowhere else and more than 35 million people who call this area home. They hold one-fifth of the world's fresh surface water and provide drinking water to the majority of people who live around their shores. They are central to the region's manufacturing economy, in addition to being a major source of recreation and tourism dollars. They are the region's economic, ecological, and spiritual lifeblood. They deserve protection.

Though the lakes look clean and clear from years of improving water quality, decades of development and industrialization have left their mark in the form of reservoirs of toxic sediments. While the pollution itself can't be seen, its impacts on the environment, people, and economy are clear. We have many of the tools and much of the knowledge to clean up this toxic legacy. However, generating the will, the resources, and the community involvement needed to take action remains one of our greatest challenges. This guide is designed to help engage communities by laying out a roadmap for cleanup success and providing information on how we can move forward. We hope that community involvement will help society generate the will to take action. By taking action, we can leave our children with water safe for fishing and swimming as well as a vibrant, sustainable economy based on something more valuable than gold – clean, clear water.

how it happened...

NATIONAL PARK SERVICE



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Pollutants come from many sources and cycle throughout the ecosystem.

Until about 150 years ago, sediments entered the Great Lakes very slowly. Moving water pried particles of clay, silt, and sand from matted plant roots and washed them downhill into streams, where more water carried them to river mouths and the lakes beyond. When the water slowed down, the particles dropped out, sank to the bottom, and became sediments.

Settlement and industrialization of the Great Lakes Basin changed this natural process in two ways. First, by clearing vast areas for farming and development, we broke through the matted net of roots that held soils in place, allowing water to wash them downstream much more quickly. Second, rapid industrialization and increasing use of pesticides and other chemicals released a toxic cocktail of pollutants from industrial smokestacks and runoff from roads and fields. Rain and river water mixed these poisons with the soils and carried them downstream. Most of the poisons settled out with the sediments at the bottoms of our rivers, harbors, and bays. The poisons have been pouring out of discharge pipes and sewers, leaching from hazardous waste dumps, and even raining from the sky long enough to have built up dangerous levels in the sediments of many areas around the Great Lakes. The process continues today.

...the problem

Just as the rushing waters accumulate more poisons as they move downstream, poisons also accumulate in the bodies of animals as they move up the food chain. Toxic sediments provide homes and food for plants and creatures – if they don't kill them first. Laboratory tests show that contaminated sediments can be lethal to small crustaceans and insect larvae.[1] Though small and inconspicuous, these creatures occupy a strategic position at the base of aquatic food chains. The organisms that survive exposure to toxic sediments retain some of the toxic chemicals in their bodies. Many chemicals, like heavy metals, PCBs, and other organic compounds, bind themselves to fat or muscle tissues. When smaller organisms are eaten by larger organisms, the chemicals build up or biomagnify. Animals at the top of the food chain, like trout, mink, bald eagles, and people, store more of the chemicals in their bodies each time they eat a contaminated meal.

The governments of the United States and Canada identified 42 areas around the Great Lakes, termed Areas of Concern or AOCs, that have significant pollution problems. All of them suffer the effects of polluted sediments – a toxic legacy that threatens our environment, health, and livelihoods.

Toxic sediments damage our environment. Polluted sediments pose the greatest risk to fish-eating birds and wildlife. Polluted sediments may not kill most fish, birds, or animals, but they can cause birth defects, reproductive failure, and other problems that make long-term survival difficult. For example, studies show that bald eagles living on the shores of the Great Lakes have a significantly lower rate of reproductive success than bald eagles living near inland waters. Double-crested cormorants nesting near the polluted waters of Green Bay are twice as likely to lay eggs with deformed embryos and forty times more likely to have chicks with crossed bills as birds nesting in less polluted surroundings.[2] Mink experience reproductive failure when they eat fish containing as little as 0.3 to 5 ppm (parts per million) PCBs, levels commonly found in Great Lakes fish.[3] Fish in some rivers have much higher than average rates of tumors, because of pollutants in the sediments. Some of the most polluted sites, like Indiana Harbor, are almost barren – few species of fish and other organisms are able to survive the poisons in the sediments.

Toxic sediments threaten our health. Poisons build up in our own bodies when we eat fish from the Great Lakes, just like they do in the bodies of bald eagles. Cancer, developmental problems, immune disorders, learning difficulties and disabilities, reproductive problems, and neurological disorders can all be caused by consuming fish laced with chemicals found in sediments around the Great Lakes.[4] Those most at risk are often least aware of the problem or unable to shift to a different source of food. These people include expectant mothers, developing children, people who rely on self-caught fish as a major food source, and those with cultural ties to eating fish.

BILL STAPP

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[1] Landrum, et. al. 1999.
[2] Colborn, et. al. 1996.
[3] Aulerich, et. al. 1977.
[4] Colborn, et. al. 1996; Greater Boston Physicians for Social Responsibility, 2000; US Department of Health and Human Services, 2000.

The Poisons

The pollutants that place our environment, health, and livelihoods at risk fall into six categories: nutrients, bulk organics, metals, halogenated hydrocarbons or persistent organics, polycyclic aromatic hydrocarbons, and pesticides.

- Nutrients include compounds of nitrogen (ammonia among them) and phosphorous. In small amounts, these nutrients are essential to life. In larger amounts, they cause explosions of algae growth and are toxic to fish.
- Bulk organics are a class of hydrocarbons (chemicals that contain only carbon and hydrogen) and include things like oil and grease. Bacteria that break down bulk organics may use up the oxygen necessary to maintain aquatic life.
- Metals like chromium, manganese, lead, cadmium, and mercury can be toxic to plants, animals, and human beings.
- Halogenated hydrocarbons, or persistent organics, get their name from the fact that each molecule includes a halogen (chlorine, bromine, fluorine, iodine, or astatine). They are persistent because as very stable compounds, they are resistant to decay. Many are highly toxic, such as PCBs and dioxins.
- Polycyclic aromatic hydrocarbons, or PAHs, are a group of organic chemicals that includes several petroleum products and byproducts. Among these are naphthalene, used to make mothballs, and pyrene which causes cancer in fish.
- Pesticides, such as DDT, often persist in the environment for long periods of time. Many, but not all, pesticides also fit in one of the above categories.

All of these poisons can take several forms. Some are dissolved or suspended in the water, while others chemically bind to mineral particles or decaying matter that make up sediments. The amount of contaminants that sediments can hold depends chiefly on two characteristics: the average size of the sediment particles and the amount of organic matter in the sediments. Fine (tiny) particles, clay, and fine silts can hold more contaminants than coarser sands and gravels because the smaller particles provide far more surface area per unit volume to which contaminants can bind. Many contaminants also bind more easily to organic substances than to inert inorganic matter.

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In most states, the first line of defense against these health impacts has been to implement fish consumption advisories – one of the most visible and costly results of the contamination in our waterways. All of the Great Lakes and the majority of their tributaries have fish consumption advisories. The advisories recommend that people limit or avoid consumption of many Great Lakes fish.

Some agencies and industries believe that if we use fish consumption advisories to keep people from eating polluted fish, there will be no risk to human health and thus no reason to clean up polluted sediments.[5] However, advisories are not one hundred percent effective. A recent study found that only about half of all Great Lakes sport anglers were aware of the advisories; and only one third of all women and one fifth of all minority anglers knew of the advisories.[6]

Crossed-bill syndrome can result from exposure to persistent organic chemicals.

This study shows that fish advisories fail to protect the populations at greatest risk. Moreover, relying on fish advisories means giving up our right to safely catch and eat fish from certain areas. This may be unacceptable to those who want to be able to take their children fishing and eat their catch. It is impossible for those who rely on fish as a primary food source or for whom eating fish is a cultural necessity. We must consider all of these issues and recognize that the advisories will remain in effect for generations unless we remove the source of contamination, namely the contaminated sediments.

Toxic sediments damage our livelihoods. Polluted waterways and fish consumption advisories cost communities valuable tourism dollars, as many anglers choose to fish in places where they can eat their catch. A recent study estimated that toxic sediments in the Lower Fox River and Green Bay cost northeastern Wisconsin $65 million in lost recreational fishing and associated tourism revenues between 1981 and 1999. The study also noted that these losses could be turned around by removing the contamination and lifting the fish consumption advisories.[7]

Toxic hotspots also restrict economic growth, urban waterfront development, and revitalization. Contaminated fish have caused commercial and charter boat fisheries to close their doors, putting people out of work. Industries pay more to ship their goods in and out of Great Lakes ports because contaminants prevent channels from being fully dredged. A 1,000 foot long ship must forfeit over 500,000 pounds of cargo for every inch of sediment accumulation in navigation channels.[8] In places like Indiana Harbor, where pollution has restricted dredging for over 20 years, shipping channels are not deep enough for fully loaded ships. Ships leaving Indiana harbor must leave 8.6 million pounds of cargo on shore each year.[9] Toxic sediments dramatically increase the costs for routine navigational dredging as well. Across the Great Lakes, state and local taxpayers pay three to five times more in dredging costs than they would if there were no contaminants, just to keep their ports open.[10]

[5] USEPA, 2001.
[6] Anderson, 1996.
[7] US Fish and Wildlife Service, 2000.
[8] Lake Carriers Association, 1995.
[9] Ibid.
[10] Miller, 2000.

the solution

We do not have to live with this toxic legacy. We have the tools and the knowledge to clean up these toxic sites. We can leave our children with water that is safe for fishing and swimming and with harbors that promote economic growth. Now we must generate the will to take action. This guide provides information to help get the ball rolling.

This guide describes the tools and techniques that can be used to clean up sites with polluted sediment. It begins with an overview of the cleanup process, the opportunities for citizen input, and the broader issues that must be factored into any cleanup plan. It then discusses all of the major techniques and technologies available for sediment cleanup, touching on the pros and cons of each.

The guide is designed to serve as a resource for citizens who are evaluating or developing cleanup plans for sediment sites. It raises questions that people should ask about each cleanup strategy and presents the range of solutions available to address polluted sediment sites. We hope that this guide will help demystify sediment cleanup and will make it clear that there are solutions to this complex problem.

how sediment cleanup usually works

The cleanup process begins with the identification of a site-specific problem, such as tumors on fish or a lack of common bottom-dwelling animals. The first step is to broadly assess the extent of the problem and determine its cause and impacts. More specific evaluations follow in the form of a site assessment and a risk assessment. Site assessment involves extensive sampling to determine the location of the contamination, the nature of the contaminants, the physical characteristics of the site and the sediments, and the impacts of things like water flow, boat traffic, and animals on the site. Risk assessment evaluates the exposure of both humans and wildlife to pollutants, as well as the potential for subsequent health impacts.

After collecting information about the site and the problem, the community at large and environmental agencies must decide what the goals for the site should be. Agencies usually consider this to be a risk management decision, or defining the "acceptable level of risk". For communities, this means deciding what to protect and how quickly to protect it. For example, a community might have to decide whether the goal is to clean up the fish so that people can safely eat them or to rehabilitate the mink population. Then they must decide whether they should achieve the goal in 10, 20, or 100 years.

This guide is designed to help inform these decisions by explaining the options for meeting sediment management or cleanup goals and the tradeoffs associated with various options. In general, the more active cleanup options will meet site cleanup goals more quickly and permanently, but they cost more than low-effort strategies and can require the control or disposal of wastes. The lowest cost options may ultimately meet cleanup goals, but they often require much longer periods of time to be effective and are not necessarily permanent fixes to the problem. The specific tradeoffs associated with each sediment management option, as well as the broader, overarching issues described below, should be considered as part of any "risk management decision" involving polluted sediments.

Thinking About Risk

Risk assessment is the most commonly used method of evaluating and quantifying risks to human health and the environment from pollution. However, it is important to note that risk assessment is an imperfect science at best and cannot account for many factors. Even the most detailed risk assessments:

- cannot account for exposure to multiple pollutants or an existing body burden of pollution (all of us already have many industrial chemicals and metals in our bodies);
- do not do a good job of assessing the risk of developmental, reproductive, or other non-cancer impacts;
- are often based on an adult male, rather than a person more sensitive to impacts such as a pregnant woman or child;
- cannot account for genetic variability that may cause some people to be more sensitive to pollution than others; and
- usually evaluate the risk to the average person, thus missing potential health impacts to people who might have a much greater exposure to pollution because of their lifestyle. A prime example of this would be those who eat large amounts of fish for either cultural or subsistence reasons.

Risk assessments give us a rough idea about the potential impacts of pollution and have a place in defining an environmental problem. However, they are not perfect and should always be used with many other sources of information to help guide a decision.

Community Involvement: A Must

Community members should be involved in cleanup decisions from the outset of the cleanup process. After all, it is community members themselves who live, work and play near polluted waters and whose children will live with the results of cleanup decisions made today. Communities should not let special interests call the shots. Instead, community members should bring their real world concerns and issues to the table. Without community input, it is all too easy for decision-makers to make cleanup decisions based primarily on cost or ease of implementation. Members of the general public can provide a very different perspective, particularly on questions such as how long we should wait for risks to human health and the environment to decline.

CARL ZICHELLA, SIERRA CLUB

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Unfortunately, the level of public involvement varies from site to site and is usually dependent on the extent to which the agencies or industries in charge of the cleanup have sought citizen input. In an effort to increase community participation in sediment cleanups, the Sierra Club and Lake Michigan Federation developed a model public involvement plan that agencies or industries can apply to any cleanup effort. The plan is available from both organizations[11] and can also be found at *www.sierraclub-glp.org.* However, even at sites where extensive public participation may not be a high priority, we hope that this guide will provide community members with the information needed to weigh cleanup options, make informed decisions, and get involved.

[11] For copies of the report, contact either Sierra Club Midwest Office, 214 N. Henry St., Madison, WI, 53703, (608) 257-4994 or Lake Michigan Federation, 700 Washington Ave., Suite 150, Grand Haven, MI, 49417, (616) 850-0745.

weighing the options—criteria for choosing a cleanup strategy

There are basically two options for contaminated sediments: leave them there or dig them up.

Leaving them there either means doing nothing and hoping that the waterbody's natural processes will cover the poisons, or trying to contain the contaminants in place and prevent them from entering the ecosystem. Options for leaving toxic sediments in place include natural recovery, capping, biological and chemical treatment.

Digging them up (dredging them) removes toxic sediments from the aquatic environment relatively quickly and allows the ecosystem to recover without the presence of poisons. This guide will describe several kinds of dredges and ways to dispose of or treat dredged sediments.

There is no one-size-fits-all solution to sediment problems; sites will often require a mix of cleanup options to most effectively address the problem. Some of the criteria to consider when choosing cleanup options include:

Site conditions – Sediment and water characteristics can limit the options for any given site, particularly when considering leaving contaminants in place. This is not a viable option where strong currents, boat traffic, or other conditions wash pollutants downstream. However, dredges and treatment technologies are available that can address most site conditions.

Type of contaminant(s) – Some treatment methods only work well for specific contaminants.

Extent of contamination – Some options are better for bigger sites, some for smaller.

Risks to humans and the environment – Both short- and long-term risks must be considered when choosing an option. If left in the waterbody, contaminants pose long-term risks to human health and the environment. While some cleanup options may disrupt the aquatic environment in the short-term, they can generally eliminate the long-term risks posed by in-place pollution.

Cleanup goals – Removing contaminants from the aquatic ecosystem will generally meet cleanup goals more quickly and with greater permanence than other options. The speed and desired level of cleanup may eliminate some options.

Costs – While cleanup can be expensive, it is important to recognize that cleaning up a waterbody can result in many economic benefits for the local community and industries, such as increased tourism, recreation and fishing, less expensive port maintenance, waterfront redevelopment, and elimination of fish consumption advisories.

WI DEPARTMENT OF NATURAL RESOURCES

considering the consequences

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Indiana Harbor (above).

In addition to site specific criteria, there are overarching issues that need to be considered when choosing a sediment management strategy. Some of these issues tend to be given short shrift, perhaps because the impacts would be felt in the long-term, or far downstream, or by parties not otherwise involved in the cleanup. Because they are not often discussed in detail, we've provided some additional information on these issues below.

Looking at the big picture and over the long-term:

Industries often argue that the cost and negative impacts of dredging should preclude its use in favor of a less invasive cleanup option. However, these arguments ignore the fact that whatever disruptions dredging may cause are relatively short-lived, while there may be very long-term impacts to human health or the environment from leaving the pollutants in place. In addition, removing pollutants from the ecosystem via dredging will likely achieve the site cleanup goals much more quickly than less intensive cleanup options. The bottom line is that the impacts of in-place pollutants must be compared to the benefits of their absence from the ecosystem into the future, for as long as it would take to reach the site cleanup goals under either option. In many areas, this means looking out well over 100 years if pollutants are left in place. This type of analysis makes a strong case for spending money now to avoid leaving this problem for our children and grandchildren.

Another factor to consider is the long-term predictability and permanence of any cleanup solution. It is very difficult to predict the long-term fate of pollutants in the environment, particularly in an active river system or harbor. If left in place or covered by a cap, there is always a possibility of the pollutants being disturbed by natural or human forces. Storms, flood events, ice scour, and organisms burrowing into the sediments can stir up pollutants, as can boat traffic, navigational dredging, river channelization, and dam removal. For example:

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• More than 20 years of data for specific cross sections of the Fox River in northeast Wisconsin show that the river channel has moved back and forth over time as currents change, so that sediments might build up in one area for a few years, only to wash away again a few years later. In some spots, the depth of the riverbed changed by as much as 6 feet over time, as sediments alternatively eroded away and built up. This means that even if pollutants are currently buried, and clean sediment is accumulating on top of them, they may later be exposed as currents shift.

• Fox River monitoring during a sediment dredging project showed that the weekly arrival and departure of a coal boat stirred up significantly more pollution than the dredge.

• Fox River monitors also revealed measurable spikes in pollution levels downstream of contaminated hotspots during and after heavy rain events.

These factors must be considered when deciding how to deal with polluted sediments. We've often heard the claim that a river is depositional – that sediments are building up and burying the pollution – so we don't need to clean it up. While this may be true in some areas, it does not acknowledge that we can neither predict nor control natural processes over time, and that we run the risk of having to deal with the pollution tomorrow if we leave it in place today.

Ecological impacts on a broad system:

When pollutants are washed downstream, they have an impact on a broader ecological system that must be considered when selecting a cleanup solution. For example, many Great Lakes contaminated sediment sites are located in rivers or harbors where they leach pollutants downstream into the lakes themselves. The EPA has determined that these sites are a major source of fish consumption advisories across the lakes. Recent research shows that, at least in the Great Lakes, these pollutants are not buried once they reach the lakes, but are recycled back into the food web and even into the atmosphere.[12] The lakes can evaporate significant quantities of some persistent pollutants like PCBs, adding to a global pool of contaminants. While it is extremely difficult to quantify the contribution of a particular sediment site to this broad problem, we must be aware that there are broader, ecosystem-wide impacts of pollution – beyond what a risk assessment is able to measure. This is why polluted sediments are of concern, even if "nobody is eating the fish". We should discuss these issues when deciding how quickly to meet cleanup goals or whether or not to leave pollutants in place.

Financial impacts on other parties:

Finally, as previously noted, polluted sediments and a contaminated waterway can impose substantial costs on industries and the local economy. However, most of the companies who have to pay higher costs or who lose business because of the pollution are not the same companies who caused the problem in the first place. Thus, the industry responsible for the pollution does not often have a direct, economic interest in its cleanup. In addition, some of the costs imposed on others by contamination are relatively difficult to measure. This can lead to a disparity in which the cost of implementing the cleanup itself seems to be given greater weight in a cleanup decision than the costs imposed on other businesses by the pollution.

All of these things are broad issues that communities should consider when trying to find solutions to a polluted sediment problem. However, it is critical to understand the technical merits and tradeoffs associated with each cleanup technique when evaluating cleanup options. The remainder of this document is dedicated to explaining, in plain language, the technical requirements, effectiveness, costs, special considerations, and pros and cons for each sediment management option, from natural recovery to dredging and treatment.

[12] The Delta Institute, 2000.

POLLUTION PROBE

Natural Recovery is Naturally Risky!

Natural recovery is risky because water bodies are dynamic places. Contaminants can erode away and wash downstream, either gradually from ongoing natural and human processes, or due to a specific event like a storm or a flood that causes a great rush of water to scour the bottom. A PCB hot spot in Saginaw Bay was subject to such an event. The area had been identified as depositional but was washed out by a major storm in 1990. Now the ecosystem is exposed to the PCBs which are so dispersed they cannot be removed.[13]

Natural Recovery

Natural recovery (sometimes referred to as natural attenuation) refers to leaving contaminated sediments in place and waiting for depositional processes to cover them with clean material, biological or other natural processes to break them down, or water to wash them downstream where they may pollute another ecosystem. It means taking no action to clean up the site, other than making sure that the original sources of pollution are controlled and monitoring the sediment contamination. It can require a long period of time under natural recovery before a site meets the cleanup goals; and there is a fair amount of uncertainty over whether or not the goals will ever be achieved. However, natural recovery may be viable under certain circumstances, especially if contamination is minimal and dispersed over a large area.

Site Conditions
Sites left to natural recovery must be depositional and be expected to remain that way. Unfortunately, we cannot predict natural events that would change the depositional character of any waterway. Contamination levels must be low, with minimal releases of contaminants to the water and surrounding ecosystem, preferably because the contaminants are covered with cleaner sediment. Furthermore, contaminants should not be leaching out the bottom of the site into groundwater. There should be very little human or natural disturbance

[13] National Research Council, 1997

NATURAL RECOVERY

Pros	Cons
• Compared to other options, natural recovery is cheaper up front. • Natural recovery does not disrupt bottom ecosystems.	• Ecosystem recovery takes a long time – in many cases, centuries – and there is no guarantee of success. • Natural recovery has been the default option for all of the Great Lakes for more than 30 years, yet we still see the negative impacts of contamination. • Fish consumption advisories, health risks, and other impaired uses of the waterway will persist. • Even if contamination is covered by cleaner sediments, there is still a risk that the cleaner sediments will be washed away in the future, reintroducing the above problems. • Natural recovery requires long-term, indefinite monitoring. • If the site starts to erode in the future, it will have to be cleaned up using some other option. • Site requirements are so stringent that few places are suitable for natural recovery.

US EPA

Sediment plume from the Maumee River emptying into the western basin of Lake Erie

at the site. The site should not be in a major transportation corridor or be subject to future dredging. Dams along the waterway pose a special risk. Altering a dam in any way would affect water flows and subsequently the shape of the river bottom and banks.

Special Considerations
Natural recovery requires ongoing monitoring to ensure that the site remains depositional and that pollutants continue to be buried. If any of the measurements indicate that the site is starting to erode, other options must be employed.

Monitoring should determine:
- how fast sediment is covering the contaminants,
- how deep the contaminant levels are (i.e. whether the site is remaining depositional),
- how fast the sediments are releasing chemicals,
- the amount of contaminants that bottom-dwelling organisms are taking in,
- the extent that contaminated organisms migrate out of the area or are harvested, and
- how the chemicals change as they lay in the sediment ("in bed transformation rates").[14]

Costs
Concrete costs for natural recovery strategies include initial site assessment and long-term, indefinite monitoring. Natural recovery strategies also include hidden costs such as:
- maintaining and distributing fish advisories indefinitely,
- increased costs for navigational dredging,
- lost fishing and tourism revenue,
- health effects from continued exposure to the contaminants, and
- funding for other cleanup options should the site become erosional.

[14] Ibid.

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Cap placement

Capping

Just as it sounds, capping consists of covering contaminated sediments with clean material. Capping attempts to create a barrier between poison-laced sediments and the ecosystem. The simplest and cheapest caps are clean sediments, sand, or gravel. Geotextiles, or specially made fabrics, and armored caps made out of cement blocks or other armoring materials are more expensive cap options. Geotextiles can be hard to place and subject to tears, but are specially designed to contain contaminants. Though sturdy, armored caps tend to be leaky unless they are combined with geotextiles. Conventional dredging and construction equipment can place the cap, but they must be controlled with extreme precision.

Site Conditions

The site requirements for capping are similar to those for natural recovery. Even though caps create a barrier between contaminants and the ecosystem, they can erode or be damaged by storms, boat traffic, anchors, and other disturbances. For this reason, contamination levels should be low. The waterbody must be depositional at the site of the cap (again, this could change over time) with very few disturbances to the water or sediments. Navigational traffic should be minimal. The site should never be considered for navigational dredging. Dam modifications significantly change water flow and place any downstream caps at risk. Finally, the sediments must be firm enough to support the cap, otherwise the capping material can sink through the sediments and leave them exposed.

Special Considerations

Caps must be constructed to withstand pressures from above and below. From above, burrowing organisms dig into the cap. Contaminants below the cap, especially ammonia and some forms of nitrogen and phosphorous, can leach upwards. Caps should be at least as thick as the sum of the distance that pollutants will seep through the cap and the distance that organisms will dig down into it. In other words, a cap should ensure that the deepest digging worm will not reach the highest escaping pollutant.

After a cap is placed, monitoring requirements almost mirror those of natural recovery with a few additions. When monitoring the contaminant levels in the sediment by depth, movement of the sediment or contaminants into the cap layer is important. Monitoring should also track cap depth across the width and breadth of the project to check for any shifting and assure cap integrity over time.

Costs

Capping costs include site assessment, cap material, placement monitoring to ensure sediments are confined, cap transportation, cap placement, post-placement monitoring to ensure the cap's integrity, and any bottom ecosystem restoration. In some cases capping material can be found for free, though geotextiles and armoring material must be purchased. Capping costs must also include the price of maintaining and distributing fish consumption advisories in the short-term and the long-term risk of damage or destruction of the cap. Although cap design can account for mild erosional forces, major events that may destroy the cap are unpredictable and unpreventable. If a cap is compromised, the need for fish advisories may return. While capping seems to reduce costs by eliminating the need for dredging in the short-term, on-going monitoring, and potential repair and cleanup increase costs in the long-term.

CAPPING

Pros

- Compared to treating in place or dredging, capping is less expensive up front.
- Capping is relatively easy to implement.
- Capping can be effectively used to speed ecosystem recovery after a dredging project.

Cons

- Capping requires long-term, indefinite monitoring.
- Cap placement can stir up contaminated mud which may resettle outside the cap.
- Outside forces work to degrade the cap. Gradual erosion, burrowing organisms, ice and boat scour, anchors, trawling, and big natural disturbances all threaten the effectiveness of caps. Even the sturdiest caps degrade over time and become more susceptible to storms and floods. No cap can guarantee to withstand all that nature can dish out.
- Caps change the flow of water around them. Water moving around the cap changes speed and forms eddies and other turbulence. Ultimately, caps themselves could help bring on their own demise by changing the patterns of erosion and deposition altogether.
- Caps decrease the depth of the water and limit future navigational uses of the waterway.

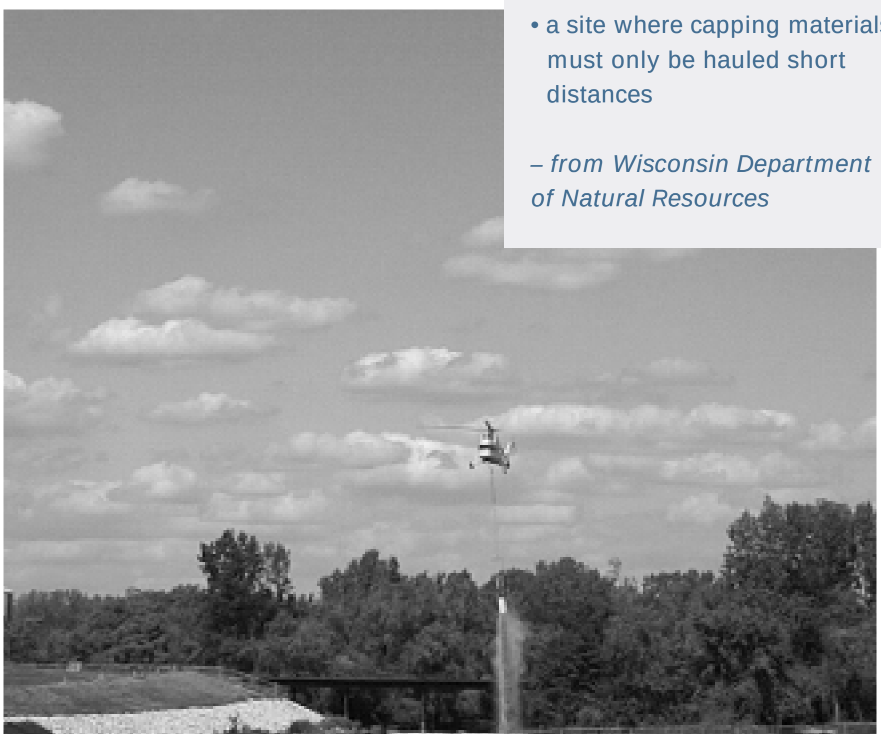
Capable of Capping?

Capped sites should have:

- a level bottom
- mild water currents, especially along the bottom
- deep water that is relatively isolated from storm-induced currents or shallower water that is protected from erosive forces
- no nearby obstructions or structures
- a site where capping materials must only be hauled short distances

– from Wisconsin Department of Natural Resources

Cap placement using a helicopter



EPA, GREAT LAKES NATIONAL PROGRAM OFFICE

Treating It in Place

Technologies that treat contaminants in place use chemicals or microorganisms to lock contaminants into place or to destroy them. The three categories of this treatment type include: chemical, biological, and immobilization. Chemical treatment mixes chemicals into the sediments to break down the contaminants. Biological treatment provides the nutrients or other materials that microscopic organisms need to break down the contaminated material. In some cases, the actual microorganisms may be added. Immobilization involves adding chemicals to lock contaminants in the sediments by changing the physical and/or chemical characteristics of the sediments.

The technologies for treating sediments in place are similar to those used to treat sediments once they are dredged. See the Biological Treatment (p. 41) and Chemical Treatment (p. 47) sections for more information.

Applicability in Question

The applicability of these technologies is relatively limited. Since chemicals and microorganisms work on very specific pollutants, the combination of pollutants found at many sediment sites may pose problems. Take, for example, a site polluted with toxic metals and organic compounds. If microorganisms were added to break down the organic compounds, they could be killed by the toxic metals.

Special Considerations
In-place treatment is still in its trial stage. However, innovations happen quickly in this field and we should be prepared to test new technologies as they develop. Currently, pilot projects show mixed results and illustrate the problems with trying to control processes at the bottom of a dynamic waterbody. These technologies may work better in controlled environments after sediments have been removed and confined. In some cases, a wall can be constructed around the site and the water drained off, allowing the sediments to be treated in a more controlled environment. Once treatment is completed, the walls are removed.

Costs
The cost to implement these technologies includes site assessment and monitoring during the application of the chemicals or microorganisms, while the pollutants are being destroyed or immobilized, and following treatment. With chemical and biological treatments, monitoring should continue until treatment successfully destroys the pollutants. Immobilization, however, requires long-term monitoring to ensure that the contaminants remained confined. The cost of the additives ranges widely. More common materials are less expensive than rare or highly technical materials. Specialized equipment may be required to apply and mix the additives without churning up the sediments or losing the additives to the surrounding ecosystem. Costs must also include any changes to the ecosystem resulting from the additives. All of the hidden costs of contaminated sediment (impaired uses, fish contamination, health risks, etc.) will remain in the short-term as the degradation or immobilization process gets under way. If the additives are not successful, the costs of additional treatment strategies need to be incorporated into treatment cost.

TREATING IT IN PLACE

Pros

- Initially, treatment can be cheaper than dredging.
- Some methods destroy contaminants.

Cons

- None of these technologies has been used on a large scale.
- Several pilot-scale studies have indicated difficulties in applying treatments and mixing them adequately.
- Additives must be precisely, thoroughly, and uniformly applied to the sediments. Real-life conditions at the bottom of a waterbody make this process extremely difficult.
- As chemicals or microorganisms work to degrade contaminants or immobilize sediments, they can produce heat or change in volume, thus altering the physical aspects of the environment.
- The environmental requirements for biological breakdown of contaminants may change at each stage of degradation. Without isolating the application site, it is virtually impossible to micro-manage these conditions.
- The applicability of these technologies is relatively limited and very substance specific. Many treatments have trouble with multiple pollutants.
- No biological treatment methods have been found to effectively deal with PCBs when used full scale in a waterbody.

digging them up

WI DEPARTMENT OF NATURAL RESOURCES

Hydraulic dredging project

Digging contaminated sediments up, or dredging contaminated areas, actually removes toxic sediments from the waterway for treatment or disposal. Several kinds of dredges are available for cleanups. Each varies in cost and effectiveness. As with any strategy to address contaminated sediments, the initial conditions of the sediment, (the type and extent of contamination, the kind of soils, water conditions, etc.) play a large role in what dredges are chosen.

Dredging provides the only opportunity to remove contaminants from the aquatic ecosystem, often breaking their link to the food chain. It is the fastest way of achieving cleanup goals and restoring a site. New dredging technologies enable us to remove polluted sediments more quickly, cleanly, accurately and effectively than ever before.

Many people fear that dredging will stir up contaminated sediment and release toxins into the water column or relocate them downstream. Although dredging can resuspend some contaminants, the amount is generally minimal compared to what the sediments may already be releasing downstream. For example, a 1998 dredging pilot project on the Fox River in Wisconsin removed a PCB hotspot that leached as much as 4-5 kg of PCBs to the river in a year. The dredging itself released just over 2 kg of PCBs, only half of what the hotspot would have released without the dredging. And, by removing the hotspot, the dredging prevented future PCB releases from that site.

It is also important to remember that, if the sediments are significantly polluted, the river bottom and river water are already degraded. Dredging may disrupt the bottom of the river, but that probably doesn't matter much if the bottom is polluted. And while dredging may slightly increase pollution levels in the water over the short-term, the contaminant levels are probably already high. In the case of the Fox River, PCB levels in the water currently exceed the state's water quality criteria by as much as 50,000 times. The dredging projects only raised the levels slightly for a short period of time, and they permanently removed hotspots of PCBs that were contributing to the high levels in the water.

Dredging and sediment management technologies and techniques have come a long way in minimizing resuspension and transport downstream. Dredges designed specifically for removing contaminated sediments use special cutting heads and suction to reduce the amount of resuspension. These new dredges have successfully removed sediments with extremely low resuspension rates.

Specific dredging techniques can also reduce sediment resuspension. First and foremost, an experienced dredge operator is crucial to the success of the project. Many people who deal with contaminated sediment remediation note that the dredge operator's experience and abilities can have a profound effect on the amount of resuspension.[15]

[15] USEPA Great Lakes National Program Office, 2001.


WI DEPARTMENT OF NATURAL RESOURCES

Hydraulic dredge operator on the Fox River

The dredge operator can affect resuspension almost as much as the choice of the dredge.

- If the dredge goes too fast, resuspension increases.
- If the dredge cuts too deeply, more sediment will be loosened than the dredge can handle.
- If the cut is too shallow, dredges with moving cutterheads may dislodge the sediments with too much energy, like an electric mixer halfway out of the batter.

Various types of monitors (video, sonar, etc.) can provide feedback to operators as they are dredging so that they can adjust as they go along, reducing resuspension and adjusting the characteristics of the dredged material to fit treatment specifications. Finally, an increasing number of projects are using Global Positioning Systems, or GPS, for added dredging precision.

A variety of tools can be used to help contain any sediments or contaminants that dredging does stir up. Solid barriers, like coffer dams or sheet pilings, can be placed around dredge sites to keep resuspended sediments from moving downstream. Though expensive and difficult to insert and remove, these structures will withstand strong water currents, wind, boat wakes, ice heave, and other disturbances. Cheaper and easier to work with, silt curtains and silt screens can be anchored to the bottom and held up with floats. Silt curtains do not allow water to pass through them, whereas silt screens allow water to flow through. Both types of barriers are increasingly used to contain resuspended sediment, with very good results. If oils are released in the dredging process, oil booms and absorbent mats can be used to soak them up.

In practice, dredging has effectively removed contaminated sediments with virtually no losses to the environment. The short-term risks of minimal sediment loss must be weighed against the long-term benefits of removing the bulk of the contamination from the ecosystem, thereby eliminating the risk of further detrimental effects at that site.

Choosing a dredge

Dredges are suited to remove different kinds of sediments under different conditions. No dredge is suitable for all circumstances; each has its own set of pros and cons that may or may not meet the goals set for a particular cleanup. Two sets of criteria must be considered when choosing a dredge: the characteristics of the site and the characteristics of the dredge. Site characteristics are important because some dredges handle different kinds of sediments and water conditions better than others. The ultimate fate of the dredged material makes the dredge characteristics important. Often, treatment and disposal methods require dredged material to be delivered at a certain rate and in a certain condition. Selecting the best dredge for the job means making sure not only that it can handle the on-the-ground conditions, but also that it produces dredged material at the right rate and with the right characteristics for further treatment and/or disposal. Dredge-specific characteristics like availability and cost also factor in.

Site Characteristics

Type of sediment – Some dredges handle coarse, loose sediments while others deal more effectively with packed sediments. Also, some dredges are able to chew through minor debris, others cannot.

Depth of water and sediments to be dredged – Each dredge is able to dredge to a certain depth. Some perform better in shallow water than others.

Amount of sediment to be dredged – Some dredges are good for small jobs, others for large ones.

Water current – The anchoring mechanism varies with the dredge. Some anchors can handle currents, while others require still water.

Site access – Some dredges are more maneuverable than others. Maneuverability counts when working in close quarters or where obstacles need to be avoided. In particularly small or hard to reach areas, hand held dredges and/or divers may be used.

"Don't let the differences in dredge cost be the major factor in dredge choice. The physical constraints of the site, the type of dredging, and the ultimate fate of the dredged material are the critical factors that will determine the best dredge for the job."

– Jan Miller
Environmental Engineer
US Army Corps of Engineers

Dredge Characteristics

Amount of water that comes up with the dredged material – Treatment technologies can handle different amounts of water in the dredged material. When excess water is pulled up with the sediments, it adds to the cost of the project in two ways. First, it adds extra weight and volume that needs to be transported. Second, treatment and disposal options will likely require sediment dewatering (see p. 37). The extra costs can be worth it, however. Hydraulic dredges tend to bring up the most water with sediments, but they offer one of the cleanest ways to dredge. In the dredge table on page 28, this characteristic is described as the percent solids by weight. The greater the percent solids, the less water the dredge brings up.

Range of production rates – Transportation methods and treatment technologies can only handle so much dredged material at a time. If the dredge is producing dredged material too slowly or too quickly, a storage site may be needed to either accumulate enough to transport or hold sediments that must wait to be treated. In the dredge table on page 28, this characteristic is described by cubic yards of sediment dredged per hour.

Dredge accuracy – The dredge needs to be very accurate for two reasons. First, it needs to ensure that all the contaminated sediments are removed. Second, it needs to minimize the amount of clean sediment brought up with the contaminated sediments. Clean sediments that are needlessly dredged must be transported, treated and disposed after mixing with contaminated sediments, adding to the project's cost.

Resuspension – The dredge descriptions below note the resuspension issues particular to each dredge. Resuspension rates vary by the dredge, site characteristics, and the experience of the dredge operator. For further discussion of resuspension see p. 17.

Cost – Costs vary widely with each project. Site and sediment conditions, treatment technique and project goals all help determine costs. Generally, dredging costs range from $15 to $50 per cubic yard. Bigger jobs are cheaper because of economies of scale. In other words, the fixed costs (mobilizing the dredge, setting up the dredge site, etc.) can be spread out for larger jobs, working out to fewer dollars spent per cubic yard of sediment dredged. Most Great Lakes cleanups are small, less than 500,000 cubic yards, and tend to be at the higher end of the price range per cubic yard dredged.[16] The cost differences between dredges are small enough that cost should be one of the last considerations when picking a dredge. The physical constraints of the site and the dredge along with the requirements for the ultimate treatment and disposal of the sediment are of primary importance.

[16] Miller, Jan. 2001.

Environmental clamshell dredge

BOB QUEEN, WI DEPARTMENT OF NATURAL RESOURCES

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Shielded cutterhead of hydraulic dredge

ENVIRONMENTAL MECHANICAL DREDGES

Pros	Cons
• Widely available. • Brings up a high percentage of solids. • Has special fittings that reduce resuspension 30-70% below the traditional clamshell dredge. • Horizontally, it is a very precise digging tool. It is excellent in close quarters. • Can be used in very deep water. • Can be used with very consolidated sediments.	• Production rate is low compared to hydraulic dredges. • Does not work well in strong currents. • Needs high overhead clearance.

Types of dredges

There are two basic types of dredges: mechanical and hydraulic. Closely related to earth moving equipment like backhoes, mechanical dredges use mechanical force to scoop up sediments and load them onto a transportation vehicle or directly into a land-based containment area. Hydraulic dredges work like vacuums, using strong pumps to suck up contaminated sediments from the bottom. Generally, hydraulic dredges resuspend less sediment than mechanical dredges as they operate. Dredges that use a combination of mechanical force to loosen sediment and hydraulic force to pump it up are often referred to as hybrid dredges. Some hydraulic dredges use special pumps, called pneumatic pumps, to raise sediments from the bottom. Pneumatic pumps pull up less water and disturb the bottom much less than a regular hydraulic dredge.

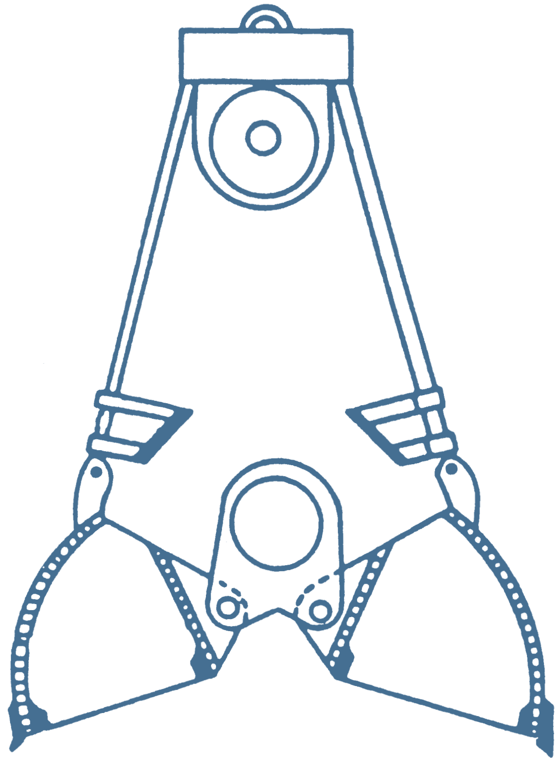
The next section describes many kinds of dredges. At the end of the section, a table provides specific data on each dredge, along with some pros and cons for each dredge.

Digging It Up: Mechanical Dredges
The most widely available dredges in the US, mechanical clamshell dredges excel at removing debris and pulling sediments out of waterways without adding much water. They are most suitable for removing gravel, sand, and very cohesive sediments like clay, peat, and highly consolidated silt. They can operate in very tight spaces without interfering with shipping. Many mechanical dredges tend to leak and resuspend large quantities of sediment; however, several kinds of mechanical dredges have been specially designed to minimize leaking and resuspension. These dredges are the only mechanical dredges that should be considered for contaminated sediment cleanup.

Enclosed Bucket Dredge and Cable Arm Dredge

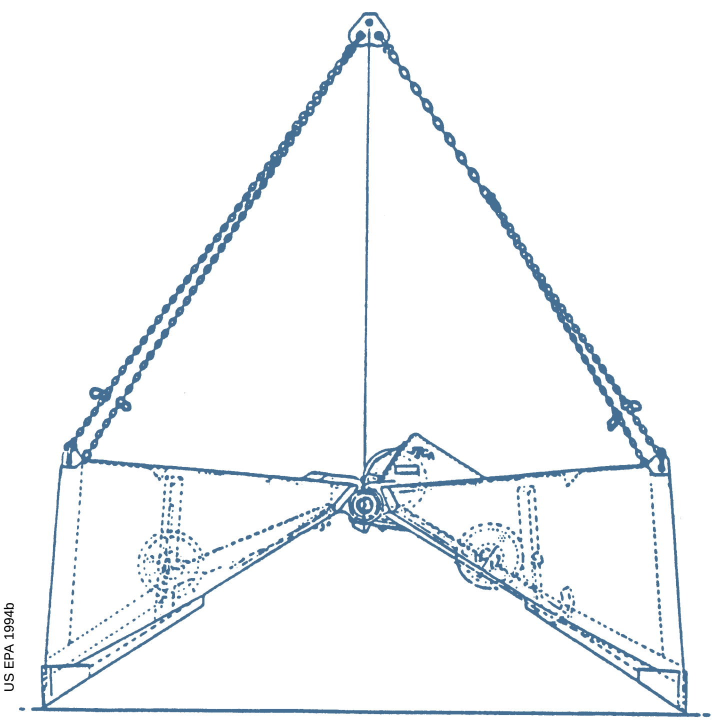
These are clamshell dredges that were specially designed to minimize resuspension. The clamshell dredge gets its name from how it looks. Clamshell dredges have a bucket made of two halves; together they resemble a clamshell. The bucket is attached by a cable to a crane that is mounted on a flat-bottomed barge or on land. The barge can be moved short distances by anchors, but must be towed for longer trips. To dredge, the operator drops the open clamshell into the sediment. As it is pulled up, the halves close together, trapping the sediments inside. It dredges sediments by the bucketful and dumps them into a barge or scow. Clamshell dredges are classified by how much sediment they can hold in their buckets – anywhere from 1 to 50 cubic yards. Typical clamshells hold between 2 and 10 cubic yards per bucket.

The enclosed bucket and Cable Arm dredges seal shut with gaskets and tongue-in-groove joints to fully contain contaminated sediment. The Cable Arm has the added advantage of being better able to control how far it dredges into the sediment. It can also remove sediments in layers, leaving a flat surface after dredging. It can dredge more precisely than the clamshell, bringing fewer clean sediments up with the polluted ones. Enclosed bucket and Cable Arm dredges resuspend 30 to 70% less sediment than clamshell dredges.



US EPA 1994b

Figure 1: Enclosed Bucket Dredge



US EPA 1994b

Figure 2: Cable Arm Dredge

Figure 3: Cutterhead Dredge

US ARMY CORPS OF ENGINEERS

HYDRAULIC DREDGES	
Pros	**Cons**
• Much less resuspension than mechanical dredges.	• Tend to clog, increasing resupension and interrupting job.
• Some are widely available.	• Do not handle consolidated sediment well.
• Often very precise dredgers, bringing up minimal clean sediment.	• Pipelines carrying sediment slurry may be navigational obstructions.
• Faster than mechanical dredges.	
• Closed system reduces environmental exposure.	

Sucking It Up: Hydraulic and Pneumatic Dredges

There are four main components to hydraulic and pneumatic dredges: the dredge head, the dredge head support, the suction pump, and the pipeline to transport dredged sediments. Hydraulic dredges tend to be identified by their dredge heads, while pneumatic dredges tend to be identified by the type of pump they use. The dredge head is the part of the dredge that is inserted into the sediments. Often, the dredge head is fitted with a cutterhead that loosens the sediments so that the suction pump can pump them to the transport, treatment, or disposal site. For some jobs, the cutterhead can be removed and the suction pump can be simply used like a vacuum. Hybrid dredges are hydraulic dredges that use mechanical means rather than a simple cutterhead to loosen sediments. The dredge head support holds the dredge in the water. The dredge head support can be a simple cable, a special ladder with the dredge attached at the bottom, or a sophisticated hydraulic arm.

Hydraulic systems suck in a slurry, a combination of sediments and water. Pneumatic systems pull in sediments with very little water in them. Unlike mechanical dredges, hydraulic and pneumatic dredges are closed systems: once the sediments enter them, they have no contact with their environs until they reach the transport, treatment, or disposal site. Since both types suck sediments in rather than just dig them up, they resuspend much less than mechanical dredges. The slight resuspension that does take place with hydraulic and pneumatic dredges occurs as the cutterhead dislodges sediments or the dredge head is moved.

Hydraulic dredges can be anchored and moved in several ways. Many use spuds, special poles that extend down from both sides of the dredge, to anchor to the bottom. The dredge can move by “walking,” using the spuds as legs. One spud is lifted and the dredge’s momentum pivots it on the anchored spud. The first spud is then re-anchored and the dredge "steps" forward. The dredge itself moves forward with the water currents, by pulling itself along a guide wire, or by its own propulsion. Dredges can also use guide wires without spuds to move. For example, two anchor wires can be run parallel to the edge of the dredge site. A third wire runs perpendicular to and between the two anchor wires. The dredge cleans along the third wire. After sediments along the length of the third wire are dredged, the ends of the third wire are moved down the anchor wires so that the next row can be dredged.

Cutterhead Dredge

The cutterhead dredge is the most common hydraulic dredge. It uses a rotating cutterhead to loosen sediments. A hydraulic pump transports them to the treatment or disposal site via a pipeline that can be up to 15 miles long. Usually, the dredge is towed into position and anchored with two spuds mounted on the stern or anchored to sites on land. Two cables controlled by winches swing the dredge back and forth. Sediment shields, gas collection systems, underwater cameras, and sensors have all been used with this type of dredge to maximize accuracy and minimize resuspension.

Portable Hydraulic Dredge

A smaller version of the plain suction dredge, the portable hydraulic dredge is easily moved and effective in shallow water. Portable hydraulic dredges usually have pipes that are less than 24 inches in diameter.

PNEUMATIC DREDGES

Pros	Cons
• Brings up sediments with very little water, up to 80% of the sediments' original density. • Very low resuspension. • Provides continuous, uniform flow of dredged sediment. • Effective at low power. • Closed system reduces environmental exposure.	• Can clog, increasing resuspension and interrupting job. • When moved around dredge site can suck up lots of excess water.

Plain Suction Head Dredge

The plain suction head dredge is essentially a cutterhead dredge without the cutterhead. It works like a vacuum, simply sucking up sediments with a pipe. Water jets can be added at the suction mouth to help dislodge sediments, but they may increase resuspension. It can be maneuvered by cables and winches or by divers.

US EPA 1994b

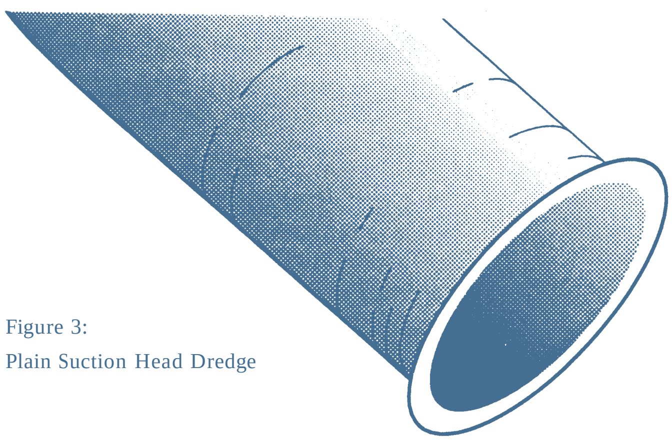


Figure 3:
Plain Suction Head Dredge

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Figure 5: Horizontal Auger Dredge

HYBRID DREDGES

Pros	Cons
• Can work with a wider variety of sediments than hydraulic dredges. • Low resuspension compared to mechanical dredges. • Faster than mechanical dredges. • Closed system reduces environmental exposure.	• Can clog, increasing resuspension and interrupting job. • Some cutter heads increase resuspension over hydraulic dredges. • Pipelines carrying sediment slurry may be navigational obstructions.

Horizontal Auger Dredge

This commonly used dredge has a type of screw, or auger, to break up sediment and carry it to the dredge pump. A retractable mud shield over the auger can control resuspension, but increases the probability that the dredge will clog. Four anchored cable wires hold the dredge in place and move it like a pendulum from side to side. The horizontal auger dredge can remove layers of sediment between 4 and 20 inches thick. Two common brands of horizontal auger dredge include the Mudcat and the Little Monster.

US EPA 1994b

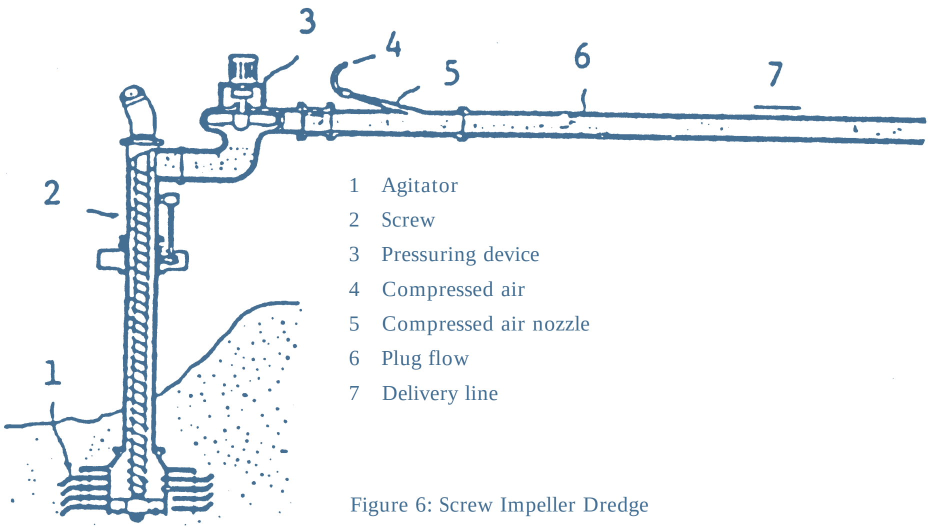


Figure 6: Screw Impeller Dredge

Screw Impeller Dredge

This dredge is a large screw with an agitator at the bottom. The screw sinks into the sediment and the agitator loosens the sediment. The screw then brings the sediments to a centrifugal pump that pressurizes the slurry and delivers it via a pipeline.

Specialty Dredges

The following dredges are innovative pneumatic and hydraulic dredges. Though not widely used in the United States, they were specifically designed to dredge contaminated sediments.

Eddy Pump

The Eddy Pump uses a swirling hydraulic eddy current to suck up contaminated sediments. A rotor is inserted into the sediments and spins, forcing sediments into an uptake chamber. When the pump operates, the surface of the sediment collapses downward to the imbedded nozzle like a milkshake being sucked up through a straw. There is little or no sediment resuspension because there is no cutterhead and the intake nozzle is completely imbedded in the sediment.

SCENIC HUDSON, ADVANCES IN DREDGING

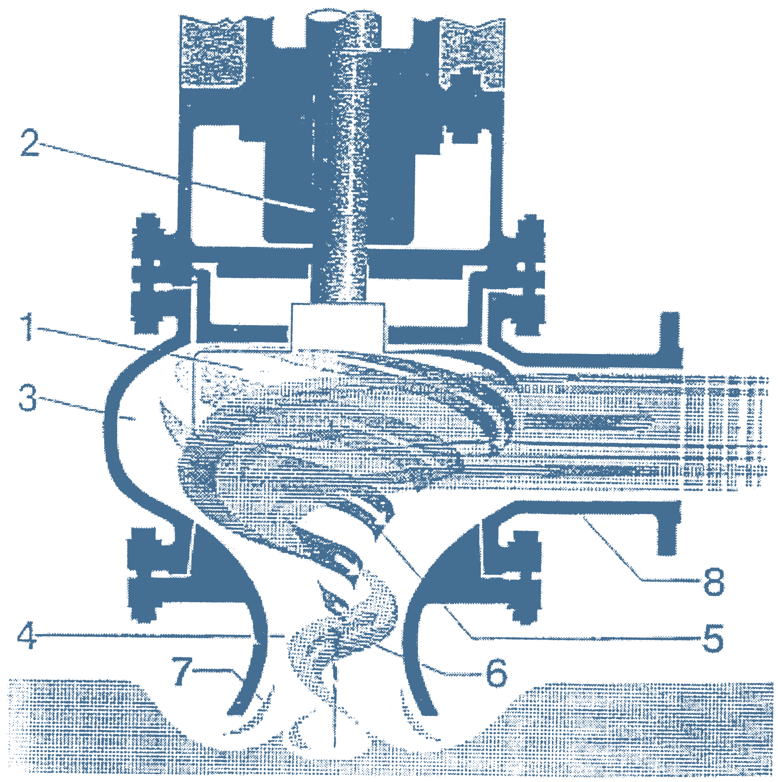


Figure 7: Eddy Pump Dredge The Eddy Pump consists of an energy generating rotor (1) attached to the end of a drive shaft (2) and placed within a volute (3). As the rotor begins to spin, it sets into motion the fluid present within the volute and the adjoining intake chamber (4). At normal operating speeds, 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 (eg. 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)

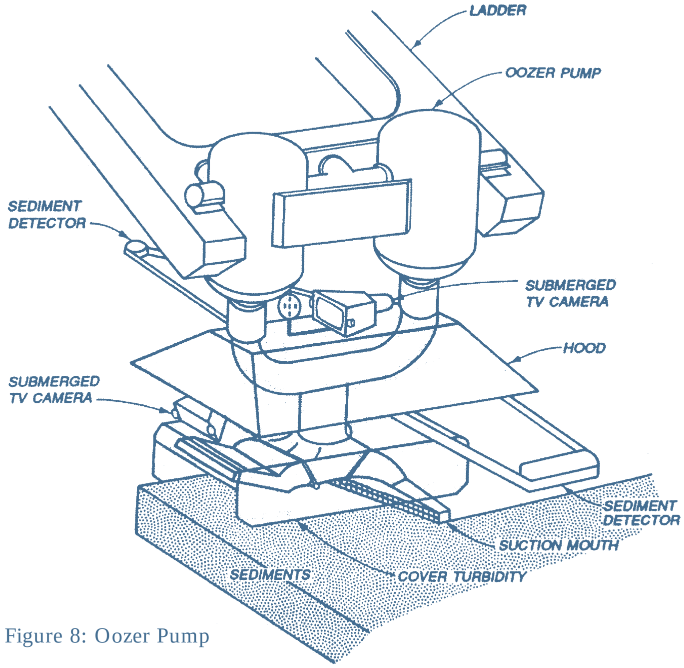


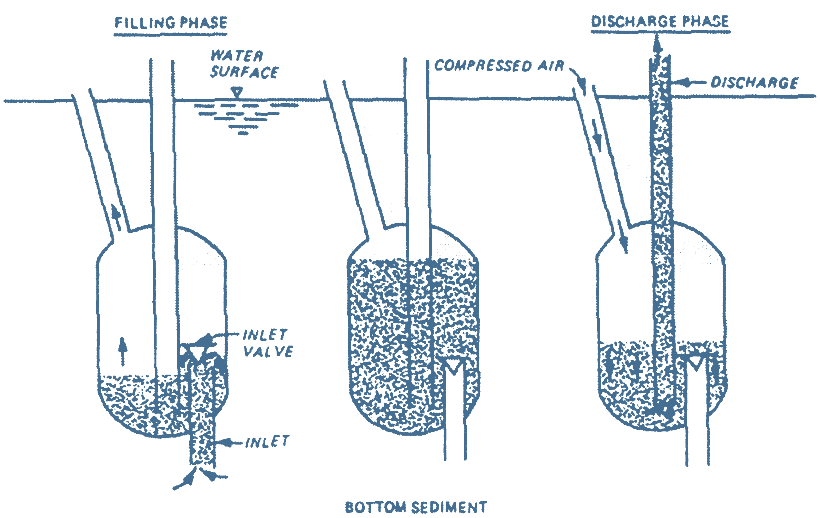
Figure 8: Oozer Pump

Oozer Pump
By changing the air pressure in its two cylinders, the Oozer Pump creates pneumatic force that sucks up sediments through its dredge pipe – much like the Pneuma Pump discussed next. The whole process is made more efficient with a centrifugal vacuum. The Oozer Pump is mounted on a ladder and operated like a conventional cutterhead. Five acoustic sensors measure the density of sediment layers and underwater television cameras aid the operator. Other accessories are available, including cutterheads for loosening sediment and gas scrubbers for collecting toxic gases.

Pneuma Pump
By changing the air pressure in its three cylinders, the Pneuma Pump creates pneumatic force that sucks up sediments through its dredge pipe – much like the Oozer Pump. The Pneuma Pump acts like a piston pump: as each cylinder fills with sediment, the compressed air acts as a piston and forces sediments through a valve to the discharge pipe line. It also has a vacuum system to help in shallow water. The Pneuma Pump can either be suspended from a crane or barge or mounted on a ladder like a conventional cutterhead dredge. The best dredging results occur when Pneuma Pumps are mounted on a ladder.

Figure 9: Pneuma Pump

SCENIC HUDSON, ADVANCES IN DREDGING



Airlift Dredge
The Airlift dredge can be operated from land or supported by a crane or barge. It uses a rotating cutterhead to loosen sediments. It then releases compressed air into a riser pipe that is open on both ends. As the compressed air expands, it creates a current that carries water and sediment up into the pipe.

Amphibex Dredge
The Amphibex dredge is a combination hydraulic and mechanical dredge. Like a backhoe, the Amphibex dredge has a bucket which can be used to remove debris such as large rocks, garbage, and tree limbs. Screw-shaped (auger) cutterheads loosen sediments and feed them to a hydraulic intake. The self-propelled dredge is held in place by spuds and side stabilizing arms, providing great flexibility in positioning and maneuverability. The dredge can crawl along land or through shallow water, slide down banks, and float.

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. It can remove sediments at 30 to 50 percent solids by weight.

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.

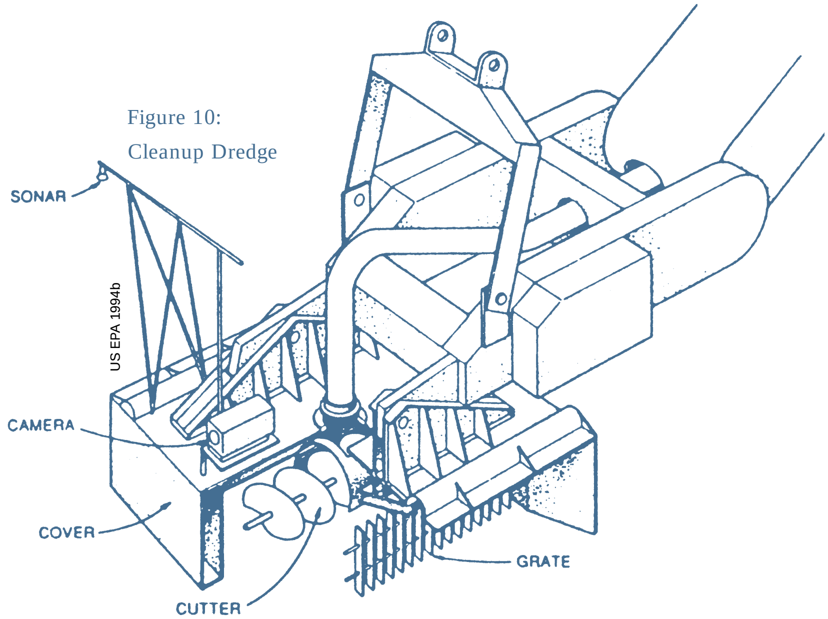


Figure 10:
Cleanup Dredge

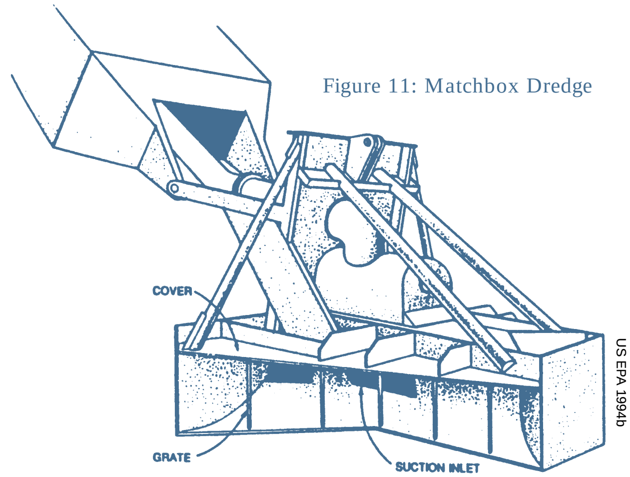


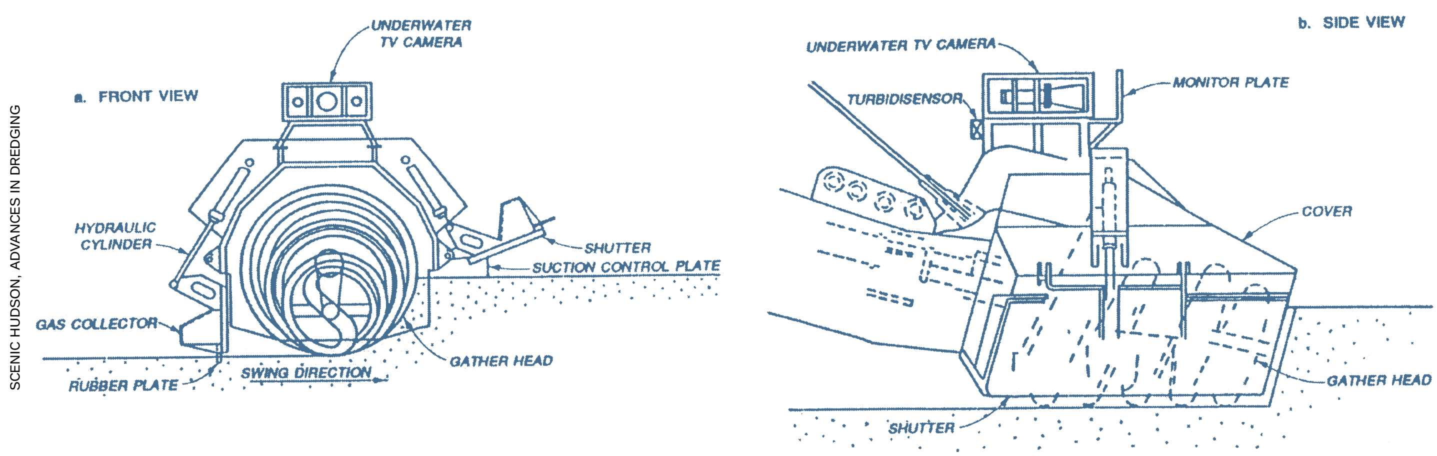
Figure 11: Matchbox Dredge

Clean-up Dredge
The hybrid Clean-up dredge uses a shielded auger (screw) to dislodge sediment as it swings back and forth. The rotating auger pushes the sediments with its threads to a hydraulic pump. A cover and movable wing contain resuspended sediment and gas bubbles while minimizing the amount of water taken in by the dredge. Grates positioned next to the auger keep debris from clogging the dredge. The dredge is equipped with sonar to monitor dredging depth and a TV camera to monitor resuspension. The Clean-up dredge works well with soft mud or sand.

Refresher System
Another type of cutterhead dredge, the Refresher uses a helical auger, or screw, to loosen the sediments. It is also equipped with positioning equipment and valves to prevent back flow if there is an emergency shut down. A cover and shutters minimize resuspension and water uptake. The cover is flexible and can be adjusted to the bottom contour with hydraulic controls.

Matchbox Dredge
The Matchbox dredge uses hydraulic pistons to loosen sediments. The sediments are then sucked through a grate to screen out debris and then into a funnel intake. A cover with valved openings on each end, resembling a matchbox, encloses the grate and the funnel intake. As the dredge is swung from side to side, the valve in the direction of the swing opens so that sediment may enter. The cover is designed to reduce water inflow and collect gas bubbles escaping from the sediment.

Figure 12: Refresher System



	Dredge Name	% Solids by Weight	Production Rate	Dredge Accuracy	Resuspension	Sediment Type
MECHANICAL	Enclosed Bucket	Near original density [1,2]	30-600 yd^3/hr [1,2]	Information not available	Enclosed bucket and Cable Arm dredges resuspend 30 to 70 % less sediment than clamshell dredges	Gravel, sand, consolidated silt, clay
MECHANICAL	Cable Arm	Near original density [1,2]	30-600 yd^3/hr [1,2]	Horizontal: 0.4 in [5]	Enclosed bucket and Cable Arm dredges resuspend 30 to 70 % less sediment than clamshell dredges	Gravel, sand, consolidated silt, clay
HYDRAULIC	Cutterhead	10-20 [1,2]	33-3,270 yd^3/hr [1,2]	Vertical: 12 in Horizontal: 0.4 in [2]	Strongly influenced by the specific dredge design and operation	All types including clay, silt, sand, hardpan, gravel and rock
HYDRAULIC	Plain Suction Head	10-15 [1,2]	1,000-10,000 yd^3/hr [1]	Vertical: 12 in Horizontal: 0.4 in [2]	Virtually none without water jets	Soft, free- flowing material or granular material like sand
HYDRAULIC	Portable Hydraulic	10-40 [1]	5-50 yd^3/hr [1]	Maneuvered by hand	Virtually none	Soft, free- flowing material
HYDRAULIC	Horizontal Auger	10-40 [1]	50-160 yd^3/hr [1,2]	Vertical: 6 in Horizontal: 0.5 in [2]	Virtually none	
SPECIALTY	Eddy Pump	70 ▼Lower if dredge head is picked up and moved a lot or if dredge is clogged [1,3]	310 yd^3/hr [1]		Virtually none	Loose, free flowing material
SPECIALTY	Oozer	25-80 ▼Lower if dredge head is picked up and moved a lot or if dredge is clogged [1,2,3]	330-800 yd^3/hr [1]	Vertical: 12 in Horizontal: 0.4 in [2]	Only if dredge is moving too fast	Loosely consolidated silt or clay
SPECIALTY	Pneuma	25-80 ▼Lower if dredge head is picked up and moved a lot or if dredge is clogged [1,2,3]	60-2,600 yd^3/hr [1]	Vertical: 12 in Horizontal: 0.4 in [2]	None	Loosely consolidated silt or clay
SPECIALTY	Airlift	25-40 [1,2]	60 yd^3/hr [1]	Vertical: 12 in Horizontal: 0.1 in [2]	Very low	Sand, silt, clay
SPECIALTY	Amphibex	45 [4]	90 yd^3/hr for sand 100 yd^3/hr for sludge [4]	Information not available	Information not available	All types, has rake to remove debris [4]
SPECIALTY	Clean-Up	30-40 [1,2]	500-1,960 yd^3/hr [1,2]	Vertical: 12 in Horizontal: 0.4 in [2]	Only with starting and stopping pump and changes in swing direction	Soft mud, sand; silty clay
SPECIALTY	Matchbox	5-15 [1,2]	24-80 yd^3/hr [1,2]	Vertical: 12 in Horizontal: 0.4 in [2]	Very low	Consolidated silt, loosely packed sand
SPECIALTY	Refresher	30-40 [1,2]	65-1300 yd^3/hr [1,2]	Vertical: 12 in Horizontal: 0.4 in [2]	Increases with speed of dredge	All types

[1] Cleland, 2000 [2] USEPA, 1994b. [3] Miller, 2001. [4] Normrock Industries, Inc., 1995-2000. [5] Environmental Dredging Guide, Cable Arm Inc.

** The above information was not available for the screw impeller, wide sweeper cutterless, and waterless dredges.

Dredging Depth	Pros	Cons
0-157 ft [1,2]	• Widely available • Brings up solids without much water • Horizontally, it is very precise, it excels in close quarters • Can be used in very deep water • Can be used with very consolidated sediments • Does not leak as much as clamshell	• Does not work well in strong currents • Needs high overhead clearance
0-157 ft [1,2]	• Widely available • Brings up solids without much water • Horizontally, it is very precise, it excels in close quarters • Can be used in very deep water • Can be used with very consolidated sediments • Does not leak as much as clamshell • Does not leave a cratered sediment surface	• Does not work well in strong currents • Needs high overhead clearance
3-60 ft [1,2]	• Most common hydraulic dredge in the U.S. • Very versatile and efficient • Can operate continuously, reducing costs	• Tends to leave raised rows of sediments on the sediment surface • This can be minimized with innovative dredging techniques
5-160 ft [1]	• Well suited to removing unconsolidated material • Virtually no resuspension without water jets • Highly maneuverable	• Ineffective for consolidated sediments • Optional water jets increase resuspension
2-50 ft [1]	• Convenient for isolated, hard to reach areas • Economical for small jobs can be operated in water as shallow as 2 feet • Since it is maneuvered by hand, can go around rocks and large debris	• Does not perform well in water • Production rates tend to be low
2-16 ft [1,2]	• Leaves sediment surface flat • Infrared light, echo and depth sounders all monitor dredge position • Able to handle muck and chew through woody debris	• Not effective in shallow water • Difficult to maneuver in high winds
3-100 ft [1]	• Low weight • Does not need much energy • Does not pull out much water with sediments, can pump sediments with as little as 5% water • Can handle debris very well	• Not effective for consolidated sediments
0-160 ft [1,2]	• Sediments can be removed at 30-80% of the density in the waterway • One study found suspended solids at background concentrations within three meters of dredge • More efficient at low power than conventional centrifugal pumps • Equipment does not agitate sediments, has very limited contact with them–minimizing resuspension.	• Debris causes the pump to clog, increasing resuspension
0-500 ft [1]	• Sediments can be removed at up to 80% of the density that they are found in the waterway • Continuous and uniform flow • More efficient at low power than conventional centrifugal pumps • Equipment does not agitate sediments and has very limited contact with them – minimizing resuspension.	• Debris causes the pump to clog, increasing resuspension
20ft and deeper [1]	• Relatively high solids concentration • Can be put together relatively easily • Can handle a wide range of sediment types • Very efficient in deep water	• Does not work in water shallower than 20 feet • Relatively expensive
19.5 in to 21 ft [4]	• Very good in hard to reach sites, shallow water, strong currents, and rough coastlines • Relatively high solids concentration	
3-80 ft [1,2]	• Virtually no resuspension • Special tools to monitor dredge accuracy and resuspension • Produces uniform slurry	• Will not work for highly compacted sediments
3-85 ft [1,2]	• Very low resuspension • Has a computer to maintain optimal dredging efficiency	• Debris tends to clog the dredge
3-115 ft [1,2]	• Can operate in shallow or deep water • Less resuspension than a conventional cutterhead dredge	• In two different projects, resuspension increased four to five times as the dredging speed doubled

disposal options

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Confined disposal facility in Saginaw, MI

There are four major options for contaminated sediments once they are dredged: Confined Disposal Facilities (CDFs), upland landfills, beneficial reuse and treatment. Treatment can be used along with any of the three other options. In some cases, treatment is necessary to prepare the sediment for reuse or disposal. In other cases, treatment reduces the amount of sediments that need to be disposed or destroys contaminants altogether. Though more expensive at the outset, treatment technologies often provide a way to permanently remove contaminants, eliminating any future risks of exposure.

Confined Disposal Facilities (CDFs)

This disposal method uses cofferdams, dikes or other structures to isolate contaminants in a portion of the waterway. In Waukegan Harbor in southern Lake Michigan, for example, a boat slip was walled off, contaminated sediments were placed inside the walls, and the whole thing was then capped like a hazardous waste land fill. Note, though, that hazardous waste landfills have bottom liners to prevent leaking, and this CDF did not. Confined disposal is the most widely used disposal technology in the Great Lakes, mainly because they were constructed as an inexpensive means of containing navigational dredge spoils. Generally, CDFs were not designed to hold highly contaminated dredged material. Between 1960 and 1994, 50 CDFs were constructed around the Great Lakes.[17]

CDFs are prone to leaking. Figure 13 illustrates a typical CDF and the ways in which contaminants can escape. The dredged sediment sits at the bottom in the saturated layer. Confined disposal facilities are designed to hold saturated material that is 10 to 50 percent solids by weight. The unsaturated layer consists of capping material and soil. CDFs are usually covered with vegetation. Dikes at the sides of the CDF contain the contaminants and capping materials. The weir is a special pipe that channels surface runoff to a wastewater treatment plant. Contaminants can escape the confines of the disposal facility by leaching through the bottom into groundwater, volatilizing (evaporating) off the top into the air, being taken up by the vegetation at the top, or seeping through the sides. Each of these pathways must be limited as much as possible. CDFs require extensive monitoring programs to ensure that contaminants are not escaping at unacceptable levels.

Containment risks are similar to those posed by capping. There is a risk that contaminants can leak through the containment into the surrounding ecosystem. CDFs will always be subject to forces working to break them down, like ice scour,

[17] USEPA, 1994a.

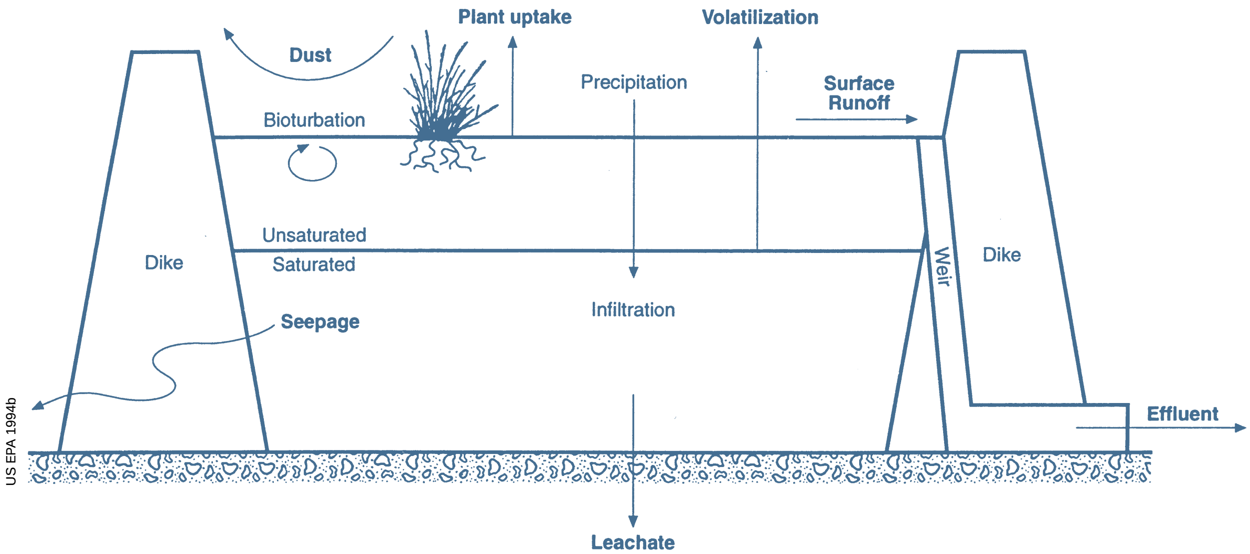

Figure 13: Potential Contaminant Loss Pathways from a CDF

waves, storms, etc. Also, the structure itself alters water flows and could create more erosive forces.

Areas suitable for a CDF must have low water flow and no boat traffic. Backwater areas, slips, turning basins, and some wide areas of rivers are examples of acceptable locations, though the effects of the physical containment structure on flow patterns, flooding, navigation, and habitat need to be assessed. Ideally, the containment area should not be subject to erosive forces, though this can never be guaranteed.

Construction of the isolation chamber confers most of the cost of containment. Monitoring plays a key role, before, during, and after the construction process. In cases like Waukegan Harbor, other ongoing costs include the continuous operation of drawdown wells to ensure that water is always being pulled into the containment structure rather than being released. Waste water treatment systems add to the costs. Containment also provides a more controlled environment in which chemical or biological treatment might be applied. If successful in destroying the contaminants, the cost of long-term monitoring would be eliminated.

CONFINED DISPOSAL FACILITIES

Pros	Cons
• Disposal in CDFs is cheaper than in upland landfills. • CDFs can be located closer to the dredge site, reducing the need to handle and transport contaminated sediments. • CDFs can provide a controlled area for the use of some advanced treatment technologies.	• Contaminants may leak out of the CDF. • Control of some contaminant-loss pathways may be expensive. • CDFs require long-term monitoring and waste water treatment. • Other uses of CDF sites that contain contaminated materials must be carefully considered. • CDFs provide limited disposal space. • It can often be very difficult to site new CDFs.

Upland Landfills

Very simply, landfills are holes in the ground augmented with several kinds of barrier systems. Liners cover the bottoms and sides of landfills while water drainage and collection systems also help prevent leaking. Since landfills are not equipped to deal with much excess water, dredged material needs to be dewatered before landfill disposal. Finally, caps or covers keep contaminants from seeping out the top. Toxic and hazardous waste landfills are required to have better safeguards because they house dangerous materials. Modern-day landfills are fairly effective at containing contaminants.

There are three kinds of upland landfills: standard solid-waste landfills, toxic waste landfills, and hazardous waste landfills. Toxic and hazardous waste landfills are subject to more stringent regulations. Highly contaminated sediments must go in toxic or hazardous waste landfills while less contaminated materials can go in standard solid-waste landfills.

Landfills are cordoned off into cells. Generally, only a few cells are loaded at a time. It is possible to put contaminated sediments in an accessible cell and go back at a later date to treat the sediments.

Landfills charge a fee when they accept material. Monitoring and wastewater treatment costs are included in the fee. Toxic and hazardous waste landfills can be three to six times more expensive than standard solid-waste landfills, making it more expensive to dispose of highly contaminated material. Because landfills charge by volume, it is often cost-effective to use one or more separation technologies (described in the next sections) to reduce the volume of sediment that needs to be disposed.

UPLAND LANDFILLS	
Pros	**Cons**
• Landfilling may be the most cost effective option for small volumes of contaminated sediments. • In cases where contaminants are tightly bound to sediments or are immobilized or encapsulated via a technology, landfilling offers a relatively safe means of sequestering contaminants from the environment.	• There is a risk that the landfill may be compromised and toxic material will leak into groundwater or surrounding lands. • Space in landfills is very limited and it is becoming increasingly difficult to site new ones. • Landfills require long-term monitoring and waste water treatment. • Contaminated sediments must usually be transported longer distances for upland landfilling, increasing costs and the risk of accidents.

Beneficial Reuse

Historically, dredged sediments have been used for a number of projects including beach nourishment; replacing eroded soils; amending marginal soils for agriculture, horticulture and forestry; building wildlife habitat or wetlands; construction fill; and daily caps for landfills. All of these projects have been referred to as beneficial reuse. The use of contaminated sediments for these projects, however, can call the term "beneficial" into question. Using contaminated sediments in any project where they will be exposed to the ecosystem or food web defeats the purpose of dredging them in the first place. Currently, there are no federal guidelines on the beneficial reuse of contaminated sediments. Sometimes, inappropriate "beneficial reuse" projects have provided a convenient, cheap way to dispose of contaminated sediments.

Beneficial reuse projects do hold promise – as long as contamination levels are very low and the use does not directly expose the ecosystem to contaminants. For example, sediments with very low contaminant levels may be considered for landfill cover or as construction fill. The treatment technologies described below increase the options for beneficial reuse. Often, cleaner portions of sediment can be separated out. Some treatment technologies extract contaminants while others permanently lock them into a hardened material. After testing to ensure low contaminant levels, any of these sediment products can be considered for beneficial reuse projects. Several agencies are currently exploring markets for products made from treated sediments from the New York/New Jersey harbor. The ability to produce a safe, marketable product from treated contaminated sediments could defray the costs of dredging and treatment.

treatment options

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Treatment techniques attempt to change contaminated dredged material so that it meets the criteria and goals set by the community, the planning team, the site owner, and/or regulatory agencies. Treatment technologies can remove contaminants from dredged material, destroy contaminants, or change the contaminants in some way so that they no longer pose a threat to the environment. In some cases treatment produces recyclable or re-useable material.

Treatment techniques are available for several different types of contaminants in sediment. Many techniques were tested during government-sponsored demonstration programs.[18] A number of technologies have been successfully used at full scale in recent years. The general types of treatment technologies are discussed below.

Contaminants usually attach to solid particles in sediment. Sometimes, contaminants are more likely to attach to particles made out of a specific material or to particles of a specific size. Often organic material and fine particles, those less than about 40 microns (micrometers) in diameter (smaller than a grain of salt), hold the majority of the contaminants. The physical and chemical properties of different types of sediments make sediment treatment very project specific. Properties affecting the success or failure of treatment technologies include:

Type and strength of bonds between contaminants and sediment particles – fine particles usually have a higher surface electrical charge than larger particles. The charge binds contaminants very tightly to small particles.

Number of different types of particles present in the sediment – most sediments consist of many different kinds of materials. Contaminants preferentially bind to some types of materials. For example, organic material in sediments often contains the highest concentration of pollutants.

How easy it is for oxygen to enter and chemically alter the sediments (oxidation-reduction potential) – dredged material initially does not have much oxygen bound to it. After excavation, oxygen begins to seep in and bind to sediments in a process called oxidation. Higher oxygen levels can cause contaminants (mainly metals) to leach out of the sediments. This could be good or bad depending on the goals of the project. For example, oxidation is a very necessary part of bioremediation.

pH and changes in pH (acid or alkaline conditions) – metals bind more tightly to sediments depending on their acidity or alkalinity. Most metals tend to bind tightly in alkaline conditions and leach in acidic conditions.

Particle size distribution – Fine particles like clays and silts are more difficult to handle while sand is typically easier to handle. Smaller particles can hold more contaminants than larger particles because they have more surface area per volume. More surface area means more places to which contaminants can bind. Smaller particles also tend to pack more tightly, leaving

[18] Netherlands Institute for Water Management and Waste Water Treatment, 1992; USEPA, 1994b; Wardlaw et al 1995.

very little space between the particles (pore space). With so little space between the particles, there is little room for contaminants to move around when subjected to treatments intended to release them from the sediment.

Agglomerations – contaminants and naturally occurring materials can form complexes, called agglomerations, which are difficult to handle chemically or physically.

Dangerous properties – dredged material can have toxic, caustic, or other properties that make the material hazardous to workers and the environment and require special handling.

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Sediment monitoring and sampling vessel known as the Mudpuppy.

Discovering Sediment Characteristics and Testing Technologies

All treatment projects require an accurate assessment of the quantity, composition, and location of the dredged material. Without this information, it is impossible to choose the most appropriate treatment methods. Moreover, preliminary research helps avoid problems sometimes associated with treating sediments. Each dredge load may contain pockets of different kinds of sediments. The amount of dredged sediment and differences between the sediments in each dredge load (heterogeneity) can be underestimated, causing problems at the treatment site. Preliminary research can help mitigate these problems and determine the appropriate treatment option.

Preliminary research includes two studies that examine the specific characteristics of the dredged material and the contaminants. Potential treatment technologies are chosen based on the results of these studies.

Characterization Study – A characterization study analyzes a composite sample of the dredged material to determine its chemical and physical properties. Among other things, characterization study determines the size of the particles in the sediment and the density of the sediment. The characterization study is different than the site characterization process performed before dredging (see p. 7).

Broad Treatability Study – This laboratory evaluation determines whether the sediment is treatable and, if so, what treatment methods are likely to succeed. Broad treatability studies assess characteristics like:

- concentrations of contaminants on differently sized particles,
- concentrations of chemicals in parts of the sediment that are of different densities,
- settling characteristics,
- thermal properties,
- how tightly metals are bound to sediment particles,
- sediment density at different water contents, and
- biological properties (including types of microorganisms present).

Next, two kinds of demonstrations determine whether the treatment technologies will work for particular sediments.

Bench Scale Demonstrations – Once the broad treatability study determines which treatment methods are likely to work, selected technology vendors can perform bench scale studies. Bench scale tests, often simply called bench tests, help determine which technology is best suited for the project.

Each vendor performs in-house tests on a composite sample of the contaminated sediment. Bench tests use laboratory equipment that might not be similar to equipment used for full-scale treatment. Some vendors will perform bench scale tests at no charge. Bench tests should be inspected by either the project manager or a specialized audit firm.

Pilot-Scale Demonstrations – These on-site tests are not always necessary but should be considered – especially if the chosen technology is unproven at the commercial scale. A pilot test usually lasts two to four weeks. The vendor treats some material for a specified time to adjust the treatment process so that it runs as efficiently as possible for the particular sediment found at the site. Once the adjustments have been made, the vendor performs a series of audited performance runs. The results of the performance runs determine whether or not to proceed to full scale.

Just in Case: Safety Features

The two main safety risks when handling contaminated sediment are air emissions and spills. There are a variety of safety features that can be used with treatment technologies to reduce the risks posed by air emissions and spills. Some technologies come with safety features built in. Often, these safety features are called "mitigating measures."

Some chemicals, known as volatile chemicals, tend to evaporate easily. Typically volatile contaminants will stay put when sediment is undisturbed, but will evaporate (volatilize) after sediment is dredged and exposed to air. Some treatment processes produce volatile emissions even when the contaminants themselves are not volatile. For example, as a treatment process breaks down organic molecules, smaller, lighter, more volatile molecules may form and escape. Off-gas collection systems contain and treat volatile emissions. If the treatment technology does not already have an off-gas collection system built in, testing prior to the project will determine whether one is needed.

Spills pose another risk when handling contaminated sediments. There is always a small chance that equipment will fail or storage containers will be compromised, spilling contaminated sediments. Also, in case any part of the process from dredging to treatment is stalled, storage space for sediments should be provided to prevent backup or spills.

Some of the more common safety features are:

Off-gas collection and treatment – Volatile contaminants (off-gases) are either collected by routing air emissions directly through a filter or "scrubber," or by using a vacuum system to collect air and then route it through a filter system. Scrubber systems spray a liquid or fine particle mist into the off-gas that knocks the contaminants out of the air. Filter systems may be made of fabric (an air bag or membrane), activated carbon, absorbent foam, liquid (the gas actually passes through a liquid such as an organic solvent) or natural organic matter such as peat moss or compost (a biofilter).

Temporary cover – In the event that off-gas collection mechanisms fail to contain volatile emissions or their reliability becomes suspect, the sediment handling and treatment areas should be completely enclosed in temporary structures that resemble greenhouses. Within these structures, an air ventilation system routes all indoor air through a filter system.

Spill containment – Spill containment structures help contain sediment or liquid spills. Earthen berms are often used to contain spills at temporary outdoor sites. These earthen curbs surround the treatment site or handling area. In some cases the berm and entire treatment or handling area is covered with a thick plastic liner and re-covered with sand or earth. For permanent or indoor sites, containment structures consist of concrete or asphalt treated with a plastic coating to prevent contaminants from penetrating the pores of the material. Spill containment areas should hold at least 125% of the maximum expected volume of the contaminated sediments. For outdoor sites, the structures must be even larger to contain the rainwater from any storms that may coincide with a spill.

Extra storage space – It is always a good idea to have additional storage space for untreated sediment, water or treated sediment. While the process flow calculations predict the normal storage volumes needed, operations seldom proceed "normally".

pre-treatment technologies

As the name implies, pre-treatment technologies physically or chemically change the sediment before it goes to the main treatment process or for disposal. Many pre-treatment technologies reduce the volume of dredged material that needs further treatment or disposal or improve the physical quality of the dredged material for further handling and treatment. Some pretreatment techniques try to separate cleaner portions of the dredged material from the more contaminated parts. Others separate the water in the dredged material from the solids. Most sediments must undergo pre-treatment before being disposed or treated further. At the very least, sediments almost always must be de-watered.

Pre-treatment technologies can be used for sediment containing any or all pollutants, though not all pollutants can be removed with pre-treatment. Pre-treatment does not destroy contaminants, it only tries to separate them from the clean sediment or prepare the sediment for further handling. Pretreatment technologies yield:

- water;
- a smaller, fine-grained, contaminated sediment portion;
- a coarse-grained, cleaner portion of sediment; and
- large debris such as logs, litter, rocks, and shellfish.

Effectiveness
Often, over 90% of the contaminants can be removed from the cleaner (sand) portion but in some cases the removal rate is 50% or less from the other portions.[19] Note that the contaminated portion of the sediment will have higher concentrations of pollutants than the untreated sediment did. The cleaner portion is removed, leaving the same amount of pollutants in a smaller volume of fine-grained, contaminated sediments. The contaminated portion goes for further treatment or for proper disposal. Treated water, if clean, is discharged to surface water. If not, it is sent through a water treatment system.

Size and Set-up Time
Pre-treatment structures are portable and relatively easy to set up and take down. For small jobs, the setup might take a week or less. For large jobs, setup could take two to four weeks. The size of pre-treatment structures is completely dependent on the size of the job and the specifications for treatment. If settling basins are not needed (see below), the footprint should be less than 1/4 acre. With a settling basin, a footprint of several acres may be needed.

Treatment Rate
Pre-treatment equipment is sized to suit the project, therefore almost any treatment rate is possible. Often, 50 tons of wet sediment can be treated per hour – with the exception of passive de-watering techniques. Passive de-watering techniques can take years.

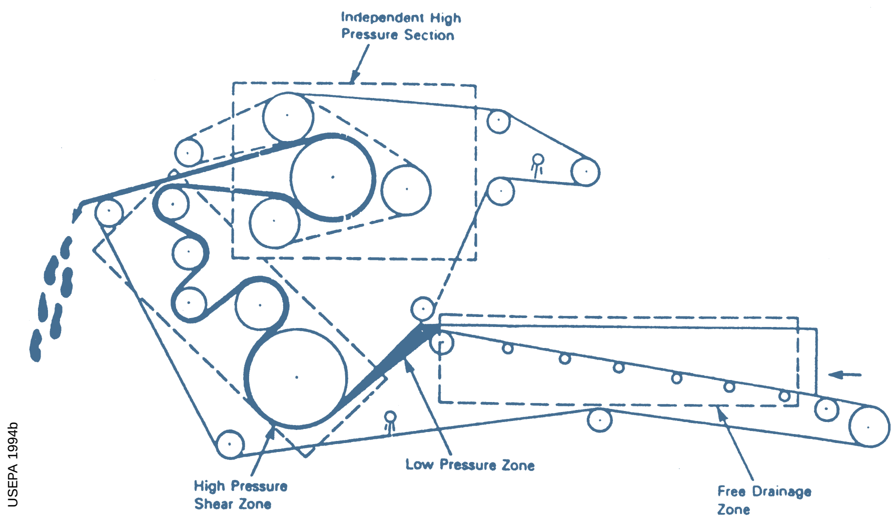
Cost
Usually more than one pre-treatment technology is used for a project. A typical pre-treatment system includes screening, dewatering, and size separation. Depending on how many technologies are used, pre-treatment technologies cost between $10 and $50 per ton (approximately $15 and $75 per cubic yard) of sediment treated.

▶ **The major pretreatment technologies include:**

- **Dewatering**
- **Separation (by size, density and magnetic force)**
- **Water Treatment**
- **Washing**

[19] Wardlaw, 1995.

Figure 14: Belt Filter Press



Dewatering

Dewatering is one of the first steps in handling dredged material. A lot of water accompanies dredged sediments, especially if hydraulic dredges are used. It is often necessary to remove some water before treatment or transport. Physical methods are generally used to dewater sediment. Physical dewatering methods include:

Clarification – spreading out the sediments in a specially designed tank or pond, or in a Confined Disposal Facility, barge, or small portable tank and allowing the solid particles to settle, sometimes with the addition of a chemical settling aid. The water above the sediment (supernatant) is then removed and sent for further treatment or disposal.

Which Dewatering Methods Are Best?

Volatile contaminants like PCBs can evaporate along with water in most drying processes, releasing toxic chemicals to the air. Mechanical dewatering methods (centrifuges and filter presses), though more expensive, dry the sediments faster and thereby minimize evaporative pollution.

"Lagooning" – long-term settling and consolidation of the solids in a shallow disposal cell.

Evaporative techniques – allowing water to evaporate from the sediments after they have settled and the surface water (supernatant) has been removed.

Centrifugation – rapidly rotating wet sediments in a chamber, using centrifugal force to drive water out of the solids and through a membrane or screen and trapping the solids in the chamber.

Filtration – passing the water through a filter material such as sand, cloth or paper and catching the solids on the filter material (this process is used for water containing up to about 2% solids).

Filter presses – squeezing water out of solids using high pressure rollers or plates.

Dewatering methods can be coordinated with the other treatment and disposal options.

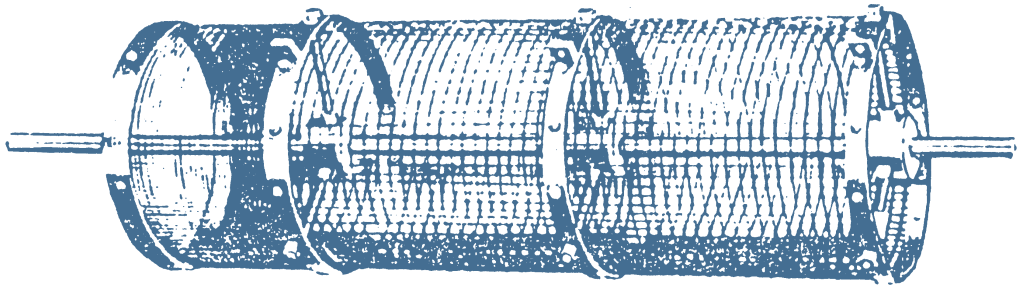
Separation Techniques

Separation techniques try to separate the contaminated portions of the sediment from the cleaner portions. Portions that are clean enough may be reused or recycled. Separation techniques always produce a portion of the sediment that has to be additionally treated or disposed. In many cases, separation technologies reduce the overall cost of the project because they reduce the volume of contaminated sediment that needs further treatment or disposal. Dredged sediment can be separated by size, density and magnetic force. Size and density separation processes separate the smaller, usually more contaminated particles from the relatively clean sand and gravel. Magnetic separation removes metals from the sediment.

Size separation

Most dredged material contains a small amount of debris, such as plant material, metal products, animal shells and bones, rocks, aggregates of finer particles, and litter. This material can damage handling and treatment systems, impede the flow of sediment, and carry a high contaminant load. A number of technologies have been designed specifically to separate this material. These include coarse screens, trommels (rotating drums with holes in the sides), and skimmers.

Since contaminants tend to bind to fine particles, technologies that separate larger particles from fine particles effectively remove cleaner portions of sediment from more contaminated portions. Hydrocyclones or screens accomplish this task quite easily. Hydrocyclones are small conical chambers with an outlet at the bot-



USEPA 1994b

Figure 15: Trommel

tom (small end of the cone) and a lip at the top of the cone that allows water to spill over it into an outer collection chamber. The sediment slurry is injected into the hydrocyclone at very high pressure and speed. The pressure and speed are very precisely calculated to achieve the desired separation. The injection force swirls the slurry around the cone. Bigger and heavier particles move downwards and out the bottom of the hydrocyclone, while smaller particles and water move up the sides of the cone and out over the top lip. Hydrocyclones separate particles by size very effectively. Multiple hydrocyclones can be adjusted to "cut" the sediment into any number of particle sizes.

Hydrocyclone separation of dredged material can play a central role in the treatment process, especially when followed by a washing step like flotation or attrition scrubbing (see below) to further clean the larger particles. For example, hydrocyclones are at the core of the permanent treatment facility for dredged material at Hamburg Harbor, Germany.

Density separation

Some separation techniques are based on particle density (the number of particles in a given volume). Heavier particles tend to settle faster than lighter ones, forming a heavier, more dense layer of sediment at the bottom. In addition to hydrocyclones (which separate by size and density), the following technologies separate by density or settling rate:

Dense media settling basins – also called upflow classifiers; these are tanks in which there is a constant upward flow of water. When the dredged material is fed to the tank, heavier particles sink while the water carries lighter, more contaminated particles upward.

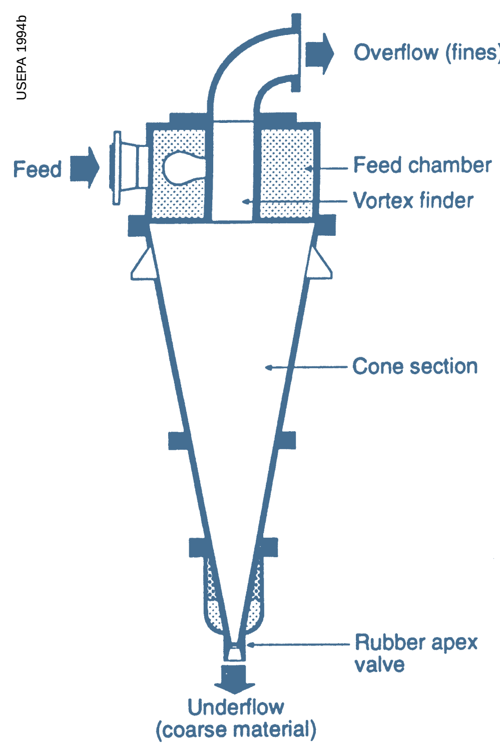
Longitudinal passive settling basins – these are essentially long narrow basins. The dredged material is fairly swiftly fed into one end of the basin. The larger, generally cleaner particles settle quickly and build up at the head end of the basin, while the lighter, smaller particles are carried farther into the basin. When the material builds up to a pre-determined level, it is removed using earth moving or dredging equipment.

Screw classifiers – these long inclined basins are equipped with a large Archimedes screw that lies in the trough of the basin. Dredged material is fed to the bottom end of the basin. Sand and other heavy materials settle at the bottom of the screw. As the screw turns, it carries the dense material up the incline until it spills out the top into a container. Lighter material and water flow out over the bottom lip of the basin.

Magnetic separation

Magnetic techniques separate metallic objects or particles from sediment. The objects removed are generally larger than about 1 mm (0.04 inches). There are a variety of different configurations for magnetic separation. Usually the sediment

Figure 16: Hydrocyclone



PRETREATMENT	
Pros	**Cons**
• Relatively inexpensive and can reduce the cost of further treatment or disposal.	• Can produce air emissions that must be controlled.
• Technology is well developed and relatively easy to operate.	• Dewatering and water treatment can be difficult; may need extensive bench and pilot scale testing.
• Full soil washing systems are an excellent choice for sediment that is more than 50% sand.	• Full soil washing systems are not recommended for sediment that is less than 30% sand.

passes over a magnetic plate or through a magnetic drum. The magnetized surface retains metallic objects while the remainder of the sediment continues through. Periodically the flow of sediment is shut off and the magnetic field is reversed. The metallic objects then fall off the surface of the chamber and are collected for recycling or disposal. Magnetic separators are effective at removing large metal objects but their efficiency diminishes as the size of the metal particles decreases. They cannot remove molecular-sized metals.

Water Treatment

Dredging and treatment projects often produce large quantities of excess water. In most cases, this water is contaminated and needs some treatment before it is discharged to sewers or receiving waters. There are a wide range of commercially available water treatment options. Most of the contamination in water is bound to solid particles suspended in the water. Many water treatment technologies use two techniques to remove the suspended solids:

• Filtration systems use sand filters, membrane filters, or bio-filters to remove solids. All are effective in specific situations.

• Enhanced settling systems include clarifiers, upflow classifiers, and settling tanks or basins. Chemicals added upstream of a settling tank or basin often increase the settling rate, though some sediments will not settle out of a slurry even with chemical settling aids.

Soil Washing

The silt and sand particles removed by size or density separation techniques sometimes need to be treated to reduce contamination. Washing provides a cost-effective way to treat larger particles. The main washing systems are froth flotation and attrition scrubbing.

Froth flotation is an advanced separation and washing technique that uses the chemical and physical characteristics of contaminated sediment particles. Special frothing chemicals are added to the dredged material in a large basin. Air is then forced through the mixture from the bottom of the basin. The violent

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Soil washing process

action of the air entering the mixture causes turbulence that removes the contaminants from the surface of the larger particles. The chemical additives cause a froth to form and trap the contaminants and fine particles. The froth mixture floats to the surface of the basin. The froth is then easily removed and sent for disposal or further treatment.

Attrition scrubbers are essentially large washing machines. Several mixers, resembling propellers, churn the sediments in a large basin. The force of the sediment particles grating against one another removes contaminants from the surface of the particles. The process produces contaminated wash water and clean solid particles.

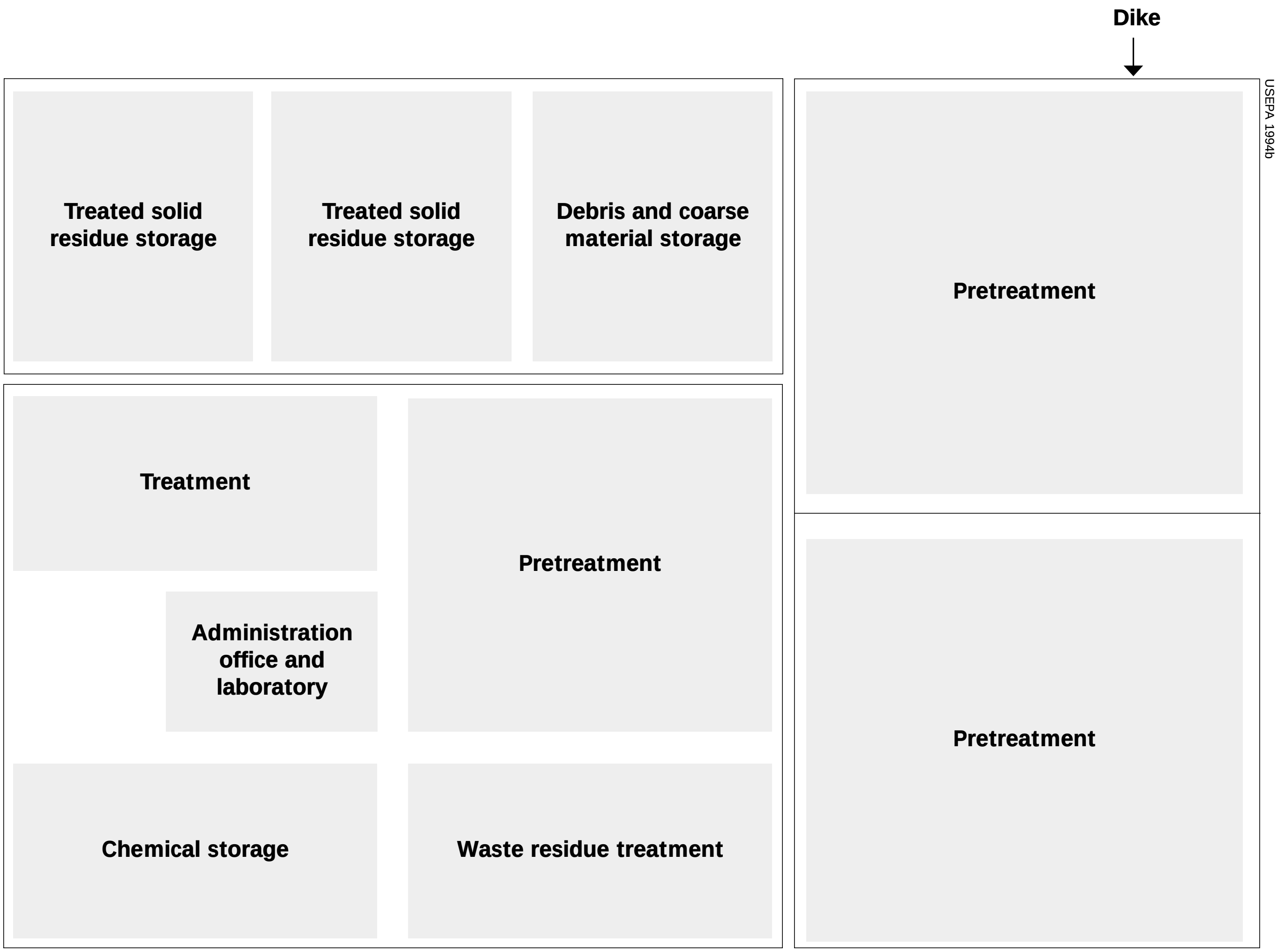

Figure 17: Hypothetical sediment management and treatment site

Soil washing systems combine a number of pre-treatment systems in a treatment train to produce a specific result. Most soil washing companies assemble treatment trains in different configurations for each job based on the specific sediment, contaminants and treatment criteria.

After pre-treatment, one or more of the separated sediment portions proceed to the treatment step or to disposal. Clean portions may be used beneficially or disposed.

Treatment Trains

Dredged material often contains widespread contaminants such as heavy metals, petroleum hydrocarbons, organochlorine compounds and other chemicals. Mixtures are generally more difficult to treat than single contaminants because they may require two or more treatment technologies in a series. When different technologies are used in combination in order to fully treat contaminated sediment, the sequence of treatment technologies is called a “treatment train”. For example, sediment may be dewatered, separated, treated to remove organic chemicals, and finally treated to remove toxic metals.

treatment technologies

Treatment processes can be grouped as follows:

- Biological treatment;
- Phytoremediation;
- Metal extraction;
- Chemical treatment of organics;
- Thermal treatment; and
- Immobilization

This classification scheme is flexible. Some technologies do not fit easily into any of these categories; others fit in more than one category.

The next section will describe each treatment category. At the end of each section, there is a table highlighting the pros and cons of each technology.

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Biological treatment unit at Sheboygan, WI

Biological Treatment

Biological treatment techniques use microorganisms or plants to "eat", or degrade, organic contaminants. Biological treatment that uses plants is called phytoremediation. The recipe for biological treatment is relatively straightforward: air, water, nutrients, microorganisms or plants, and contaminated sediment. Each type of biological treatment puts the ingredients together in a different physical form. Over the course of treatment, the ingredient levels must be maintained.

Since phytoremediation is a little different than biological treatment with microorganisms, phytoremediation is discussed in the following section. In this section, biological treatment refers to the use of microorganisms.

Biological treatment techniques are particularly effective for removing petroleum hydrocarbons and PAHs from sediment.[20] Research on biological treatment in the early 1990s brought rapid breakthroughs in treatment efficiency.[21] Biological treatment is now considered "mainstream" and is the most common treatment option for petroleum and PAH contaminated sediments.

Biological treatment techniques require bench scale studies. Bench scale tests determine the optimal types of microorganisms, water content, oxygen levels, and nutrient levels. They also identify the breakdown products produced by the microorganisms. Breakdown products may be toxic and/or volatile. Finally, bench scale tests determine whether the microorganisms are human pathogens.

Does It Work?
Biological treatment can destroy 90% or more of some contaminants under certain conditions. It is not effective for metal or chlorinated organic contaminants like PCBs.

Emissions
Biological treatment systems usually control liquid and solid emissions very well. Water should not escape because the treatment area should be water-proof. After the sediment is placed for treatment, it is handled very little. However, bio-

[20] Stokman, 1995; Wardlaw, 1994.
[21] Netherlands Institute for Water Management and Waste Water Treatment, 1992.

SCAT compost turner

logical treatment systems are often left exposed, allowing volatile contaminants to escape to the air. The treatment process should be contained or covered to control air emissions. Any byproducts may be either recycled, landfilled or destroyed. The microorganisms eventually die because their food has been used up. Their bodies remain in the treated material and are usually indistinguishable from the sediment mixture.

Sediment Conditions and Contaminants
Coarse materials (stones, clay balls, debris) are usually screened out of the sediment prior to treatment. The sediment's water content is also adjusted to fit the chosen process.

Biological treatment can be used for sediments with a variety of contaminants, though it is mainly used for non-chlorinated organic contaminants. Though not removed, metal contaminants may be present in the sediment. However, if the concentration of metals is high, it can kill the biological organisms used for treatment. Furthermore, all contaminants at extremely high levels can be toxic to living organisms. Therefore, biological treatment cannot be used if initial contaminant levels are extremely high.

Size and Setup Time
The specific treatment process, equipment, and treatment area can be designed to suit the sediment. The size of the treatment facility determines how much sediment can be treated at one time. Since treatment takes a long time, sometimes up to two years, it works well when lots of space is available and all of the sediment can be treated in one batch. The technology is made to be portable and reusable and is relatively easy to set up and take down. For small jobs the setup might take a week or less. For large jobs setup takes two to four weeks.

Cost
Biological treatment can cost between $40 and $100 per ton (approximately $60 and $150 per cubic yard) of sediment treated. The cost will increase with the initial concentration of contaminants, the percent of fine-grained sediment and the resistance of the contaminants to biological degradation. Light petroleum hydrocarbons are very degradable, heavy PAHs are difficult to degrade. The cost also varies depending on how clean the project goals require the sediment to be. A higher cleanup standard increases the cost because the process needs to run longer.

▶ **The main types of biological treatment include:**

- **Solid phase**
- **Bioslurry systems**
- **In place treatment, discussed in Treating it in Place, p. 16**

Solid Phase Systems

Solid phase systems, also called landfarming systems, treat dredged material with less than 60 percent water. The dredged material is spread out on a pad or directly on the ground (this can be done in a CDF). Solid phase biological treatment needs large areas of land (e.g. 25 acres would be needed to treat 50,000 yd).

There are two kinds of solid phase treatment:

Composting – The sediment and nutrient mixture is placed either in biopiles (large mounds) or in windrows. The water content of biopiles is adjusted by watering the surface. In some cases, air content can be regulated with an air distribution system that forces air into all parts of the pile. Windrows are long rows two to three yards high and three to four yards wide at the base. Windrows are turned periodically by a special machine to ensure that water, air, and nutrients are mixed in the sediment.

Pad farming – The sediment is spread in a thin layer less than a yard high. Periodically, a tractor and farm implements are used to mix air, water, and nutrients into the sediment.

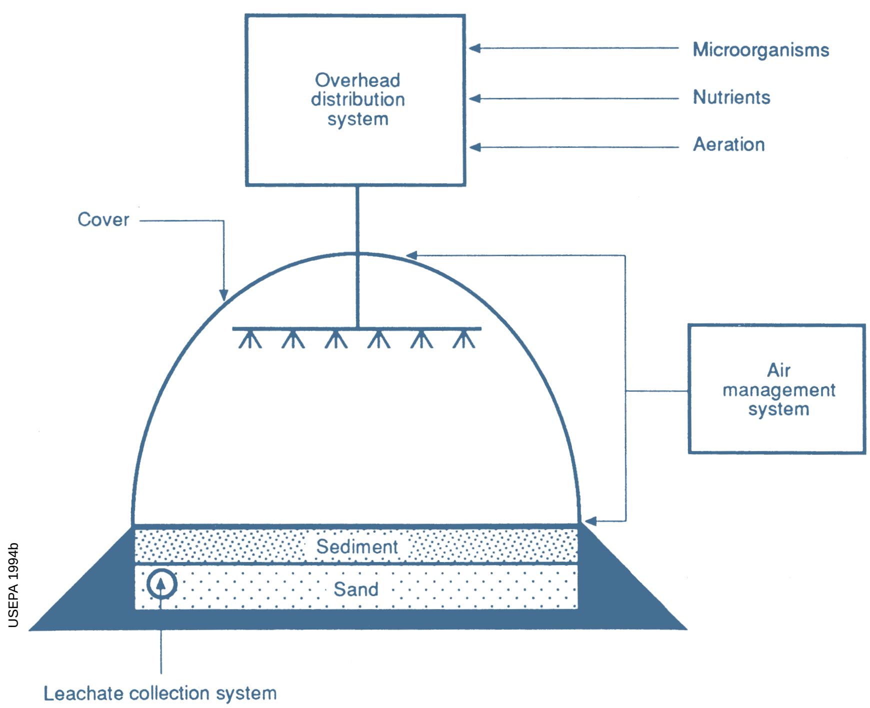
Bioslurry Systems

Bioslurry systems treat dredged material that is in the liquid phase, or more than 70 percent water. Sediment is placed in an enclosed reactor or open treatment basin (possibly a CDF). Bioslurry systems need much less space than solid phase systems, though closed reactors can be very tall. Closed systems are better at controlling the temperature, oxygen content and volatile emissions than open systems. Open systems are faster and less expensive than closed systems. Both types actively mix oxygen and nutrients into the sediments. Bioslurry systems often need an additional carbon source, such as sewage sludge, to ensure that a healthy population of microorganisms develops. After treatment, the sediment must be dewatered. The removed water can be re-used for the next batch of sediment or treated and discharged.

BIOLOGICAL TREATMENT

Pros	Cons
• Preserves the soil-like characteristics of dredged material. Thermal and chemical treatments often strip sediment of organic material.	• Does not destroy metal contaminants.
• Good at degrading petroleum-based contaminants such as fuels, oils, non-chlorinated solvents, and PAHs. Biological treatment is often the treatment of choice for these chemicals.	• Has not been shown to be effective at treating many chlorinated organic contaminants such as PCBs. Effectiveness with higher molecular weight PAHs is generally low (50% breakdown).
• Relatively inexpensive.	• Some of the smaller molecules created by the biological degradation of contaminants may be toxic and/or volatile.
• Easy to implement (although an expert in micro-biology is needed for bench scale tests).	• Some of the microorganisms encouraged to grow in the treatment system may be human pathogens.
• Requires little or no maintenance, little chance of a mechanical failure.	• The most difficult process to monitor. It is difficult to design a monitoring program that adequately characterizes the amount of inputs and levels of contaminant break down for all of the sediment.
	• Conditions can be very different from one part of the sediment to another. A third party should be responsible for the monitoring.
	• Air emission controls are crucial when biologically treating sediments contaminated with volatile chemicals.
	• Relatively slow option. Treating one batch of contaminants could take up to two years.
	• Bioslurry treatment has rarely been used at full scale due to operational problems.

Figure 18: Closed Biological Treatment



Grace Dearborn Inc., of Mississauga, Ontario (now Grace Bioremediation Technologies) conducted a pilot scale solid-phase biological treatment of PAH contaminated sediment at Hamilton Harbor, Canada in 1992/93. The object of the demonstration was to biologically degrade PAHs to the greatest extent possible with a nominal treatment target of 100 ppm. The initial concentration of PAHs was 1140 ppm. Soil berms approximately 1.0 meter high enclosed a rectangular area approximately 47 x 7 meters. A greenhouse structure housed the treatment pad. Grace-Dearborn patented bulking material ("Daramend") was blended in with the sediment. The sediment was tilled regularly and the optimal water content was maintained. The treatment reduced PAHs by approximately 90% over 359 days of treatment, to 110 ppm total PAHs. PAHs in both the tilled and untilled control plots (no Daramend) were reduced by approximately 50%.

Phytoremediation

Phytoremediation uses plants to collect contaminants, most commonly metals, through their root systems or algae to collect contaminants directly through their cell walls. Sediments are spread in a specially designed cell or on a treatment pad. Plants are then encouraged to grow on top of the sediments. Once the plants have done their job, the mature plants are harvested for use (eg. trees are used for lumber) or disposed. Generally the concentration of metals in the plants is not a concern to humans or animals unless ingested. In most cases, lumber grown in phytoremediation plots should be restricted to industrial uses (railways, utility poles, etc.).

A challenge associated with phytoremediation is that the plants can attract wildlife, which may damage the treatment system or feed on the plants, ingesting high doses of contaminants and making them available to the food web. Plants that are a natural food source for wildlife should be isolated with greenhouses, mesh covers, and/or fences.

PHYTOREMEDIATION	
Pros	**Cons**
• Can be relatively inexpensive for metal removal	• A very long-term treatment option
• Can produce lumber or another usable product	• Needs to be strictly controlled to prevent the spread of contamination to animals and humans
• Little maintenance required	• Performance has been inconsistent
	• Can remove some contaminants, but may not be able to meet specific cleanup objectives.

Does It Work?
The sediment characteristics, the mixture and concentration of contaminants, and the plants' ability to absorb contaminants all influence the effectiveness of phytoremediation.

Emissions
Emissions from phytoremediation come in two forms: air emissions and biological products. After the sludge is spread out in a cell or treatment pad, contaminants may evaporate into the air. These air emissions can be controlled by placing the treatment system under a greenhouse. When the plants begin to remove contaminants from the sediments, the plants themselves become contaminated. Phytoremediation needs to be strictly controlled to prevent the spread of contamination to animals and humans.

Size and Setup Time
Phytoremediation often requires lots of space for growing plants. The footprint depends on how much sediment is to be treated. The technology is made to be portable and reusable and is relatively easy to set up and take down. For small jobs the setup might take a week or less. For large jobs setup takes two to four weeks.

Cost
Very few full-scale phytoremediation projects have been done to date. The costs for phytoremediation are estimated to be approximately $2 and $75 per ton (or approximately $40 and $115 per cubic yard).[22]

[22] USEPA, 2000.

METAL EXTRACTION	
Pros	**Cons**
• Is the only method to clean metals from sediment. • Can be very effective in some cases – mainly when only one easily extractable metal is present. • When very high metal concentrations are present (more than 10% metal), can produce a recyclable metal fraction.	• Can have trouble extracting more than one metal at a time. • Metal extraction (other than phtyoremediation) is expensive when compared with disposal of sediment in a CDF or landfill. • Performance of metal extraction systems has been inconsistent.

Metal Extraction

Unlike organic chemicals, metals cannot be destroyed. They can only be removed from or immobilized in the sediments (see Immobilization and Fixation, p.55). Metals are often quite difficult to remove. Most metals tend to bind tightly to sediment particles. In addition to those from man-made pollution, metals can occur naturally and can be found in a variety of chemical forms within the same sediment. Sometimes, they are not removable at all because they are present in a number of different chemical compounds.

Does It Work?
Metal extraction techniques exhibit extremely variable treatment efficiencies depending on the mix of metals, the chemical and physical properties of the sediment, and the budget. Removal efficiencies range from 40 to 90 percent. While a removal efficiency of 40 percent may seem poor, in some cases it is enough to meet the treatment objective. On the other hand, even 90 percent efficiency may not be enough for some projects.

Emissions
The byproducts and emissions from metal extraction processes are dependent on the type of sediment, the type of contaminants, and the chemicals used in leaching or washing. Some systems have a number of liquid, solid and vapor byproducts or emissions. The sediment may not be uniform, so the chemical reaction and byproducts produced will not be uniform and some could be toxic. If the sediment contains contaminants that are highly reactive, there may be hazardous or dangerous residuals or emissions. The leaching or washing solution may be recycled with the contaminant going to a disposal facility or the mixture may be disposed. Treatment of mercury contaminated sediment requires air emission controls because mercury forms a gas voltilizes easily. Generally speaking, all emissions and byproducts can be captured and disposed or recycled.

Size and Setup Time
Metal extraction technology is made to be portable and reusable, but can be complex to set up. For small jobs, the setup might take a month or less. For large jobs, setup could take two to four months. Generally speaking, metal extraction units do not have a large footprint. The entire unit may fit in one or two tractor-trailers.

Treatment Rate
Most treatment units can treat five to ten tons of sediment per hour, but there are systems available that can treat up to 50 tons per hour.

Cost
Metal extraction costs between $100 and $250 per ton (approximately $150 and $375 per cubic yard) of sediment. The cost of metal extraction increases with its effectiveness because it takes more time and chemical additives to extract more metal.

Emerging techniques may ultimately reduce the cost of metal treatment. For example, biochemical extraction with sulfur producing bacteria has had promising results for the removal of heavy metals, except lead. This process uses microbes that produce sulfuric acid while consuming organic pollutants. The sulfuric acid in turn lowers the pH of the soil, making the metals more mobile. The metals must then be removed from the soil.

▶ **The basic categories of metal extraction are:**

- **Leaching**
- **Flotation (also discussed in Pretreatment)**
- **Electrokinetics and Sonic Mixing**
- **Phytoremediation (discussed in the previous section)**

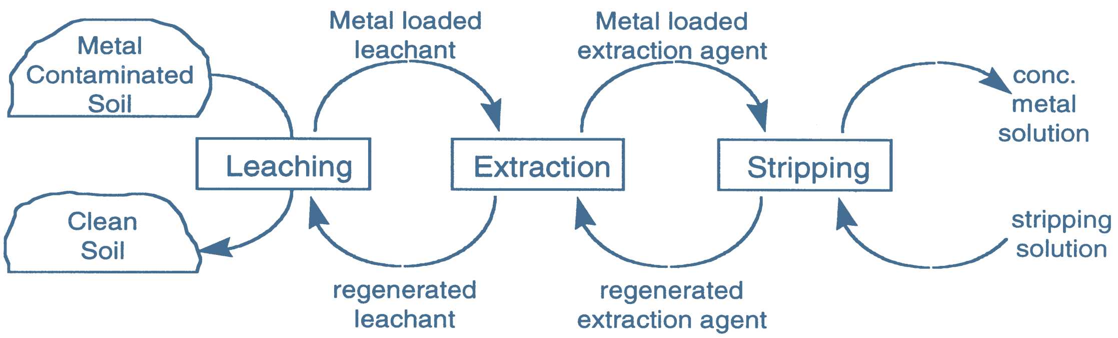


Figure 19: Process flow diagram of the Cognis Terramet metal extraction technology

Leaching

Metals can be removed from sediment by passing a "leaching" solution through the sediment. Leaching solutions change the chemical properties of the sediment and/or the metal so that the metal leaves the surface of the sediment and dissolves in the leaching solution. The leaching solution is then collected and the metal removed by another chemical process. Acid leaching solutions are most commonly used since many metals are more soluble at low pH (acids have a low pH). Sometimes, chemicals called "chelating agents" (pronounced KEE-lay-ting) are used in the leaching solution. Chelating agents bind to metals under some chemical conditions, but release them very easily under other conditions.

Technologies in this category are most effective when the dredged material is contaminated with just one or two metals and may have some problems if a number of metals are present. Although extraction methods can remove heavy metals from dredged material, they can be very costly. Figure 19 illustrates the process flow of a metal extraction technology.

Flotation

The mining industry originally developed flotation processes to separate metals from crushed ore. In a flotation cell, dredged material is mixed at high speed with a frothing chemical and air. Complexes of fine metal-bearing particles, chemical additives and air bubbles form and float to the top of the cell where they can be easily skimmed off. The heavier, larger particles sink to the bottom of the cell and are referred to as "tailings". Tailings have much lower metal content than the froth and may be clean enough to re-use. This technique is a volume reduction technique, much like soil washing.

Electrokinetics and Sonic Mixing

Electrokinetic techniques use electricity to force metals toward an electrically charged object (electrode). This can be done in the solid phase or in the slurry phase. After the metals have concentrated at the electrode they can be removed. Similarly, sonic techniques use sound waves to cause the metal ions to gather together in a water solution. Once concentrated, the metals can be removed. Neither electrokinetic nor sonic techniques have been successfully commercialized.

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CHEMICAL TREATMENT OF ORGANICS

Pros	Cons
• Essentially all emissions and byproducts can be captured and disposed or recycled. • In some cases, for example when PCBs are the only contaminant and natural organic material content is low, chemical treatment can be very effective. • Solvent washing can be very specific to the target contaminants, preserving the soil-like qualities of the sediment. • Can be inexpensive in some cases.	• Adding chemicals to contaminated sediment can cause unpredictable results. Since sediment may not have uniform characteristics, the chemical reaction may not be uniform and may produce toxic chemicals. • For most sediments, chemical treatment is either ineffective or very expensive. For example, sediments with high organic content require a great deal of oxidant. • May leave a residue of the chemical additives in the sediment.

Solvent extraction pilot project

Chemical Treatment of Organics

Chemical treatment techniques extract, destroy, or alter contaminants in dredged material with chemical solutions.

Does It Work?
At high cost, chemical treatment can remove 99% of the organic contaminants. At lower cost, it can remove 90 to 95% of the organic contaminants. The amount of removal or destruction may be limited by many factors such as the physical and chemical nature of the sediment. Heavy metals cannot be destroyed with chemical treatment.

Emissions
The byproducts and emissions from chemical treatment depend on the type of sediment, the type of contaminants, and the actual chemicals used in treatment. Some systems produce a number of liquid, solid and vapor byproducts or emissions. Most chemical treatment systems have emission control systems built in. More control systems can be added for specific purposes.

Sediment Conditions and Contaminants
Some chemical treatment technologies have trouble treating very fine-grained sediment like clay. Coarse material, including stones, clay balls, and debris, is usually screened out of sediment to be treated.

Size and Setup Time
Generally speaking, chemical treatment units are not large. The entire unit may fit on one or two tractor-trailers. The technology is made to be portable and reusable, but can be complex to set up. For small jobs the setup might take a month or less and for large jobs setup could take two to four months.

Treatment Rate
Most treatment units operate at 5-10 tons per hour, but systems are available that can treat up to 50 tons per hour.

Cost
Chemical treatment methods can cost between $75 and $200 per ton (approximately $115 and $300 per cubic yard) of sediment treated, depending on the level of efficiency required and the initial concentrations of contaminants. The cost of chemical treatment increases with its effectiveness because it takes more time and chemical additives to destroy a larger amount of contamination.

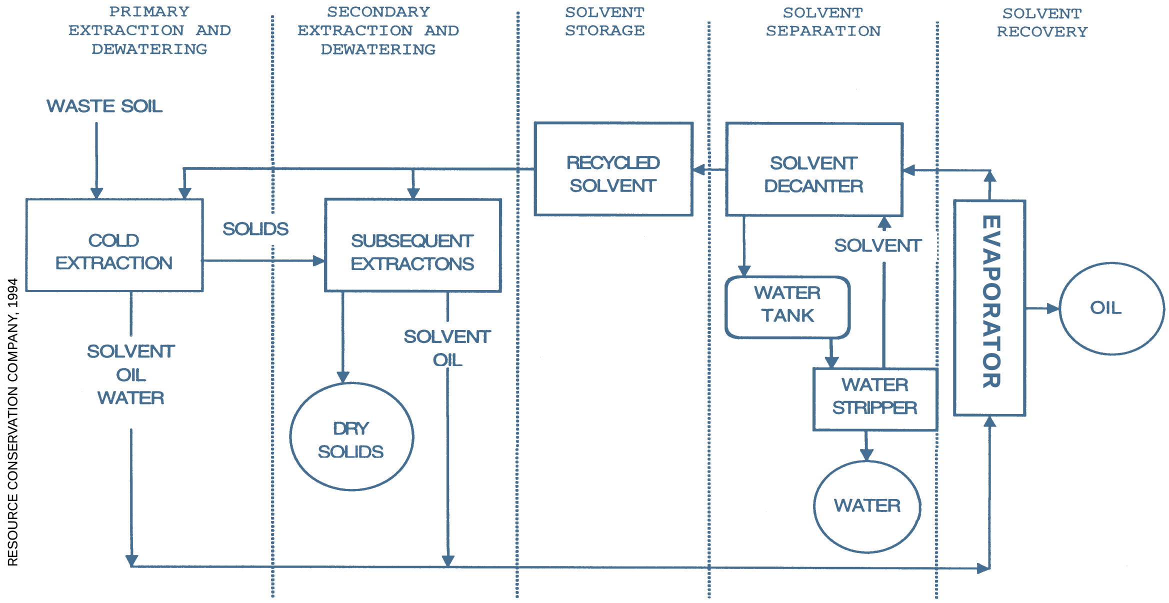

Figure 20: Schematic diagram of the BEST solvent extraction process

▶ **The categories of chemical treatment are:**

- **Extractive**
- **Reactive**

Extractive Technologies

Organic contaminants can be extracted by washing the sediments with organic solvents or with water-based solutions. In some cases, the contaminants can be removed from the used solvent. The contaminants are destroyed or disposed of while the solvent is recycled. In other cases, the solvent and contaminant mixture is destroyed or disposed of. These processes can achieve removal efficiencies better than biological treatment but generally not as high as thermal treatment. There are several commercial-scale extractive units available. Figure 20 is a process flow diagram of a solvent washing process.

Reactive Technologies

Oxidizing

A strong oxidizing agent can destroy organic contaminants in dredged material. Oxidizing agents, like hydrogen peroxide, ozone, or "wet air," are chemicals or compounds that encourage oxygen to bind to organic compounds. Oxygen breaks large organic molecules apart, forming smaller molecules like methane. A potential problem with these techniques is that oxidizing agents may break down all organic compounds, not just the contaminants. This means that a great deal of oxidizing agent is used up in the oxidation of naturally occurring organic material.

Dechlorinization

Chlorinated organic contaminants such as polychlorinated biphenyls (PCBs) can be subjected to a chemical treatment that removes the chlorine from the molecular structure. Most dechlorinization techniques use an earth metal such as sodium or potassium. The metal reacts with the chlorine atoms in the contaminant, yielding harmless or less toxic organic molecules and salts.

Complexing

Some contaminants can be "complexed" to render them less harmful or change their structure altogether. A chemical complex is an agglomeration (combination) of two or more molecules. There are a number of chemicals called "complexing agents" that bind to other chemicals to form complexes. Complexing agents are often used as an intermediate step in treatment. They render the contaminant less harmful and form a larger chemical unit which may be more easily removed from the sediment. Fairly recently, complexing agents in the form of small beads, called imbiber beads, have been tested on contaminated dredged material. Each bead can bind a significant number of contaminant molecules. The beads then must be removed and decontaminated, requiring additional sophisticated technologies.

Thermal Treatment

Dredged materials or residues from other types of treatment that are very seriously contaminated with organic material may be treated thermally. Thermal treatment techniques are often expensive, but they can achieve very high removal and destruction efficiencies. In theory, thermal treatment can destroy or remove all organic contaminants and mercury. Metals (other than mercury) cannot be treated with thermal destruction or removal systems, however, vitrification (see below) does bind metals into a glass-like product.

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Thermal Desorption

Emissions
Thermal treatment systems produce gas and liquid waste that must be managed carefully. Emissions common to all the techniques are discussed here. Emissions specific to a technology are discussed in the section for that technology.

Thermal processes create gases. Some are condensed and treated in cooling systems. Ultimately some are released to the environment after cooling, scrubbing (see Just in Case: Saftey Features, p. 35) and filtering. If the equipment is not operated properly or if a system failure occurs, air emissions can be significant. Dioxins and furans are of special concern. If chlorinated organics are present in the feed sediment, dioxins and furans could be emitted to the air. Two of the four types of thermal treatment technologies discussed below have the potential to create dioxins and furans: incineration and vitrification. Since no oxygen is present in thermal desorption or reduction, no dioxins or furans are produced.

Liquid wastes from thermal processes include water condensed from the off-gas and cooling water. When scrubbers are used to clean air emissions, scrubber water becomes a waste as well. All liquid waste must be treated before it is disposed or released to receiving waters.

Monitoring Requirements
Monitoring of thermal treatment technologies is fairly straight-forward but must be done on a "mass-balance" basis. This means that all inputs and outputs must be weighed and analyzed for contaminant concentrations, and all internal surfaces of the equipment must be inspected or sampled before and after the treatment. Monitoring of any thermal process can be expensive, especially if dioxins and furans are to be monitored.

▶ **There are four types of thermal treatment:**

- **Thermal Desorption;**
- **Incineration;**
- **Thermal Reduction; and**
- **Vitrification.**

Thermal Desorption
Thermal desorption uses heat to turn organic contaminants and mercury, a volatile metal, into gases and remove them from the solid portions of the sediment. The toxic gases are condensed and collected as a liquid residue of substantially less volume than the original sediment. Although this technology does not destroy the contaminants, the remaining volume of contaminated liquid requiring further treatment is much smaller, thus reducing the costs of subsequent treatment or disposal.

Does It Work?
In theory, thermal desorbers can remove all organic contaminants from all sediments. All organic molecules become vapors (volatilize) at temperatures above approximately 600°C. Most thermal desorbers are designed to reach this temperature. In practice, however, thermal desorbers have difficulty treating very fine-grained (clay) sediments because the spaces between the particles are so small

The ATP thermal desorption technology was demonstrated at the Wide Beach Development Superfund Site, in Brant, New York, in 1991. Three test runs were performed with a pilot scale unit. PCB contaminated soil and sediment was treated to below 2 ppm (the project objective) in each test run. In fact, the average PCB concentration in the treated sediment and soil was 0.043 ppm. No breakdown organic products were detected in the treated soil and no dioxins or furans were detected in stack gases.

that the contaminants cannot escape. It is also difficult maintaining consistent temperatures across all of the sediments being treated.

Emissions
There is little or no possibility that dioxins and furans will be formed inside the desorption chamber because no oxygen is present. However, thermal desorbers can produce significant particulate emissions that must be captured.

Size and Setup Time
The technology is made to be portable and reusable but can be complex to set up. For small jobs the setup might take a month or less and for large jobs setup could take 2-4 months. Generally speaking thermal desorption units do not have a large footprint. The entire unit may fit in two or three tractor-trailers and take up 1-2 acres when set up.

Treatment Rate
Most treatment units operate at 5-10 tons per hour but systems are available that can treat at up to 50 tons per hour.

Cost
Recently, thermal desorption costs have dropped dramatically. Some thermal desorbers are now priced competitively with landfills and biological treatment. The cost is typically between $35 and $100 per ton (approximately $55 and $150 per cubic yard) of sediment.

THERMAL DESORPTION

Pros	Cons
• If operated properly should not have air emission problems. • Very effective (in theory) for most contaminants and most types of sediments. • Low cost compared to other thermal techniques. • No possibility of dioxin or furan production.	• Has difficulty with fine-grained sediment. • Prone to process upsets and breakdowns. • Can produce bad air emissions if not operated properly or if emission controls not in place. • Need to remove as much water as possible from sediment before treatment.

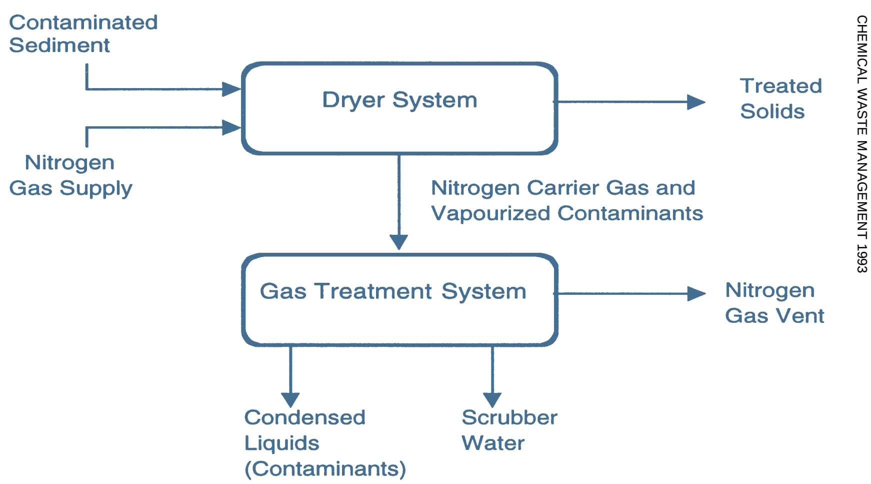


Figure 21: Process flow diagram of the XTRAX thermal desorber.

Incineration

Incineration is currently used to dispose of both hazardous and municipal wastes. Incinerators burn trash, dredged material, or other waste streams, destroying all organic matter. However, existing hazardous and municipal waste incinerators are a major source of dioxins, furans, mercury, and other hazardous air pollutants.

Sediment Conditions and Contaminants

All types of sediment can be incinerated, though clay can sometimes pose a challenge. Sediments must be dewatered before they are incinerated.

Does It Work?

Incinerators can destroy essentially all organic contaminants from all sediments. Incinerators operate at very high temperatures. If sediments stay in the incineration chamber long enough, all organic molecules burn. In practice, however, incinerators have difficulty treating very fine-grained (clay) sediments because the clay forms lumps and hardens in the heat. Fluidized bed incinerators try to solve this problem by blowing air or another gas through the sediment to prevent lumps from forming. Incineration does not destroy metals. Mercury volatilizes and must be removed from the stack gas. Other metals remain in the burned remains of the sediment and must be disposed.

Emissions

Dioxins and furans will be produced during the incineration process. Afterburners can reduce dioxin and furan emissions enough to meet air emissions standards, but they cannot completely eliminate dioxin and furan emissions. An afterburner is a second burner unit that burns any organic molecules in the off-gases from the first burner. The burned remains of sediment contain heavy metals and other toxic chemicals and must be disposed of properly. Monitoring of incineration is usually carried out by firms that specialize in monitoring as monitoring of stack gases must be done in a precise manner.

Size and Setup Time

Incinerators are usually considered "transportable" not portable. This means they are large and can be complex to set up. For small jobs the setup might take a few months or less but for large jobs setup could take 6-12 months. Generally speaking incinerators do not take up too much land, although they may be rather large facilities. The system may occupy 1-2 acres of land.

Treatment Rate

Most treatment units operate at 5-10 tons per hour but systems are available that can treat at up to 50 tons per hour.

Cost

Because the energy requirements for incinerators are high and air emission requirements are strict, incinerators tend to be the most expensive type of treatment. Incineration typically costs between $300 and $900 per ton (approximately $500 and $1350 per cubic yard) of sediment.

INCINERATION

Pros

- Designed to meet 99.9999% destruction requirement.
- Very effective for most contaminants and most types of sediments.

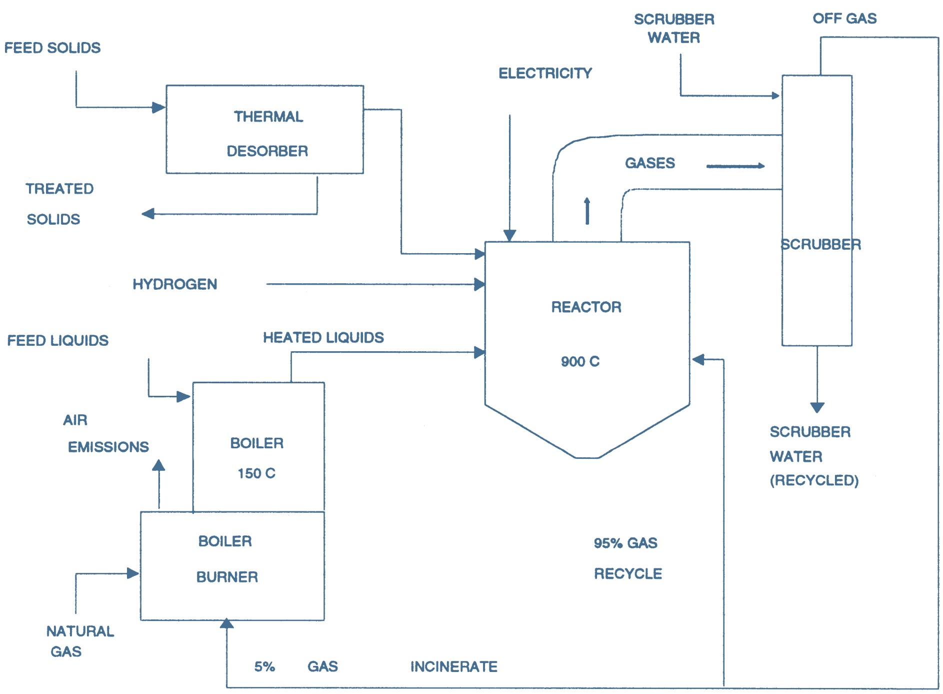
Cons

- May have difficulty with fine-grained sediment (certain types of incinerators).
- Prone to process upsets and breakdowns.
- Can have bad air emissions if not operated properly or if emission controls not in place.
- Need to remove as much water as possible from sediment before treatment.
- Expensive when compared to other treatment types.
- May produce dioxins and furans.

Eco Logic, a Canadian company, conducted the first pilot-scale demonstration of thermal desportion at Hamilton Harbor in 1991. Approximately 12 cubic meters of sediment contaminated with PAHs was removed from the harbor using a Cable Arm dredge. The Eco Logic technology achieved a destruction and removal efficiency of better than 99.9% for total PAHs. The stack gas emissions for all air quality parameters measured, most importantly PCBs, PAHs, dioxins, furans, metals and particulates, were well below the Ontario's Clean Air Program ambient air quality guidelines.

HEADWATER ENVIRONMENTAL SERVICES, INC.

Ecologic thermal reduction



ENVIRONMENT CANADA, 2000

FIGURE 22: Schematic diagram of Eco Logic thermal reduction technology

Thermal Reduction

A relatively new type of thermal treatment, thermal reduction uses very high temperatures (same temperature range as incinerators) in the presence of hydrogen gas to transform organic molecules into lighter and less toxic products. With hydrogen present instead of oxygen, a chemical process known as "reduction" occurs. Chemical reduction is, in one sense, the opposite of incineration, which is an oxidative process. The advantages of these systems over incinerators are that they do not produce dioxins and furans; and they are not affected by the presence of water in the dredged material.

Thermal reduction cannot treat solid material. These units use a thermal desorption system (see above) to volatilize and remove contaminants. The gaseous contaminants are then sent to the reduction reactor. The company that invented this treatment technology, Eco Logic, remains the only provider of the service. Figure 22 is a schematic diagram for the Eco Logic Thermal Reduction process.

Does It Work?
Thermal reduction systems can, in theory, destroy all organic contaminants from all sediments. In practice, thermal reduction systems are limited by the quality of the thermal desorption system used to remove the organic molecules from the sediment (see discussion of limitations of thermal desorbers above). Heavy metals, with the exception of mercury, cannot be treated with thermal reduction. Heavy metals remain in the sediments after the thermal desorption part of the process. Mercury is removed in the desorption process.

Emissions
Air emissions can be recycled to the reactor to further reduce any remaining organic molecules. If the equipment is not operated properly or if a system failure occurs, air emissions can be significant. Dioxins and furans can never be produced during the treatment process because there is no oxygen present in the reactor.

The Eco Logic company has developed an "on-line" monitoring system that is used mainly to control the process but is a great help to the environmental monitoring.

Sediment Conditions and Contaminants
Sediments do not have to be dewatered for thermal reduction to the same extent as for other thermal processes. Fine grained sediments can pose a challenge to the thermal desorber because the space between the particles is so small that it is difficult for the contaminants to pass through the spaces and out of the sediment.

Size and Setup Time
This technology is usually considered "transportable" not portable. This means they are large and can be complex to set up. For small jobs the setup might take a few months or less but for large jobs setup could take 6-12 months. Generally speaking thermal reduction units do not have a large footprint. The system may occupy 1-2 acres of land.

Treatment Rate
The smallest thermal reduction units operate at 5 tons per hour but units can be built to handle up to 50 tons per hour.

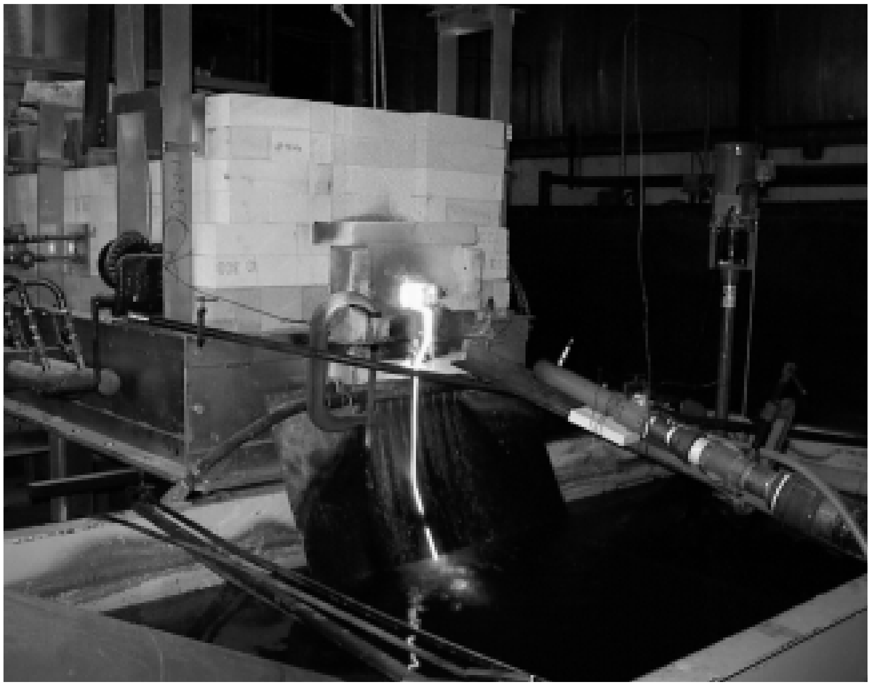
Cost
The cost is typically between $150 and $350 per ton (approximately $225 and $525 per cubic yard) of sediment.

THERMAL REDUCTION	
Pros	**Cons**
• If operated properly should not have air emission problems.	• May have difficulty with fine-grained sediment.
• Very effective (in theory) for most contaminants and most types of sediments.	• Prone to process upsets and breakdowns.
• Can achieve 99.9999% destruction for some contaminants in some situations.	• Relatively expensive compared to other technologies.
• No possibility of dioxin or furan production.	• Depends on the performance of the thermal desorber (the first step in the process) for the overall treatment efficiency.
• Water in the sediment does not affect the process.	

Vitrification

Vitrification heats up sediments like an incinerator, forcing organic contaminants and mercury out of the sediments in a gaseous state and destroying them either in the primary chamber or in an afterburner. Mercury must be captured and scrubbed from the off-gas. The technique also immobilizes other metal contaminants, a distinct advantage in some situations. The process runs at a temperature high enough to melt sand and metals in the dredged material (>900°C). After cooling, the dredged material turns into a hard slag-like product that traps the metals permanently. Most technologies in this category produce a product such as gravel or bricks which can be used as building material. A disadvantage of vitrification is the high energy consumption and the flue-gas emissions produced. Vitrification has rarely, if ever, been used at full scale in North America, though several bench-scale and pilot scale demonstrations have been performed.

WI DEPARTMENT OF NATURAL RESOURCES



Minergy vitrification pilot project, Winneconne, WI

VITRIFICATION	
Pros	**Cons**
• If operated properly should not have air emission problems.	• Prone to process upsets and breakdowns.
• Very effective (in theory) for most contaminants and most types of sediments.	• Can have bad air emissions if not operated properly or if emission controls not in place.
• Immobilizes non-volitile metals in the vitrified sediment.	• Need to remove as much water as possible from sediment before treatment.
	• May produce dioxins and furans.

Does It Work?

Vitrification systems can remove or destroy all organic contaminants from all sediments. They operate at very high temperature, and if the residence time (time in the heating chamber or afterburner) is long enough all organic molecules will oxidize (burn). Metal contaminants are trapped in the vitrified material.

Emissions

Vitirification systems with an "after-burner" (a second burner unit that burns any organic molecules in the off-gases from the first burner) should be able to meet the most stringent air emissions standards. Dioxins and furans may be produced during the vitirification process.

Sediment Conditions and Contaminants

Vitirification systems do not have the same problem with fine grained sediments as other thermal treatment systems do.

Size and Setup Time

These systems are usually considered "transportable" not portable. This means they are large and can be complex to set up. For small jobs the setup might take a few months or less but for large jobs setup could take 6-12 months. Generally speaking vitrification units do not have a large footprint. The system may occupy 1-2 acres of land.

Treatment Rate

Vitirification systems can be designed to treat from 5-50 tons per hour.

Cost

Not enough projects have been done to establish a price range A pilot project in Wisconsin indicates that at full scale the cost could be less than $40-60 per ton ($60-90 per cubic yard).

Immobilization by Fixation or Solidification

Immobilization attempts to lock contaminants in the dredged material either by chemically binding the contaminants to the solid particles (fixation) or physically preventing the contaminants from moving (solidification). In some cases, a combination of physical and chemical immobilization is used. After this type of treatment, the dredged material is usually placed in a disposal site or used as a construction material (where allowed by law).

Fixation – Fixation techniques focus on chemically binding contaminants to prevent them from entering the environment. There are a number of different approaches to fixation. One involves adding large quantities of chemicals that raise the pH of the material, making it more alkaline, and thus immobilizing most types of metals. Another technique uses a silica solution to "encapsulate" contaminants that are bound to sediment particles. This technique is not always effective – especially with high levels of organic contamination.

Solidification – Solidification uses a cementing substance or high-temperature melting (see Vitrification section above) to encapsulate and stabilize contaminants. After the addition of a cementing substance, the dredged material can be allowed to harden in a large mass in a fill site or formed into smaller blocks or bricks.

Does It Work?

The main disadvantage of immobilization techniques, and the reason many countries do not allow immobilized dredged material to be used as construction material, is that the contaminants remain in the dredged material. The effectiveness of immobilization may be short-term. Contaminants may leach from the material after a number of years. However, the leachable fraction of the contaminants can be reduced by at least 99% in the short-term.

Emissions

Adding chemicals to contaminated sediment can cause unpredictable results. If the sediment is not uniform, the chemical reaction produced will not be uniform. This commonly results in an unexpectedly large release of volatile organic compounds. In addition, if the sediment contains contaminants that are highly reactive there may be hazardous or dangerous residuals or emissions.

Catastrophic releases of contamination, water or solids are unlikely because most processes are

IMMOBILIZATION

Pros	Cons
• If carried out properly should not have air emission problems; if volatile emissions are a problem then these can be controlled with containment and treatment systems. • Very effective (in theory) at reducing the leaching of contaminants for most contaminants and most types of sediments. • Low cost. • Easy to implement. • May be able to produce construction materials with treated sediment.	• Does not destroy the contaminants – this may be a long-term concern. • May be difficult to gain approval or to find a disposal site for treated material. • Can have bad air emissions if not operated properly or if emission controls not in place. • Difficult to predict the longevity of the fixation or solidification. If the conditions change at the disposal site (pH, temperature, oxidation-reduction potential, leaching rate) then the effectiveness of the treatment may be impaired.

Product of cement-lock process

EPA, GREAT LAKES NATIONAL PROGRAM OFFICE

"batch" processes. One batch is treated at a time in a relatively controlled environment. The chemical additives themselves may have some dangerous properties. They are often extremely acidic, extremely alkaline or extremely reactive. If the correct dose of chemicals is added, the end result should be a relatively neutral and inert material.

It is easy to monitor the process and perform leachate tests on the treated material. It is difficult to analyze the treated material to determine if contaminants have been destroyed (as some vendors claim), or are merely bound in the sediment.

Sediment Conditions and Contaminants

Fixation and stabilization can be used on any type of contaminant in theory, but in reality they are difficult to use for very high concentrations of organic contaminants. Any type of sediment may be treated as long as additives can be specifically tailored to work with the particular mix of sediment and contaminants.

Size and Setup Time

Typically the processes are very mobile and easily set-up and decommissioned. For small jobs a system could be set-up in one to two weeks. Generally speaking fixation/stabilization processes do not have a large footprint. The entire unit may fit in one or two tractor-trailers. Large amounts of space may be required to cure the treated material, but the treated material can also go directly to the disposal area.

Treatment Rate

The process can be designed to treat at almost any rate since "off-the-shelf" equipment is used for mixing the sediment and fixatives. The limiting factor may be the space available for curing the treated sediment.

Cost

Immobilization techniques typically cost between $10 and $50 per ton (approximately $15 and $75 per cubic yard), not including the cost of disposal.

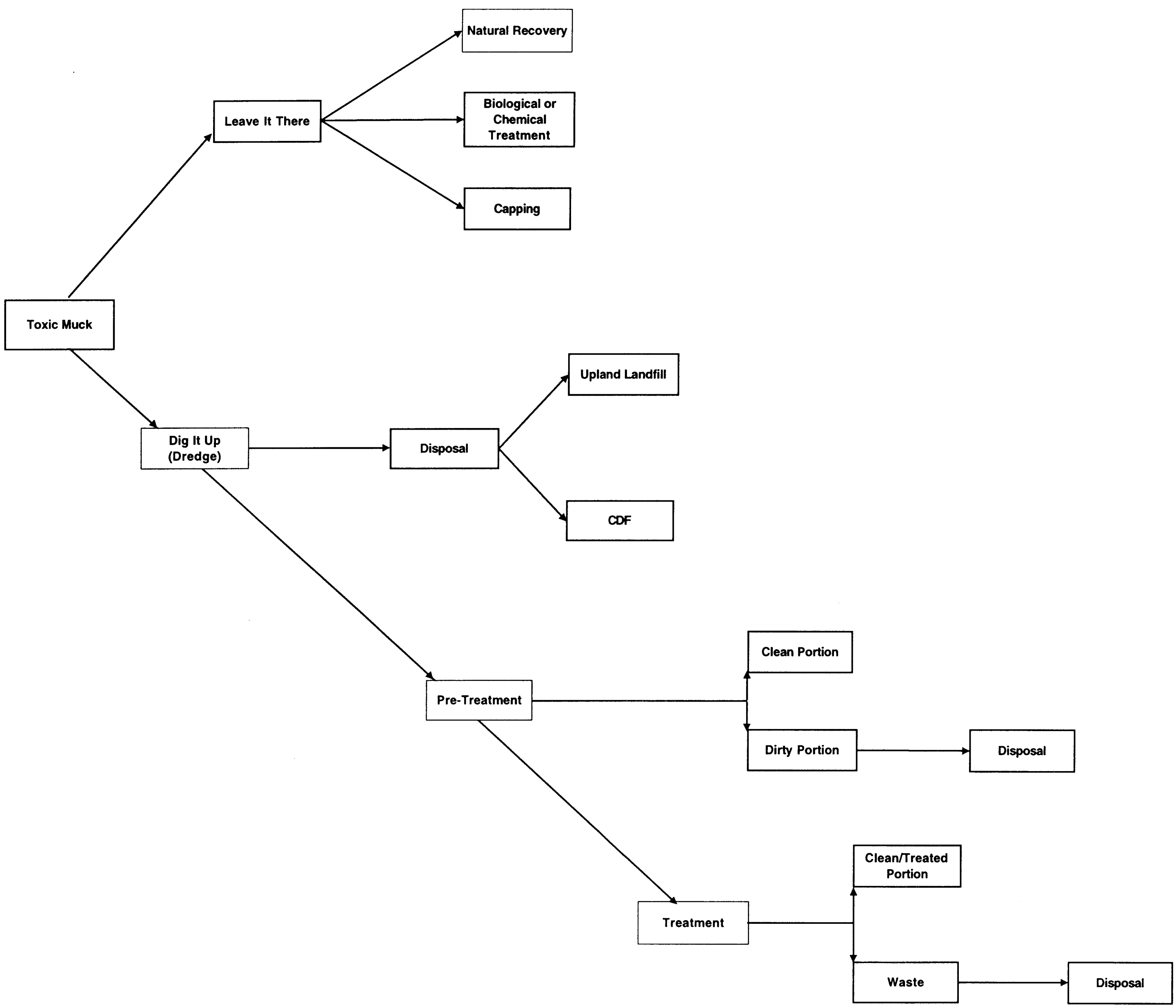

JIM GRINDROD

moving forward

It is clear: we have the tools and knowledge to clean up toxic sediment sites. The time to act is now. The legacy of industrial pollutants at the bottom of Great Lakes rivers and harbors is a major barrier to a healthy ecosystem and sustainable economy. Fixing this problem will require time and money, but the dividends of this investment, measured in economic growth and environmental health, will be well worth the cost. The alternative—doing nothing—is not acceptable. Residents and visitors of the Great Lakes region have lived with that alternative for more than 30 years and continue to suffer its effects every day.

This guide, along with the other resources described in the Appendices, provides an overview of the tools and techniques we can use to get cleanups underway. It is time to put these tools to good use. Using these resources, we can help assemble and evaluate cleanup plans. We can make informed decisions and have constructive dialogues with regulators and communities. We can invest in permanent solutions to toxic problems by testing and developing treatment technologies. We can leave our children water that is safe for fishing and swimming and harbors that promote economic growth. We can achieve our vision of a healthy aquatic ecosystem that supports a vibrant, sustainable economy throughout the Great Lakes basin. Now we simply must generate the will to take action and start down the road to healthy harbors and restored rivers.

Appendix A:
Roadmap to Remediation



Appendix B: Where can I find the information I need?

Volume and distribution of contaminated sediments

- Remedial Investigation (Superfund Site Assessment)
- Remedial Action Plans
- USEPA or Corps district offices
- State resource agencies

Sediment chemical and physical characteristics

- Remedial Investigation
- Remedial Action Plans
- USEPA, Corps, or other Federal agencies
- State resource agency

Waterway bathymetry and hydraulic characteristics

- Remedial Investigation
- Navigation charts from the National Oceanic and Atmospheric Administration, the U.S. Coast Guard, or the Corps Flood control/insurance studies by the Federal Emergency Management Agency or the Corps
- State resource agencies
- Local harbor/port authorities

Waterway navigation use

- Waterborne Commerce of the United States (US Army Corps of Engineers)
- U.S. Coast Guard offices
- State transportation and resource agencies
- Local harbor/port authorities

Availability of local lands for use

- State transportation and resource agencies
- Local agencies (departments of planning, zoning or economic development)

Significant environmental resources to be protected

- State resource agencies
- U.S. Fish & Wildlife Service

State and local environmental regulations

- State resource agencies
- County departments of health
- Local agencies (departments of zoning, transportation or environment)
- Impacts of contaminants on human health and the environment
- Remedial Investigation
- State resource agencies
- U.S. Fish & Wildlife Service
- Natural resources damage assessment (NRDA)

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

Appendix C: Glossary

absorbent mats – mats used to soak up oily material

Areas of Concern – forty-two geographic areas around the Great Lakes basin where pollution and development have severely damaged local ecosystems. The governments of the United States and Canada designated the Areas of Concern in 1987.

armored caps – stone, cement, or other hard material placed over contaminated sediments in an effort to isolate contaminants from the ecosystem.

barge – a flat bottomed boat used for transport, similar to a scow.

beach nourishment – using sediments or sand to build up a beach, replacing eroded material.

bench-scale – testing and evaluation of a treatment technology on small quantities of sediment (several kilograms) using laboratory-based equipment that is not directly similar to the full-sized equipment that would be used for an actual cleanup.*

benthic – pertaining to the bottom of a body of water. Benthic community refers to the micro-organisms, plants, and animals that live at the bottom of a body of water.

biological treatment – the use of micro-organisms or plants to treat pollutants in sediments. Micro-organisms destroy pollutants by "eating" them. Plants remove contaminants from the sediments and store them in their stems or leaves.

biomagnification – the increase in concentration of a pollutant from one link in a food chain to another. Animals low on the food chain take in pollutants and store them in their tissue or body fat. As predators eat contaminated prey, the pollutants in the prey build up in the predators. The predators end up with higher concentrations of the pollutants in their bodies. Animals at the top of the food chain have the highest concentrations of pollutants stored in their bodies.

capping – covering contaminated sediments with clean material in an effort to isolate them from the surrounding ecosystem.

chemical treatment – the use of chemicals to destroy or immobilize pollutants in sediments.

coffer dam – a temporary, water tight enclosure built in the water. Coffer dams prevent the transport of sediments downstream during dredging operations.

composite sample – a sample of air, water, or solids (sediment) made up of a number of samples mixed together. Spatial composite samples are made up of samples taken at roughly the same time but at different places. Temporal composites are taken from the same place at different times.

demobilization – the process of removing construction equipment from a work site.*

depositional – describes a waterbody or portion of a waterbody where sediments fall out of the water and are deposited on the bottom. The opposite of erosional.

effluent – dilute wastewaters resulting from sediment treatment and handling. Effluents include discharges, surface runoff, wastewater, etc. from a confined disposal facility or landfill.*

erosional – describes a waterbody or portion of a waterbody where sediments on the bottom and banks are scoured by moving water. The opposite of depositional.

feasibility study – a study that includes evaluation of all reasonable remedial alternatives, including treatment and nontreatment options.*

geotextiles – specially designed synthetic fabrics that allow water to flow through but retain sediments. Geotextiles may be used as part of a contaminated sediment cap or as barriers to prevent the transport of sediments downstream.

leachate – includes waters that had direct contact with sediment, or precipitation that has soaked into sediments in a confined disposal facility or landfill.*

mobilization – the process of bringing construction equipment to a work site.*

natural recovery – refers to leaving sediments alone in the hopes that natural processes cover them up with non-contaminated material.

oil boom – synthetic foam floats encased in fabric and connected with chains or cables. Oil booms contain oil floating at the top of a waterbody.

oxidation-reduction potential – a measure of the amount of oxygen available in a substance. If oxygen (or chemicals that behave like oxygen) are not available, then the material is said to be in a reduced state.

petroleum hydrocarbons – fuels and byproducts derived from crude oil or coal.

pilot-scale – testing and evaluation of a sediment treatment technology with scaled-down but essentially similar processors and support equipment as used in full-sized operation to treat up to several hundred cubic meters of sediment.*

pneumatic pumps – pumps that use changes in air pressure to move material from one place to another.

resuspension – the process by which particles of sediment are stirred up and suspended in water.

scow – a flat-bottomed boat with square ends that is used to carry bulk material like sediments or sand, similar to a barge.

silt curtains – impermeable material that redirects the flow of water in an effort to prevent the transport of resuspended sediment downstream.

silt screens – permeable material that lets water through but retains sediment. Used to prevent the transport of resuspended sediment downstream.

site characterization – all field work leading up to remediation of a zone of contaminated sediments. This includes gathering the following data:
• physical data such as water depth, water currents, sediment depth and layering, location, temperature, and sediment type;
• chemical data such as concentration of contaminants and naturally occurring chemicals, pH, biological oxygen demand, and oxygen availability; and
• biological data such as types and numbers of animals and plants near the zone, biological damage observed in animals and plants, and history of animals and plants before and after contamination.

spud – retractable “leg” that extends from the bottom of a dredge to the sediments below to anchor it in place and facilitate movement.

weir – in a Confined Disposal Facility, a pipe that carries wastewater or surface runoff to a wastewater treatment plant.

volatile substances – compounds that prefer to be in the gaseous state at normal temperature and pressure. Volatile substances found in contaminated sediment are physically trapped in the pores of the material, dissolved in water, or attached to solid particles. Since sediment is usually cold and undisturbed, it can retain volatile substances for a long time. If sediment is disturbed or heated, volatile gases will escape, causing potential hazards for site workers and the environment.

*Denotes definitions from USEPA. 1994a.

Appendix D: Additional Resources

Coast Alliance
http://www.coastalliance.org

Great Lakes Environmental Research Laboratory (GLERL)
http://www.glerl.noaa.gov/
Scientists at this federally funded laboratory study the biological, chemical, and physical processes that occur in natural ecosystems, especially in the Great Lakes. GLERL has five research programs that cover coordinated ecosystem research, climate variability and change, marine hazards, pollutants, and exotic species.

Great Lakes Commission
http://www.glc.org
Eight states – Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, and Wisconsin – formed the commission in 1955 to help them manage the Great Lakes. The commissions provides the states with research, advice, and advocacy on issues of development, use and protection of water and land resources in the Great Lakes Basin.

International Association for Great Lakes Research (IAGLR)
http://www.iaglr.org
This association of sientists publishes the quarterly Journal of Great Lakes Research and hosts an annual conference on Great Lakes research. Conference sessions and Journal publications cover a wide range of research airmed at understanding the world's large lakes and the human communities around them.

International Joint Commission Great Lakes Water Quality Board Reports
http://www.ijc.org/boards/wqb/
Canada and the United States created the International Joint Commission because they recognized that each country is affected by the other's actions in lake and river systems along the border. The two countries cooperate to manage these waters wisely and to protect them for the benefit of today's citizens and future generations.

Lake Michigan Federation
http://www.lakemichigan.org

Scenic Hudson
http://www.scenichudson.org

Sierra Club
see: http://www.sierraclub.org and http://www.sierraclub-glp.org
and the following reports are available from the Sierra Club Great Lakes Program, 214 N. Henry St, Suite 203, Madison, WI 53703:
- *Clean Lakes, Clean Steel: A Citizens' Guide to the Great Lakes Steel Industry*
- *Clean Lakes, Clean Sediments: A Citizens' Guide and Common Sense Action Plan*
- *Clean Lakes, Clean Jobs: A Case for Cleaning Up Contaminated Sediments*
- *Something's Fishy: What you don't know about polluted fish can hurt you*
- *Great Lakes: Great Progress, Great Challenges; 25 Years of Progress Thanks to the Clean Water Act and Great Lakes Water Quality Agreement*

U.S. Environmental Protection Agency Remediation and Characterization Innovative Technologies (REACH IT) Database
http://www.epareachit.org/index3.html
REACH IT is a comprehensive list of existing treatment technologies. Site users can search by technology, contaminant, media, site name, or a combination of these. REACH IT has access to information about the more than 370 treatment technologies provided by over 250 firms. The site provides information regarding treatment options for five contaminant groups including VOCs, SVOCs, Fuels, Inorganics, and Explosives.

U.S. Army Corps of Engineers Center for Contaminated Sediments
http://www.wes.army.mil/el/dots/ccs/index.html
The U.S. Army Corps of Engineers Center for Contaminated Sediments (CCS), consolidates research expertise to deal with the problem of contaminated sediments. The Center coordinates and facilitates contaminated sediment activities among Corps organizations, the Department of Defense, other federal and state agencies, academia, and the private sector.

U.S. Army Corps of Engineers Environmental Effects of Dredging and Disposal (E2-D2) Literature Database
http://www.wes.army.mil/el/e2d2/
Environmental Effects of Dredging and Disposal literature database contains over 3,000 references pertaining to the environmental effects of dredging and dredged disposal projects.

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

U.S. Environmental Protection Agency
Hazardous Waste Clean Up Information (CLU-IN)
http://clu-in.org/
CLU-IN provides excellent descriptions of several remediation treatment types including Thermal Desorption, Soil Washing, Phytoremediation, Bioremediation and Clean Oxidation.

U.S. Environmental Protection Agency
Assessment and Remediation of Contaminated Sediments (ARCS) Program Publications
http://www.epa.gov/glnpo/arcs/arcsguide.html
This site provides a more in-depth guide to contaminated sediment options.

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Never doubt that a small
group of thoughtful,
committed citizens can
change the world. Indeed,
it's the only thing that ever has.

—Margaret Mead