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Cleaning Up Contaminated Sediment

A Citizens' Guide

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1 Introduction

Sediments have been collecting on the bottoms of the Great Lakes — and in the beds of tributary rivers — ever since the lakes were formed by the melting of the glaciers thousands of years ago. The loose, unconsolidated particles that make up the sediment may originate in soil worn away by physical or chemical erosion, or they may come from the decomposition of shells or wood chips.

Wind, water, ice and gravity carry these particles from their place of origin. Once they reach a river or lake, currents and storm waves can keep them suspended, often carrying them great distances. But in quiet waters, they sink to the bottom.

Contaminated Sediments at the bottom of rivers harbors and lakes are often a significant source of toxic pollutants

Before large numbers of people came to the Great Lakes Basin, the natural processes of sedimentation created changes in the lakes and their tributaries, but they did no harm. The industrialization of the basin changed that. In the first century or so of industrial and urban development, we paid little attention to the wastes our prosperity created. The usual approach was to run a pipe to the nearest river bank or lakeshore and pump the waste directly into the water.

Over the decades, heavy metals and toxic organic chemicals — both municipal and industrial wastes and herbicides and pesticides from farm runoff — mixed with the particles of rock, soil, and decomposing wood and shell in the sediments collecting in rivers and harbors in the Great Lakes Basin.

Even after serious clean-up efforts began on the lakes in the late 1960s, little attention was paid to the toxins hiding in the muds on the bottom. The obvious first priority was stopping the discharge of new contaminants from factory outfalls and municipal wastewater facilities. Many people thought that lake bottoms were a safe place for toxic materials.

The environmental problems caused by contaminated sediments first began to be noticed in the early 1980s. One clue was the increase in concentrations of the pesticide DDT and the widely used group of industrial chemicals called PCBs in the tissues of Great Lakes fish. The use of DDT had been forbidden in the United States since 1972 and PCBs had been banned — except for use in closed systems — in 1979. In the years immediately following the ban, levels of these chemicals in the tissues of fish and other animals dropped. But then, with levels still unacceptably high, the decline stopped. In some cases, levels actually began to go up again.

Studying this alarming trend, scientists discovered that some of the increase came from the air. Chemicals, some from sources hundreds, even thousands of miles away, were being deposited in the lakes. Other scientists turned their attention to the bottoms of our lakes and rivers where toxins, deposited during decades of environmental carelessness, were hiding in the mud.

River beds and lake bottoms are not quiet places. Storms and propellers of passing ships often stir up the sediments, resuspending contaminants already buried. Bottom-dwelling animals add more disturbance. Many of these

animals feed in the mud, taking in toxins and storing them in their bodies. When sludge worms or insect larvae from this bottom-dwelling — or "benthic" — community are eaten by larger animals, the toxics are part of the meal. At each link in the food chain the concentrations of toxins get higher, in some instances, thousands of times higher.

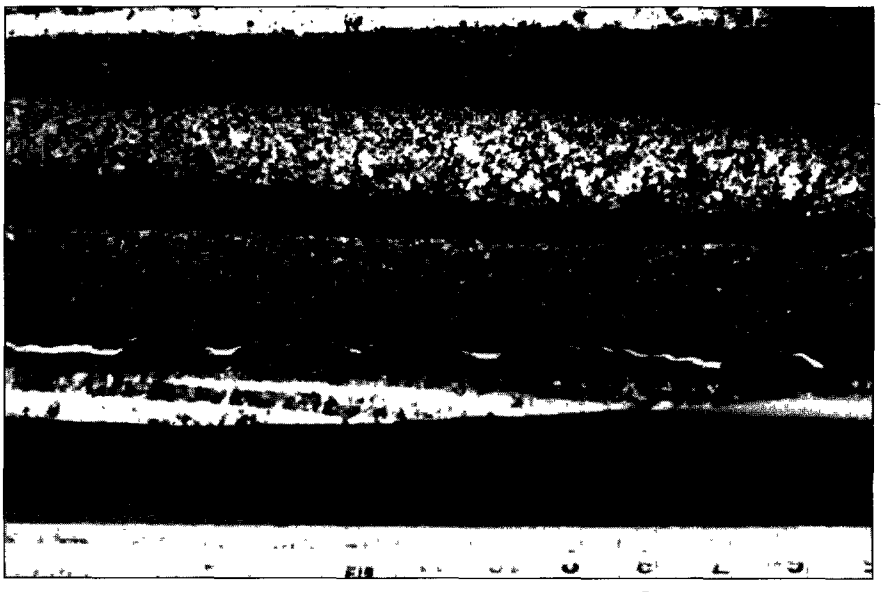
At the top of the Great Lakes food chain, we find large lake trout and salmon that are considered unsafe to eat because of the heavy concentrations of toxic substances in their tissues. Fish-eating birds nesting around the Great Lakes, among them bald eagles, double-crested cormorants, and Caspian and Forsters terns, suffer low reproductive rates or produce offspring with serious birth defects.

Recognizing that contaminated sediments are a problem was a major step. But with that recognition came the equally important realization that no one knew exactly what to do about the problem. That realization led the U. S. Congress to authorize a study and demonstration program on the best ways to assess and clean up contaminated sediments.

The authorization, contained in the Clean Water Act of 1987, called upon the Great Lakes National Program Office (GLNPO) of the U.S. Environmental Protection Agency to conduct the project. In 1987, the U.S. and Canada also ratified a second revision of their 1972 Great Lakes Water Quality Agreement (the first revision was in 1978). The document directs the U.S. EPA to work with its counterpart, Environment Canada, to establish compatible methods for evaluating sediments, to develop "common methods to quantify the transfer of contaminants to and from bottom sediments" and develop a standard approach for managing the problem, to evaluate existing clean-up technologies, and to manage long-term remedial actions.

The EPA response to the congressional action and the international agreement was to create a program called ARCS (Assessment and Remediation of Contaminated Sediments). The specific aims of the ARCS Program were to measure concentrations of contaminants at priority sites on the Great Lakes, to determine ways of gauging the effects of these concentrations on aquatic life, to recommend ways to measure risks to wildlife and to human health posed by the contaminants, and to test technologies that might be used to clean up the sediments.

This guide describes the work the ARCS Program has done and how the knowledge that has been gained can be applied to areas where contaminated sediments are causing environmental degradation.



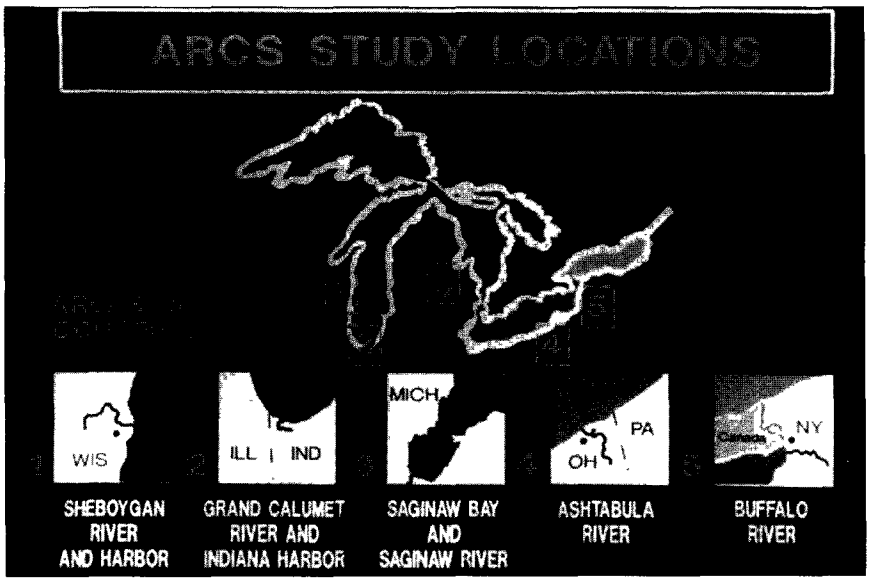
"Core" samples are obtained to understand how pollution levels vary with depth

2 How the ARCS Program worked

Four separate work groups were created to handle various aspects of the ARCS Program.

The Toxicity/Chemistry Work Group collected and quantified data on contaminants in sediments and studied the effects these contaminants have on fish and other aquatic life.

The Risk Assessment/Modeling Work Group studied risks to humans and wildlife created by existing conditions and compared them to the risks that would result from various possible alternatives available for remediating sediment problems.



The ARCS program focused on five areas of concern: Sheboygan (WI), Grand Calumet River (IN), Saginaw River (MI), Ashtabula River (Ohio), and Buffalo River (NY).

The Engineering/Technology Work Group tested and evaluated technologies that might be used to clean up toxics in sediments.

The Communication/Liaison Work Group collected and disseminated information to citizens about ARCS and contaminated sediments and provided opportunities for citizens to participate in the work of the program.

LOCATING THE PROBLEM

The International Joint Commission, a binational body set up by treaty between the U.S. and Canada to oversee the Great Lakes and other boundary waters, has identified 43 heavily polluted harbors, estuaries and tributary rivers on the five Great Lakes as "Areas of Concern (AOCs)." Contaminated sediments are considered to cause major problems in all but one of these AOCs. Congress directed the ARCS Program to concentrate its efforts on five of these areas, two each on Lakes Michigan and Erie, and one on Lake Huron.

The five are:

The **Sheboygan River** in Wisconsin: This river flows into Lake Michigan at the city of Sheboygan, Wisconsin. The River is heavily contaminated with PCBs from industries on its banks.

The **Grand Calumet River** and Indiana Harbor Canal in northwestern Indiana: Surrounded by major industries, including steel, chemicals and oil refining, the river and harbor are heavily polluted with both organic chemicals and heavy metals.

The **Saginaw River** which flows into Lake Huron at Bay City, Michigan: Sediments in the river bottom contain both heavy metals and PCBs.

The **Ashtabula River** which flows into eastern Lake Erie at Ashtabula, Ohio: The river is contaminated with heavy metals, PCBs and other chlorinated organic compounds.

The **Buffalo River** which flows into Lake Erie at Buffalo, New York: The river is contaminated with complex organic chemicals called polynuclear aromatic hydrocarbons (PAHs) and heavy metals.

These five sites contain many different contaminants as well as different kinds of bottom sediments. The Sheboygan River had already been designated as a National Priority Site by the Superfund program, as had Fields Brook, a tributary of the Ashtabula River.

DELINEATING THE PROBLEM

Scientists with the ARCS Toxicity/Chemistry Work Group — abbreviated Tox/Chem —

began by compiling lists of likely contaminants present at each of the sites. This list was created from information from earlier studies as well as the historical record of industries located in the area. These lists helped direct the investigation.

Tox/Chem collected sediment samples from Indiana Harbor, the Buffalo River and the Saginaw River. Scientists working with the Superfund program had already collected samples from the Sheboygan and Ashtabula rivers.

Using the Research Vessel (R/V) **Mudpuppy** — a small, shallow draft boat designed for working in the cramped dimensions of Great Lakes rivers and harbors — scientists collected grab samples from the surface of the sediments. They also collected core samples that provided a cross-section of sediment layers extending as much as 20 feet below the sediment surface. Core samples are essential because in many cases the most contaminated sediments lie well below the surface. For example, at one location in the Saginaw River, lying one foot below the surface of the bottom sediments, is a layer of black, oily silt containing concentrations of cadmium, chromium, and lead three to 15 times greater than that found in the sands above them. In some cases, highly contaminated sediments were found as much as 13 feet below the sediment surface.

Using a satellite-based global positioning system (GPS), scientists were able to map with great precision the locations from which the samples were taken. Many samples were needed from each site under investigation, in part because contaminants are usually not evenly distributed over the bottom. In general, contaminants concentrate in fine-grained sediments such as silts and clays rather than in sand or gravel.

Once the samples gathered by the **Mudpuppy** had been analyzed, precise, three-dimensional maps of the bottom could be drawn showing where contaminants were concentrated.

The Tox/Chem Work Group concluded that an integrated assessment approach was necessary to measure the seriousness of any contaminated sediment problem. An integrated approach requires the use of a whole group — or "suite" in the scientific jargon — of chemical and biological tests measuring the amounts of contaminants in the sediments, the bioavailability of these contaminants, and the effects of the contaminants on living things.

Bioavailability is a measure of the likelihood that contaminants will either enter the food chain or directly affect aquatic organisms rather than staying tightly bound to the sediments. Several sediment characteristics have been identified as having an effect on bioavailability. For example, higher levels of organic carbon and acid volatile sulfides in the sediments reduce bioavailability of some contaminants.

Toxicity tests measure some of the effects contaminants have on living things in controlled laboratory conditions. Various water tests were performed with whole sediments on what's called pore water. Pore water is held between the sediment particles and on elutriates which are created by mixing sediment and pure water. Each of these phases measures a different degree of availability of contaminants to organisms.

The toxicity tests measured the toxicity of the sediments by exposing various test organisms — both animals and plants — to whole sediments, pore water, or elutriates and studying the effects of that exposure. For example, tests were performed on larvae of a small crustacean called **Hyallela azteca.** Crustaceans also include shrimps, lobsters, and crabs. **Hyallela azteca** were exposed to whole sediments for periods ranging from seven to 28 days. At the end of the test period, the scientists measured survival, growth and the number of males reaching sexual maturity.

Another test used a small crustacean called **Diporeia** (formerly known as **Pontoporeia**

Lying one foot below the surface of the bottom sediments is a layer of black, oily silt containing concentrations of cadmium, chromium, and lead three to 15 times greater than that found in the sands above them.

hoyi), an animal that is quite common in the Great Lakes. This test measured both survival rates and the extent to which the "pontos," as they are called, avoided contact with contaminated sediments. In 90 percent of the cases, pontos reacted to contaminants by moving away from them.

The Toxicity/Chemistry Work Group ultimately decided on a short list of eight bioassay tests from which two or three should be chosen to measure biological effects.

Scientists also measured the levels of contaminants in the tissues of fish caught at the sites, and they tested sediment samples for mutagenicity. Mutagenic substances can cause changes — mutations — in genetic material that can produce tumors or birth defects.

Bottom dwelling organisms, such as this midge, tip scientists as to how polluted sediments are

In addition to toxicity and chemistry tests performed, studies of the animals that actually lived in and on bottom sediments in the three areas were also done. The animals of these benthic communities are often the link between contaminants in the sediment and the rest of the food chain. Healthy communities in clean sediments tend to have far more species than communities in contaminated sediments. In some cases, the presence or absence of particular species, called indicator species, reveals the extent of damage to the ecosystem from contamination. For example, highly polluted bottoms like Indiana Harbor may only be populated by sludge worms. Sludge worms belong to a group of animals called oligochaetes. This group also includes earthworms. They are adapted to polluted conditions where there is very little oxygen in the water.

Where pollution is a little less severe, the larvae of some species of midges are part of the community, although many of them show deformities. Cleaner bottoms will have more species of midges along with mayfly larvae, various crustaceans and clams. At the three sites tested by ARCS, sludge worms and pollution-tolerant midge larva accounted for 90 percent of the total number of species present. Indiana Harbor had the fewest total species. Only two midge specimens were discovered and they were both deformed. The Buffalo River had the most species. The survey of the benthic communities showed a consistent pattern: high pollutant contamination meant an impoverished community with few species; and cleaner bottoms supported a richer, more diverse benthos. This result clearly indicated the ecological effects of contaminated sediments.

The extensive series of tests conducted by the Tox/Chem Work Group demonstrated that contaminants in sediments do indeed affect both the benthic community and the fish swimming in the water above contaminated sediments. Humans eating a lake trout may ingest toxins that entered the food chain through a sludge worm's burrowing into sediments contaminated with PCBs. The question of risk to humans and to wildlife was examined by the Risk Assessment/Modeling (RAM) Work Group, whose work will be described in the next section.

Members of the Toxicity/Chemistry Work Group have prepared a final report called **The ARCS Assessment Guidance Document** that summarizes both what they learned about assessing the nature and extent of contaminated sediments and how they learned it. The guidance is for scientists, administrators and others who have to deal with contaminated sediment problems. The document offers detailed instructions on how to gather samples, analyze their chemical and physical characteristics, and determine the biological effects of contaminants present in sediments. It compares how various species react to contaminants in the sediments and evaluates specific testing methods. The document also makes specific recommendations on what tests should be conducted to evaluate the degree of contamination in sediments, and includes a discussion on Quality Assurance/Quality Control procedures.

Quality Assurance/Quality Control — usually abbreviated as QA/QC — is based on the recognition that no measurement can be taken as absolutely exact. The goal of a QA/QC Program is to enable scientists to establish the level of uncertainty associated with each set of data they collect.

Section summary:

KEY FACTS ABOUT CONTAMINATED SEDIMENTS

- A large number of toxins have been found in contaminated sediments. These fall into two categories: metals, such as cadmium, mercury, chromium, and lead, and organics, such as PCBs and PAHs.
- Contaminants are typically distributed in a patchy pattern in sediments.
- The physical and chemical nature of the sediments affects the bioavailability of contaminants.
- Evaluating the seriousness of any sediment contaminant concentration requires an integrated sediment assessment approach, including tests of the physical and chemical nature of the sediments and the contaminants as well as biological tests that measure the effects of the contaminants on aquatic life.
- Contaminants in sediments enter the food chain in a variety of ways.
- The benthic community in contaminated areas typically contains a less diverse mix of species than benthic communities in clean areas. Usual species are those adapted to polluted conditions.

3 What harm can it do?: The question of risk assessment.

The investigations of the Tox/Chem Work Group tell us that contaminated sediments harm the environment. They do enter food chains and eliminate species from the benthic community. But an answer to the general question, "Are they harmful?", leads us to some very specific questions: How much harm? How much of an effect do the deposits in this place have on the people and animals who live near them? What remedial action can we take to gain maximum improvement in the situation at the least cost?

Surveys at the five ARCS sites showed that eating contaminated fish was the most prevalent "pathway" for exposure to toxic substances

In the ARCS Program, these questions were considered by the Risk Assessment and Modeling (RAM) Work Group. The goal of the RAM Work Group was to develop and demonstrate a risk assessment framework that could identify existing risks to both humans and wildlife at sites with contaminated sediments, estimate the impact that various remedial alternatives might have and compare existing risks with potential risks that could be created by remedial action.

To achieve that goal, the RAM Group developed a 10-step, standardized process that could be applied to any contaminated site. The process is described in a publication called **The ARCS Risk Assessment and Modeling Overview Document.**

The RAM Work Group studied all five ARCS sites, but it looked most intensively at the Buffalo and Saginaw rivers. At those two sites, RAM scientists collected their own samples of sediment, water and fish to supplement the information gathered by the Tox/Chem Work Group. They also studied uses of these areas by both humans and wildlife in order to identify pathways of exposure through which contaminants might reach people or animals. All this data was plugged into the ten-step framework.

Step one in the ten-step approach is an initial screening of potential Areas of Concern. This has already been done for the Great Lakes by the International Joint Commission through its identification of 43 Areas of Concern on the lakes — 42 of which have significant problems with contaminated sediment. Step two, called Risk Assessment Planning, begins with the gathering of everything that is already known about the site. Necessary information includes physical features, a list of contaminants likely to be present and the expected locations of contaminant concentrations. Data about human and wildlife populations and the pathways through which they might be exposed to the contaminants provide the basis for preliminary estimates of the level of risk created by the contaminants.

This review of existing information is the basis for a first approximation of objectives for remedial action as well as for the creation of a short list of possible remediation actions. It also reveals gaps in essential data that might need to be filled by additional field work — which is Step Three in the process.

It is a safe generalization to say that the more we know about a contaminated site the more certainty there will be in any predictions

we make about the effects of remedial action. Of course in real situations our desire for more information will always run up against limits in time and, especially, money. Decisions on how available resources are used have to be made on a case-by-base basis. The Tox/Chem Work Group has produced an **ARCS Assessment Guidance Document** that describes field sampling methods that should be used to gather data.

Field surveys of the ARCS sites enabled the RAM Work Group to identify fish consumption as the most significant pathway between contaminants in sediments and human beings at those sites. Other possible routes include drinking water and direct exposure from swimming.

Step four of the process is creation of a baseline risk assessment. This is an estimate of the risks to humans and wildlife created by the existing situation. The baseline assessment identifies which contaminants and exposure pathways pose the greatest risk, supports conclusions as to whether remediation is needed, and provides a standard for evaluating the effectiveness of any action taken.

Step five is the ranking of subareas within the Area of Concern. Contaminants are typically distributed unevenly over the bottom. Mapping their distribution allows us to designate hot spots which might be priority areas for clean up.

Step six is the screening of possible remedial alternatives. The idea is to eliminate courses of action that obviously cannot be used at the site and to reveal gaps in information that would need to be filled by further field testing before any remedial action could be undertaken.

Step seven uses a technique called mass balance modeling to trace the fate of contaminants entering an area of concern. The quantities of contaminants coming into a system are called "loadings." Once these toxic loadings reach the water, any of several things can happen to them. If they sink to the bottom, they may be stored in sediments or they may enter the food chain in the bodies of benthic animals. If something — the propeller of a passing ship, storm waves, the thrashing of spawning carp — lifts them out of the mud and into the water, they may enter the food chain through the bodies of free-swimming organisms. They may be transformed or degraded into other, perhaps less harmful, substances. Or they may be transported out of the system — from the Saginaw River, for example, into Saginaw Bay.

To create a mass balance model, scientists plug information gathered on the actual distribution of contaminants in the system into sets of equations that create a mathematical model of that system. The computer model simulates the physical movement of water, sediment and contaminants in the system as well as the movement of contaminants in the food chain. With mass balance modeling, we can estimate the likelihood that humans and wildlife are being exposed to contaminants from sediment at levels that are known to be harmful.

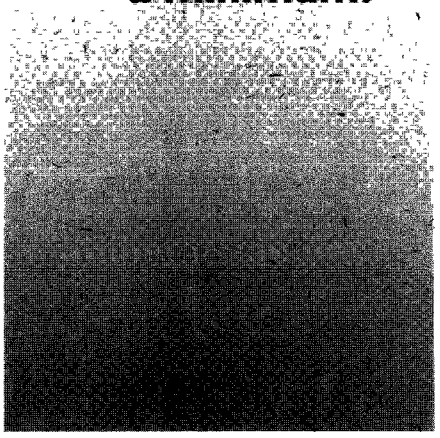
The results produced by the computerized models are combined with all the other information gathered from the site to provide the data needed for step eight, the comparative risk assessment. This assessment gives us the most precise information we can get about the results that are likely to follow from various courses of action.

For example, if we reduce loadings to zero, that is, stop all discharges of a particular contaminant, will we see a quick decline in concentrations of that chemical in the system? Or is the outflow from the system so slow that it would take years for the contaminants now in the system to be flushed out?

What about the contaminants already present in the sediments? Suppose we just leave

What about the contaminants already present in the sediments? Suppose we just leave them where they are. What kind of effect would they have on the environment five, ten or twenty years into the future?

What remediation method will give us the greatest improvements for the money spent or reduce undesirable side effects to a minimum?



them where they are. What kind of effect would they have on the environment five, ten or twenty years into the future?

Suppose we carefully map the bottom of the Ashtabula or the Buffalo or any other Area of Concern and just dredge the nastiest of the hot spots, the places with the highest concentrations of contaminants. Would that remove enough contaminants to produce a major improvement in the richness and diversity of the benthic community? Would it lead to significant declines in contaminant levels in fish tissues?

Would the improvement be greater if we dredged the entire bottom? Would the difference be sufficient to justify the additional expense? What remediation method will give us the greatest improvements for the money spent or reduce undesirable side effects to a minimum?

Step nine is the selection of a final remedial alternative. The choice here is based on the information gathered so far, on predictions generated by the mass balance model, and on political and economic factors. The ARCS Program gathered the information needed to make this selection, but it did not actually decide on plans for the sites studied, leaving those decisions to the stakeholders in each AOC.

Once remedial action has been taken, step ten requires the continued monitoring of the site to determine if the action has had the desired effect.

With all of this information available, Remedial Action Plan (RAP) Teams can make informed, scientifically defensible decisions as to the optimal remedial actions.

What can be done?: The technology of remediation

4

The ARCS Engineering/Technology Work Group concerned itself with what we do after we discover that a body of sediments is contaminated and that the contamination creates a significant hazard.

Developing a plan for remediating a contaminated sediment situation involves a long series of choices. Should the sediments be left where they are but somehow isolated from the environment? If they must be dredged, what method should be used? Will all the sediments containing contaminants be removed, or will efforts be concentrated only on the hottest of the hot spots? How are the dredged sediments to be transported? If they are to be treated, which method should be used?

Several factors have to be taken into account in making these decisions. The most important include:

1. **The location of the sediments.** Are they in a busy shipping lane that must be dredged periodically to maintain the depths needed for navigation, or are they in untraveled waters where maintenance dredging is not required? Are they in open waters, or in tight corners, up against docks or other structures where some kinds of dredges could not maneuver? Can equipment be placed on the nearest shores or is this land inaccessible or otherwise unsuitable for such use?
2. **The extent of the contaminated deposit.** Is it confined to a small area, or is it spread along four miles of river channel? Is it confined to the topmost layers of sediment, or does it extend deep into the bottom deposits? Will a clean up require the removal of 10,000 cubic yards of material or 500,000?
3. **What is down there with it?** The bottoms of many harbors are littered with everything from shopping carts to old cars. The presence of such debris influences the choice of dredging methods.
4. **What contaminants are present?** Treatment methods are designed to handle specific classes of contaminants, for example, metals or chlorinated compounds. Some heavily contaminated sediments might require two or more treatments to remove all the problem materials.
5. **How available are the various kinds of equipment and technology that might be used in a remedial action?** For example, clamshell dredges are widely used and widely available, but some types of specialty hydraulic dredges are quite rare and may not be accessible without a long wait. Similar problems can arise with the equipment needed for various treatment technologies.
6. **How much money is available?** In most situations, this is the biggest question of all. Treating sediments to remove or neutralize contaminants is expensive. And the more material that needs dredging or treatment, the more expensive the operation.

The rest of this section will be devoted to discussion of the various technologies available to reduce or eliminate the hazards created by contaminated sediments. We will describe the situation as of mid-1994. But things are changing fast in this area. New technologies are being introduced regularly while other ideas, once thought promising, are being dropped.

However, through all these changes, the broad categories are likely to remain the same. New dredging tools may be developed, but they will probably all fall within the categories of mechanical or hydraulic. New treatments will most likely be new versions of such existing forms as solvent extraction or bioremediation. So while this guide cannot keep you up-to-date on each new development, it can provide you with a framework for understanding innovations as they come along.

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The first decision that has to be made in developing a remedial design is whether the hazards can be sufficiently reduced with the material left in place — **in situ,** to use the Latin term favored by scientists — or if the sediments must be removed by dredging.

The "clamshell" dredge is the most common removal technique currently in use

NON-REMOVAL TECHNOLOGIES

The use of Non-Removal Technologies is feasible only if dredging is not required for navigation reasons and if the contaminated area is in waters where storms or other disturbances will not wash away capping material. The choices are:

1. **Capping.** Material is placed on top of the contaminated sediments. The simplest and cheapest caps are such materials as sand, gravel or clean sediment. The cap must be thick enough to prevent benthic organisms from burrowing into the contaminated layers and to effectively prevent the loss of contaminants from the sediments through the cap and into the water. More expensive caps may use special materials called geotextiles. In the Sheboygan River in Wisconsin, several small areas heavily contaminated with PCBs have been capped with alternating layers of gravel and geotextiles topped with a layer of larger rocks called cobbles. The total area covered is 20,000 square feet, the equivalent of a square about 140 feet on each side.
2. **Containment.** This method isolates a portion of a waterway by enclosing it within cofferdams, dikes or other structures. In Waukegan Harbor in Southern Lake Michigan, a boat slip was walled off in this way, additional contaminated sediments were placed inside the walls, and the whole thing was then capped like a hazardous waste landfill.
3. **Treatment in situ.** Chemicals are applied to the sediment to destroy the contaminants. At this point, this is a possibility, not a practical alternative. It is very difficult to be sure that all the contaminated material has been treated. The uncertainty is greatest for the deepest sediments, and they may be the most contaminated. "Overtreatment," that is, applying more chemicals and covering a larger area than the contaminated zone is a possible answer to this problem, but overtreatment raises costs. Releasing the treating chemicals into the waterway can also cause problems.
4. **Immobilization in situ.** Also called solidification or stabilization, this involves mixing cements or other materials into the sediments to alter their physical and chemical make up so that contaminants cannot escape. The solidifying materials must be tested in the laboratory on the specific sediments to be treated before each individual attempt to use this method.

Part of the cost of **in situ** methods — especially of capping and isolating — lies in the continuing monitoring that must be done to make sure that the caps, dikes or cofferdams are still working.

Removing sediment

5

Until recently, dredging was a job done solely to keep channels and harbors deep enough for boats or ships. The goal was to get the work done as quickly and cheaply as possible. If sediments escaped from the dredge and drifted off, the only concern was whether they came to rest somewhere out of the way.

Environmental dredging is very different from traditional navigational dredging of uncontaminated sediments. In environmental dredging, resuspension of sediments — and their associated contaminants — must be carefully controlled. If we lift contaminants from the bottom only to scatter them through the water, the dredging could do more harm than good. Environmental dredging may require the use of barriers such as oil booms, which sit on the water surface, or silt screens and silt curtains, which extend from the surface to the bottom to confine resuspended sediments. Concerns about resuspension have also stimulated the creation of new dredge designs which will be discussed below.

The sudden release of contaminants into the water that may accompany dredging has to be taken into consideration in any decision to dredge a particular site. However, the harm this sudden influx of contamination may do has to be balanced against the damage that can be done by a slow, gradual release of toxics that extends over many years as the sediments remain in place.

MECHANICAL DREDGES

The **bucket** or **clamshell** dredge is the most widely used dredge in the Great Lakes. Its two hinged halves are opened wide and then dropped onto the bottom where they sink into the sediment. The operator then raises the dredge, causing the halves to swing together, enclosing a load of sediment. The closed bucket is then raised above the water, swung over a barge, and opened, allowing the sediment to drop onto the barge.

Bucket dredges are excellent for use in close quarters, such as around docks or breakwaters. Their main disadvantage is that sediment can spill out of the top of the bucket as it is raised. The **watertight bucket,** originated by the Japanese but now manufactured by U.S. firms as well, uses covers on top of the bucket to minimize spillage. Typical designs also use rubber gaskets, tongue-in-groove joints or a "matchbox" design to make the buckets more watertight. One design removes sediment in layers, leaving a flat sediment surface.

Backhoes, which are mainly used for excavations on land, can be used in water if sediments are in shallow water very near the shore. Other types of mechanical dredges, among them bucket ladders, dippers and draglines, create far too much resuspension to be usable for contaminated sediments.

HYDRAULIC DREDGES

In essence, hydraulic dredges are enormous vacuum cleaners that simply suck sediments from the bottom. They may be equipped with rotating blades, augers or high-pressure water jets to loosen the sediment. The most common type used in the U.S. is called a **cutterhead.** It uses rotating blades to loosen sediments.

Rotating augers are, in effect, large drills which not only loosen the sediments but also pull them into the dredge. Equipment such as sediment shields and gas collection systems can be added to these dredges to reduce resuspension of sediment or the escape of volatile contaminants into the water.

Hydraulic dredges have a very high capacity — that is, they can remove a large volume of material in a short time. However, their pumps pull in a lot of water with the sediment. Dredged materials pulled up by mechanical dredges are typically about half water and half solids by weight. Hydraulic dredges bring up a

Until recently, dredging was a job done solely to keep channels and harbors deep enough for boats or ships. The goal was to get the work done as quickly and cheaply as possible. If sediments escaped from the dredge and drifted off, the only concern was whether they came to rest somewhere out of the way.

slurry that is likely to be 80 to 90 percent water and just 10 to 20 percent solids. This means that if you remove a given quantity of sediment with a hydraulic dredge you will have a much larger volume of material to transport,

In many Great Lakes harbors, confined disposal facilities (CDFs) such as this one in Chicago are used to store contaminated sediments

store or treat. Larger volumes usually mean more expense and greater potential for contaminants to be released during processing of the dredged material.

Debris is also a problem with hydraulic dredges. Cutterheads can break up some large pieces, but in general, any debris larger than the suction pipe cannot be removed with hydraulic equipment.

PRETREATMENT AND STORAGE

Once we have removed contaminated sediment from a waterway, we have to decide what to do with it. The U.S. Army Corps of Engineers began using confined disposal facilities (CDFs) to contain contaminated dredged materials in the Great Lakes in the early 1970s. They have provided a way to isolate sediments and the contaminants they contain.

CDFs must be big enough to hold large quantities of dredged sediments. Even at very hazardous concentration levels, contaminants amount to only a very small fraction of the mass of those sediments. When we use CDFs, we are building and maintaining a home for thousands of pounds of sediments for every pound of toxic material we isolate.

Pretreatment may be needed to remove large pieces of debris from dredged sediments or to separate sediment particles into relatively uniform size fractions so they can be treated effectively. Dewatering may also be necessary to reduce the volume of material requiring treatment or storage. Technologies used for producing a uniform particle size are well established in the mining industry. Dewatering methods have been taken from the processes used to treat municipal waste water.

CDFs can be used for the temporary storage of sediments awaiting treatment. Many treatment methods are quite slow. It could take years to treat all the contaminated sediment in one harbor. By using a CDF, we can get dredging done quickly and efficiently, removing contaminants from the environment with minimum interference from navigation and at the lowest possible cost. Then we can treat the sediments at the CDF.

Treatment technologies

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The need to find ways to clean up our environmental problems has inspired research into a broad range of technological methods for either removing contaminants from soil or sediment, or breaking them down into harmless components. Some of these technologies are ready for use in full-scale field operations. Others have been tested only in laboratories. In this section, we will provide a brief overview of the present state of sediment treatment.

THERMAL DESTRUCTION TECHNOLOGIES

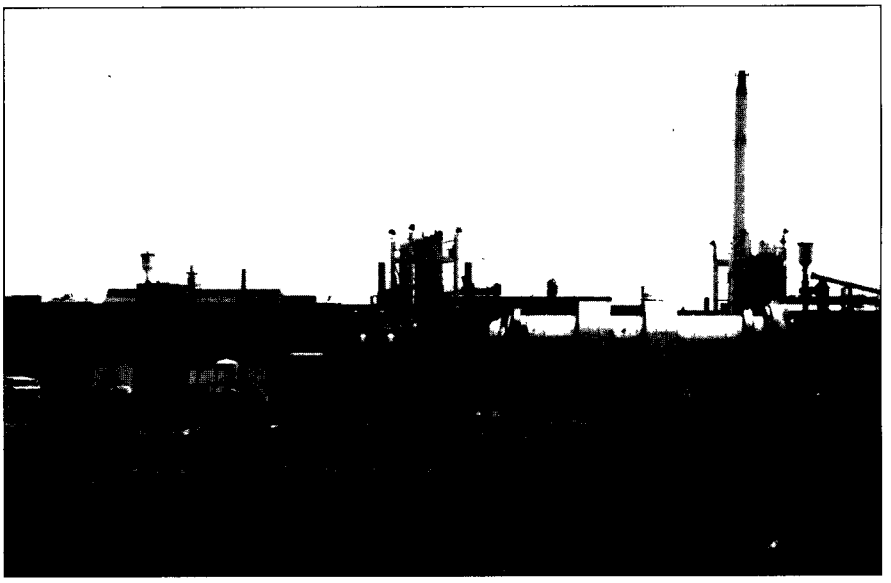
"Thermal destruction" is a fancy way of saying that these processes use heat to destroy contaminants. Heat is used mainly against organic contaminants such as PCBs, PAHs, dioxins and furans, petroleum hydrocarbons, and pesticides. Organic contaminants are compounds with their major components being such innocuous elements as carbon, oxygen and hydrogen. Their toxicity is a result of the specific ways these elements are combined. Heat can sever the chemical bonds that hold the compounds together, rendering them less toxic. Examples of thermal destruction technologies are incineration, pyrolysis and supercritical oxidation.

THERMAL DESORPTION TECHNOLOGIES

These technologies use heat not to destroy contaminants but to separate them from the sediments. Sufficient heat is applied to vaporize water, organic compounds and some volatile metals. These can then be destroyed in an afterburner or collected as liquid for further treatment. A thermal desorption technology was demonstrated on a pilot-scale by the ARCS program at the Buffalo and Ashtabula Rivers. It achieved removal efficiencies up to 96 percent for PAHs from the Buffalo and up to 97 percent for PCBs from the Ashtabula.

Advantages of thermal desorption over thermal destruction include lower energy requirements because lower temperatures are used and emissions are reduced, and it is less likely that toxic compounds will be formed by this process. There is also no need to add other chemicals to the sediments to make the process work.

Disadvantages include the need for an additional destruction process for the vaporized compounds and lower effectiveness with the less readily vaporized organic compounds.



This low temperature thermal destruction unit was used to treat contaminated sediments in Waukegan Harbor

IMMOBILIZATION TECHNOLOGIES

Sediments can be solidified by adding cements, thermoplastics or other materials. They can also be chemically stabilized by adding substances that bind contaminants and keep them in-place.

Heat can immobilize contaminants through a process called vitrification. This process uses very high temperatures (up to 2900 degrees F.) to convert contaminated soils or sediments into a glass-like substance that is strongly resistant to leaching. In addition to immobilizing contaminants, this process also destroys some organic compounds. A small scale demonstration of this process was conducted with sediments from the New Bedford Harbor Superfund site in Massachusetts.

Bacteria have long been used to treat sewage and industrial waste waters, and recently they have been applied to the treatment of organic compounds in soils, sediments and sludges.

SOLVENT EXTRACTION TECHNOLOGIES

Chemical solvents can be added to sediments to separate contaminants from particles and water that make up the bulk of the material. Once the contaminants have been separated, they can be subjected to further treatment. By separating the contaminants before further treatment, the amount of material that needs to be treated can be reduced by as much as 20 times.

Solvent extraction could be used mainly to deal with organic contaminants such as PCBs and petroleum hydrocarbons, although some heavy metals can be removed with acidic solutions.

One solvent extraction process, the Basic Extractive Sludge Treatment process (B.E.S.T.) was demonstrated on a pilot-scale by the ARCS Program with sediments from the Grand Calumet River. The process achieved a better than 96 percent removal rate for both PCBs and PAHs.

CHEMICAL TREATMENT TECHNOLOGIES

These use special chemicals called reagents added to sediment to destroy contaminants. Heat can also be used to accelerate the chemical reactions. Examples of these processes are the Base Catalyzed Decomposition (BCD) process and the Ecologic process, both of which were tested on a bench-scale by the ARCS Program.

BIOREMEDIATION

Bacteria have long been used to treat sewage and industrial waste waters, and recently they have been applied to the treatment of organic compounds in soils, sediments and sludges. The ARCS Program participated in a pilot-scale test of bioremediation on PCB-laden sediments from the Sheboygan River in Wisconsin.

Bacteria are known to be able to break down PCBs, but the question of whether bioremediation is a practical method of dealing with this group of chemicals is still very much open.

SEDIMENT WASHING

This is an adaptation of technology that has long been used in mining and mineral processing to separate solids suspended in water into sets of different sized particles. It was demonstratec by the ARCS Program on a pilot-scale with 300 cubic yards of sediment dredged from the Saginaw River. Sediments in the Saginaw are mostly sand, but the contaminants are concentrated in the finer particles, the silts and clays that are mixed with the sand. By separating silts and clays from the sands, the process can substantially reduce the amount of material that needs to be treated. At Saginaw, 80 percent of the material fed into the process emerged as sand clean enough to be used for beneficial purposes such as beach nourishment. The remaining 20 percent, the finer particles, contained the contaminants and could be treated further by one of the previously discussed technologies.

Summary

Things are happening fast in the field of remediation technology. Anyone interested in keeping up-to-date on developments in this dynamic field should look at the databases prepared by Environment Canada and the U.S. EPA. The Canadian database, called SEDTEC is available from Wastewater Technology Centre, 867 Lakeshore Road, Burlington, Ontario, Canada, L7R 4L7. The U.S. database, called VISITT is available from PRC Environmental Management, Inc., 1505 PRC Drive, McLean, VA 22102.

Public involvement

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The ARCS Program was conducted with the Great Lakes ecosystem as its specific laboratory, but the issues raised and the problem-solving strategies considered are increasingly relevant nationwide.

Wherever you live, there is likely to be a lake or a stream that has been under long-term or periodic stress from contaminants dumped from the end of a factory waste stream, a farm field or city street, a hazardous waste dump, or settling out of the sky from smokestacks. Many of these contaminants lodge in sediments where they are gradually re-exposed to the environment and continue to cause damage over a period of many years.

With new information on assessment and treatment available from the ARCS Program, other public and private research, new knowledge about the extent of contaminated sediment and its effect on wildlife and people, many new opportunities will arise for clean-up.

Some of this clean-up will still be expensive, however. Strong public involvement will be necessary to ensure that the long-term economic and environmental benefits of contaminated aquatic land reclamation are considered along with the costs of failing to take action.

Citizens can also play a role in shaping contaminated sediment clean-up plans for their areas by asking questions that will elicit specific responses from researchers about methodologies and hoped-for results. Questions developed by citizens active in the ARCS Communication/Liaison Work Group in response to remediation efforts at the five ARCS sites may also be relevant in other locations. They include the following:

1. Has any testing been done to find out whether this sediment is contaminated? What chemicals did the researchers look for? On what basis did they make these choices? Was biological testing done?
2. What kind of sampling was done? Were "grab" samples done or was a core taken? Was the core homogenized before being analyzed or was it analyzed in separate layers? How deep was each layer? How deep was the whole core? How deep is unconsolidated material thought to go at this site? How much of that do you think is likely to show anthropogenic effects (human-caused mess)?
3. If testing has been done, what contaminants were found? Are there both organic compounds and heavy metals? Are any of them persistent toxic compounds that are likely to build up in the fatty tissue or muscle of fish or other organisms?

Citizens must actively participate in sediment remediation decisions in their areas

4. What is the physical makeup of sediment at this site (proportion of clay, silt, sand, for instance)? Contaminants don't bind to sand and so will escape through the water column. They bind most strongly to clay and silt and so can be captured by sediment dredging, disposal and treatment.
5. What disposal options are being considered? On what basis? Short-term economic concerns only or long-term protection that will limit future liability problems?

Strong public involvement will be necessary to ensure that the long-term economic and environmental benefits of contaminated aquatic land reclamation are considered along with the costs of failing to act.

6. Will dredging be limited to a navigation channel or (in the case of a river or other stream as opposed to open ocean or big lake) will the slopes on either side of the channel be dredged as well to prevent recontamination? Are there high levels of contaminated sediments farther upstream than the proposed site to be dredged? What is your strategy for preventing recontamination from upstream sediments moving down to cover the dredged area?
7. Is your remediation plan linked to pollution prevention of active sources?
8. What before and after monitoring is planned — both for dredging activities and for storage?
9. Is any habitat restoration proposed in concert with the sediment removal — or as mitigation for the loss of habitat to be caused by the dredging and disposal operation?
10. Have you mapped priority hot spots for clean-up within the overall area to be remediated?
11. Have you considered the impact of sediment resuspension during dredging and what safeguards are in place for minimizing their impact?

Meaningful public involvement in the planning and decision-making stages will continue to be important in efforts to remediate contaminated sediment sites.

ARCS INFORMATION LIBRARIES

Buffalo, NY — Buffalo and Erie County Public Library, Science Department, Lafayette Square, Buffalo, NY 14203, (716) 858-7101; J.P. Dudley Branch Library, 2010 South Park Avenue, Buffalo, NY 14220, (716) 823-1858; Great Lakes United, Cassety Hall, State University at Buffalo, 1300 Elmwood Avenue, Buffalo, NY 14222, (716) 886-0142.

Indiana Harbor Canal/Grand Calumet River, IN — Gary Public Library, 220 W. 5th Street, Gary, IN 46402, (219) 886-2484; East Chicago Public Library, 2401 East Columbus Drive, East Chicago, IN 46312, (219) 397-2453; Reference Library, Indiana University NW, 3400 Broadway, Gary, IN 46408, (219) 980-6580.

Saginaw River, MI — Hoyt Library, Michigan Room, 505 James Street, Saginaw, MI 48605, (517) 755-0904; Bay City Branch Library, 708 Center, Bay City, MI 48708, (517) 893-9566.

Sheboygan River, WI — Mead Public Library, 710 Plaza 8, Sheboygan, WI 53081, (414) 459-3432.

Ashtabula River, OH — Ashtabula County District Library, 335 W. 44th, Ashtabula, OH 44004, (216) 997-9341.

Additional Repositories — Library, Great Lakes National Program Office (GLNPO), USEPA, 77 W. Jackson Blvd., Chicago, IL 60604. International Joint Commission Library, University of Windsor, Windsor, Ontario N9A 6T3, (519) 973-7023.

For more information about the U.S. EPA's ARCS program, call the EPA Hotline: 1-800-621-8431 or write ARCS, Great Lakes National Program Office, U.S. Environmental Protection Agency, 77 W. Jackson Blvd., Chicago, IL 60604.