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Understanding Contaminated Sediments: Bioavailability of Contamination

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An Overview of the Problem

Figure 1. Posted warning from the Indiana Dept. of Environmental Management next to a river.

The ecological and health effects associated with contaminated sediments are of national and international concern. In the past, municipal and industrial wastewaters were discharged into rivers and streams without adequate treatment (Figure 1). Even now, improperly functioning and failing septic systems add to water quality problems.

Pollutants in the wastewater, such as metals and hydrophobic organic compounds, chemically attach to particles in the water and eventually settle to the bottom. Although wastewater discharges have continued to improve, the sediments that were once a repository for hydrophobic chemicals are now a source of chemical contamination to the benthic (bottom) and pelagic (water column) ecosystems.

What Are Sediments?

Fine soil or mineral particles that settle to the bottom of the water or are suspended in it are classified as sediments (Figure 2). Our increased ability to measure chemicals in the environment has brought a new awareness that soil particles, and the chemicals attached to soil particles in the water, may pose an environmental problem.

Is This A National Problem?

The U.S. Environmental Protection Agency (EPA) has designated contaminated sediments as one of the agency's top concerns. Sediment contamination is an important issue, not only because of concerns associated with human health threats and ecological problems, but also because of the economic impacts associated with disposal of contaminated sediments.

The EPA estimates that, overall, ten percent of the nation's lakes, rivers and bays contain sediments contaminated with toxic chemicals. These chemicals impair the health of the fish living in those waters. Health problems of individuals and wildlife that consume contaminated fish have been documented.

Fifteen percent of the nation's lake acreage and five percent of the nation's river miles are under state-issued fish consumption advisories. Fish consumption advisories recommend limits on the amount of fish eaten on a weekly or monthly basis, based on the species of fish and overall length of that fish.

Figure 2. Sediment in the upper reaches of Lake Panorama in central Iowa

In addition to having health concerns, economic activity may be affected by sediment contamination due to loss of recreational and commercial fishing and through the increased costs of disposal of contaminated dredge material.

Why Should I Care About What's in the Sediments?

Benthic sediments are a habitat for bottom dwelling organisms such as insects, worms, shellfish and some fish. Many of these organisms obtain their food from the sediments in which they live. Species tolerant to contaminated sediments may replace native species that are intolerant of contaminated sediments. A change in the population inhabiting the sediments will impact the animal species that live in the water above the sediments due to a change in food resources.

A fish may consume food such as phytoplankton, zooplankton and other animals from contaminated sediments and the surrounding waters. Although pollutants may be excreted by a fish, most of the persistent contaminants are stored in the muscle and fat tissue and gradually build up or bioaccumulate. The concentrations of persistent contaminants in larger lake fish may be a million times higher per weight than contaminant concentrations in the surrounding waters. The process by which a contaminant increases in concentration as it rises in the food chain (phytoplankton → zooplankton → fish) is known as biomagnification.

Impacts that Contaminated Sediments have on the Ecosystem and Beyond

- Tumors and other deformities in bottom-dwelling fish;
- Degraded bottom communities, which results in a loss or reduction in fish food;
- Degraded habitats for both fish and wildlife;
- Bioaccumulation of contaminants go up the food chain, which results in fish and wildlife advisories;
- Possible human health risks from exposure to sediment-derived contaminants;
- Restrictions on navigational dredging; and
- Restrictions on re-use of dredged material.

How Do the Sediments Become Contaminated?

Figure 3. Tile outlet into drainage ditch

Contaminants come from a wide range of sources including contaminated runoff from cities, suburbs and farms, air pollution, some industries and recreational activities. This is nonpoint source pollution (Figure 3). Nonpoint source pollution comes from sources that cannot be directly identified. On the other hand, point source pollution can be identified based on an observable release–for example an industrial stack discharge (Figure 4).

Figure 4. Industrial stack illustrating point source pollution.

Contaminants may be physically or chemically bound to sediment particles. While the list of chemicals that can be bound to sediments is almost endless, here are a few of the more common pollutants:

- Persistent chlorinated organics such as polychlorinated hydrocarbons (PCBs);
- Metals such as mercury, zinc, and lead;
- Polyaromatic hydrocarbons which includes pesticides, oils and fuels; and
- Incomplete combustion of organic compounds.

Could Contaminants Pose a Health Risk?

It appears as though some contaminants are less likely to be incorporated into the chemical makeup of an organism. This refers to bioavailability of a chemical to an organism. Bioavailability is the measure of the uptake of an ingested substance by the body as assessed by its concentration in the blood. Therefore, the contaminant levels found in the environment and available to organisms may not correlate with actual risk or health problems.

Remediation. Is It the Answer?

Sediment removal is an expensive venture (Figure 5), from removing and placing the sediment in an appropriate despository to incineration or land filling the contaminated

Figure 5. Hydraulic dredge on a river in Indiana.

materials. An alternative to sediment removal is managing it in place, which can also lead to sediment solidification. Managing contaminated sediment in place requires a complete chemical, biological and physical understanding of the fate and mobility of contaminants. This includes information on groundwater flow, wave action, resuspension via boaters and ships and storm action, as well as diffusion and bioturbation.

If impacted sediments are left in place, it is critical to evaluate potential pathways by which contaminants may pose an ecological or human health risk and to monitor, minimize, or eliminate these pathways.

A possible approach to this problem is to remediate the site. Remediate means to solve a problem. The use of biological organisms, such as microorganisms and plants, to consume and reduce contaminants found in sediment, soil or groundwater is referred to a bioremediation.

In a non-polluted environment, bacteria, fungi, protists, and other microorganisms are constantly at work breaking down organic matter. When an organic pollutant, such as oil, contaminates an environment, some of the microorganisms may die, while others capable of eating the organic pollutant will survive.

Bioremediation works by providing pollutant-eating, tolerant organisms with fertilizer, oxygen, and other conditions that encourage rapid growth. The organisms can then break down the organic pollutant at a correspondingly faster rate.

Bioremediation of a contaminated site typically works in one of two ways. As in the case described previously, ways are found to enhance the growth of whatever pollutant-eating tolerant microbes might already be living at the contaminated site. Another, less common method of bioremediation , is to introduce specialized microbes to degrade specific contaminants.

Bioremediation provides a good strategy for cleaning up some types of pollution, but it will not work for all types of pollution. For example, bioremediation may not provide a feasible strategy at sites with high concentrations of chemicals that are too toxic to most microorganisms. However, it provides a technique for cleaning up pollution by enhancing the same biodegradation processes that occur in nature. Depending on the site and the kinds and amounts of contaminants, bioremediation may be safer and less expensive than alternative solutions. Bioremediation also has the advantage of treating the contaminants in place. This means that costs may be lower because large quantities of soil, sediment or water do not have to be dug up or pumped out of the ground for treatment.

Figure 6. Chemical discharge plume in the Calumet River,in Indiana

There is one main disadvantage to bioremediation and that is the amount of time needed for the process to occur. Bioremediation may require anywhere from 30 to 100 years, depending on the site and the contaminants.

Assessing the Steps Toward Remediation

Contaminated sediment management efforts are never 100 percent effective. There is always some residual contamination that must be managed, either passively, through monitoring, or by remedial actions. The Sediment Management Workgroup (www.smwg.org), comprised of stakeholders from federal, state, and local governments, universities, and professional organizations, suggests the following managment consider-ations for contaminated sediments:

- The management strategy should be based on sound science and risk assessment/risk management principles, taking into consider-ation site-specific conditions.
- On-site remediation should be based on a complete understanding of contaminant movement and uptake and exposure pathways in aquatic biota.
- Weighing the risks and benefits of intrusive sediment management over allowing a system the opportunity to undergo natural recovery. In this manner, actions that have the least potential to disrupt natural systems while still achieving remediation in a reasonable time can be fully evaluated and considered.
- Site-specific risk assessment and risk manage-ment decisions will provide the basis for sediment management strategy. Based on this evaluation, some sites will require dredging, some sites may rely on natural recovery and other sites may need a mix of remedial action.

More information on this subject may be found at the following:

Bioavailability of Contaminants in Soils and Sediments: Processes, Tools, and Applications. National Research Council of the National Academies. 2003. ISBN 0-309-08625-6.

Sediment Management Workgroup at <www.smwg.org>

Great Lakes National Program Office at <www.epa.gov/glnpo>

Sediments Remediation Action Team at <www.rtdf.org/public/sediment/default.htm>

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Glossary of Terms

Bioaccumulate: The net accumulation of a contami-nant in an organism from all sources, including air, water, and food. For example, toxic chemicals tend to bioaccumulate in the muscle and fatty tissues of fish, and these toxins increase in concentration as they are pased from the prey to the predators (biomagnification).

Bioavailability: The extent to which a substance is absorbed and circulated in the body.

Biodegradation: The breakdown of organic material into simpler components by microorganisms.

Biota: The plant and animal life of a particular region.

Bioturbation: The rearrangement of sediments by organisms that burrow through them and ingest them.

Fungi: Molds, mildews, yeasts, mushrooms, and puffballs. The fungi represent a group of organisms that lack chlorophyll and therefore are not photosynthetic. They are important in the environment as decomposers.

Hydrophobic: Literally *water fearing*, nonpolar compounds that are immiscible with water.

Nonpoint Source: A pollution source that cannot be defined as originating from discrete points such as a pipe discharge. Areas of fertilizer and pesticide applications, atmospheric deposition, manure, and natural inputs from plants and trees are types of nonpoint source pollution.

Phytoplankton: Microscopic plants.

Protists: Freeliving or colonial organisms with diverse nutritional and reproductive modes.

Sediment Solidification: The process by which contaminated sediment is mixed with cement-like material. The hardened material is typically left on site.

Zooplankton: Small, often microscopic, animals that drift in the currents. They feed on detritus, phytoplank-ton, and other zooplankton. They are preyed upon by fish, shellfish, whales and other zooplankton.

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Figure 2 photo courtesy of Lynn Betts, NRCS.

Figure 3 photo courtesy of Lynn Betts, NRCS.

Figure 4 photo courtesy of Lake Michigan Federation.

Figure 5 photo courtesy of Tim Thompson, citizen.

Figure 6 photo courtesy of U.S. Environmental Protection Agency, Region 5.

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