United States Environmental Protection Agency

Research and Development

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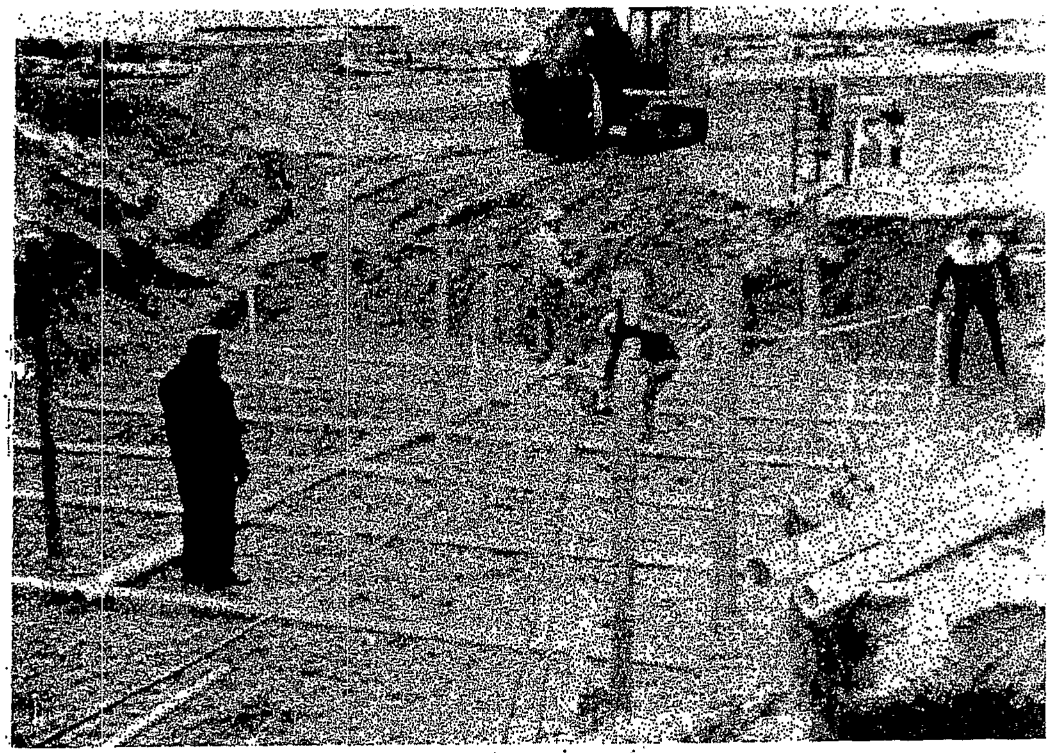
EPA

Understanding Bioremediation

A Guidebook for Citizens



Cover Photo:

***Bioremediation at a Coast Guard station in Traverse City, Michigan.* A 95,000-liter aviation fuel spill contaminated ground water with xylene, benzene, and toluene. Bioremediation brought the ground water within U.S. drinking water standards within 6 months.**

UNDERSTANDING BIOREMEDIATION:
A GUIDEBOOK FOR CITIZENS

Bioremediation—a process that uses microorganisms to transform harmful substances to nontoxic compounds—is one of the most promising new technologies for treating chemical spills and hazardous waste problems. In order to improve this technology and better understand its capabilities, the U.S. Environmental Protection Agency (EPA) is encouraging field tests and evaluation of waste site cleanups using bioremediation.

As bioremediation is considered more frequently as a cleanup alternative, citizens need information about this process to help them contribute to informed decision-making regarding the cleanup of waste sites in their communities. This brochure answers some questions about what bioremediation is, where it can be used effectively, and its advantages and disadvantages.

What is bioremediation?

Bioremediation uses naturally occurring microorganisms, such as bacteria, fungi, or yeast, to degrade harmful chemicals into less toxic or nontoxic compounds. Microorganisms, like all living organisms, need nutrients (such as nitrogen, phosphate, and trace metals), carbon, and energy to survive. Microorganisms break down a wide variety of organic (carbon-containing) compounds found in nature to obtain energy for their growth. Many species of soil bacteria, for example, use petroleum hydrocarbons as a food and energy source, transforming them into harmless substances consisting mainly of carbon dioxide, water, and fatty acids. Bioremediation harnesses this natural process by promoting the growth of microorganisms that can degrade contaminants and convert them to nontoxic by-products.

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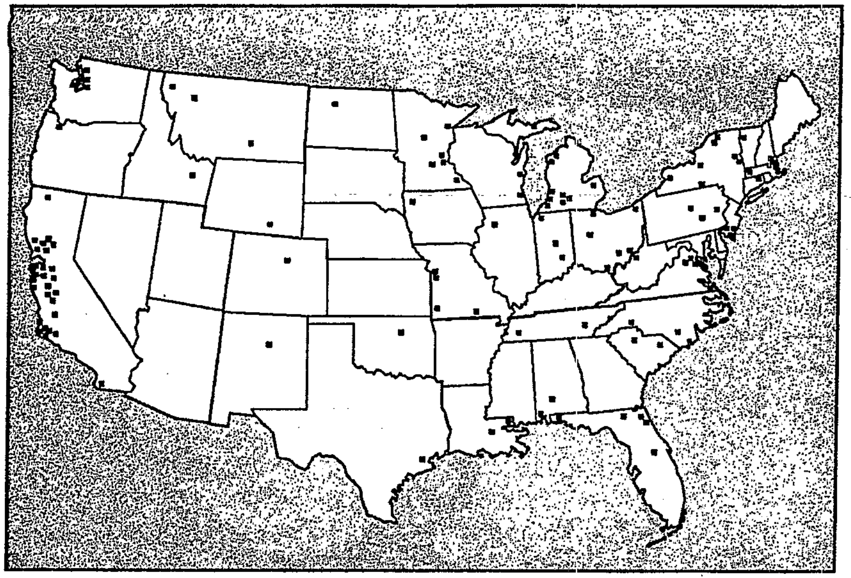
If biodegradation is a naturally *occurring process*, why do some biodegradable organic chemicals persist in the environment?

A number of environmental conditions can slow down or stop the biodegradation process. For example:

- The concentration of the chemical may be so high that it is toxic to the microorganisms.
- The number or type of microorganisms may be inadequate for biodegradation.
- Conditions may be too acidic or alkaline.
- The microorganisms may lack sufficient nutrients (such as nitrogen, phosphorous, potassium, sulfur, or trace elements), which they need to use the chemical as a food source. (Petrochemical residues, for example, are not "nutritionally balanced.")
- Moisture conditions may be unfavorable (too wet or too dry).
- The microorganisms may lack the oxygen, nitrate, or sulfate they need to use the chemical as an energy source.

In many instances, these environmental conditions can be altered to enhance the biodegradation process. To accomplish this, samples are collected at the site and analyzed to determine what types of microorganisms are present and what nutrients and climatic conditions (such as pH, moisture, temperature, and oxygen levels) can enhance microbial degradation. For example, if inadequate nitrogen or phosphorous are available, these nutrients can be added to enhance the growth of the microorganisms. If the concentration of the waste is too high, other chemicals or uncontaminated soil can be added to reduce toxicity so that biodegradation can occur.



Bioremediation projects are being considered, planned, or implemented at over 100 sites across the country.

Table 1. Classes of Chemicals that May Be Suitable for Bioremediation

Class	Example	Using Aerobic Biodegradation Process	Using Anaerobic Biodegradation Process
Monochlorinated aromatic compounds	Chlorobenzene	◐	
Benzene, toluene, xylene		◐	●
Nonhalogenated phenolics and cresols	2-methyl phenol	◐	●
Polynuclear aromatic hydrocarbons	Creosote	◐	
Alkanes and alkenes	Fuel oil	◐	
Polychlorinated biphenyls	Trichlorobiphenyl	◐	●
Chlorophenols	Pentachlorophenol	◐	●
Nitrogen heterocyclics	Pyridine	◐	
Chlorinated solvents			
Alkanes	Chloroform	◐	●
Alkenes	Trichloroethylene	◐	●

What are the advantages of bioremediation?

Bioremediation can be an attractive option for several reasons:

- It is an ecologically sound, "natural" process. Existing microorganisms can increase in numbers when a food source (the contaminants) is present. When the contaminant is degraded, the microbial population naturally declines. The residues from the biological treatment are usually harmless products (such as carbon dioxide, water, and fatty acids). The bioremediation process is carefully monitored to reduce the possibility that a product is more toxic than the original pollutant.
- Instead of merely transferring contaminants from one environmental medium to another (for example, from water to the air or to land), bioremediation destroys the target chemicals.
- Bioremediation is usually less expensive than other technologies that are often used to clean up hazardous waste. For example, cleaning up a site with bioremediation may cost $45 to $50 million, while it may cost $140 million if an incinerator must be built to dispose of the wastes.
- Bioremediation can often be accomplished where the problem is located. This eliminates the need to transport large quantities of contaminated waste off site and the potential threats to human health and the environment that can arise during such transportation.

What are the disadvantages of bioremediation?

Several limitations have prevented more widespread use of bioremediation as a cleanup technology:

- Research is needed to develop and engineer bioremediation technologies that are appropriate for sites with complex mixtures of contaminants.
- Cleanup using bioremediation often takes longer than other remedial actions, such as excavation and removal of soil or incineration.
- In some cases, depending on the parent compound, by-products may be formed. Some of these by-products may be toxic. The process must be carefully monitored to ensure the effectiveness of degradation.

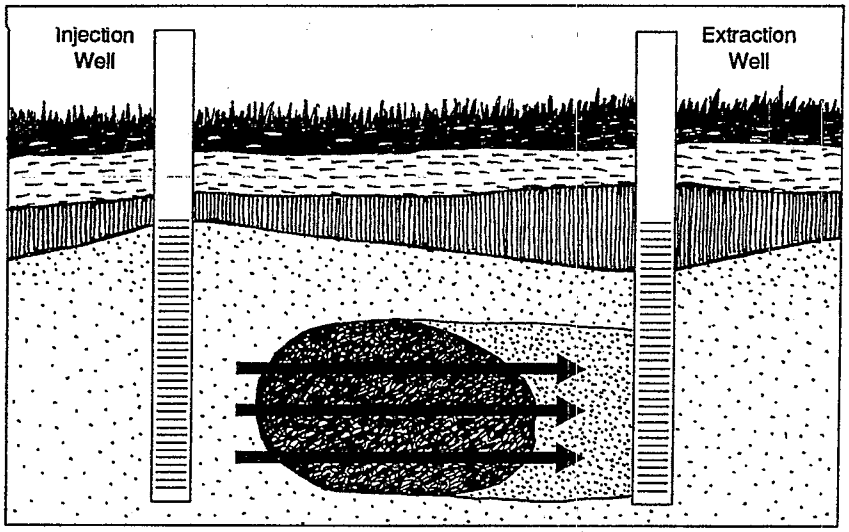


Figure 1. Ground-water treatment using extraction and injection wells.

source (such as air, pure oxygen, hydrogen peroxide, or ozone), and reinjecting the water using injection wells or trenches (Figure 1). Subsurface drains (Figure 2) can also deliver nutrients and oxygen to depths of about 40 feet or less.

Contaminants above the water table can be biodegraded *in situ* if the soil is relatively porous and permeable to air and water. A treatment solution containing nutrients can be delivered directly to the surface using spray irrigation, flooding, or ditches. Venting wells can be installed at intervals throughout the contaminated area to deliver oxygen to the contaminated soil.

Aboveground bioremediation

A variety of aboveground biological treatment processes can effectively treat soil and water contaminated with organic chemicals. *Composting* is one method for treating soil containing hazardous organic compounds. Highly biodegradable materials, such as wood chips, are combined with a small percentage of biodegradable waste materials. Air can be provided by mixing the compost material or by forced air systems. Composting can also occur in closed bioreactors.

Slurry-phase treatment (Figure 3) combines contaminated soil or sludge with water to create a slurry, which is then biodegraded in a mobile

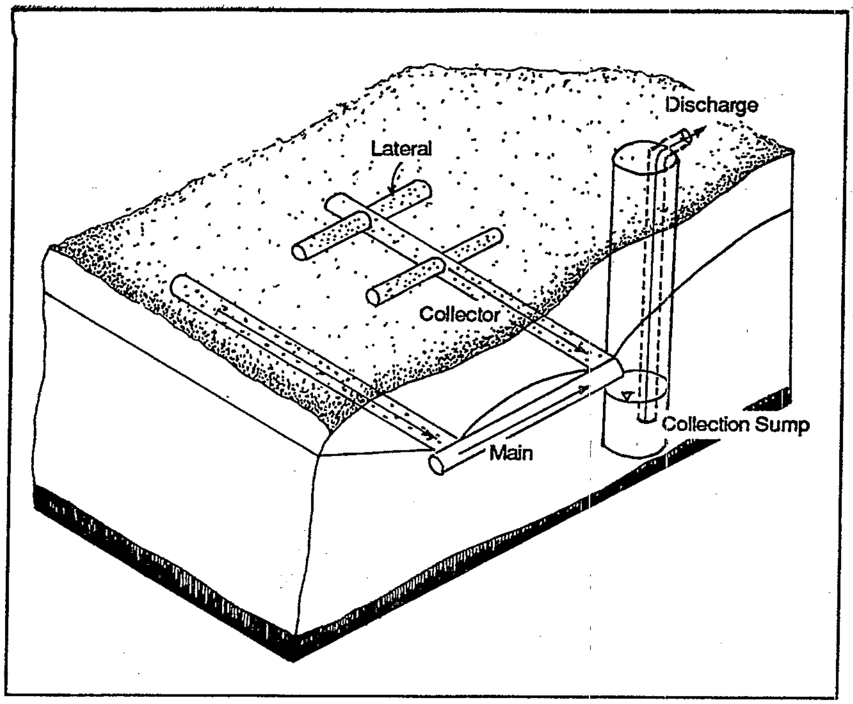


Figure 2. Subsurface drain.

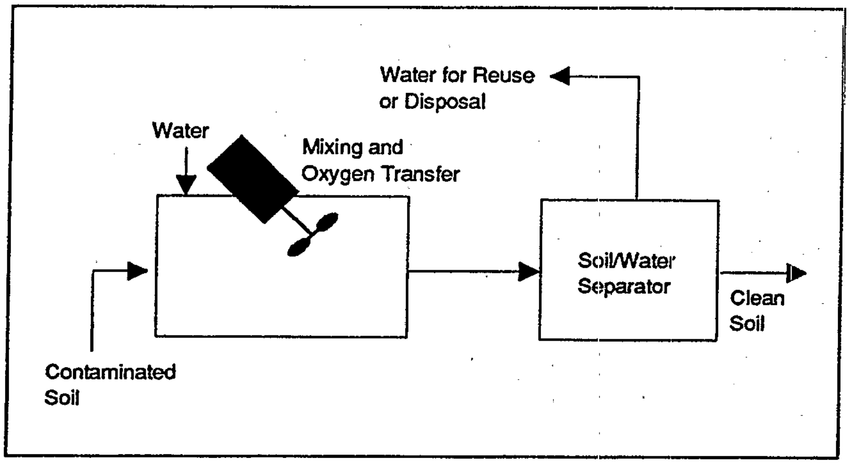


Figure 3. Slurry-phase treatment.

more effective after dechlorination, can be used to complete the soil restoration. Researchers are working to develop methods combining biological, chemical, and physical treatment processes to handle a variety of contaminants at hazardous waste sites.

What steps must be taken before bioremediation can be used at a hazardous waste site?

Careful information-gathering and evaluation of remediation options are required before bioremediation is selected as the cleanup technology for a hazardous waste site. An in-depth site investigation, including extensive sampling and laboratory analysis, is conducted to determine the nature and extent of the contamination, to obtain a description of the environmental characteristics of the site, and to make an initial assessment of appropriate remediation technologies. Questions that must be answered to evaluate bioremediation as a remediation technology for the site include the following:

- Are the chemicals at the site potentially biodegradable?
- Are any of the contaminants potentially toxic to microbial degradation processes? Is another type of treatment necessary before bioremediation can be used?
- What levels of contamination represent the clean-up goals for the site?
- What are the microbiological characteristics of the environment at the site? (For example, do aerobic or anaerobic organisms predominate?)
- Is the environment appropriate for bioremediation or can environmental conditions be adjusted to make it more appropriate for biological treatment (such as alteration of pH, preremoval of toxic metals, or changes in moisture content)?
- What are the microbiological needs of the site? (For example, would nutrients or bacteria that can break down specific substances need to be added?)

If bioremediation is identified as a potentially applicable remediation technology, treatability studies are conducted to further evaluate this option. These are laboratory and pilot studies that test potential approaches to bioremediation for the site. Bioremediation is then compared to other remedial action alternatives with respect to performance, reliability, ease of

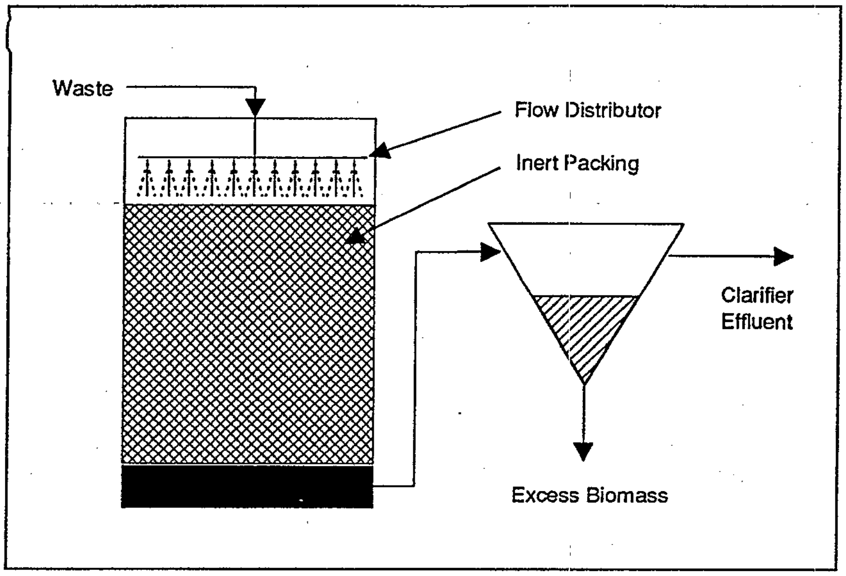


Figure 6. Trickling filter.

implementation, safety, regulatory issues, public health and environmental concerns, and costs, and the most appropriate alternative is selected.

Bioremediation is a technology that holds enormous promise for the future. It can be a nondisruptive, cost-effective, and efficient means of destroying harmful chemicals at many chemical spill and hazardous waste sites. As scientists learn more about its capabilities and develop practical techniques to biodegrade an increasing number of wastes, bioremediation is likely to take a prominent place among the technologies used to clean up and protect the environment.

What are some additional sources of *information about* bioremediation?

RCRA/Superfund Hotline

800-424-9346 outside of Washington D.C.; 202-382-3000 in Washington, D.C. For the hearing impaired, the number is TDD 800-553-7672 or 202-475-9652.

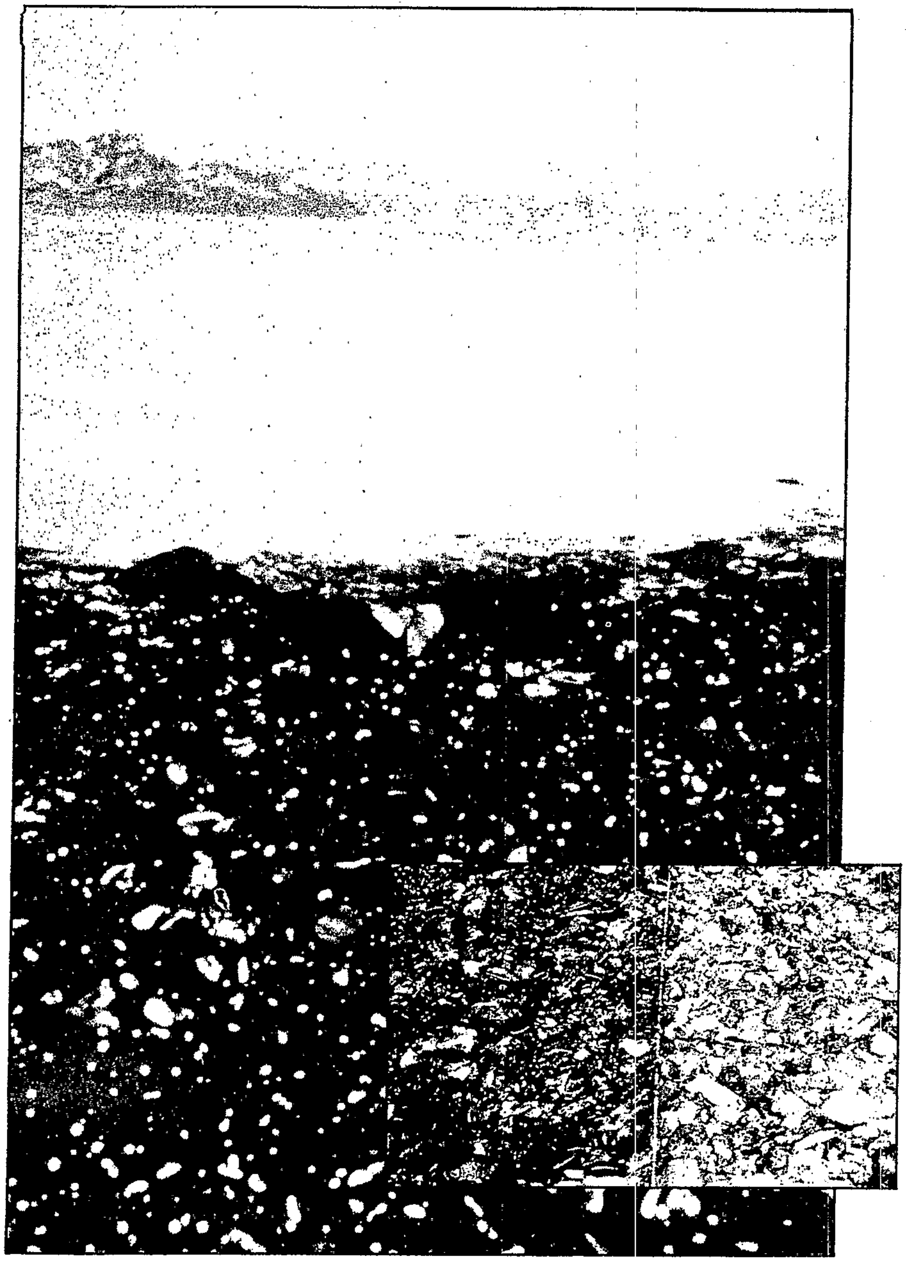
Publications

Office of Research and Development, U.S. Environmental Protection Agency. *Bioremediation of Hazardous Wastes.* EPA/600/9-90/041. September 1990.

This document summarizes the results of bioremediation research projects under EPA's Biosystems Technology Development Program.

Office of Research and Development, U.S. Environmental Protection Agency, *Alaskan Oil Spill Bioremediation Project: Update.* EPA/600/8-89/073. July 1990.

This brochure describes field and laboratory studies initiated following the Exxon Valdez oil spill to evaluate the effectiveness of bioremediation to remove oil from contaminated beaches.



Following the Exxon Valdez oil spill, patches of oil spread onto an estimated 1,000 miles of shoreline in Alaska. Inset shows that a site where nutrients were applied to enhance biodegradation is much cleaner than a site where no nutrients were added.

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