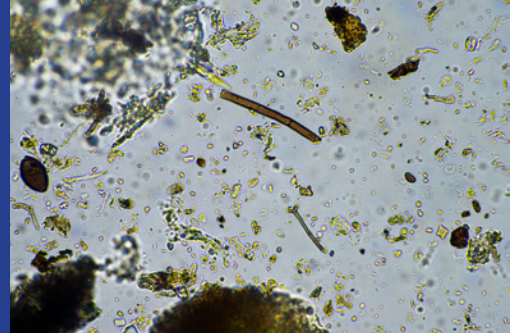




Bioremediation

by Jose Antunes

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Environmental contamination of water, soil, other environmental media, and consequently of living organisms, continues because of improper disposal and widespread use of novel contaminants, like 1,4-dioxane and per- and polyfluoroalkyl substances (PFAS).

Several techniques can be used to remediate (treat or remove) a wide range of contaminants. For novel compounds that have been identified as harmful to the environment and to humans, physical and chemical strategies are often the primary means of remediating contaminated materials. However, when those are not sufficient, biological methods for remediation—also referred to as bioremediation—can sometimes provide an effective means to address contamination. While chemical methods exploit chemical characteristics of the contaminants, such as their ability to be oxidized, and physical methods exploit contaminants' physical properties, like their ability to evaporate, biological methods exploit the systems and enzymes (biological molecules that act as catalysts or speed up reactions) in organisms to remove or destroy contaminants.

What is Bioremediation?

Bioremediation is a set of biological methods (or techniques) that use living organisms to treat environmental contamination. Bioremediation was first discovered in the 1960's when George M. Robinson identified bacteria capable of consuming petroleum components. These technologies have developed further since that time, to address different environments (aerobic and anaerobic ones, for example), as well as contaminants previously thought of as not biodegradable (such as 1,4-dioxane).

Bioremediation's use of living organisms can include those as large as trees or as small as bacteria and fungi. Trees, for example, can create an ideal environment in the soil or in groundwater that is in and around their roots where contaminants

(like BTEX—benzene, toluene, ethylbenzene, and xylene—volatile organic compounds found in petroleum products) can interact with bacteria and fungi to break them down. Trees can also uptake contaminants from the soil or groundwater through their roots and into their leaves, where contaminants (like selenium) can evaporate, or into other parts of the tree where contaminants can be trapped (as with arsenic) or broken down (as with TNT). Bacteria have perhaps been the most widely implemented mode of bioremediation for groundwater contaminants that are more difficult to break down.

Implementation

Environmental remediation generally requires site-specific plans, and the broader applicability of each type of remediation method varies. Classic physical and chemical methods are generally well accepted for appropriate types of sites and contaminants. Bioremediation, however, is highly dependent on the organisms used and the environment in which they are used, in addition to the target contaminant. This has meant that there has been a higher burden of proof for those trying to use bioremediation to prove that the method proposed would work for a particular site.

As bioremediation techniques have advanced, however, greater certainty about their applicability has been achieved, and verification that they will work has been easier to demonstrate.

Relevant Regulatory Guidance

Federally, the Environmental Protection Agency (EPA) has cited bioremediation methods as environmentally friendly techniques and included them under its Green Remediation Best Management Practices. Under the Resource Conservation and Recovery Act (RCRA) as well

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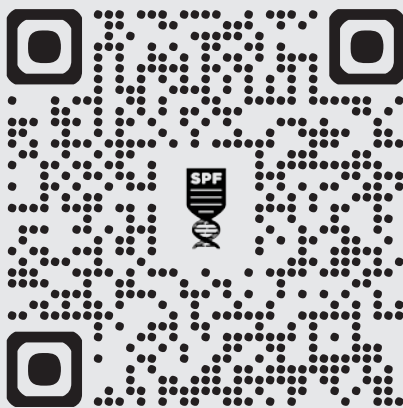
REFERENCES

Full references are available on the web-based version of this note, which can be accessed using the QR code below or at rockinst.org/blog.

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Science Notes are short memos that describe scientific and technological artifacts, concepts, principles, and research related to policy topics and legislative proposals.

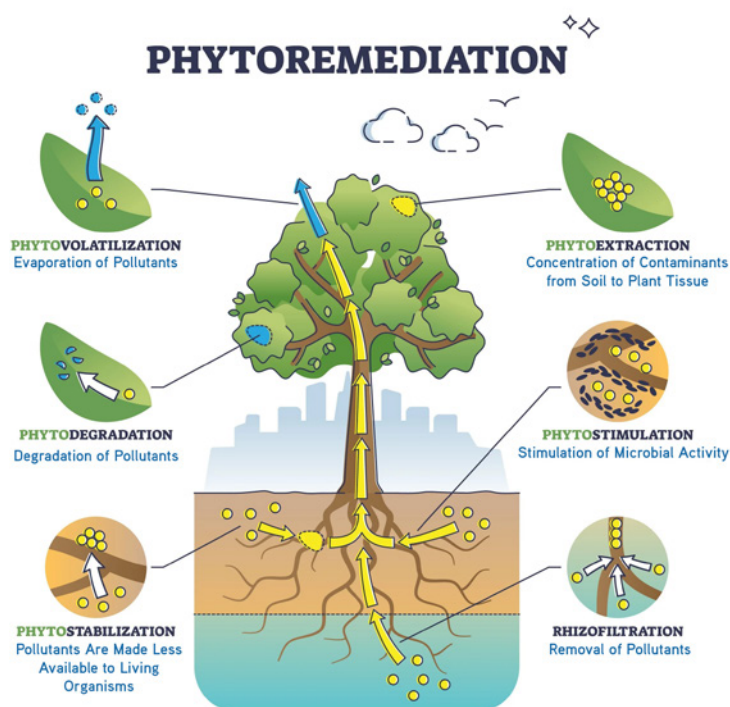
MORE INFO



as under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, commonly known as Superfund), the EPA includes as a best practice the use of *in situ* (onsite) bioremediation methods, like biostimulation (adding nutrients or adjusting conditions to stimulate native microbes) and bioaugmentation (introducing non-native microbes known to degrade particular contaminants). In New York State, the Department of Environmental Conservation (DEC) also includes the use of bioremediation under state codes, rules, and regulations, and technical guidance as an acceptable method for dealing with contamination.

TABLE 1 | Selected Bioremediation Methods

Type of Bioremediation	Organism Used	Description
Monitored Natural Attenuation	Native Microbes	Monitoring contaminant concentrations over time as native microbes carry out degradation (<i>in situ</i>).
Biostimulation	Native Microbes	Stimulating native microbes to carry out degradation more quickly by adding oxygen, nutrients, or electron donors (<i>in situ</i>).
Bioaugmentation	Non-Native Microbes	Amending the contaminated area with non-native microbes known to degrade the contaminant of interest (<i>in situ</i>).
Phytoremediation	Plants	Cultivating plants on contaminated soils to evaporate, degrade, or promote bacterial degradation of contaminants (<i>in situ</i>).
Biopiles	Native Microbes	Extracting soil from contaminated site and placing it in a pile of an impermeable liner where conditions can be better monitored and adjusted (<i>ex situ</i>).
Bioreactors	Native or Non-Native Microbes	Contaminated media is pumped into a bioreactor where microbes (native or non-native) are maintained at optimal growth conditions and can quickly degrade contaminants (<i>ex situ</i>).



SOURCE: "Phytoremediation," British Hemp Alliance, accessed September 11, 2026.