Report on

**Phytoremediation: Using Plants to Remediate Soil and Groundwater Contamination**

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## ABSTRACT

Phytoremediation is a process in which plants and trees are used to remediate sites contaminated with heavy metals, pesticides, radionuclides, and organic chemicals. Although this technology is relatively new, it is progressing quickly and may become the preferred method for cleaning up many sites because it is cost-effective, aesthetically pleasing, and requires little maintenance.

Report on

# PHYTOREMEDIATION: USING PLANTS TO REMEDIATE SOIL AND GROUNDWATER CONTAMINATION

## I. INTRODUCTION

The United States Environmental Protection Agency has a list of over 30,000 industrial and municipal sites that are in need of hazardous waste treatment and removal at an estimated cost of over $400 billion worldwide (Phytotech). Given the tremendous amount of money and effort that will be spent on remediating these sites, it is clear that an efficient and cost-effective method is needed that can be applied to many different sites.

Phytoremediation, using plants to treat contaminated soil and groundwater, may be the method needed to meet the needs of environmental scientists and engineers who are faced with the task of repairing the damage. This technology is still in the research and development stage, but preliminary results are promising.

## II. OVERVIEW OF PHYTOREMEDIATION

Phytoremediation is a natural process involving the use of plants to cleanup and/or immobilize contaminants in soil or groundwater. It can be used for organic chemical spills such as trichloroethylene (TCE) and atrazine and for inorganics, including heavy metals. There are four different mechanisms for phytoremediation: rhizofiltration, phytostabilization, phytodegradation, and phytoextraction.

**Rhizofiltration**

Rhizofiltration is the use of plant root systems to absorb, concentrate and precipitate heavy metals from polluted aqueous streams. Hydroponically grown plants such as Indian mustard and sunflowers have been demonstrated to remove toxic metals such as lead, copper, and chromium from industrial waste streams.

Rhizofiltration has never been tested as far as economical feasibility goes, but it shows promise due to its ability to treat high volumes of contaminants, reduced volume of secondary waste, and the possibility of reclamation and recycling of the metals (Dushenkov 1239). Another bonus is that this science can be directly applied to effluent streams, polluted rivers, or groundwater systems.

**Phytostabilization**

Some contaminants are attracted to the hydrophobic surfaces on organic matter and can bond to a plant’s root tissue and become immobilized. This bonding decreases the spread of the contaminants to other areas of the soil. Phytostabilization has been tested by DuPont in order to contain contaminants at polluted sites and prevent soil leaching. At these sites, soil amendments such as alkalizing agents, phosphates, mineral oxides, and organic matter are mixed into the soil with the goal of making heavy metals more insoluble. This makes it easier for the plants to absorb the metals through their root systems. Then grasses are planted at the site in order to reduce erosion and to start the process of phytostabilization. (Matso 49)

**Phytodegradation**

Some plants have the ability to break down certain chemicals into less harmful substances. For instance, hybrid poplar trees have been shown to oxidize trichloroethylene (TCE) to carbon dioxide (Newman 1066).

**Phytoextraction**

Phytoextraction occurs when the contaminants are removed from the soil by the plant and concentrated in the plant tissue. When this process is used the plant must be harvested and disposed of as a hazardous waste. In phytoextraction, the plant acts as a filter and lightweight container for contaminant removal. The advantage is that the contaminated plant weighs much less than the contaminated soil would if excavated and hauled away.

Generally, this process is used at sites contaminated with inorganics and metals such as lead, nickel, cadmium, and zinc. Certain plants known as "hyperaccumulators" concentrate the metals in the plant roots and tissue. Using plants to accomplish this can actually be faster than conventional pump and treat technology. According to Scott Cunningham of DuPont, "It takes a long time to go from your influent pump to your extraction well. But if you view plants as miniature extraction wells and if you have 10,000 of them per acre, you don't have to transport the materials as far." (Matso 48-49)

Currently, phytoextraction is the most researched and documented phytoremediation technology available. Many companies have begun to market this technology commercially, including a company called Phytotech in Monmouth Junction, New Jersey. According to an article published in the Boston Globe (March 1997) Phytotech has discovered many plants that are specialized to cleaning up particular contaminants. These include Indian mustard greens for removing lead, chromium, cadmium, zinc, and copper and sunflowers for removing radioactive and other toxic metals from soil.

One of the disadvantages of phytoextraction is that the roots are difficult to harvest, making it essential that the metal be absorbed all the way to the top of the plant. This has proved to be problem with lead extraction because lead tends to stay in the roots of the plants unless chelating agents and electro-osmosis are used.

## III. PHYTOREMEDIATION REQUIREMENTS

### Design Considerations

There are a number of parameters that must be considered when deciding whether phytoremediation is the best method to use on a particular site.

**Soil and Land Requirements .** Phytoremediation works best in tight soils with limited groundwater flow. However, any soil that can support a plant population is suitable for phytoremediation.

Contaminated aquifers need to be within 20 feet of the surface in order for plant roots to be able to effectively treat them. It is not currently possible to treat all contaminated aquifers with phytoremediation due to depth and area constraints. Some aquifers may be too deep while those in urban areas may not have the required above-ground area to allow a sufficient number of trees or plants to be planted.

However, according to John Kerr of the US EPA, "approximately 80% of the polluted groundwaters are within 20 m of the surface , which means that a significant number of sites are accessible to plant root systems. The future looks even better, according to Edward Gatliff of Applied Natural Science, "I'm finding, with trees, that I can readily go 20 ft. And next spring [1996], I'm hoping to conduct a pilot study to access an aquifer in Virginia at 45 ft" (Matso 48). He has also found that poplars and weeping willows can pump between 50 and 350 gallons of water per day per tree, making them much faster than regular pump-and-treat systems.

Another advantage of phytoremediation as far as soils go is that the plants can remove contaminants that are trapped in the micropores of the soil. Gatliff estimates that micropores can trap up to 70% of the soil solution and recommends that phytoremediation be used as a "finisher and polisher" in these cases after other methods have been used (Matso 48)

**Plant Selection and Compounds to be Treated .** The type of compound to be treated greatly influences the type of plant that is selected. Table I illustrates the various kinds of vegetation and the contaminants they have successfully treated.

**Table I** Applications of Plant Selection (adapted and expanded from Howe)

| Plant | Toxin | How it works |
|---|---|---|
| Indian mustard greens | Heavy metals | Removes lead, chromium, cadmium, zinc, and copper from soil; it has also been used to control selenium levels |
| Goosefoot | Salt pollution from petroleum production | These salt-resistant weeds have cleaned up oil-patch areas ravaged by brine spills. |
| River Reeds | Runoff from airplane de-icing agents | In tests, the reeds rapidly broke down glycol antifreeze into water and carbon dioxide. It's not yet clear whether the reeds or the microbes they attract do the job. |
| Poplar Trees | TCE, petroleum, atrazine, other groundwater contaminants | These deep-rooted trees have been used to halt the spread of contaminated groundwater. |
| Alfalfa | Fertilizer spills | Special alfalfa strain that absorbs nitrogen only from the ground, not the air, removed 30% more than the standard alfalfa varieties. When the plants turn yellow and die, the nitrogen removal is complete. |
| Kochia and Multiflora Rose | Herbicide spills at agrichemical dealer lots | Used in combination, the tumbleweed-like kochia plant and the woody multiflora rose halt the spread of herbicides. |
| Sunflowers | Radionuclides | Shown to remove uranium from water and have been successfully used at sites contaminated from the Chernobyl disaster. |

**Cost**

Cost can be the decisive factor for which method to use in site remediation. Phytoremediation is estimated to be approximately half the cost (or less) of other technologies that are presently available. For instance, when sunflowers were used to remove uranium from contaminated water in Ohio it cost \$2-\$6 to clean a thousand gallons of water. Compare that to methods like dredging and biological and filtration techniques which can cost as much as $80 per thousand gallons of water (Naj).

Grasses were used at an Astoria, Oregon site to remediate polyaromatic hydrocarbons (PAHs) to below legal limits. The owner of the site had originally planned to excavate the soil and pay to haul it to a landfill at a price of $200-$600 per ton. Ari Ferro of Phytokinetics says that phytoremediation of the site cost about $80 per ton and the process was completed in one growing season. Phytotech used soil additives and Indian mustard plants to clean up lead contamination at a Trenton, New Jersey site at $150,000 per acre. Excavation and landfilling of the soil at this site was estimated at $300,000 per acre (Kim 41).

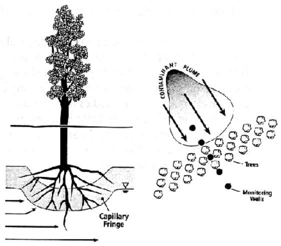
Because of the relatively low cost of phytoremediation, it is the method of choice for many people who are faced with large-scale clean-up costs. Even if phytoremediation is not the principal technique used, it can be employed later or used as a preventative measure. Peter Palmer, vice president of engineering at Geraghty and Miller, incorporates trees in his landfill designs. He says that he doesn’t trust landfill caps because they often fail to contain the leachate. “Instead, we plan to plant trees on the landfill. The trees not only promote degradation and/or mobilization of contaminants, they also suck out excess water” (Matso 48).

## IV. CASE STUDIES

### Chevron Diesel Site

Phytokinetics is currently conducting a field study at Ogden, Utah in conjunction with the Environmental Protection Agency's Superfund Innovative Technology Evaluation (SITE) program. In this study, both grasses and poplars are being used to cleanup the total petroleum hydrocarbons (TPHs) that have leaked into the groundwater. The grasses are being used to remove the TPHs from the surface soils while the poplars are planted in barrier layers to block the flow of groundwater and to remove the contaminants by concentrating them in the poplars themselves.

**Figure 1** Poplars are dependent on large volumes of groundwater for moisture, creating a cone of depression in the saturated zone and blocking movement of contaminant plumes. (Drawing courtesy of Phytokinetics)




**Occidental Chemical Company Site**

This site, located in Grand Island, New York, was studied by the EPA and University of Washington researchers for remediation of trichloroethylene (TCE) from 1995-1997. This organic compound has been used for many years as an industrial degreaser and as a solvent for dry cleaning. TCE is a major contaminant of groundwater and soil in the United States and is also potentially carcinogenic. This establishes a vital need for a method to safely and quickly remove TCE from water and soil and preferably break it down into something less harmful at the same time.

The University of Washington researchers saw that pump-and-treat procedures and bioremediation, as well as comparable methods were too slow (taking anywhere from decades to centuries in some cases) and they looked to phytoremediation as a possible solution. Hybrid poplars were developed that had more rapid growth rates and more extensively developed root systems than ordinary poplar varieties.

This allowed faster results since the more quickly a tree grows, the more water it takes in and potentially treats. The hybrid poplars used in this study had growth rates of 3 meters per year and after five years had an average diameter of 13 centimeters (Newman 1062). The average pumping rate was estimated at 200 liters per day (Kim 39).

The results of the study showed that the poplar trees absorbed TCE through their root systems and transpired the contaminant though their leaves. The groundwater had an original pollutant concentration of 18 ppm and extraction wells on the other side of the tree barrier show that 95% of the TCE is removed (Kim 39).

**Uranium Removal with Sunflowers**

Rhizofiltration was tested at a former uranium processing facility in Ashtabula, Ohio by Phytotech in 1995. Phytotech collaborated with the U.S. Department of Energy to use sunflowers to remove uranium from water. A greenhouse was built at the Ohio site and the six-week-old sunflower plants were grown in troughs with their roots submerged in the contaminated water. The inlet water contained 100-400 ppb uranium and the outlet water contained 1-5 ppb uranium (Kim 39 and Naj ).

## V. CONCLUSION

Phytoremediation is a technology with tremendous possibilities. It has applications for remediation of groundwater, brownfields, industrial effluents, radioactive waste, and landfills. The power of plants to clean the environment has barely been tapped and as more research is conducted, the capabilities will continue to expand.

Phytoremediation is aesthetically pleasing to people who live and work around the area while it is being cleaned up and is perceived as a more natural solution than large amounts of equipment and noisy machinery. The cost is inviting because phytoremediation can be undertaken for less than half the cost of other technologies and in some cases the pollutant (e.g. copper) can be reclaimed and recycled. Phytoremediation projects also require less maintenance.

Already, some municipalities have recognized that planting poplars or willows along rivers and streams can reduce the volume of non-point-source pollution that is introduced into the water system. As the general public becomes more familiar with the benefits of phytoremediation, this technology will be used in more remediation strategies and new applications will be discovered.

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