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Applied Phytoremediation

In greenhouse and field studies, phytoremediation has been shown to be an effective and 'environmentally friendly' method of remediation, compared to conventional methods. However, some doubt still exists as to the usefulness of phytoremediation, and whether it could actually be applied to waste sites in a safe and timely fashion.

The following tables are information pooled from various researchers and workers in the field of phytoremediation. While phytoremediation has some limitations, it has been shown to be a viable method of waste remediation and can be the best option for a given situation.

Tables 1- 3 from "Phytoremediation" (Belz, 1998)
http://www.cee.vt.edu/program_areas/environmental/teach/gwprimer/phyto/phyto.html

Table 1 – Advantages and disadvantages of phytoremediation
Table 2 – Chemical that plants can remediate
Table 3 – Current remediation possibilities

Table 4 - 5 from "Phytoremediation, Technology Evaluation Report" (Schnoor, 1997)
Prepared for; Ground-Water Remediation Technologies Analysis Center

Table 4 – Cost advantage of phytoextraction for metals
Table 5 – Cost advantage of phytoremediation (rhizosphere bioremediation)

Table 6 – Listing of company's currently using and offering phytoremediation services for waste remediation, ranging from heavy metals to organics. Also, vary in firms devoted solely to phytoremediation to environmental restoration firms, which offer phytoremediation as one of their many services.

Table 1

Advantages:	**Disadvantages:**
Aesthetically pleasing.	Can take many growing seasons to clean up a site.
Solar driven.	Plants have short roots. They can clean up soil or groundwater near the surface in-situ, typically 3 - 6 feet (Ecological Engineering, 1997), but cannot remediate deep aquifers without further design work.
Works with metals and slightly hydrophobic compounds, including many organics.	Trees have longer roots and can clean up slightly deeper contamination than plants, typically 10-15 feet (T. Crossman, personal communication, November 18, 1997), but cannot remediate deep aquifers without further design work (see Figure 2).
Can stimulate bioremediation in the soil closely associated with the plant root. Plants can stimulate microorganisms through the release of nutrients and the transport of oxygen to their roots.	Trees roots grow in the capillary fringe, but do not extend deep in to the aquifer. This makes remediating DNAPL's in situ with plants and trees not recommended.
Relatively inexpensive - phytoremediation can cost as little as $10 - $100 per cubic yard whereas metal washing can cost $30 - $300 per cubic yard (Wantanbe, 1997).	Plants that absorb toxic materials may contaminant the food chain.
Even if the plants are contaminated and unusable, the resulting ash is approximately 20-30 tons per 5000 tons soil (Black, 1997).	Volatization of compounds can transform a groundwater pollution problem to an air pollution problem.
Having ground cover on property reduces exposure risk to the community (i.e. lead).	Returning the water to the earth after aquaculture must be permitted.
Planting vegetation on a site also reduces erosion by wind and water	Less efficient for hydrophobic contaminants, which bind tightly to soil.
Can leave usable topsoil intact	

Table 2

Chemicals plants can remediate

Plant	Chemical
Arabidopsis	Mercury
Bladder campion	Zinc, Copper
Brassica family (Indian Mustard & Broccoli)	Selenium, Sulfur, Lead, Cadmium, Chromium, Nickel, Zinc, Copper, Cesium, Strontium
Buxaceae (boxwood)	Nickel
Compositae family	Cesium, Strontium
Euphorbiaceae	Nickel
Tomato plant	Lead, Zinc, Copper
Trees in the *Populus* genus (Poplar, Cottonwood)	Pesticides, Atrazine, Trichloroethylene (TCE), Carbon tetrachloride, Nitrogen compounds, 2,4,6-trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-1,3,5 triazine (RDX)
Pennycress	Zinc, Cadmium
Sunflower	Cesium, Strontium, Uranium
genus *Lemna* (Duckweed)	Explosives wastes
Parrot feather	Explosives wastes
Pondweed, arrowroot, coontail	TNT, RDX
Perennial rye grass	Polychlorinatedphenyls (PCP's), polyaromatichydrocarbons (PAH's)

Table 3

Some current remediation possibilities

Plant	Chemicals	Clean-up numbers	Source
Pondweed, Arrowroot, Coontail	TNT & RDX	0.016-0.019 mg of TNT / L per day & 0.133 - 0.291 mg RDX / L per day	Betts, 1997
Poplars	Nitrates from fertilizers	From 150 mg/L to 3 mg / L in under 3 years	USEPA, 1996
Mustard Greens & Pumpkin Vines	Lead	45% of the excess was removed	Ecological Engineering, 1997
Halophytes	Salts	Reduced the salt levels in the soils by 65%	Ecological Engineering, 1997
Pennycress	Zinc & Cadmium	108 lb / acre per year & 1.7 lb / acre per year	Chaney, 1995
---		Hydrocarbons	From TPH concentrations greater than 100 ppm to TPH concentrations less than 10 ppm in less than a year. Geraghty & Miller, 1997
Poplar Trees	Atrazine	Lab: 91% of the atrazine was taken up in 10 days	Burken & Schnoor, 1997
Indian Mustard Seedlings	Lead(II), Strontium(II), Cadmium(II), Nickel(II), Cesium(I), Cromium (IV)	Lab: Concentration in the plant was 2000 - 100 times the concentration in solution	Salt et al, 1997
Sugar Beet cell cultures	Nitroglycerin (GTN)	Lab: From 1.8mM GTN to undetectable levels in 20 hours	Goel et al, 1997

Table 4

Cost Advantage of Phytoextraction for Metals
(Phytotech Technical Summary, 1997)

Type of Treatment	Cost/m^3 ($)	Time Required (months)	Additional factors/expense	Saftety Issues
Fixation	90-200	6-9	Transport/excavation Long-term monitoring	Leaching
Landfilling	100-400	6-9	Long-term monitoring	Leaching
Soil extraction, leaching	250-500	8-12	5,000 m^3 minimum Chemical recycle	Residue disposal
Phytoextraction	15-40	15-40	Time/land commitment	Residue disposal

Table 5

Cost Advantage of Phytoremediation (Rhizosphere Bioremediation)
of Soils Using Fine-Rooted Grasses Compared to Other Techniques
(E. Drake, Exxon, Anandale, NJ, personal communication)

Type of Treatment	Range of Costs $/Ton
Phytoremediation	$10-35
In situ Bioremediation	$50-150
Indirect Thermal	$20-220
Soil Washing	$120-300
Solidification/Stabilization	$80-200
Solvent Extraction	$240-340
Incineration	$360-440
Soil Venting	$200-1,500

Table 6

Company's and their Services/Products

Company
Applied PhytoGenetics, Inc. http://www.appliedphytogenetics.com/apgen/index.htm Chlorinated Pesticide Site - Louisiana - Greenhouse Feasibility; Project Completed Manufactured Gas Plant Site - Georgia - Greenhouse Feasibility; Project Completed Wetlands to Treat Chlorinated Solvents - Georgia - Field Demonstration and Monitoring Soils and Sediments; PAHs, Phenolics and Heavy Metals - New Jersey - Greenhouse Feasibility, Field Demonstration and Monitoring PAH Contamination, Industrial Site - Upper Midwest - Field Demonstration and Monitoring Hydrocarbon Remediation - Canada - Field Demonstration and Monitoring
Ecolotree http://www.ecolotree.com/ TCE Contamination in Groundwater -U.S. Air Force Base - Greenhouse Feasibility and Field Demonstration Ecolotree®, Inc. uses engineered vegetative systems to contain and clean up problem chemicals that can harm humans and the environment. This technology is called "phytoremediation." The plants, primarily hybrid poplar trees, legumes, and grasses, can provide effective and economical solutions to environmental problems. Incorporated in 1990, Ecolotree is the oldest and most experienced phytoremediation company in America, with 55 sites planted across the United States and one in Europe. Planted locations include landfills, contaminated soil and groundwater sites, municipal and industrial wastewater treatment sites, brownfield sites, agrochemical spill areas, riparian stream filters, and animal feed lot perimeters.
CH2M HILL http://www.ch2m.com/phyto/ Remediation and Reuse of Nitrogen-Contaminated Groundwater - Mill Creek Correctional Facility Decontamination of Soil at Decommissioned Oil Refinery - Petroleum Company, Kansas Treatment of Oily Waste Through Land Application - Texaco, Anacortes, Washington Remediation of Diesel-Contaminated Soil Through Cultivation of Grass and Clover - Daishowa Paper Mill, Port Angeles, Washington Remediation of Wood Preservative Wastes Through Plant Cultivation - Union Pacific Railroad, Laramie, Wyoming Residual Petroleum Waste Remediation Through Tree Cultivation - Weyerhaeuser Phytoremediation of Petroleum Hydrocarbons - Pacific Islands

Argonne National Laboratory-East
http://www.es.anl.gov/htmls/cbt10-phyto.html

The 317/319 areas at Argonne National Laboratory-East (Argonne-E) are contaminated by volatile organic compounds (VOCs) in soil and groundwater and low levels of tritium in the groundwater from past waste disposal practices. As part of a nationwide effort to find more cost-effective and environmentally friendly remediation technologies, the U.S. Department of Energy (DOE), through the Accelerated Site Technology Deployment (ASTD) program, funded the deployment of a phytoremediation system in the 317/319 areas at Argonne-E. The main objectives of this deployment, which was selected in place of the baseline approach of an asphalt cap and extraction wells, are to hydraulically contain groundwater migration and to remove the VOCs and tritium within and downgradient of the source areas.

Applied Natural Sciences, Inc. (ANS) was founded in 1993 to provide specialized environmental remediation services.

Applied Natural Sciences, Inc
http://www.treemediation.com/

TreeMediation®, ANS' proprietary phytroremediation system, uses phreatophytic trees and other vegetation to treat environmental contamination in soil and ground water.

Findlay, Ohio - TCE

Lafayette, Louisiana - TCE/TPH

Oconee, Illinois - Nitrogen/Pesticides

Wastewater/Leachate Treatment

Wilmington, North Carolina - Nitrogen

A "mature tree" study has been completed at Cape Canaveral Air Station. Live Oak, Saw-tooth Palmetto and Scrub Oak species in the midst of a TCE plume were evaluated for TCE transpiration and TCE transformation rates. Evapotranspiration rates were also measured. Mature trees were used in this study to obviate the waiting period for whips to grow into mature trees.

The Airforce Center for Environmental Excellence
http://www.afcee.brooks.af.mil/afceehome.asp

An initial planting of 110 trees in 1998 was followed by 200 (early 2000) and 150 (spring 2000) additional trees at Travis AFB, CA. The plantings are being used as hydraulic control for a TCE plume. This is a long-term test of the ability of trees to control the movement of groundwater.

A similar study is taking place at Altus AFB, OK. One hundred ten non seed-bearing hybrid cottonwood trees were planted in the fall of 1998. The plantings are being used as hydraulic control for a TCE plume. Soil moisture, groundwater levels, climatic conditions and sap flow rates are monitored remotely in this demonstration. A report on the results of the study will be released in the summer 2001.

A new effort was launched in the summer 2000, with five large-scale plantings planned for Fairchild, Offutt, Hill and Whiteman AFBs. Plantings should be complete by early 2001.

TreeTec Environmental Corp.
http://www.treetec.com/index.html

TreeTec Environmental Corp. is engaged in the business of using trees and tree growth technology to remove contaminants from degraded water, soil and air.

June, 2000 - TreeTec Environmental Corp. completed the installation of a vegetative barrier system pilot study for the control of landfill ammonia at the U. S. Air Force's Cape Canaveral Air Station, Cape Canaveral, Florida.

ERIN Consulting Ltd
http://www.erinconsulting.sk.ca/index.html

ERIN Consulting Ltd. was founded in 1995 as an environmental consulting firm. We offer a wide range of environmental services to companies in Canada and the world. Our staff expertise ranges from biology to engineering and planning. Our clients include companies in oil and gas, mining, manufacturing, education, communications, public housing, and government sectors.

Phytoremediation project for SaskTel - Greenhouse study to evaluate the potential use of jack pine for phytoremediation of a diesel spill. - Design and implementation of a research project. The project was to determine what levels of diesel fuel jack pine trees could withstand and remediate.

Phytokinetics
http://www.phytokinetics.com/

Phytokinetics was one of the first companies to recognize the potential of phytoremediation. Since 1994, we have been providing clients with a cost-effective cleanup technology. Today, Phytokinetics is involved in site cleanup throughout the United States. We are currently working with BP Amoco, Chevron, the US EPA, and other privately owned companies to remediate contaminants in soil and groundwater.

Control of groundwater contaminant plumes

Stabilization, biodegradation, or removal of contaminants in soil

Control of agricultural and industrial runoff

Prevention or reduction of leachate formation from landfills and other contaminated sites

Treatment of contaminated groundwater, wastewater, or leachate

Phytotech Division of Edenspace Systems Corporation
http://www.edenspace.com/

Edenspace Systems Corporation is a biotechnology systems company that uses innovative, plant-based products and services to restore and enrich our surroundings. It's goal is to spearhead a revolution in manufacturing and architecture that will see a profound integration of plants in a multitude of industrial and residential settings.

Incorporated in October, 1998 and headquartered in Reston, Virginia, Edenspace today is the world leader in the use of proprietary techniques to remove minerals from water and the ground using special plant cultivars and amendments.

Edenspace maintains laboratory, growth chamber, and greenhouse facilities near Princeton, New Jersey. In 1999, the company acquired Phytotech, Inc., a pioneer in metal phytoextraction.

Verdant Technologies Inc.
http://www.verdanttech.com/

Verdant Technologies is a company of scientists and engineers focused on the commercial development of phytoremediation technologies. The men and women of Verdant Technologies have conducted groundbreaking laboratory, greenhouse, and field tests to demonstrate the potential of phytoremediation.

Verdant's staff is recognized by both the scientific community and by industry as leaders in phytoremediation. They have assessed various types of trees, including those that would be native to environmentally sensitive sites for their phytoremediation potential against multiple chlorinated solvents, aromatic compounds, and various pesticides.

Compounds successfully remediated using phytoremediation technology include: carbon tetrachloride, trichloroethane, tetrachloroethylene, ethelyne dibromide, chlorobenzenes, and trichloroethylene.

Lynntech, Inc.
http://www.lynntech.com/index.html

Lynntech is an experienced developer of in situ soil and ground water clean-up methods, many of which have been field tested at sites throughout the U.S. Their focus is on electroseparations (electrokinetics) for in situ removal of heavy metals from soil.

Recent research has been focused on the use of plants (phytoremediation) and the development of low-cost barrier methods to prevent the migration of contaminants in the subsurface.

The Bioengineering Group, Inc.
http://www.bioengineering.com/about_tbg.html

The Bioengineering Group, Inc. is a consulting firm with expertise in the use of vegetation for construction projects designed to optimize environmental benefits.

They provide a full range of consulting services in the field of bioengineering for erosion control, water quality, and habitat restoration.

Area of Expertise in Phytoremediation.

Geomatrix Consultants, Inc
http://www.geomatrix.com/

In 1984, a group of recognized authorities in the earth sciences founded Geomatrix. Their goal was to create a company large enough to solve diverse, complex scientific and technical issues—yet small enough to deliver personal service and consistently excellent results.

Today Geomatrix is rated one of the top environmental engineering consulting firms. Our staff of 300 people, working from offices throughout North America, delivers in-depth services in the fields of engineering; applied environmental and earth sciences; air quality, toxicology and ISO 14000; decision analysis and risk assessment.

Offer phytoremdiation services

MSE Technology Applications, Inc
http://www.mse-ta.com/

Innovative technologies are being developed and demonstrated through U.S. Department of Energy funding to advance them technically to address DOE waste sites requiring cleanup. This cleanup could include containment/stabilization or control/treatment of the waste.

They use Phytoremediation as a control/treatment option.