FACT SHEET

Phytoremediation Advances

Introduction

Phytoremediation is the use of plants to remediate or contol contaminants in soil, groundwater, surface water, or sediments. This fact sheet focuses on recent advances in the application of phytoremediation and provides examples of full-scale case studies.

Technology Background

Phytoremediation can be used to treat organic compounds (petroleum hydrocarbons, chlorinated compounds, pesticides and explosive compounds), inorganic compounds (salts, heavy metals and radionuclides), and to promote hydraulic control through the uptake of water. Phytoremediation is literally and figuratively a green technology that is typically passive with respect to energy inputs, though these systems do require maintenance. See Naval Facilities Engineering Systems Command [NAVFAC] (2020), Federal Remediation Technologies Roundtable [FRTR] (2020) and Interstate Technology & Regulatory [ITRC] (2009) for additional background information and Kansas State University (2020) for details on specific plant species and their phytoremediation potential.

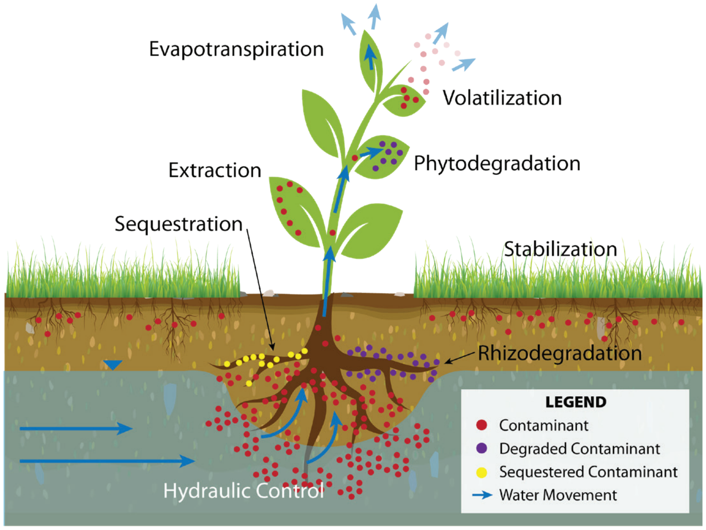

Figure 1. Phytoremediation Mechanisms (Courtesy of Trihydro Corp.)

How Does It Work?

Phytoremediation can work through several mechanisms which are shown in Figure 1.

- ☐ **Extraction –** uptake of contaminants into plant structures.
- ☐ **Stabilization –** minimizing movement of contaminants by intercepting precipitation and physical stabilization of soil.
- ☐ **Sequestration –** immobilizing contaminants by precipitation or complexation in the root zone.
- ☐ **Volatilization –** movement of contaminants through the plant to the atmosphere.
- ☐ **Hydraulic control –** use of plants' consumption of water (i.e., transpiration) to influence groundwater.
- ☐ **Degradation –** transformation in the root zone (rhizodegradation) or leaves (phytodegradation).

How Can It Help?

Phytoremediation offers the following potential benefits:

- ☐ Semi-passive technology that can treat residual impacts in a nonintrusive way,
- ☐ Applicability to a wide range of contaminants, particularly those that are present at a shallow depth,
- ☐ Ability to influence groundwater flow at some sites with little energy inputs and while generating little to no waste, and
- ☐ Green and sustainable technology.

Recent Advances | Case Studies | Lessons Learned

Recent Advances

1,4-Dioxane treatment with phytoremediation leverages the high solubility and low sorption of this compound, which passes through the plant to the atmosphere via phytovolatilization (Aitchinson et al., 2000). The semi-passive nature of phytoremediation can be well-suited for dilute plumes that cannot be efficiently treated with other technologies.

Per- and poly-fluoroalkyl substances (PFAS) treatment is an area of active research. Many PFAS are sorptive, particularly the longer-chain compounds, and thus could potentially be addressed by stabilization or sequestration mechanisms. Uptake of some PFAS compounds into plants has been documented in the literature (Zhang et al., 2019). Additionally, the highly diverse microbial communities that can develop in the root zone (i.e., rhizosphere) could potentially support PFAS degradation, though biodegradation of PFAS compounds is still being investigated (Huang and Jaffe, 2019).

Phytoforensics is the collection and analysis of plant tissue samples samples for site characterization (Vroblesky, 2008). It can be used to assess the general extent of subsurface impacts or to identify previously unknown hotspots within contaminant plumes. Figure 2 shows the outcome of a phytoforensics study from the phytoremediation project at Naval Base Kitsap (Cellucci et al., 2016).

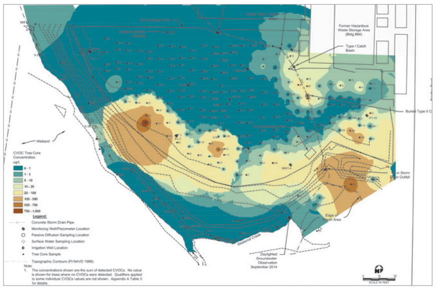

Figure 2. Chlorinated VOC Concentrations in Tree Cores (Source: Cellucci et al., 2016)

Coupling phytoremediation with other remedies has been applied at some sites. Plants can be placed inside subgrade biogeochemical reactors (SGBRs) (EnviroWiki, 2020; Trihydro, 2020) with synergies between plants, bacteria, and use of impacted groundwater for irrigation (Figure 3). Phytoremediation can also be used with anaerobic bioremediation systems with organic carbon emitted by plants stimulating microbial communities.

Figure 3. Tree Poles Planted in SGBR (Courtesy of Trihydro Corp.)

Inoculation with endophytes is the introduction of bacteria, fungi, or other microorganisms that live inside plants. The endophyte protects the plant from toxicity and can result in better growth at contaminated sites (Doty et al., 2017). Inoculation can be performed prior to planting or applied to plant root zones after planting.

Engineered plants, also called transgenic plants or genetically modified organisms, are plants in which a gene associated with degradation of a contaminant is placed into a plant that is then used for phytoremediation (ESTCP, 2020; Figure 4).

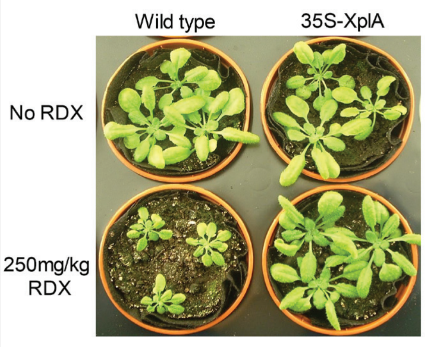

Figure 4. Pottted Experiments of Engineered Plants (Courtesy of ESTCP)

New planting methods of implementing phytoremediation have been developed and patented. The TreeWell® is placement of a tree inside a vertical cylindrical liner that is impermeable on the sides and open on the top and bottom. This allows treatment of intervals below the top of the water table (ITRC, 2021; Figure 5).

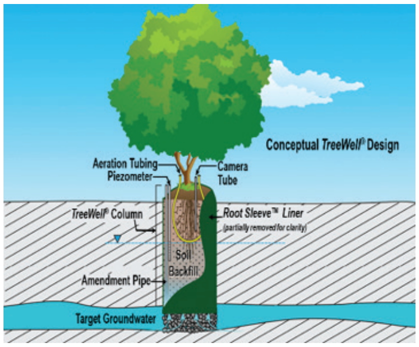

Figure 5. TreeWell® System (Courtesy of Geosyntec)

Case Studies

Site Name	Site Info	Type of Phytoremediation Application	Overall Result	Citation
Site DP039, Travis Air Force Base, CA	TCE Groundwater Plume, 0.1 to 10 mg/L	Tree stand with 480 Red Bark Eucalyptus trees planted above mid-point of TCE plume. Anaerobic SGBR used in source and biobarriers used at leading edge.	TCE concentrations were reduced by 90% to 99% in phytoremediation area. Phytoremediation was responsible for at least 55% of TCE mass removal.	Parsons, 2010
Former Manufacturing Site, Sarasota, FL	1,4-Dioxane Plume	Hybrid poplars planted in TreeWell® System at 158 locations	Phytoremediation allowed for shutdown of pump and treat system resulting in substantial cost savings. Cone of depression formed beneath trees. 1,4-Dioxane concentrations were reduced by 90% to 99% at some wells inside the planting area.	ITRC, 2021
Former Industrial Site, Lincoln County, WY	1,4-Dioxane, Benzene, and Diesel Range Hydrocarbon Plume	Combined phytoremediation and SBGR. 21 tree poles planted to 12 ft depth inside SBGR trenches. Impacted groundwater pumped with solar system to trees and SBGR. Perforated piping and passive venting used for aerobic conditions in SBGR.	1,4-Dioxane, benzene, and diesel range hydrocarbon concentrations have been reduced by up to 95% since system started. 100% survival of trees after two growing seasons.	Trihydro, 2020
J-Field, Aberdeen Proving Ground, MD	Chlorinated VOCs (PCA, TCE, DCE and others) at tens to hundreds of mg/L	Hybrid poplar tree stand planted above high concentration area.	Cone of depression observed below phytoremediation tree stand. cVOC volatilized from and extracted into trees.	Mahoney and Sprenger, 2018
Spring Valley Arsenic, Washington, DC	Arsenic impacts in surficial soil	Phytoaccumulation by Chinese Brake Fern planted in spring and harvested in fall.	Arsenic concentrations reduced to acceptable levels in over half of properties after one growing season. Others required multiple replantings.	Bean, 2017
Sharon Steel Farrell Works Disposal Area, Hermitage, PA	Metals impacts from historical steel manufacturing slag/ sludge	Constructed wetlands and groundcover for stabilization (and possibly sequestration) of metals and to prevent erosion and run-off.	Phytoremediation used as part of integrated remedies at historical waste disposal site.	USEPA, 2020

Return to Menu

Lessons Learned

Lessons Learned

- ☐ Performing the operations, maintenance and associated monitoring are critical parts of phytoremediation success. This need for maintenance is sometimes overlooked. Though plants become more self-sufficient as they grow, some care is needed to enhance survival and growth of seedlings. Phytoremediation is not a purely passive technology, particularly in the first few seasons. Irrigation, fertilization, and mowing may be required as plants begin to establish themselves. If irrigation is needed care should be taken that plants don't depend entirely on potable water and don't interact with contaminants.
- ☐ Cages or fencing may be needed to prevent fatal browsing of young plants by wildlife. The need for this infrastructure should be verified during on-site monitoring.
- ☐ Planting multiple types of plant species is a good practice to mitigate against the potential for diseases that are specific to one particular species.
- ☐ Mowing during the growing season and/or herbicide application prior to planting or at the end of the growing season (for next season's weeds) can help keep new plants from being crowded out by weeds.
- ☐ Drought should be closely monitored and can be addressed by temporary irrigation measures.

Disclaimer

References

Aitchison, E.W., S.L. Kelley, P.J.J. Alvarez, and J.L. Schnoor. 2000. "Phytoremediation of 1,4-dioxane by hybrid poplar trees." *Water Environment Research*, 72(3), 313.

Bean, C. 2017. "Core Concept: Phytoremediation Advances in the Lab but Lags in the Field." *Proceedings of the National Academy of Sciences (PNAS)* 114(29), 7475-7477, July 18.

Cellucci, C., J.G. Burken, C.A. Limmer, and M. Meyer. 2016. Using Tree Core Sampling to Recharacterize Chlorinated Solvent Groundwater Plumes at Phytoremediation Sites, Palm Springs, CA, May.

Doty, S.L., J.L. Freeman, C.M. Cohu, J.G. Burken, A. Firrincieli, A. Simon, Z. Khan, J.G. Isebrands, J. Lukas, and M.J. Blaylock. 2017. "Enhanced Degradation of TCE on a Superfund Site Using Endophyte-Assisted Poplar Tree Phytoremediation," *Environmental Science & Technology (ES&T)*, 51(17), 10050-10058.

EnviroWiki. 2020. Subgrade Biogeochemical Reactor (SBGR).

ESTCP. 2020. Phytoremediation of Explosives from Contaminated Soil by Transgenic Grass project team webpage.

Federal Remediation Technologies Roundtable (FRTR). 2020. Phytoremediation technology profile webpage.

Huang, S. and P.R. Jaffe. 2019. "Defluorination of Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS) by Acidimicrobium sp. Strain A6," *Environmental Science and Technology (ES&T)*, 53, 11410-11419.

Interstate Technology and Regulatory Council [ITRC]. (2009). Phytotechnology Technical and Regulatory Guidance and Decision Trees.

ITRC. 2021. Technical / Regulatory Guidance: 1,4-Dioxane, February.

Kansas State University. 2020. "Phytoremediation Database".

Mahoney, M. and M. Sprenger. 2018. Practical Applications of Phytotechnologies at Contaminated Sites, June 28, 2018.

NAVFAC. 2020. RITS Seminar "Phytoremediation: State of the Practice and New Advances".

Parsons. 2010. Technical Report: Phytostabilization at Travis Air Force Base, June.

Trihydro Corporation. 2020. Remedy Implementation and Groundwater Monitoring Report, Former Mountaineer Refinery.

USEPA. 2020. Superfund Site: Sharon Steel Corp (Farrell Works Disposal Area), Hermitage, PA webpage.

Vroblesky, D. A. (2008). User's guide to the collection and analysis of tree cores to assess the distribution of subsurface volatile organic compounds (No. 2008-5088). US Geological Survey.

Zhang, W., Zhang, D., Zagorevski, D. V., & Liang, Y. (2019). "Exposure of *Juncus effusus* to seven perfluoroalkyl acids: Uptake, accumulation and phytotoxicity," Chemosphere, 233, 300-308.