PHYTO-3

Phytotechnology Technical and Regulatory Guidance and Decision Trees, Revised

February 2009

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The Interstate Technology & Regulatory Council
Phytotechnologies Team
Tech Reg Update

EXECUTIVE SUMMARY

Phytotechnologies are a set of technologies using plants to remediate or contain contaminants in soil, groundwater, surface water, or sediments. These technologies have become attractive alternatives to conventional cleanup technologies due to relatively low capital costs and the inherently aesthetic nature of planted sites.

This document provides guidance for regulators, who evaluate and make informed decisions on phytotechnology work plans, and for practitioners, who have to evaluate any number of remedial alternatives at a given site. This document is an update to *Phytoremediation Decision Tree* (PHYTO-1, 1999) and *Phytotechnology Technical and Regulatory Guidance Document* (PHYTO-2, 2001) and replaces the previous documents entirely. It merges the concepts of both previous documents and includes new and, more importantly, practical information on the process and protocol for selecting and applying various phytotechnologies as remedial alternatives.

The technical descriptions of phytotechnologies in this document concentrate on the functioning mechanisms: phytosequestration, rhizodgradation, phytohydraulics, phytoextraction, phytodegradation, and phytovolatilization. For example, the application of phytotechnologies as a hydraulic control for groundwater is described as phytohydraulics (transpiration). This approach was selected to provide both scientific accuracy and a basic understanding of these mechanisms to the reader. Decision trees (Remedy Selection, Groundwater, Soil/Sediment, and Riparian Zone) help guide the user through the application of phytotechnologies to a remediation project.

Frequently Asked Questions and Rules of Thumb (👍)

Often, the best response that can be provided to some of the most common questions encountered about phytotechnologies is, "It depends…." Many factors influence phytotechnologies, such as soil conditions, climate, suitable plant species, and associated rhizosphere microbes. Therefore, every project is unique and must be custom designed, installed, and operated. The following answers to frequently asked questions provide a brief, generalized understanding and direct the reader to the relevant sections of the document for further information.

> During the implementation/ growth stage of a remediation project using phytotechnologies, the project should clearly focus on managing potential exposure.

Mechanisms

Q: What is the difference between the terms "phytoremediation" and "phytotechnologies"?
From the regulatory perspective, cleanup goals can be remediation, containment, or both. Phytotechnologies include containment strategies in addition to (phyto-)remediation strategies. Other remedial goals also include prevention, polishing, and restoration/end use (Section 2.2.1).

Q: How do phytotechnologies work?
They use vegetation to sequester, extract, or degrade toxic chemicals located in soils, sediments, groundwater, surface water, and air. There are six major mechanisms associated with phytotechnologies: phytosequestration, rhizodegradation, phytohydraulics, phytoextraction, phytodegradation, and phytovolatilization (Section 1.2).

Q: What contaminants can be treated with phytotechnologies?
Typical organic contaminants ("organics") such as petroleum hydrocarbons, gas condensates, crude oil, chlorinated compounds, pesticides, and explosive compounds can be remediated using phytotechnologies. Typical inorganic contaminants ("inorganics") that can be addressed include salts (salinity), heavy metals, metalloids, and radioactive materials. Extensive databases are available covering a wide range of contaminants treated using phytotechnologies (Section 2.3.1).

Q: Do the plants become contaminated in this process?
For organic contaminants, the octanol-water partition coefficient (log K_{ow}) typically needs to be between 1 and 3.5 for uptake by plants to occur (Section 1.2.4). For inorganic contaminants, including essential plant nutrients, uptake is specific to the element and plant species (Sections 1.1.1 and 1.2.3). According to the current research, there is little or no accumulation of volatile contaminants in plant roots, wood, stems, leaves, or fruit. Plants may accumulate metals or other toxic materials that reach contaminated levels, but several mechanisms exist that often limit the uptake and/or persistence of nonessential compounds in the plant (Sections 1.2 and 2.5.1.3).

Q: Do plants release contaminants into the air? If so, how much and how often?
Possibly; there is an established mechanism known as phytovolatilization (Section 1.2.6) whereby volatile chemicals are taken up by a plant and released through leaf surfaces. However, extensive samplings in the field show that minimal amounts of volatile contaminants are emitted from plants (Section 2.5.3.3).

Q: If fruit and nuts are produced, are they safe for humans and animals?
Probably, but test them to be sure (Section 2.5.3.3).

Efficacy

Q: Will phytotechnologies work on my site?
It depends; however, decision tees have been developed which will help to determine whether a phytotechnology would be applicable at a site (Section 2.3.2)

Q: How deep do plant roots grow?
Typical rooting depths for herbaceous, upland species such as grasses and forbs are 1–2 feet; however, depths down to 5 feet have been reported as within the range of influence under some situations (Section 1.3). Furthermore, prairie grasses have root systems that can reach 10–15 feet below ground surface (bgs). Regardless, in general, 70%–80% of the root structure will be within the top 1–2 feet of soil (including tap-rooted species) with exploratory roots sent deeper and laterally. However, local soil conditions (nutrient content, moisture, compaction, etc.) will dictate the ultimate depth to which any plant will reach. Furthermore, the depth of penetration may progress as the plants grow year over year (Section 2.3.2.3). For wetland species, typical

depths are less than 1 foot due to oxygen limitations (Section 1.3). For trees, typical depths are 10–15 feet but often require special culturing practices (Section 2.4.3.2). Typical penetrations can be 3–5 feet per year when planted into a borehole or trench. The maximum practical depth is generally down to 25 feet bgs using these practices, although deeper depths can be reached under certain circumstances. The deepest influence of a phytotechnology system was measured at 40 feet bgs. A general rule of thumb, however, is that trees will not access deeper than 5 feet into the saturated zone (Section 2.3.2.2).

Q: How fast do plants grow? How long do they live?
Plant growth rate and longevity depend on species, soil, and climate. “Annual” species grow and die within a single season. Others, such as trees and other herbaceous perennials, continue to grow over years. Fast-growing species such as hybrid poplars can grow 5–10 feet (2–3 m) per year in the first few years. However, in general, those species that grow rapidly tend to be shorter lived (Section 2.5.2.1).

Q: How long does it take for the system to become effective?
In some cases, the application of phytotechnologies can have an immediate effect on contaminant concentrations upon planting. In other cases, it may require several seasons before the plant can interact with a contaminated zone at depth. Furthermore, it may depend on whether the plant itself is directly or indirectly involved with remediating the contaminant (i.e., phytodegradation or simply stimulating biodegradation in the rhizosphere—rhizodegradation; Section 1.2).

Q: What happens in winter when the plants are dormant?
Water consumption and contaminant uptake essentially stop when plants are dormant. Degradation by microbes and the rhizosphere effect continue but at a reduced rate. Efforts to estimate the rate of remediation should account for the dormant conditions (Section 2.4.1).

Q: How long until cleanup is achieved?
It depends on the criteria set forth in defining the cleanup objectives for the site. Furthermore, it depends on the type, extent, and concentration of contamination, continuing sources, obstructions, soil conditions, hydrologic/groundwater conditions, and other site characteristics, the plant species, growth rate, and climate conditions (Section 2.2). Complete restoration will depend on the type of phytotechnology applied at the site (Section 1.3).

Design and Implementation

Q: Which plant species should be used? How are plants selected for a remediation?
All plant selections must be made based on site-specific conditions. Climate, altitude, soil salinity, nutrient content, fertility, location, depth, concentration of contaminant, commercial availability, plantability, and plant hardiness are some of the determining elements (Sections 2.3.1 and 2.4.3). A variety of approaches and information resources can be used, including databases, site-specific vegetation surveys, and specifically designed tests to evaluate species (Section 2.3.1 and Figure 2-1). In addition to selecting species for the remediation, end-use considerations can be included in the initial plant selection (Section 2.3.4). Typically, 10%–15% climax species might be included in the initial design.

Q: When should planting be done?
Planting season is generally in the early spring (after the last frost), the most desirable period to establish a phytotechnology system (Section 2.2.3.2). Seeding should be done whenever is most appropriate for the species, also typically in the early spring (Section 2.4.3.1). Tree cuttings for propagation should be taken while the source tree is still in winter dormancy and should be maintained dormant (stored under refrigerated conditions) until planted into the ground. In many cases, survivability hinges on the timing of the planting, which should be planned appropriately in the design.

Q: How much or how much area should be planted?
It depends on the extent of contamination and the characteristics of the site (Section 2.2.2). A general rule of thumb for a very preliminary design during the remedy selection phase of a project is a planting density of 75 ft^2 per tree (Section 2.3.2.2). Seeding rates for common grass species (ryegrass, fescue, etc.) are typically higher than prairie species. For example, 400 pounds of a fescue/perennial ryegrass seed mix is needed to cover one acre, while only 10 pounds of a prairie grass seed mix is needed to cover the same acre. The spacing between potted plants depends on the size of the specimens, but for plants that come in palettes, typically 1–2 feet, greater for larger specimens (Section 2.4.3.1). A standard landscaping rule of thumb is that 10% of recently planted trees or potted plants will not survive the first year (Section 2.5.4).

Q: How much does it cost?
It depends. Various cost items will need to be considered, such as earthwork, labor, planting stock, planting method, field equipment, heavy machinery (typically farming or forestry equipment), soil amendments, permits, water control infrastructure, utility infrastructure, fencing, security, etc. (Section 2.4).

Operation, Maintenance, and Monitoring

Q: Isn't this just a "Do something quick and cheap in the field and then walk away" approach?
No. Like any remediation system, phytotechnologies require significant operation, maintenance, and monitoring for several years after planting. Costs can include labor, sampling, analytical, materials, field equipment, utilities, waste handling, and disposal. Once the plantation becomes established, however, the operation and maintenance (O&M) costs tend to diminish (Section 2.5). Furthermore, additional sampling and monitoring will typically be required during the initial phases compared to subsequent years. Phytotechnologies are generally long-term remedial solutions.

Q: What do you have to do for operations and maintenance?
Phytotechnology plantations may require irrigation, fertilization, weed control (mowing, mulching, or spraying), and pest control. At the onset of a planting, which too may be a reoccurring O&M event, some percentage of replanting may be required due to the lack of establishment. As a general rule of thumb, 10%–15% of the initial capital costs should be added as a contingency for replanting.

Q: In general how much water is required?
A general rule of thumb is that during establishment (i.e., before trees have reached a groundwater source) and perhaps throughout the growth of the vegetation (i.e., groundcover systems), plants should receive a total of 1–2 inches of water per week, including both precipitation and supplemental irrigation (Section 2.4.2.2). Another rule of thumb for a very preliminary design during the remedy selection phase of a project is that a tree plantation uses 10 gal per day per tree, annualized over the year (Section 2.3.2.2).

Q: When should fertilization be done? What fertilizers should be used?
Typically, regular fertilizations can be done in early spring to help the new growth and in late fall to prepare the vegetation for winterization. The formulation of the fertilizer depends on the site-specific soil conditions (Tables 2-9 to 2-11). Soil fertility can be analyzed by a local agriculture extension service using established methods (Table 2-12).

Q: What happens if the plants die as a result of a natural catastrophe or infestation?
If the plants die or are damaged, the beneficial effects are lost or greatly diminished. However, the effect can be temporary, depending on the ability of the vegetation to regrow. Contingency plans should be established for different degrees of loss (Section 2.5.3.4).

Q: If plants have to be harvested, how can one tell whether or not a plant is safe?
Analysis of plant and core tissue sampling (leaves and stems) can determine whether the plant is safe (Section 2.5.3.3).

Q: What is the easiest tissue to sample?
The aboveground tissues such as leaves, needles, stems, branches, and fruits/seeds/nuts are easiest. These are collected simply by pulling or cutting sufficient material from the plant and storing it in sealed plastic bags. For most analyses, samples of 20 g dry weight (10–15 average leaves) should be sufficient. As general rules of thumb, to estimate the wet-to-dry weight ratio for field sample collection, green stems typically contain 95% water weight, leaves 90%, fruits 85%, hardwood stems 50%, and nuts and seeds 5%. Once collected, the tissues should be stored on ice for transport to the laboratory (Section 2.5.3.3).

Q: Is the harvested material usable for commercial payback?
Yes, but it may depend on the use, harvested material, and contaminant. The material may need to be tested (Section 2.5.3.3).

Q: How do you know it is working?
Phytotechnology systems should be monitored using the same primary lines of evidence as any other alternative (i.e., concentration trends, hydrology, soil effects, etc.). That information may need to be supported by secondary lines of evidence, which generally entail analyzing the plants in some manner (Sections 2.5.2 and 2.5.3).