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Phytoremediation: Prospects and Limitations

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Human dominated industrial and agricultural landscapes are increasingly recognized as landscapes in need of remediation for human health concerns, ecological restoration as well as aesthetic reasons. For thirty years environmental regulations and standards in the United States have been applied to the release and dumping of toxins into the environment, and toward the cleanup of previously contaminated landscapes. Since contamination of human dominated landscapes was often a product of technology, technological and aggressive solutions have been the rule in the cleanup of toxic sites. Until recently (within the last decade), removal or immobilization of toxins (both organic and inorganic) in the landscape has been dealt with using *ex-situ* (off-site) techniques that generally required removal and treatment processes that were often as aggressive as the industrial landscapes themselves. With advances in bioremediation, the approach to cleanup of toxic landscapes is becoming less intrusive (*in-situ*) and increasingly site specific.

Phytoremediation is the use of plants, both herbaceous and woody, to remove or render harmless toxins in the environment. The development of phytoremediation as a cleanup technique is relatively new, and only in the 1990s has the technique become a widely considered alternative for use in toxic site remediation. Phytoremediation has become something of buzz-word in the field of landscape architecture, largely because design with plant materials is the one of the foundations of the field. This willing acceptance is easily understood in light of the apparent benefits of the technology. Phytoremediation treats soils and even (shallow) groundwater *in-situ.* It can be easily incorporated into landscape design and for this reason, is societally and aesthetically compelling. It appears to be cost effective. Finally, and perhaps most questionably, the technique appears benign, after all, growing rows of crops on a former industrial site may certainly seem an improvement. This sets up two problematic scenarios. First, landowners may approach the technique as an easy fix to problem sites and once planted, perform little else in the way of remediation. Also, phytoremediation does not necessarily remove pollutants but extracts them into plant material, and without proper plant management, harvesting and disposal, may cause increased exposure to humans, animals or the environment. Phytoremediation is a passive process, where pollutants enter plants throught the uptake of water and nutrients in the soil, it is not as some have suggested, a process of "pumping".

While each of the above advantages of phytoremediation is attractive from both a community and design sense, the scientific limitations and even safety of this technique is still not fully understood nor accepted. Phytoremediation approaches fall into four general categories. Phytoextraction is the use of hyperaccumulating plants to remove toxins from the soil and store them in their transpiration stream. Rhyzofiltration is the use of plant roots in wetland situations to retain toxins. In each of these two cases, harvesting of plant material is essential for the removal of toxins from a site. These two extraction techniques raise a whole series of questions regarding the safety of mobilizing toxins into plant material, potentially allowing them into food webs or back into communities through toxic leaf materiel. Questions arise over liability with now polluted plant material, requiring disposal into toxic landfills (although research is being done on extracting metals for reuse, referred to as "bio-ore"). The third technique, phytostabilization, renders toxins biologically inert through bonds formed between complex carbon and toxic compounds, effectively immobilizing problems substances. The final category, phytovolitilization, is an extension of the widely accepted techniques of bioremediation, yet now being attempted through the use of plant material serving as conduit for toxins from the soil to the atmosphere.

Each of the approaches to phytoremediation will inevitably be limited to plant material with an ability to perform under conditions that are often less than optimal. In the selection of hyperaccumulators, for instance, initial plant choice is often based upon the plants that will simply survive in soils with high levels of metals. Level of accumulation will be limited to these plants and their uptake capabilities. In highly contaminated sites, phytoremediation may be limited by the amount of time it would take for plants to perform uptake. For instance, if a particular species of plant were taking up 10 grams of lead per year per meter squared on a site with lead levels of 1000g/meter squared, cleanup time could be assumed to extend to 100 years. Furthermore, many plants with hyperaccumulating potential are well adapted to highly contaminated soils, but become less effective at toxic uptake when pollutant levels diminish. This raises other concerns relating to the nature of plant material used. Many plants considered for these techniques are annual crops (sudan grass, corn), and require yearly harvesting. As with any annual cropping, soil stabilization and potential soil leaching (of the pollutants themselves) are continuing concerns. Thus, planning the long term management of potential phytoremediation projects is essential.

The papers presented in this chapter address the science of phytoremediation in a range of settings and for a variety of pollutants, some of which have become ubiquitous in human dominated landscapes. While much of the early research on phytoremediation has focused on removal heavy metals from polluted landscapes, the papers offered here focus on a range of pollutants from organic herbicides and solvents to radionuclides and Selenium. As a relatively new approach to toxic cleanup, much of the current research on phytoremediation is laboratory based. Testing and controls in field research is still needed in order to fully understand the movement and final fate of pollutants using phytoremediation. In each case, particular attention is paid to the nature of pollutants, the physiography of the environment contaminated, and the mix of pollutants present.

One particular benefit of phytoremediation is the low cost involved in initial implementation of cleanup. Planting of fast growing trees or crops is generally a technique well established in agricultural settings, and is thus readily facilitated on large landscape remediation projects. Three of the four papers in this chapter deal with contamination at a landscape or regional scale, where contamination generally crosses multiple property or even state and national political boundaries. Selenium (Switras) and atrazine (Mercer) contamination are often regional scale in that excess levels are a result of large agricultural operations and in the case of selenium, represent a fundamental shift in the ecological processes of nutrient flow. Likewise, radionuclide contamination (Westhoff) is often the result of airborne clouds from specific locations, but spread uncontrollably through wind and weather. TCE contamination (Lay) may be either a site contamination problem in the area of a single dump, or a larger concern if the leaching of this organic solvent has migrated into flowing groundwater. In each case, conventional cleanup is costly and in some cases, unrealistic due to the scale of contamination.

In each of the four studies in this chapter, waste disposal continues to be an issue. While selenium and atrazine contaminated soils have shown some success using phytovolitilization, neither has been fully successful, nor fully tested in relation to by-product toxicity. Indeed, in both cases, contaminated plant matter has been mixed into livestock feed (selenium) and reapplied to fields (atrazine) at levels below legal standards. This reuse of phytoremediation by-products should raise concerns if the application is occurring where regional buildup of mobilized selenium or atrazine has been problematic. Some by-products of TCE bioremediation are often considered more dangerous than TCE itself. TCE may be transformed into an isomer of dichloroethene and vinyl chloride in bioremediation, and should raise concerns the expanded use of phytovolitilization for these compounds. While Lay points out that "plants are much easier to monitor than microbes", transpiration stream qualities are notoriously difficult to assess, and if "the fate of TCE in plants is not completely confirmed", then regulators should continue to insist upon further inquiry.

Radionuclides present a particularly vexing problem in their persistence as well in their regional and even international contamination following a large scale nuclear accident like that at Chernobyl. Because of the pervasiveness of the Chernobyl incident, remediation techniques have been studied throughout the region, and as Alex Westhoff points out in his compilation of this research, associative mycorrhizal relationships that increase plant growth have aided greatly in the uptake of radionuclides throughout the contaminated regions of Eurasia. Often, the amount of total biomass produced is directly related to the amount of toxin uptake. In situations where toxins are mobile and accessible to the transpiration stream, mycchorizal relationships aid in the growth of and uptake performed by the parent plant material. This symbiotic relationship would seem to play a beneficial role in each of the four studies reviewed in this chapter due to the relative mobility of these particular toxins.

In each of the four studies in this chapter, the mobility of toxins limits the effectiveness of phytoremediation to the upper levels of soils. With the limitation of phytoremediation to the plant root zone, mobile pollutants will have a tendency to migrate either downward in permeable soils or with the flow of water. Indeed, Lay points out that TCE has a density greater than water and tends to settle at the bottom of aquifers. This would indicate that development of larger and deeper plant root systems may be essential to successful uptake of pollutants. Clearly, detailed site analysis on any project using phytoremediation is essential to success.

Current research and focus seems to be on finding the genes that will allow plants to both perform as hyperaccumulators while at the same time grow at rapid rates in toxic soils to perform timely uptake of pollutants. This research should also raise questions about the use of non-native and genetically altered species in instances where they may threaten regional ecological systems. Much of the research offered in the four papers in this chapter focuses on these "improved" species, including various hybrid poplars (*Populus* species), tall fescue (*Festuca arundinacea* Schreb. L.), birdsfoot trefoil (*Lotus coniculatus* L.), yellow sweetclover (*Melilotus offinialis*) and sudan grass (*Sorgham sudanense*). Some of these species have an established record as invasive species beyond their natural ranges and others may pose future issues of introgression (repeated hybridization between native and non-native species) in some native ecosystems.

The drawbacks and uncertainties surrounding phytoremediation should continue to call into question the full embrace of the technique without question. Like any other technique for toxic cleanup, phytoremediation requires careful understanding of the particular site characteristics from soils, to extent of pollutants, to ultimate disposal. The papers in this chapter contribute to a further understanding of the prospects and limitations of this technique. Each indicates that phytoremediation, while attractive for cost and aesthetic reasons, carries with it certain risks and responsibilities beyond the simple replanting of a grove of trees or a restored prairie. Phytoremediation, while attractive, is not benign. Remediation of any toxic site requires continued monitoring and care to assure that pollutants pose no further threat to human or ecosystem health.