

Using poplars and willows for Phytoremediation in the USA

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1. INTRODUCTION

Phytoremediation is an emerging technology in the USA for remediating brownfields, landfills and other contaminated sites. Phytoremediation (hereafter, phyto) is the use of plants to clean up or remediate contaminated soil, sludges, sediments, and ground water through contaminant removal, degradation, and/or containment (US EPA, 1998). Phyto has been applied extensively in the Middle East (Gordon, 2001), Europe (Perttu, 1999) and in New Zealand (Wilkinson, 1999). There are several advantages to phyto compared to other clean-up technologies. Plants can effectively and economically remove, degrade, and contain contaminants in an aesthetic, natural and passive way (Westphal and Isebrands, 2002).

Short rotation woody crops such as poplars (*Populus spp.*), willows (*Salix spp.*) and *Eucalyptus* spp. are the most common tree species used for phyto because they grow rapidly, have many and deep roots, and take up large quantities of water (Isebrands and Karnosky, 2001; Kopp *et al.*, 2001; Licht and Isebrands, 2003; Mirck *et al.*, 2003; Rockwood *et al.*, 2003). Poplars and willows grow large root systems with a high proportion of fine roots that are less than 1mm in diameter. These roots not only take up substantial quantities of water and nutrients, but they also provide the surface area for microbes and beneficial mycorrhizal fungi. Poplars and willows take up a wide variety of pollutants including fertilizers (nitrate, ammonia, phosphorous), inorganic metals and metalloids, petrochemical compounds (fuels, solvents, pesticides, intermediates), and soluble radio-nuclides (Westphal and Isebrands, 2002).

In this paper, I outline phyto strategies and applications employed in the USA. Several case studies using phyto are presented, as well as potential uses of the biomass from the applications.

2. PHYTOREMEDIATION STRATEGIES

Not all contaminated sites can be remediated by phyto. Phyto is typically applied when sites have contaminants in the soil or watertable in the upper 5 m or less. However, the effectiveness of phyto also depends on soil conditions. When contaminants are deep in the soil or in deep groundwater phyto cannot be effectively applied unless it is combined with an engineered approach such as a pump and treat system. An important principle of phyto is to match the proper plant species and clone to the contaminated site and planned applications. Consideration must be given to soil, microclimate, region, and pests and diseases as well as the contaminant or mix of contaminants to be cleaned up. Moreover, poplar and willow clones

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cannot be universally used throughout the country without extensive testing. Moving clones from one region of the country does not generally work well because the trees are adapted to specific geographic regions and because certain regions have a high incidence of disease (Dickmann and Isebrands, 2001).

I recommend a "phased phyto strategy" to my clients who are first employing phyto. The phases include:

Phase I: Conduct experimental screening studies of plant materials under controlled conditions at the site using local, native plant materials, contaminated soil, and water to evaluate growth, mortality, and contaminant uptake.

Phase II: Verification, narrow the choice of Phase I plant materials for the specific site in a second year to refine first year results.

Phase III: Demonstration plantings and testing on a small scale in the ground at the site and

Phase IV: Scale up and deploy the plant material with proven merit for remediating the specific contaminants in the design chosen for the site. This conservative strategy allows assurance that the native plants are capable of the clean-up required. It also fits within the policy and administrative time frame for clean-up of brownfields and landfills (Westphal and Isebrands, 2002; Licht and Isebrands, 2003).

3. APPLICATIONS OF PHYTOREMEDIATION

Phyto applications typically include planting of short rotation woody crops in a streamside buffer, vegetation filter, *in situ* phyto planting, or a vegetative cap (Licht and Isebrands, 2003). Most applications in the US are human installed streamside buffers, and vegetative filters, although *in situ* applications are increasing. A riparian buffer or corridor consists of a strip of planted trees, shrubs and/or grasses along a wetland, stream, river or lake. Streamside buffers are planted between a contaminant source and the drainage. A riparian buffer is the strategic filter that slows and decreases the runoff flow, depositing sediments, fertilizers, herbicides, and plant debris otherwise deposited in the stream flow.

Vegetation filters are designed to manage specific sources of nutrients, municipal wastes, landfill leachates, and biofuel ash. These phyto plantings are not necessarily related to a lake, river or wetland (Perttu, 1999; Mirck *et al.*, 2003).

In situ phytoremediation plantings use trees, shrubs, or grasses installed for subsurface treatment of inorganic and organic chemical spills caused by man. These sites are often called polluted "brownfields" and result from industrial development and petrochemical use. Plants are deployed at a specific place to remediate specific contaminants.

Vegetative caps incorporate plants, soil, and associated microbes as cover alternative to clay or plastic caps installed to decommission landfill and lagoons.

Case study examples of two *in situ* plantings and a streamside buffer follow.

4. PHYTOREMEDIATION CASE STUDIES

4.1 WRR Environmental Services Company – Eau Claire, Wisconsin, USA

WRR Environmental Services Company is a waste solvent recycling facility that has been in operation for more than 30 years. It has a history of solvent release to the soil and groundwater, and has a groundwater recovery and treatment system at the site, including 48 groundwater monitoring wells. Recovered groundwater is routed through a Turbo air stripper to remove volatile organic compounds (VOC's). However, concentrations of acetone, methyl ethyl ketone (MEK), and methyl isobutyl ketone (MIBK) of the discharge water from the Turbo stripper exceed state of Wisconsin threshold concentration limits.

In 2002, WRR established a phyto treatability study designed to identify poplars, willows, and native prairie grass potential for ground water recovery, hydraulic control and/or groundwater treatment. Selected species were planted in a replicated tank experiment watered with clean water, discharge water from the stripper, and untreated water from recovery wells (Phase I). The drain water from the tanks was monitored throughout the season and health and growth of the plants recorded. Overall plant growth in discharge water was excellent (> 2 m). Hybrid willow grew the largest followed by native cottonwood (*Populus deltoides*), hybrid poplar (DN-34) and native black willow (*Salix nigra*). Water uptake was significant with poplars and willows taking up more than 75% of the discharge water presented them. During the peak season poplars and willows in the plant/soil system removed 90% of the VOC's in the discharge water. VOC concentrations in the leaves and soil were not significant at the end of the season.

The results of Phase I of the experiment were so promising that WRR decided to proceed with a side by side tank experiment and replicated a demonstration planting (Phases II and III) next to the treatability study. Those studies are currently underway with similar results to the 2002 study so far.

4.2 LaSalle Electric Utilities, LaSalle, Illinois, USA

The LaSalle Electric Utility site is a former PCB incineration ash disposal site that has been contaminated with trichloroethylene (TCE) and perchloroethylene (PCE). In 2002 two phyto studies were established to identify a way to remediate the contaminants in a cost-effective way. A replicated study of poplars and willows was established on the site of the PCE plume, and a second replicated study was established near the groundwater treatment unit (GTU) on site, where the TCE groundwater plume occurred (Rockwood *et al.*, 2003). Rooted hardwood cuttings of selected poplar clones and unrooted cuttings of selected willow clones were used in the replicated PCE study. In the GTU study selected poplar and willow clones were rooted in large pots for one year before planting. The effectiveness of the phyto is being monitored. Health and growth of the clones are periodically monitored, as well as soil fertility, groundwater contaminant concentration and general soil gas properties. Changes in aerobic and anaerobic microbes are also monitored.

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Tree growth of the poplar clones on the PCE site has been excellent. There are large clonal differences in height and diameter growth, but the “best” clones are native cottonwood (*Populus deltoides*) clones with growth of over 6m in height and 5cm in diameter in two years. The aboveground willow biomass is less, although excavation studies show significant belowground growth.

Growth of the hybrid poplar clone (I 45/51) in the GTU study is less than the other study and willow growth is greater. The belowground growth of the willows exceeds the poplar. Height growth of poplar is 2 m in two years with diameters of 3 cm. Willow growth varies by clone with heights of the “best” clones approaching 2 m. Diameter growth is less than the poplar with the “best” willow clone at about 2 cm. Preliminary harvest data show some promising uptake of TCE in the poplar stems. Additional studies are planned as the study continues in the future.

4.3 Clay County Landfill, Moorhead, Minnesota, USA

The Clay County, Minnesota landfill is leaking contaminated leachate into adjacent wetlands that exceed state of Minnesota thresholds. Two plumes of VOC contaminated groundwater have been identified – these contaminants include tetrachloroethylene, tetrahydrofuran, vinyl chloride, and dichloropropane, as well as ammonia.

In 2001, a phyto buffer of eight rows of two hybrid poplar clones were planted between the landfill and the adjacent wetland in an effort to decrease VOC contamination to the groundwater. Monitoring wells were placed along the buffer in the adjacent wetland.

After three years many of the hybrid poplar trees have height growth of over 6m and diameter growth of over 2 cm. There are clonal differences in performance and there are some problems with disease incidence and deer browsing. The monitoring wells are showing a decline in the groundwater table and there is some evidence of VOC concentration decrease although it is too early to be definitive. The phyto progress at the Clay County landfill is encouraging, and it has been decided that phyto will be part of the new landfill expansion project set for 2005.

5. DISCUSSION AND CONCLUSIONS

Phyto approaches to remediating contaminated sites in the USA are increasing as public awareness and acceptance of phyto improves, and as budgets decline in many communities. Phyto applications are usually successful if properly planned, if the site is well prepared, appropriate plant material planted, proper cultural practices are employed, and harvest plan made. Most failures are due to selection of improper plant material, poor cultural practices, such as inadequate weed control, herbivore exclusion, irrigation and/or fertilization, and planning (Dickmann and Isebrands, 2001; Licht and Isebrands, 2003).

There are many tangible and intangible economic opportunities for biomass production from phytoremediated pollutant removal systems (Licht and Isebrands, 2003). Some are from more traditional uses, although there are many new non-traditional uses under development using small diameter trees. Primary and secondary products from poplar and willow wood include bioenergy, pulp and paper, lumber, veneer and plywood, composite panels, structural composite lumber, pallets, furniture, containers, chopsticks, and animal feed. Intangible

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benefits include carbon sequestration, soil erosion control, protection plantings, urban plantings, urban plantings, environmental regulation and justice, and aesthetics (i.e., greening).

The future of phytoremediation applications of short rotation woody crops looks promising as the world's population seeks to improve their environment and economy. However, research and development on phytoremediation strategies and applications remain in their infancy.

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