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PHYTOREMEDIATION OF CHICAGO'S BROWNFIELDS:
Consideration of Ecological Approaches and Social Issues

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Abstract:
Phytoremediation is an emerging technology for remediating brownfields, landfills, and other contaminated sites. Many laboratory and field tests have demonstrated that trees and other vegetation can absorb, transform, or contain a variety of contaminants, including soft and heavy metals and volatile organics through hydraulic control, absorption, and mycorrhizal activity in the root zone. But phytoremediation can not be applied in an "off the shelf" fashion because plants grow differently on different soils, different microenvironments, and different types of contaminants. Site- and contaminant-specific protocols are needed to effectively use phytoremediation.

But trees and other plants do more than remediate pollutants. In many cases, a landscape with trees and other plants can have a significant impact on humans. For instance, a green landscape can reduce stress, reduce violence, and strengthen neighborhood ties. And because of the deep attachments many people have to trees, tree removal—sometimes an element of phytoremediation—can be problematic.

What are the implications of these ecological and social functions of vegetation for brownfield redevelopment? We address how to combine the biological and ecological issues of phytoremediation to maximize effectiveness as a clean-up technology while also outlining the potential for significant social implications of a greener human environment. A new phased phytoremediation strategy is outlined and specifics from an experiment in the Calumet region of Chicago are presented as a case study to illustrate ways to develop site specific phytoremediation protocols. Potential social implications of this and other phytoremediation applications in Calumet are also addressed.

Introduction:
Phytoremediation is an emerging technology for remediating brownfields, landfills and other contaminated sites. Phytoremediation is the use of plants to clean up or remediate contaminated soil, sludges, sediments, and ground water through contaminant removal, degradation, and/or containment [32]. Phytoremediation principles have been applied for centuries in Europe and the Middle East where agrarian cultures used plants to buffer streams from animal manure contamination [13]. Moreover, phytoremediation has been used extensively in Europe in modern times and has become popular in North America in the last 20 years [18]. There are several advantages to phytoremediation compared to other clean-up technologies. Plants can effectively and economically remove, degrade, and contain contaminants in an aesthetic, natural and passive way. Further, phytoremediation may bring the benefits of a green environment to those who live, work, and play near the phytoremediation site, benefits leading to a stronger neighborhood, greater human well-being, and redressing of past environmental injustices. These potential additional benefits of phytoremediation need further consideration and research in the context of greening brownfields.

In this paper we discuss how phytoremediation works and the potential social benefits of phytoremediation. We also outline a plan for phytoremediation research and application in the Calumet region of Chicago, Illinois, a rustbelt landscape with brownfields, active industry, and natural habitat occurring side by side.

Phytoremediation Processes:

Phytoremediation processes clean up or remediate sites in several ways. At sites contaminated with inorganic compounds such as metals, plants stabilize or remove contaminants by three mechanisms: *phytoextraction*, where plant roots absorb contaminants into the aboveground plant parts (i.e. leaves, branches, and/or stems); *rhizofiltration*, where plants adsorb contaminants onto the roots; and *phytostabilization*, where plant roots immobilize contaminants in the soil thereby decreasing soil and wind erosion of contaminants. At sites contaminated with organic compounds plants break down or remove contaminants by three mechanisms: *phytodegradation*, where, after the plant absorbs the organic contaminant, plant enzymes breakdown the contaminant to safer compounds; *rhizodegradation*, where plant roots provide the beneficial environment for microbes that in turn break down organic contaminants in the root zone; and *phytovolitalization*, where plants take up contaminants and release a safer mediated form of the organic compound into the atmosphere [32].

Most phytoremediation applications use riparian buffer strips or vegetative filters. A riparian buffer strip (or corridor) consists of a strip of planted trees, shrubs and/or grasses along a wetland, stream, river or lake [30]. Riparian buffers are planted between the contaminated area and the riparian zone and are designed to slow down and decrease the flow of contaminated water and sediments from the contaminated area to the riparian zone. Vegetative filters are phytoremediation plantings not necessarily related to a lake, river, or wetland. Vegetative filters are often used as vegetative covers for landfills as an alternative to clay or plastic caps to help contain landfill wastes. The plants control erosion, take up rainwater and decrease runoff into nearby areas [32].

In some cases, plants used for phytoremediation absorb enough contaminants that they become toxic themselves and must be removed and disposed of as hazardous waste. However, this process generates much less waste for disposal than a traditional excavation clean-up approach. If more clean-up is required, phytoremediation can be applied again. In the case of metals clean-up, the metals can sometimes be reclaimed from the plants and re-used [36].

Poplars and Willows for Phytoremediation:

A major key to phytoremediation success is how plants take up water, or hydrologic uptake. Water can transport contaminants, and it is through water that contaminants reach the plant, just as it is often through water that contaminants migrate off-site. Plants with many and/or deep roots, especially trees, pump enormous quantities of water during the growing season. In a phytoremediation application, this decreases the flow of surface water from contaminated sites toward streams, lakes and into ground water. Poplars (*Populus spp.*) and willows (*Salix spp.*) are the most common tree species used for phytoremediation because they grow rapidly, have many and deep roots, and take up large quantities of water [1, 2, 4, 17, 18]. Poplars and willows take up a wide variety of contaminants including ammonia, inorganic compounds (i.e. metals), organic compounds, pesticides and radio-nuclides (Table 1). While phytoremediation can treat toxics in the soil and water, the addition of trees may also help other pollution issues. Specifically, increased tree cover can mitigate greenhouse gas production, urban heat island effects, and airborne particulates [5, 9, 27, 28].

Poplars and willows have been used extensively in Europe as a vegetative filter for cleaning polluted drainage water from agricultural land [11] and for wastewater treatment and soil remediation combined with biomass production for energy use [2]. In North America, poplars and willows have been used extensively for phytoremediation at the research and demonstration scale [32-34, 36]. Several operational scale efforts are also underway using poplars for municipal wastewater reuse and as vegetative landfill caps [8].

Contaminant	Reference	Contaminant	Reference
Water		Organics	
Ammonium nitrogen	Aronsson & Perttu [2]	BTEX	Burken & Schnoor [7]
Nitrate nitrogen	Elowson [11]	PAH's	Burken & Schnoor [7]
		TCE	Newman et al. [26]
Inorganics	US EPA [32, 36]	TNT	US EPA [32]
Barium	"	Other VOC's	US EPA [32]
Boron	"	Others	
Cadmium	"	Formaldehyde	US EPA [32]
Calcium	"		
Iron	"	Herbicides	Burken & Schnoor [6]
Magnesium	"	Pesticides	US EPA [32]
Manganese	"		
Potassium	"	Cesium	von Fircks [37]
Sodium	"	Strontium	von Fircks [37]
Zinc	"		

Table 1. Primary contaminants taken up by poplars and willows that show promise for phytoremediation.

Matching the Plant to the Contaminant and Site:

An important principle of phytoremediation is to match the proper plant species and subspecies 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.

Each site for phytoremediation will be different. Some will be in wetlands, some will be in rubble, others in well drained sandy soils. Different plants thrive in these various conditions. Other conditions will also effect the plants ability to grow. The amount of sun, wind, and rain, the amount of stressors like road salt or vehicle fumes can effect the ability of particular plants to thrive. If the plants won't grow, they won't remediate the contaminants, so choosing the appropriate plants for the growing conditions is the first critical step.

Different plants do well at remediating different types of contaminants. Some plants are better for treating heavy metals, others for volatiles. And it is not sufficient to know, for example, that poplars can degrade TCE [26]. Some varieties of poplars do, many do not. Some plants can take up shallow contamination, other plants or planting techniques can reach deeper contamination [16]. On the other hand, phytotoxicity, or poisoning of plants by the very contaminants phytoremediation is to clean-up, is sometimes a potential outcome.

A final consideration in selecting the appropriate plant for the phytoremediation application is whether it is native to the ecosystem where the phytoremediation is taking place. This choice is particularly important for sites near natural areas that need to be protected. Non-native species (and some natives, too) could escape from the phytoremediation site, take root nearby, and potentially threaten native species of interest. Multiflora rose and purple loosestrife are two examples of garden escapees that have had drastic impacts on local ecosystems. It is important that phytoremediation projects not cause similar damage. Many of the poplars used to date for phytoremediation applications and demonstrations have European and/or Asian parentage and cannot be used in such sensitive areas. However, there are currently active poplar and willow breeding programs that are developing new subspecies for future phytoremediation use [22, 29].

In an ideal world, we would have a database to balance these various considerations and tell us which plant is appropriate for a given phytoremediation application. Unfortunately, there is no such database available and the complexities of selecting the correct plants for a specific phytoremediation application make such a database unlikely (though perhaps regional databases could be developed). Therefore, prescriptions are not available for "off-the-shelf" use of poplar and willow species, or most other plants, for phytoremediation. Finding the correct plant for the phytoremediation job takes planning and testing. One approach to matching plants to remediation and site needs is outlined later in this paper.

Plants for the People:
Along with the chemistry and silvicultural issues of phytoremediation, it is also important to understand and assess the potential *psychological* and *social* implications of phytoremediation. Environmental psychologists have investigated the impact of vegetation on human health and well being and found some dramatic impacts. For instance, views of trees and green space can significantly improve healing in hospitals, with patients requiring fewer and less strong pain killers, having fewer post-operative complications, and having shorter hospital stays [31]. Views of green space in public housing developments has been shown to reduce domestic violence and improve coping ability in the face of severe poverty [23, 24]. Views of green space are associated with greater productivity on the job [19, 20]. People perceive business districts with trees and even modest landscaping as carrying higher-quality goods, and being a preferable destination for shopping [38-40]. Trees have been shown to be critical in satisfaction with housing and increased well being [12, 21]. People care deeply about the trees in their communities, and can get very upset when trees are removed from their neighborhood or nearby park of forest preserve [10, 15].

How are these findings related to phytoremediation of brownfields? Many brownfields are in distressed neighborhoods, neighborhoods that need economic and/or social revitalization and many that have borne the brunt of environmental injustice. Recall that the findings about the impacts of trees on individuals and neighborhoods were based on the *views* of trees (as opposed to a walk in the park or active gardening). Brownfields in distressed neighborhoods are *seen* by many people on a daily basis. Phytoremediation can add trees and other plants to this view, and, therefore, phytoremediation could potentially have positive effects on the community. Residents and workers seeing phytoremediation plantings could potentially experience reduced stress, greater coping capability, increased productivity, and other effects of views of green space.

Neighborhoods with brownfields often have an image problem [14]. In the Calumet region of Chicago, a typical rustbelt landscape with many brownfields, poor image of the area was cited by local businesses as a leading impediment to economic development [3]. Trees can have an impact on this image, as indicated by the research finding greater satisfaction with neighborhood and with business districts that have trees. Therefore, combining phytoremediation with landscape design principals, such as clustering the plants or creating a swath of color, could have significant impacts for a neighborhood.

Urban forestry research also provides a cautionary note about phytoremediation. People's reaction to tree removal is often swift and intense, sometimes leading to controversy and halted projects [10, 15]. If trees and other plants are to be removed as a part of a phytoremediation application, this could produce negative reactions from local residents and workers. If it is known in the beginning that the plants will be removed, some public education about this could be in order. It won't guarantee no protest when the plants are removed, but it could mitigate the impacts.

Landscape ecology provides another cautionary note about greening brownfields [25]. Green landscapes that look appealing can also invite exploration. If a phytoremediation site is contaminated to a degree that poses serious human and wildlife health concerns, steps need to be taken to limit access to these sites [25]. Landscaping that creates the psychological and social benefits described above could run counter to this need for limited access, creating as it were, an attractive nuisance that encourages people to use the site as if it were clean open space. Where this would be problematic, design principals could minimize the likelihood of people visiting the site, or alternative clean-up techniques could be used.

Environmental psychology and other social sciences have generated useful, even dramatic, information about the impacts of views of trees and green spaces. While existing data suggests that these impacts are possible, we need long-term research tracing the impacts of newly greened brownfields and other

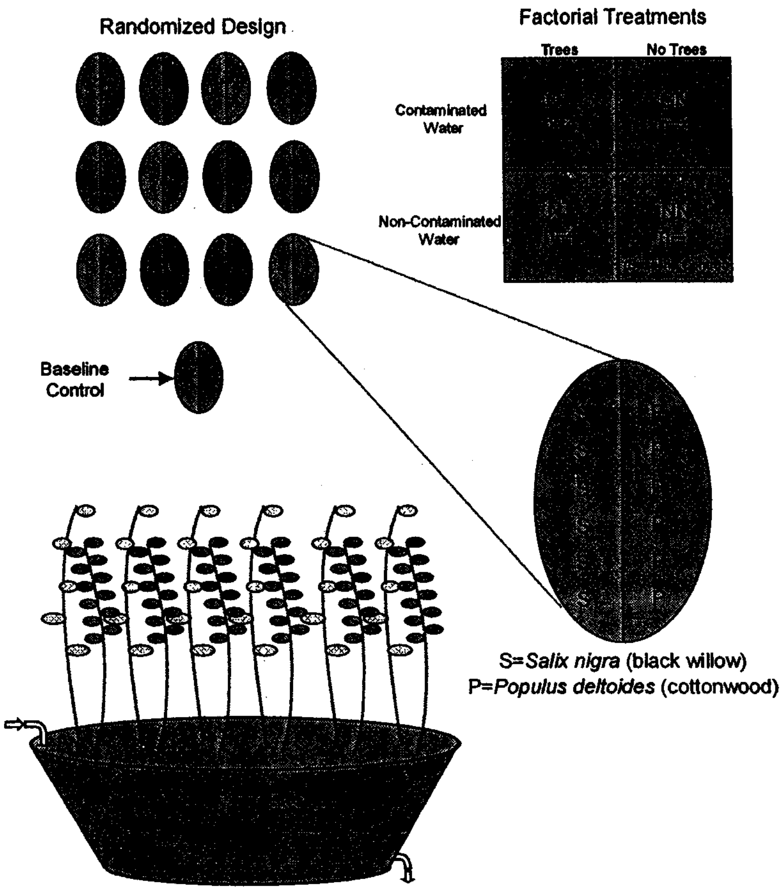

Figure 1. Schematic of 2001 phytoremediation tank experiment design—Phase I of Calumet phased phytoremediation strategy.

phytoremediation applications to determine the extent to which these benefits are realized in these settings.

Phased Phytoremediation Strategy:
We are developing a site- and contaminant specific phytoremediation protocol for a contaminated landfill in the Calumet region of Chicago. This rustbelt landscape has many brownfields adjacent to active industry and natural areas that provide habitat and recreation. The Calumet region, which includes 10% of Chicago's land base, some of the southern suburbs, and northwest Indiana along the coast of Lake Michigan, is receiving increased attention to spur ecological and economic revitalization. This revitalization program has over 50 partners from federal agencies to local, grassroots organizations. The city of Chicago and the State of Illinois have targeted their resources on this area, working with the broader partnership as a major force for change.

The site we are working on is a landfill that borders a marsh providing important bird habitat for state threatened and endangered species including the black-crowned night heron and the snowy egret. Our approach to matching the proper plant material to the site for phytoremediation is a phased phytoremediation strategy. First, we 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 I). Then, we verify, and often narrow the choice of Phase I plant materials for the specific site in a second year to refine first year results (Phase II). Next, we do demonstration plantings and testing on a small scale in the ground at the site (Phase III). Finally, after we are convinced of the merit of the plant materials for remediating the specific contaminants we scale up the application and deploy it in the design chosen for the site (Phase IV). This conservative strategy allows us to be sure 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 this landfill.

We are currently in Phase I of our phytoremediation strategy for Calumet. We are conducting a controlled phytoremediation experiment using native trees representative of species growing at the site. We are testing the ability of cottonwood (*Populus deltoides*) and black willow (*Salix nigra*) to take up contaminants from the local soil and groundwater. These contaminants include several metals and organic compounds, in quantities above ecological thresholds in Illinois [35].

Cottonwood and black willow seedlings were planted in June, 2001 in eight out of thirteen large cattle watering tanks in a replicated experimental design (Figure 1). All of the tanks contained contaminated soil from the site; four of the tanks with trees received contaminated water each week throughout the 2001 growing season, while four of the tanks with trees received non-contaminated city water, four of the tanks without trees received contaminated water to test the soil uptake of contaminants, and one tank was a baseline control with no trees and non-contaminated water. The tanks were covered with waterproof covers to exclude rainwater, and divided with weed mat to keep the cottonwood and willow roots separate.

We are currently monitoring the growth and survival of the trees, and recording the input of water quantities as well as quantities of contaminants into the tanks based on subsamples. The output from the tanks is monitored monthly with chemical lab analyses in order to develop a water and contaminant budget for the two species during the entire season. At the end of the season we will assess the phytoremediation performance, which will be used to plan Phase II of the strategy for 2002. If we continue to have positive results, we will proceed to Phases III and IV over the coming years.

If we deploy phytoremediation in a full scale buffer system, it will be highly visible from trails in the neighboring marsh, as well as from a road leading to several industrial and recreational sites. Therefore, the tree planting will alter the appearance of the landscape and might trigger some of the psychological and social benefits discussed previously. We don't know if we will need to remove trees to remove contaminants (future analysis will answer this question), but if we do the removal of the trees will need to be handled carefully. One step in this process would be interpretation of the phytoremediation plantings from the marsh trails — signs that explained phytoremediation and that the trees will be removed. Replanting of the trees, whether needed for further remediation of the site or not, would also be helpful to mitigate removal of the initial plantings.

Summary:

Phytoremediation has many advantages: it can clean-up a wide range of contaminants while also being cost-effective, natural, passive, and aesthetic. Because views of trees and green spaces can also provide important psychological and social benefits, phytoremediation has the potential to treat more than on-site contamination; it may also help to create stronger neighborhoods and industrial/business districts.

For phytoremediation to be effective, the appropriate plant needs to be matched to the site. Not only must the species and varieties used be able to remediate the contamination, but it must also be able to survive well in the growing conditions and also not threaten nearby natural areas.

Matching the plant to the site often requires research and testing. We are conducting a research experiment as part of a phased phytoremediation strategy to develop a site- and contaminant-specific phytoremediation protocol to protect an important marsh habitat from a highly contaminated landfill in the rustbelt landscape of Chicago's Calumet region. This experiment will provide additional information for clean-up of the landfill and also lead to new techniques to screen plant subspecies for phytoremediation applications. Phytoremediation holds much promise as a tool in reclaiming brownfields, as nature helps us clean up after ourselves.

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