Appendix 6

Sampling of Plant Species Studied for Phytoremediation

The following is a sampling of plant species that have been studied for phytoremediation. Some plants on this list may not be well suited for growing conditions in Puget Sound. A number of plants with identified phytoremediative abilities have not been included on this list because they are an invasive or potentially invasive weed in Washington state. These plants include such species as:

Amorpha fruticosa	(Indigo bush)	Accumulates lead
Azolla pinnata	(Water velvet)	Biosorbs metals
Bacopa monnieri	(Water hyssop)	Accumulates metals
Hydrilla verticillata	(Hydrilla)	Hyperaccumulates metals
Myriophyllum aquaticum	(Parrot feather)	Transforms and degrades a variety of contaminants
Phragmites australis	(Common reed)	Used in reed bed treatment systems (native genotypes do exist that are not considered invasive)

Related native species may not react to contaminants in the same manner as those specified. Different cultivars of the same species and various species of the same genus may differ in reactions and responses to climatic factors (McCutcheon, 2003).

GRASSES/LEGUMES

Species/Common Name	Contaminant	Process	Comments
Agropyron smithii Western wheat grass	Hydrocarbons	Rhizodegradation	Perennial grass used in pastures/lawns; shown in studies to enhance degradation of TPH and PAHs in soils (McCutcheon & Schnoor, 2003).
Agrostis castellana Colonial bentgrass	Metals	Hyperaccumulation	Perennial *A. castellana* has been shown to accumulate As, Pb, Zn, Mn and Al.
Bouteloua gracilis Blue gamma grass	Hydrocarbons	Rhizodegradation	Used for low-water use lawn and pasture grass. Has shown promise in grass mixes to enhance degradation of PAHs in soils (McCutcheon & Schnoor, 2003).
Buchloe dactyloides Buffalo grass	Hydrocarbons	Rhizodegradation/ Accumulation	Perennial grass; low maintenance, drought tolerant lawn requiring little/no mowing. In studies has been shown to reduce TPH and PAHs in soil (McCutcheon & Schnoor, 2003).
Cerastium arvense Field chickweed	Cadmium	Uptake/ Accumulation	Tufted perennial, white flowers. A Northwest (NW) native, a recent study on Vashon Island indicated uptake of cadmium (Institute for Environmental Research and Education, 2003). Additional chickweed varieties found in the NW include *C. beringianum* (Bering chickweed) and *C. fischerianum* (Fisher's chickweed).
Claytonia perfoliata Miner's lettuce	Cadmium	Uptake/ Accumulation	A somewhat succulent annual with white or pink flowers. Also known as *Montia perfoliata*. A smaller attractive variety is *Montia spathulata*. A recent study on Vashon Island indicated uptake and accumulation of cadmium (Institute for Environmental Research and Education, 2003).
Cynodon dactylon Bermuda grass	Hydrocarbons	Rhizodegradation/ Accumulation	Lawn grass; minimum maintenance but needs mowing and can be invasive. In studies where mixed with other grasses, it has reduced TPH and PAHs in soils (McCutcheon & Schnoor, 2003).

GRASSES/LEGUMES Species/Common Name	Contaminant	Process	Comments
Elymus Canadensis Canadian wild rye	Hydrocarbons	Rhizodegradation/ Accumulation	In combination with other grasses, was shown to reduce PAHs in soils (McCutcheon & Schnoor, 2003). *E. mollis* is a NW native wild rye.
Festuca arundinacea Tall fescue	Pyrene, PAHs	Rhizodegradation/ Phytoextraction	Introduced perennial grass common in the NW; studies have shown enhanced degradation of recalcitrant PAHs (McCutcheon, 2003). Also helpful in uptake of nutrients: nitrogen, phosphorus and potassium (Christensen-Kirsh, 1996).
Festuca rubra Red fescue	Hydrocarbons	Rhizodegradation	Perennial grass often used in lawn mixes; Studies have shown enhanced degradation of TPH and PAHs (McCutcheon & Schnoor, 2003).
Lolium perenne English ryegrass	Hydrocarbons/ Nutrients	Rhizodegradation/ Uptake	Perennial grass shown to uptake nutrients and to significantly enhance degradation of TPH and PAHs in soils (McCutcheon & Schnoor, 2003).
Lupinus albus White lupin	Arsenic	Rhizoaccumulation	A nitrogen fixing legume capable of growth in acidic soils with low nutrient availability. A recent study indicated an ability to take up arsenic, primarily stored in the root structure (Esteban, Vazquez & Carpena, 2003). A number of lupine varieties are native to the NW, including: *Lupinus arcticus* (Artic lupine), *L. littoralis* (Seashore lupin), *L. nootkatensis* (Nootka lupine), and *L. polyphyllus* (Large-leaved lupine).
Lotus corniculatus Birds-foot trefoil	Hydrocarbons	Rhizodegradation/ Accumulation	An introduced European annual herb; when mixed with grasses was shown to reduce TPH and PAHs in soils (McCutcheon & Schnoor, 2003). This plant is generally not recommended for introduction into constructed wetlands of the Puget Sound region (Azous & Horner, 2001).
Melilotus officinalis Yellow sweet clover	Hyrdocarbons	Rhizodegradation	Tall, sweet smelling annual; *M. alba* is more common in NW region. When mixed with other grasses was shown to degrade TPH in soils (McCutcheon & Schnoor, 2003). Also helpful in uptake of nutrients: nitrogen, phosphorus and potassium (Christensen-Kirsh, 1996).
Panicum virgatum Switch grass	Hydrocarbons	Rhizodegradation	Enhances degradation of PAHs in soils (McCutcheon & Schnoor, 2003). *P. occidentale* is a species found in the NW.
Stellaria calycantha Northern starwort	Cadmium	Uptake/ Accumulation	Low sprawling perennial. A number of varieties are common in the NW, including, *S. longifolia* (Long-leaved starwort) and *S. longipes* (Long-stalked starwort). A recent study on Vashon Island indicated uptake and accumulation of cadmium (Institute for Environmental Research and Education, 2003).
Stenotaphrum secundatum St. Augustine grass	Hydrocarbons	Rhizodegradation	Perennial grass often used in lawns; coarse-textured. Decreases TPH and PAHs in soils (McCutcheon & Schnoor, 2003).
Trifolium pratense Red clover	Hydrocarbons	Rhizodegradation	Introduced perennial herb common in the NW. When mixed with other grasses was shown to degrade TPH in soils (McCutcheon & Schnoor, 2003).
Trifolium repens White clover	Hydrocarbons PCBs	Rhizodegradation/ Metablolization	Introduced perennial herb, deep rooting; enhances microbial activity and degradation of PAHs. Nitrogen fixer, and PCB metabolizer.
Vicia spp. Vetch	Nutrients/ Metals	Uptake	Perennial herb, takes up nutrients (nitrogen, phosphorus and potassium); *V. faba* has been shown to accumulate Al (McCutcheon & Schnoor, 2003).

OTHER FORBES Species/Common Name	Contaminant	Process	Comments
Achillea millefolium Yarrow	Cadmium	Uptake/ Accumulation	Perennial aromatic herb native to the NW. Also known as *A. borealis*. A recent study on Vashon Island indicated uptake and accumulation of cadmium (Institute for Environmental Research and Education, 2003).
Allium schoenoprasum Chives	Cadmium	Hyperaccumulation	Perennial onion relative. A recent agricultural study in Israel indicated Cd was accumulated in roots and leaves (Khadka, Vonshak, Dudai & Golan-Goldhirsh, 2003).
Atriplex hortensis Garden Orach	PCBs	Metabolism	Of the spinach family, Orache is an extremely variable species; *A. patula* (Spearscale), *A. subspicata* and *A. patula* common in the NW. Shows promise transforming PAH and Graden Orach metabolizes PCBs (McCutcheon & Schnoor).
Brassica juncea Indian mustard	metals	Rhizofiltration/ Hyperaccumulation	Various species applicable for removing heavy metals (Pb, Zn, Ni, Cu, Cr, Cd and Ur) from soil or water (McCutcheon & Schnoor, 2003); B. campestris (also known as *B. rapa*) and *B. camestris* are common annual herb species in the NW.
Brassica rapa Field mustard	Cadmium, Zinc	Hyperaccumulation	Known to accumulate metals.
Digitalis purpurea Common Foxglove	Cadmium	Phytoextraction	A recent study on Vashon Island indicated uptake of cadmium; *D. lanata* (Grecian foxglove) shown to transform digitoxigenin (McCutcheon & Schnoor, 2003).
Helianthus annuus Sunflower	Metals PAHs	Extraction/ Metabolism Rhizodegradation	The common sunflower has been the subject of numerous studies and is used to extract heavy metals (Pb, Ur, Sr, Cs, Cr, Cd, Cu, Mn, Ni and Zn). Has shown promise in degrading PAHs in soil (McCutcheon & Schnoor, 2003).
Pteris vittata Brake fern	Arsenic	Hyperaccumulation	P. vittata accumulates arsenic in its above ground shoots (Caille et al., 2003).
Senecia glaucus	Crude Oil	Rhizodegradation	Observed to rhizodegrade crude oil in Kuwait; *Senecio triangularis* (Arrow-leaved groundsel), *S. pseudoarnica* (Beach groundsel), and *S. intergerrimus* (Western groundsel) are among the related perennial herbs in the NW.
Solidago hispida Hairy golden rod	Metals	Hyperaccumulation	Shown to accumulate Al. *Solidago* species shows promise for metabolizing TCE (McCutcheon & Schnoor, 2003). Related NW species include S. Canadensis(Canada goldenrod) and *S. multiradiata* (Northern goldenrod).
Thlaspi caerulescens Alpine pennycress	Cadmium, Zinc, Nickel	Hyperaccumulation	This plant is well recognized for its ability to hyperaccumulate metals. *T. arvense* (Field pennycress) is a common NW annual weed.

TREES, SHRUBS and VINES

Species/Common Name	Contaminant	Process	Comments
Acer rubrum Red maple	Leachate	Uptake	Fairly fast growing deciduous trees that have been utilized to uptake landfill leachate along with hybrid poplars (McCutcheon & Schnoor, 2003). NW species include *A. macrophyllum* (Oregon maple), *A. circinatum* (Vine maple), and *A. glabrum* (Rocky mountain maple).
Betula pendula European white birch	PAHs PCBs	Phytodegradation	Attractive European native, has been shown in laboratory tests to degrade PAHs and PCBs in solution (McCutcheon & Schnoor, 2003).
Gleditsia triacanthos Honey locust	Lead	Phytoextraction	Common honey locust (many cultivars available) has shown promise in the extraction and accumulation of lead (Gawronski, 2003).
Ilex spp. Holly	Cadmium	Accumulation	Evergreen shrub or tree. Recently shown to take up and accumulate cadmium (Institute for Environmental Research and Education, 2003).
Liquidambar styraciflua American sweet gum	Perchlorate	Phytodegradation/ Rhizodegradation	A native of the eastern U.S., grows to 60 ft., and is tolerant of damp soils. Has shown promise for phytoremediation of perchlorate (McCutcheon & Schnoor, 2003).
Maclura pomifera Osage orange	PCBs	Rhizodegradation	A deciduous tree that can withstand heat, cold, wind, drought, and poor soil. Roots have been shown to stimulate PCB-degrading bacteria in the soil (McCutcheon & Schnoor, 2003).
Morus rubra Mulberry	PAHs PCBs	Rhizodegradation	The mulberry is one of a few trees producing phenolic compounds stimulating PCB-degrading bacteria, and thus enhance the degradation of this pollutant. Mulberry has also been shown in the lab to degrade PAHs (McCutcheon & Schnoor, 2003).
Populus spp. Poplars	Chlorinated solvents, PAHs, atrazine, DDT, carbon tetrachloride	Phytodegradation/ Phytovolatilization Phytoextraction	Deciduous trees known for deep rooting and rapid growth. The focus of major attention in the field of phytoremediation, hybrids and clones have been developed for very fast growth and colonization. Poplars can absorb nutrients, such as nitrogen, at a high rate and are used in treatment of land applications of wastewater (McCutcheon & Schnoor, 2003). Known to take up and transform TCE from groundwater (McCutcheon & Schnoor, 2003). Varieties tested include *P. deltoids* (Eastern cottonwood), *P. trichocarpa* (Black cottonwood), *P. simonii* (Chinese poplar) and *P. nigra* (Lombardy poplar). *P. trichocarpa* is a NW native.
Populus tremula Aspen	Pb	Extraction	*P. tremula*, *P. treumloides* (Trembling aspen), and hybrids have shown potential to remediate contaminated water, either from the soil or water table, esp. the extraction of lead (McCutcheon & Schnoor, 2003).
Rosa spp. Paul's scarlet rose	Organic contaminants	Phytodegradation	Paul's scarlet rose is a red, natural climbing rose that can metabolize tetrachlorinated PCB 77. There are, of course many varieties. *R. gymnocarpa* (Dwarf rose) and *R. nutkana* (Nootka rose) are two Washington natives.

TREES, SHRUBS and VINES Species/Common Name	Contaminant	Process	Comments
Salix spp. Willow	Perchlorate	Phytodegradation/ Rhizodegradation Phytoextraction	Deciduous trees or shrubs needing plenty of water. *S. caroliniana* (Coastal plain willow) and *S. nigra* (Black willow) shown to uptake and degrade percholate in soils as well as phytoextract metals (Cd, Zn and Cu). Additional *Salix* ssp. and hybrids have extracted metals (Cr, Hg, Se and Zn) (McCutcheon & Schnoor, 2003). Species in the NW include, *S. commutata* (Undergreen willow), *S. lucida* (Pacific willow), and *S. sitchensis* (Sitka willow). A study on Vashon Island indicated uptake/accumulation of cadmium by *S. scouleriana* (Scouler's willow) (Institute of Env. Research & Ed., 2003).
Viola spp. Violets	Metals	Phytoextraction/ Hyperaccumulation	Perennial flowering plants with many varieties. *Hybanthus floribundus* (Shrub violet) from Australia, has been found to accumulate high concentrations of metals. A study on Vashon Island, WA found violets growing naturally to have accumulated cadmium (Institute for Environmental Research and Education, 2003). The many varieties in the NW include: *V. adunca* (Early blue violet), *V. langsdorfii* (Alaskan violet), *V. palustris* (Marsh violet), and *V. glabella* (Yellow wood violet).

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