Appendix B

Vendor's Section

Note: Information contained in this appendix was provided by the technology vendor and has not been independently verified by the U.S. EPA SITE Program

APPENDIX B – Air Force Experience and Recommendations

This section describes steps to be taken for implementing phytoremediation and establishing a short rotation woody crop. Knowledge of site-specific soil and climate conditions before planting can often decrease the probability of planting failure. This section has extensively utilized information developed by or for the Department of Energy's Biomass/Biofuel Program, Short Rotation Woody Crops Operations Working Group, and the Salix Consortia of the New York State Energy Research and Development Authority. Readers will also find additional lessons learned in the restoration of riparian zone vegetation, points of contact, helpful web sites, references to technical reports and handbooks, and sources of hybrid poplar, eastern cottonwoods, and willows are included in this section.

B.1 Introduction

Vascular plants have been on Earth over 400 million years. Flowering plants first emerged about 140 million years ago. Plants survive by exploiting their surroundings as they compete for light, nutrients and water. Plants have evolved various strategies that allow them to exploit a given ecological niche. Some plant groups are stress tolerators that can survive high salt and metal levels. Other plant groups compete "best" by growing rapidly. Because plants cannot readily move themselves from sites having adverse conditions, over time plants have developed the necessary biochemical processes to tolerate a variety of man made and natural carcinogens, mutagens, and teratogens. Some vegetation even has the ability to make compounds such as chloromethane. There are more than 3,200 chlorinated, fluorinated, and brominated chemicals produced by living organisms and natural combustion processes (Gribble). Chlorine is actually an essential element for plants. In fact, natural organohalogen compounds play an essential role in the survival of many organisms. Trees, shrubs, grasses, flowers and vegetables can readily handle low levels of halogenated hydrocarbons such as trihalomethane found in chlorinated drinking water. Another indication of this tolerance is that members of *Populus* and *Salix* families are often found in shallow ground water contaminated by trichloroethylene and its daughter products dichloroethylene, and vinyl chloride. Plants can do this because they have dehalogenase and mixed function oxidase enzymes needed to transform low levels of halogenated hydrocarbons.

Plants form the basis for agriculture and forestry. Plants have a long history of providing us with fuel, fiber, oils, medicines (quinine, digitalis, opiates), poisons (strynine, hemlock, etc.) and food. Perhaps the group to first exploit plants for environmental purposes was the Incas who planted alders in the 10th century to stabilize their planting terraces in Peru (Moore). Alders also helped maintain the fertility of the soil by fixing nitrogen. The Chinese have used trees since the 12th century to stabilize slopes and prevent erosion, while the Dutch have used trees to stabilize their earthen dikes for several hundred years. The ability of trees to act as pumps was noted in the late 19th century when *Eucalyptus* trees were planted in Italy and Algeria to dry up marshes. The incidence of malaria in these areas subsequently decreased.

Phytoremediation is a new term, but given the diverse and long history of plant exploitation through out world history it can hardly be considered a new idea. Phytoremediation is currently being practiced by some professionals with backgrounds in agronomy, biochemistry, hydrology, chemical engineering, sedimentology and industrial hygiene to clean up shallow groundwater and soil contaminated with various metals and organics. Because phytoremediation is in its commercial infancy, the people who employ phytoremediation have often designed projects with methodologies developed from personal experience. This knowledge is considered to be proprietary and zealously guarded even though much of this information is already in the public domain. About 30 years ago the United States Department of Energy embarked on a program to grow plants as a source of fiber and fuel in response to the Arab oil embargoes of the early 1970's. The outcome of millions of dollars and thousands of man years of effort is in an extensive body of public domain information on the physiology and development of short rotation woody crops. The information about individual species or clones that are most suitable for a given region, how to plant, control weeds, when and how often to fertilize, how to recognize and control plant pathogens and other pests, and how to harvest is all in the public domain. This public domain information gives detailed guidance on how to select and prepare potential sites. Research and development is also currently being conducted in the Netherlands, Finland, Denmark, Sweden, Italy, Australia, and the United Kingdom.

If shallow ground water contaminated with low level nitrates, phosphates, hydrocarbons, or chlorinated hydrocarbons is encountered at a site that is suitable to growing a short rotation woody crop, consideration should be given to employing the technology developed by the US DOE before employing any proprietary deep planting methods. This information is available on-line at the Biomass Information Network or through regional biomass energy programs.

Before initiating a phytoremediation corrective action for shallow ground water, it is imperative to determine if natural attenuation processes (i.e.,biodegration, dispersion, sorption, or volatilzation) are able to achieve site-specific remedial objectives within a comparatively reasonable time frame. If site-specific natural attenuation processes are at work and capable of reducing mass, toxicity, mobility or volume of halogenated hydrocarbons in the soil and groundwater, the site in question **MAY NOT** be considered a candidate for a phytoremediation intervention.

There are several currently available protocols and tools that have been developed by the United States Air Force, United States Geological Survey and Environmental Protection Agency to evaluate the fate of chlorinated hydrocarbons in the ground. *The Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater* has undergone extensive external and internal peer and administrative review by the U.S. EPA and U.S. Air Force. The intent of the Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater is to provide guidance for data collection and analysis to evaluate monitored natural attenuation through biological processes It is available from the National Technical Information Service. Another useful resource is BIOCHLOR Natural Attenuation Decision Support System available from the U.S. EPA Center for Subsurface Modeling Support (CSMoS). To obtain the BIOCHLOR program and user documentation go to the CSMoS web site at www.epa.gov/ada.csmos.html. Tables B.1 and B.2 show the parameters of interest when determining if natural attenuation is likely to occur in a given aquifer.

Table B.1

Analytical Parameters and Weighting for Preliminary Screening for Anaerobic Biodegradation Processes/

Analysis	Concentration in Most Contaminated Zone	Interpretation	Value
Oxygen*	<0.5 mg/L	Tolerated, suppresses the reductive pathway at higher concentrations	3
Oxygen*	>5 mg/L	Not tolerated: however, VC may be oxidized aerobically	-3
Nitrate*	<1 mg/L	At higher concentrations may compete with reductive pathway	2
Iron II*	>1 mg/L	Reductive pathway possible; VC may be oxidized under Fe(III)-reducing conditions	3
Sulfate*	<20 mg/L	At higher concentrations may compete with reductive pathway	2
Sulfide*	>1 mg/L	Reductive pathway possible	3
Methane*	<0.5 mg/L >0.5 mg/L	VC oxidizes Ultimate reductive daughter product, VC accumulates	0 3
Oxidation Reduction Potential* (ORP) against Ag/AgCl electrode	<50 millivolts (mV) <-100mV	Reductive pathway possible Reductive pathway likely	1 2
pH*	5 < pH < 9 5 > pH >9	Optimal range for reductive pathway Outside optimal range for reductive pathway	0 -2
TOC	> 20 mg/L	Carbon and energy source; drives dechlorination; can be natural or anthropogenic	2
Temperature*	> 20°C	At T >20°C biochemical process is accelerated	1

Table B-1 continued			
Carbon Dioxide	>2x background	Ultimate oxidative daughter product	1
Alkalinity	>2x background	Results from interaction between CO_2 and aquifer minerals	1
Chloride*	>2x background	Daughter product of organic chlorine	2
Hydrogen	>1 nM	Reductive pathway possible, VC may accumulate	3
Hydrogen	<1 nM	VC oxidized	0
Volatile Fatty Acids	> 0.1 mg/L	Intermediates resulting from biodegradation of aromatic compounds; carbon and energy source	2
BTEX*	> 0.1 mg/L	Carbon and energy source; drives dechlorination	2
Tetrachloroethene		Material Released	0
Trichloroethene*		Material released Daughter product of PCE	0 2[a/]
DCE*		Material released Daughter product of TCE. If cis is > 80% of total DCE it is likely a daughter product 1,1-DCE can be chemical reaction product of TCA	0 2[a/]
VC*		Material released Daughter product of DCE	0 2[a/]
1,1,1-Trichloroethane*		Material released	0
DCA		Daughter product of TCA under reducing conditions	2
Carbon Tetrachloride		Material Released	0
Chloroethane*		Daughter product of DCA or VC under reducing conditions	2
Ethene/Ethane	>0.01mg/L >0.1 mg/L	Daughter product of VC/ethene	2 3
Chloroform		Material Released Daughter Product of Carbon Tetrachloride	0 2
Dichloromethane		Material Released Daughter Product of Chloroform	0 2

* Required analysis. a/ Points awarded only if it can be shown that the compound is a daughter product (i.e., not a constituent of the source NAPL).

Table B.2 Interpretation of Points Awarded During Screening Step 1

Score	Interpretation
0 to 5	Inadequate evidence for biodegradation* of chlorinated organics
6 to 14	Limited evidence for biodegradation* of chlorinated organics
15 to 20	Adequate evidence for biodegradation* of chlorinated organics
> 20	Strong evidence for biodegradation* of chlorinated organics
	**reductive dechlorination*

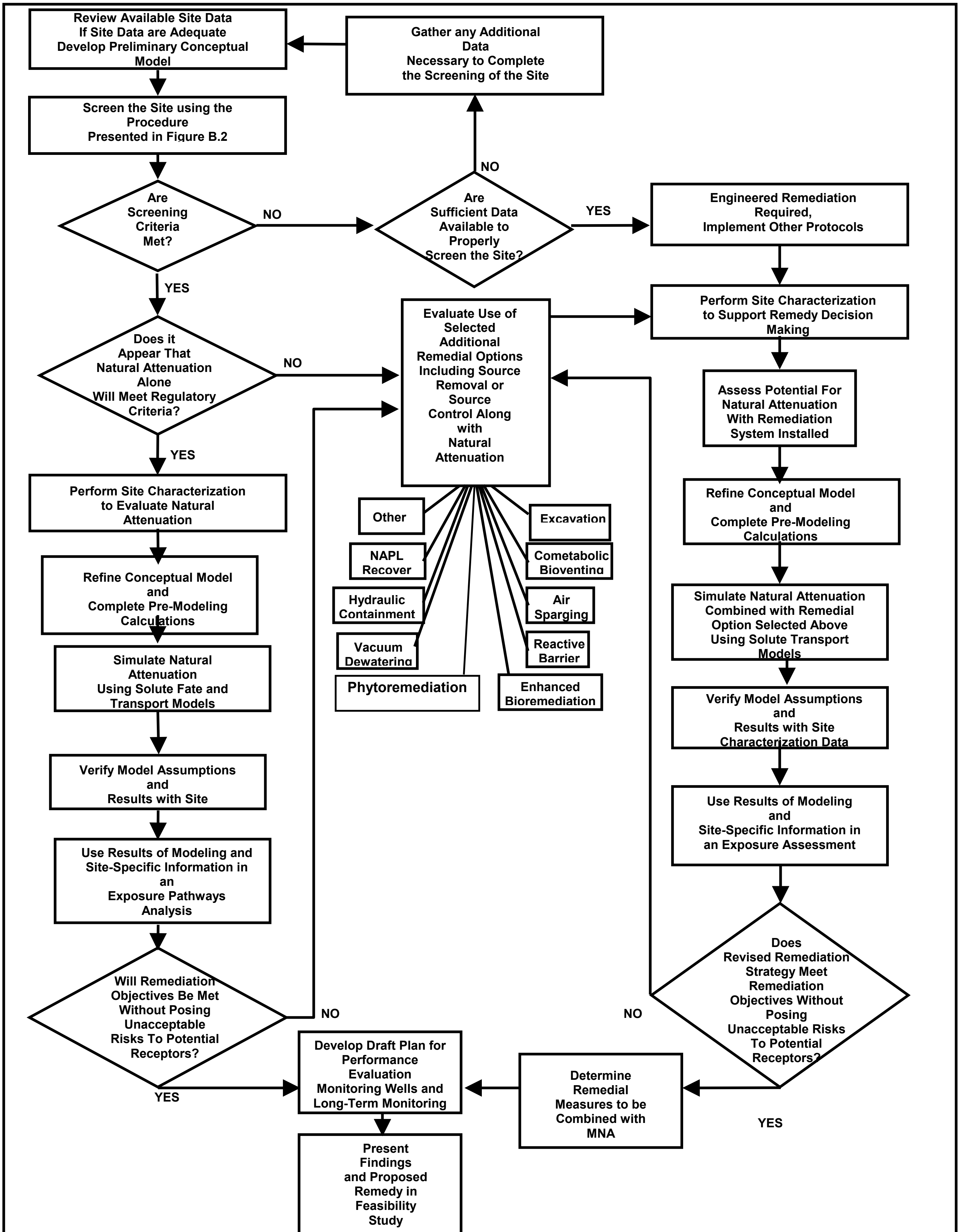


Figure B.1 *Natural attenuation of chlorinated solvents flow*

(Flowchart adapted from Technical Protocol for Evaluating Natural Attenuation of Groundwater)

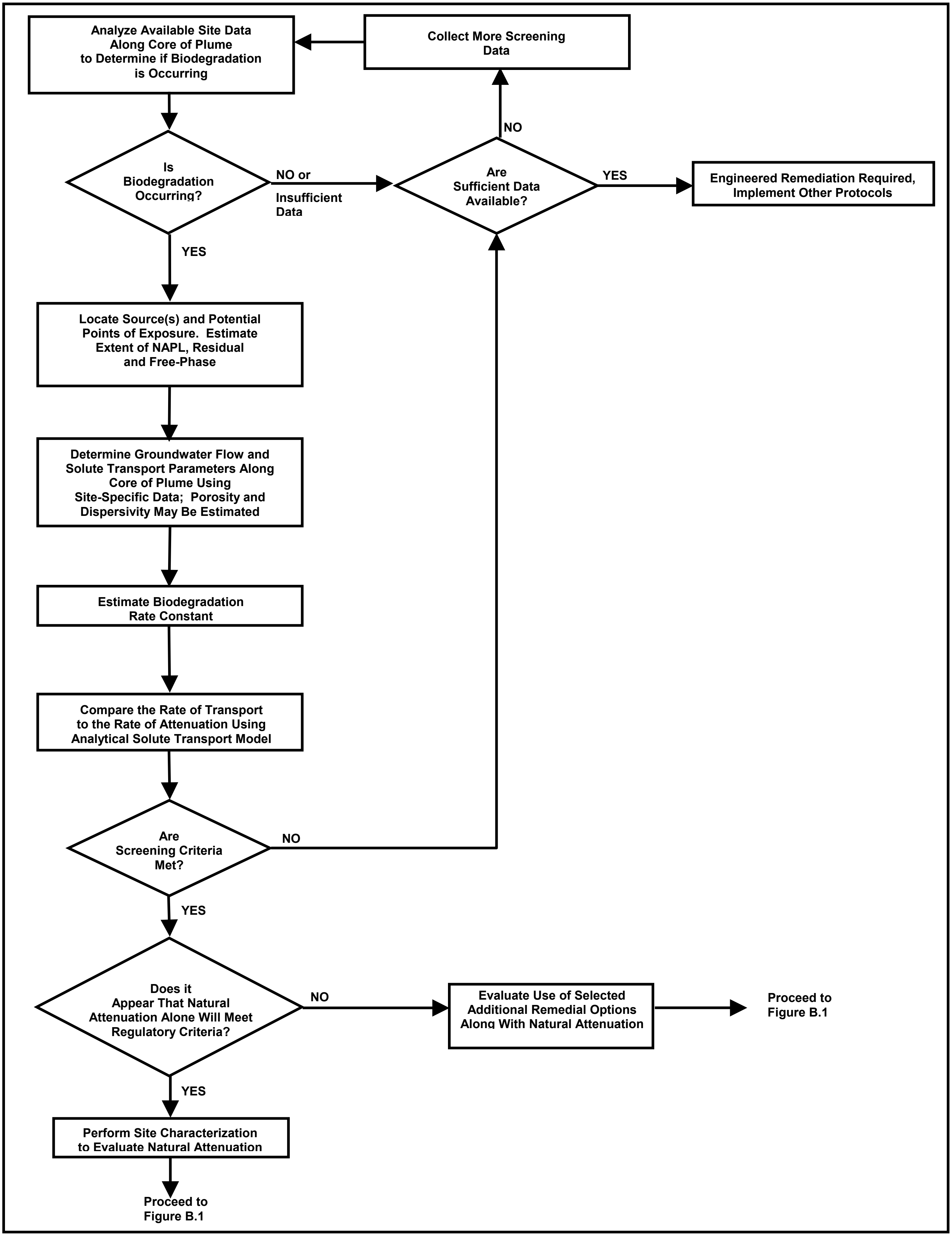


Figure B.2 *Initial screening process flow* **(Technical Protocol for Evaluating Natural Attenuation of Chorinated Solvents in Groundwater)**

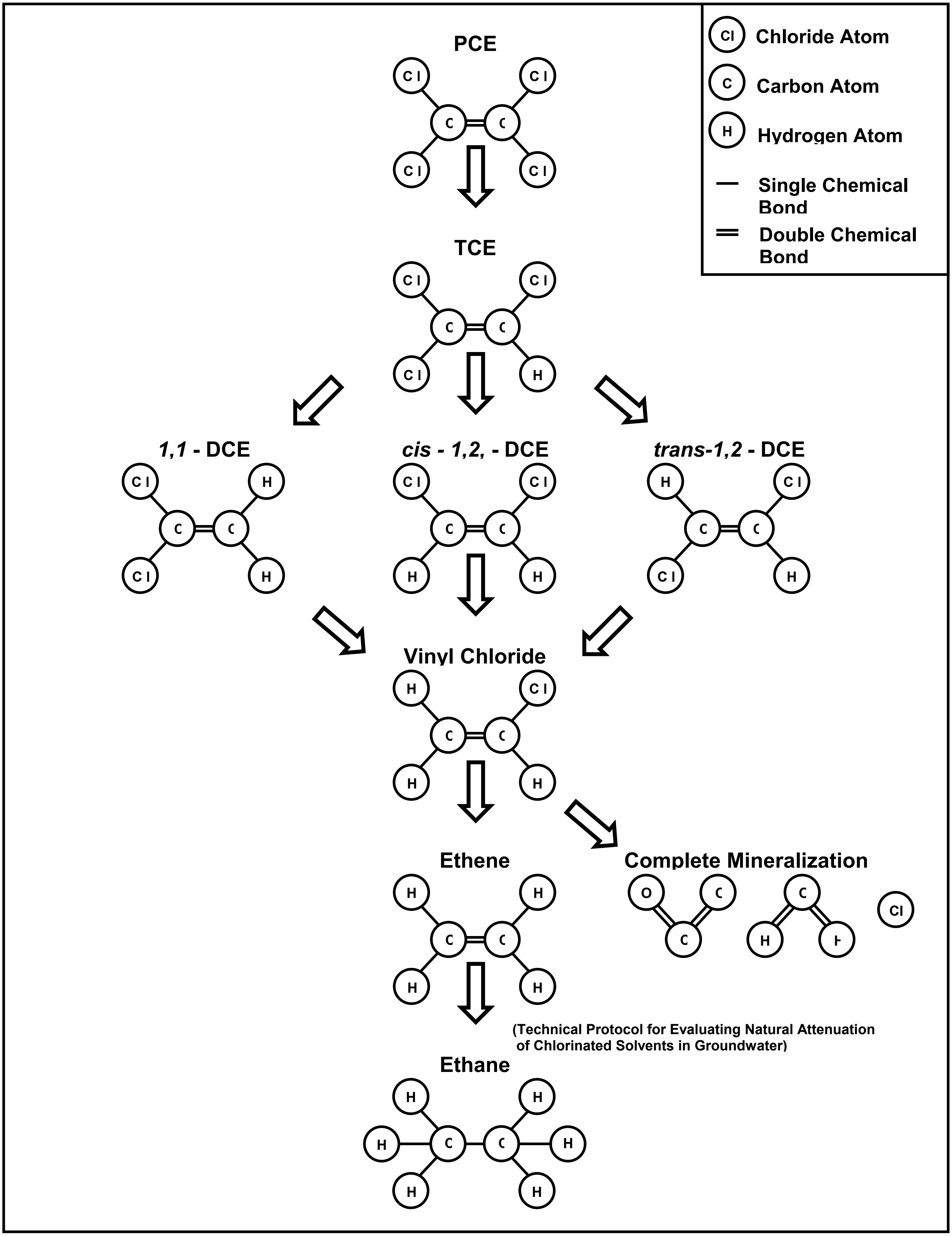


Figure B.3 *Reductive dehalogenation of chlorinated*

If the presence of any significant natural attenuation processes cannot be established from tables B.1 and B.2, the next step is to determine if the site is a candidate for the establishment of a short rotation woody crops. To determine if a site is viable for the establishment of a short rotation woody crop, a thorough understanding of site-specific hydrology and agronomic factors is essential. Failure to consider site- specific hydrologic factors such as pH, depth to groundwater and pattern of seasonal precipitation, and agronomic factors such as the nutrient status and presence of salts, soil compaction, and clay hardpans can lead to disappointment. While trees may grow at the site, there may be insufficient biomass to influence the geochemistry and hydrology of the groundwater. The establishment and management of a short rotation woody crop usually has the following goals:

1) Elimination of competing vegetation.
2) Maintenance of site productivity
3 Maximum net energy gain.
4) Maximum biomass for minimum cost

Whether a shallow groundwater site is suitable for development of short rotation crops such as cottonwoods, hybrid poplar, willow, eucalyptus, or other energy crops, requires consideration of operational factors such as location of the site, depth to groundwater, soil properties and climate. The sites should have sufficient area to plant the required biomass. Planting a few rows of trees may have subtle influences on groundwater flow. Keep in mind that the mere observation of diurnal variations in a water table does not imply hydraulic control. Potential sites should be level or gently sloping in order to use mechanical planting means whenever possible. If a site is near an airport or flight line, determine if Federal Aviation Administration (FAA) restrictions may limit height of trees. Small cuttings placed in the ground can eventually become 100 foot safety impediments to the operation of aircraft. The presence of large stones or construction debris may make large scale planting difficult and damage equipment. Another site factor is wet heavy clays that can make machine access difficult or impossible.

Hardpans are compacted soil that can tend to impair the ability of plants to send deep roots. Compaction of soil can result from vehicular traffic and natural cementation. If hardpans are present, deep ploughing may be necessary. There are vendors that specialize in ripping soil to correct this condition.

Site soil characteristics are also important for successful establishment of biomass. There are 16 nutrient elements that are essential for the growth and reproduction of plants. Thirteen of these essential elements may be supplied by the soil or supplemented by fertilizers. Plants obtain carbon, hydrogen, and oxygen from the air and water. Important soil properties are moisture and drainage, texture alteration, depth, pH, and fertility. Information on the characteristics of soil in a given county can be found from the Soil Conservation Service of the Department of Agriculture. These reports provide a general idea of the soils and climatic conditions in an area.

While soil surveys are an excellent starting point, it is strongly recommended that additional soil testing be conducted. Soil testing can provide site-specific answers to concerns about pH, salts and plant nutrient availability (i.e., nitrogen, phosphorus, potassium) and micronutrients such as manganese, iron, boron, zinc, copper, molybdenum, and chlorine. The first step is to select a laboratory to conduct the required tests. When selecting a soil testing laboratory, ask if they participate in a proficiency testing or quality assurance program. Ask to see the results of the most current evaluation. Most laboratories provide instructions on how to collect a representative soil sample. Laboratories offer a variety of soil analysis options. A routine analysis consists of pH, nitrates, phosphorus, potassium, calcium, sulfur, and conductivity. Additional testing options available at extra cost (typically $15 to $30) are analysis for micronutrients such as zinc, iron, copper, and manganese, detailed salinity testing, organic matter, texture, and boron.

A soil sample for testing should represent a uniform area. Past land use, drainage, slope, and differences in texture and color are important. Areas at the proposed site in which plants appear to be doing poorly should be tested separately. It is important to use a clean rust-free tool to avoid contaminating the soil sample with iron. Collect the sample from the soil surface to the depth desired. A clean plastic pail is a good container within which to mix soil samples. Avoid using galvanized or brass containers to prevent zinc contamination. Many soil testing facilities provide plastic bags for containing soil samples.

The pH of the soil is important because pH influences the availability of nutrients. Nitrogen is probably the nutrient that most often limits plant growth. Soil nitrogen is present in three major forms: elemental nitrogen, organic nitrogen, and nitrogen in fertilizers. Phosphorus (P) is an essential part of the process of photosynthesis.
Micronutrient deficiencies are most likely to limit plant growth under the following conditions:

1) Highly bleached acid sandy soil
2) Muck soils
3) Soil high in pH or lime content
4) Soils that have been intensively cropped and heavily fertilized with macronutrients

Some soil testing facilities provide only the results of the analysis while others also make specific recommendations based on the tests results for the crop to be grown. If recommendations are not provided by the laboratory, contact your local forester, county or state cooperative extension service for guidance. Once site-specific soil test recommendations have been made follow them. Do not apply more plant nutrients than recommended. This can create a nutrient imbalance that may adversely affect the plants being grown.

TABLE B.3

FACTORS THAT AFFECT THE PRODUCTIVITY OF SOILS FOR HARDWOODS

SOIL PROPERTY	BEST CONDITIONS	WORST CONDITIONS
Physical	Deep,>4ft, soils without pans. Loose, porous, friable soils (bulk density<1.4 g/cc). Undisturbed site with no recent cultivation or pasturing	Shallow, <1.5 ft, soils with plowpans or natural cemented pans. Strongly compacted, tight soils (bulk density >1.7 g/cc) pasturing for >20 years .
Moisture availability during growing.	Water table 3-6 ft. Level ground or lower slopes. No flooding or floods only early spring.	Water table <1 ft or > 10 ft. Ridgetops, mounds, dunes. Prone to flooding anytime.
Nutrient availability	Undisturbed site or cultivated <5 years. Organic matter (A-horizon) >3%, especially in sandy soils. A-horizon (topsoil) >6 in. Young, well-developed profile. Source of basic (calcareous) parent material in rooting zone. pH in rooting zone 5.0 – 7.5.	Recent intensive cultivation for >20 years. Organic matter (A-horizon) <1% A-horizon (topsoil) absent or <3 in. Old, highly leached profile. No basic (calcareous) parent material in rooting zone. pH in rooting zone <4.5 or >8.5.
Aeration	Wet by running water only in early spring. No mottling to 2ft. Soil color black, brown or red.	Swampy, stagnant or waterlogged condition much of year. Mottled to surface. Soil gray in color.

Table B.3 from The Culture of Poplars in Eastern North America by Donald Dickmann

Salt Stresses

Saline soils refer to a soil that contains sufficient soluble salts to impair its productivity. A soil is saline if the solution extracted from a saturated soil paste has an electrical conductivity of 4 decisiemens per meter Briggs). Saline soils are typically found in arid and semi-arid regions. Saline soils are rare in humid environments except in areas where the soil has been exposed to marine environments. In humid environments, soluble salts often migrate downward into the groundwater. Another source of salt to plants is from road de-icing salt spray that splashes or drifts onto the roadside. Plant damage from roadside salt spray is linked with the amount of salt applied and the traffic volume.

High salinity often limits plant growth by inducing water stress (Neuman). Plants exhibit a wide range of salt tolerance. Physiological esponses to salinity tend to be species specific (Newman). Some plants are very tolerant of salts (i.e., halophytes) while others are intolerant. Planting poplars or willows in areas with high soil salinity can be problematic (Briggs/Thomas). Soluble salts can produce harmful effects to plants by increasing the salt content of the soil solution and by increasing the degree of saturation of exchangeable materials (*USDA Agricultural Handbook 60*). The soluble salts that occur in soils consist of various amounts of sodium, calcium, magnesium and the anions chloride and sulfate (USDA Agricultural Handbook 60). The originof most salts are the primary minerals found in the soil and in the exposed parent rock of the Earth's crust.

Individuals attempting to plant vegetation in saline soils must carefully select vegetation that is appropriate. It is imperative that the planting material be adapted to the site-specific conditions. Failure to chose plant material phenotypically adapted to site conditions can often result in a planting failure (Briggs). Matching salinity tolerance to site-specific soil characteristics can be difficult (Briggs). Willows and poplars used for riparian revegetation were noted by Briggs to start exhibiting adverse effects when the salinity levels reach 2,000mg/l.

Flood Tolerance

Plants exhibit a wide range of tolerance to flooded or wet soil conditions. A site that is subjected to periodic flooding or wet soil conditions can impose very difficult conditions on most vascular plants. Some plants are much more tolerant of flooding and wet soil conditions than others. The fundamental difference between well drained and flooded conditions in the soil are directly and indirectly related to depletion of free oxygen (Whitlow). The absence of oxygen creates a reducing environment. Plants that are not adapted to wet or flooded soils exhibit reduced shoots and root growth and drop their leaves. Trees near rivers and streams are often subjected to flooding and wet soil conditions. Some plants can withstand complete inundation for months at a time, while others plants are completely flood intolerant. Flood tolerant plants have developed the anatomical, morphological and biochemical characteristics to withstand flooding and anoxic conditions. Factors that influence flood tolerance are the seasonal timings, duration, and depth of flooding. The seasonal timing of a flood is critical to the survival of trees and shrubs. Flooding when plants are dormant is usually not harmful. Flood tolerant and even intolerant trees like the tulip tree can withstand flooding when they are dormant. The time during which a flood occurs in the growing season, along with the depth and duration that an area is flooded can have a significant impact on the survival of developing vegetation. Within a given species, greater damaged and lower survival are associated with increased depth and duration of flooding.

Impacts of Temperature

Plants have an optimal temperature range at which they grow best. Many plants are susceptible to damage from freezing temperatures. The ability to withstand cold temperatures often limits the range of a given plant or even specific clones within a given species. Moving plant material north from southern latitudes can often be problematic. One 1976 study by Ying et. al. in Nebraska found that cuttings from Mississippi, Arkansas, and Texas suffered significant dieback during the winter. Ying et. al. concluded that trees from southern latitudes were more prone to injury in the winter because they retained their leaves late into the growing season. Another reason why plant material adapted to southern latitudes fail when moved hundreds of miles north is that they tend to leaf out earlier in the spring and are prone to damage from late frosts. To avoid these problems people attempting to establish phytoremediation plantations should know the origin of the plant material they purchase.

Wind

Living material grows in response to stresses that occur (Wood). The adaptive growth hypothesis states that a tree will grow only sufficiently strong to resist the forces that have occurred during its growth history (Wood). Wind is a ubiquitous component of the environment (Telewski). The mechanical failure of a tree is usually the result of wind rather than gravity (Vogel). Attempts to inhibit the growth of shallow lateral roots to enhance the growth of deep roots should be done with the knowledge that greater damage to tree stand productivity may be incurred from wind toppling in areas subject to high velocity winds. Wind can have profound effects on the growth and form of trees (Wind and Trees). Damage to short rotation woody crop plantations from high velocity winds is often an overlooked risk factor. Just as there are clonal differences in susceptibility to flooding and salinity, another abiotic stress is the mechanical stress from high velocity winds. Research by Harrington has shown that poplar clones proved resistant to toppling are associated with above and below ground characteristics. Harrington found that risk factors include trees that had less root system

Maryland Wind Toppled Hybrid Poplar (Photo Courtesy of Harry Compton USEPA)

development in the wind ward quadrants. Wind toppling was the least at the closest spacing. This seems to be due to reducing crown sway. Toppling was also found by Harrington to be reduced in polyclonal plots which was believed to be the result of more rapid stand differentiation or reduction in the "domino effect" by inclusion of more wind resistant clones in the mixture. Hybrid poplars deep planted in Maryland with engineering controls to inhibit shallow lateral roots had almost a 20% incidence of toppling in the wake of Hurricane Floyd (Compton).

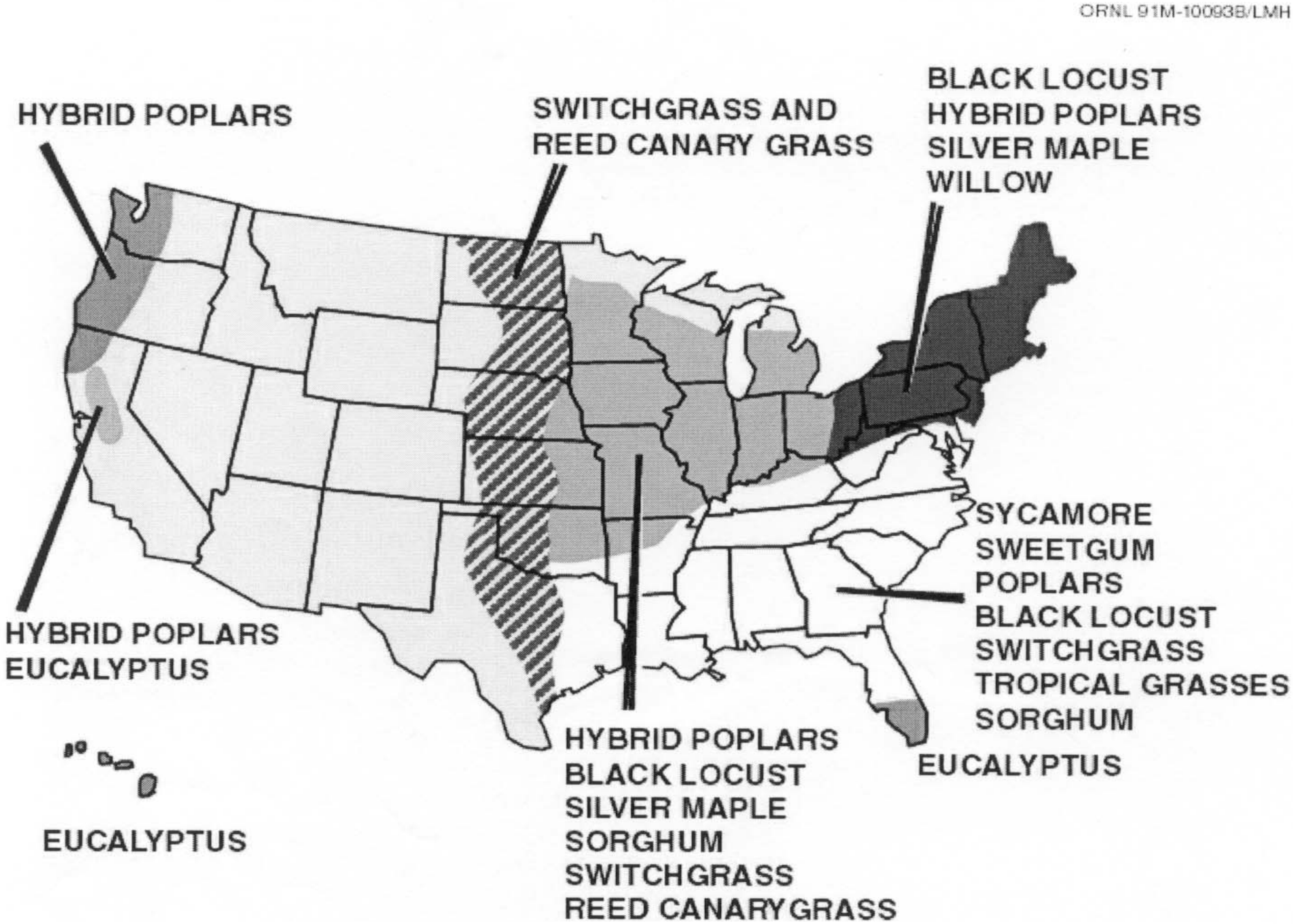
<u>Biotic Stressors</u>

Insects, fungi, viruses, bacteria, and gnawing animals can threaten the success and reduce the productivity of poplar and willow short rotation woody crops. Many readily available poplar trees are extremely susceptible to certain insect pests and diseases (Ostry). Symptoms of insect infestation and disease in poplar trees can be seen in off color foliage, missing foliage, branch die back, and cankers. Disease susceptibility among poplar clones is usually expressed by the second growing season (Hansen). Septoria cankers is more prevalent in the eastern United States and melansporia rust is more common in the western states. Trees severely stressed by one disease may ultimately be predisposed to other damaging agents such as other fungi, wood boring insects, and wind breakage. This predisposal is the case with trees severely affected by stem cankers (Hansen). While there are hundreds of insects and plant pathogens of poplars and willow, only a few are considered to be potentially dangerous (Ostry). Perhaps the most serious disease among poplar short rotation woody crops are stem canker diseases. Trees with stem canker infection often appear with dead, swollen, or shrunken patches on their stems (Dickmann). Sometimes the canker will stop and the wound will heal over time, but somtimes other fungal and bacterial infections will occur. Ready guidance about insect, disease and animal pest infestation of poplar trees is available in the *USDA Agricultural Handbook 677*. This handbook describes and illustrates with color photos the major insect, animal pests, fungal, viral, and bacterial diseases of poplars. This handbook enables growers of poplars to identify the causes of a problem should one develop. Being armed with this knowledge of the expected impact of the condition, control measures warranted, and what control measures are available enables a grower to effectively manage his crop. A careful examination of the affected trees should be made and compared to illustrative and descriptions within *USDA AgriculturalHandbook 677*. If a grower cannot determine the exact cause of problem with this handbook, it is advisable to consult a forest entomologist or forest pathologist (Ostry). Pest management information can also be obtained to Forest Service Offices listed at the end of this section.

Willows and cottonwood ecosystems are characterized by high diversity of both plants and animals (Briggs). Wildlife and vegetation have co-existed for millions of years in an on going struggle for survival by herbivores and plants. However, unlike declining water tables which can have a severe effect on trees wild life rarely significantly contributes to the decline of trees in a riparian ecosystem (Briggs). Some species like deer, rabbits, moles and beavers, however, can have an impact on newly established short rotation woody crop and riparian revegetation projects (Briggs). Moose, white tailed deer and beaver are all capable of eating large quantities of poplar and willow tree vegetation. Moose are only a problem to poplar plantations in northwest Minnesota and Sweden (Nester). Rodents such as moles, rats, and mice can also harm young shoots by gnawing off bark and damaging above ground irrigation lines. Rabbits and moles can be problematic in establishing poplar and willow plantations. In the Swedish experience, establishment of willow and poplar plantations can cause the existing population of rabbits and hares to significantly increase due to the ready abundance of food (Christersson). The best method for controlling rabbits and rodents has been to control weeds from the start of the plantation. When weeds are eliminated, moles, mice, rats, gophers and rabbits are vulnerable to potential predators.

Four hundred years ago there were approximately 60 to 100 million beavers in North America. The demand for pelts and heavy trapping pressure so severely impacted the beaver population of North America that by the 1800's beavers were extinct east of the Mississippi River. Today, however, beavers are making a come back through protective legislation and a lack of predators. Beavers are now moving into urban environments and near urban water ways, making their presence known in such diverse areas as Detroit, Ft Worth, and Washington D.C. to name a few. Beavers are gregarious and can usually be found in family groups. Young beavers leave their families at about two years. They find an area where young poplars grow and then they build a dam. Upstream they usually build a lodge and collect poplar branches for winter feed. Beavers are quite strong and can readily gnaw down and remove a thirty foot cottonwood tree almost over night. Beavers are also quite difficult to trap alive. Trapping beavers and moving them off site can require large amounts of time and effort and is usually only temporarily successful. Trapping beavers for their pelts is simply not as profitable as it used to be (Isebrands). Some states also frown on releasing live trapped beaver on to public lands. Efforts to control beavers include erecting regular fences and employing solar or battery power electric fences. Another approach has been to employ plastic shelter tubes 2-5 feet tall that allow the cuttings to grow. These preventative measures sometimes are successful but more often fail. Beavers at the Carswell Golf Course Phyto site have been an annual concern since 1996. Numerous trees have been damaged, but over all tree mortality to date has been very little. Willows and poplars readily sprout from cut or gnawed stumps. Virtually all poplars and willows coppice readily after beaver damage, harvesting or damage by fire (Dickmann). Since beavers are here to stay, beaver damage to established poplar and willow phytoremediation plantations should be taken in stride. Beaver damaged established poplar and willow trees will usually recover. While the above ground biomass is gone, subsurface biomass is still usually capable of establishing new above ground biomass. It has been our experience at Carswell that below ground short rotation woody crop biomass can still drive iron reducing conditions and reductive dechlorination of TCE in the absence of significant above ground biomass.

Beaver Damaged Trees **photo by Greg Harvey, USAF**



Map Courtesy of Virginia Tolbert (Oak Ridge National Laboratory)

For trees to reach their full genetic potential, plantation managers need to be able to select disease resistant clones and recognize various problems as they arise (Hansen). The goal of short rotation woody crops is to achieve and maintain high productivity (Mitchell). The Department of Energy has screened approximately 125 different plants as candidates for short rotation woody crops for fiber and fuel. The Department of Energy has found that certain species perform better than others in various regions of the United States. This finding is illustrated in the attached map of screened biomass candidates. After selecting the appropriate tree or trees for a given region, the next step is to select specific clones that give superior performance in a plantation. An understanding of short rotation woody crop production, stress, and ecophysiology has allowed plantation managers to achieve optimal clone-site matches at numerous sites (Mitchell). Tree breeders try to find clones that are adaptable to large areas (Hansen). Few clones however, are sufficiently stable for all situations in regions with varying soils and climates. Clones with desirable qualities such as superior growth rate and disease resistance can be selected from nursery screening trials. Promising clones selected from nursery screening trials are then planted in field trials.

Field trials are expensive and take several years to complete. Field trials have been conducted for hybrid poplars and cottonwoods by the United States Forest Service and for willows by the *Salix* Consortium of New York. Because of the time and expense involved, most poplar clones have not undergone field testing in all locations where they are now planted. The hybrid poplar field trials were conducted in eastern Ontario, the Pacific Northwest, and North Central sections of North American. A program for improving cottonwood was begun by the United States Forest Service in the early 1960’s after it became apparent that hybrid poplars from the Northeastern United States and Europe did not perform well

(Mohn). The results of the extensive hybrid poplar field trials pointed to clone stability throughout the North Central States and eastern Ontario, but site-specific stability in the Pacific Northwest (Hansen).

The greater stability of clones in the North Central eastern Ontario regions is believed to be due to a narrower climate range (Hansen). U.S. Forest Service found that clones DN 34, DN 17, and DN 182 in the North Central United States had reasonable disease resistance and biomass across a range of sites. Interestingly, Edward Hansen of the Forest Service noted that clone DN 182 performed well on sites with harsh dry conditions and also performed well on good sites with wetter conditions. But clones DN 34 and DN 17 that performed well on good sites were often affected more severely by disease on harsh sites. This observation was also noted in the Pacific Northwest field trials with other clones. The reason for the variability observed in the Pacific Northwest is believed to be that climate and soils vary greatly with distance from the ocean, elevation and which side of the Cascades Range.

The United States Forest Service has made several recommendations with respect to selecting clones for a site. First, potential tree growers should make clone selections based on their performance of half their projected rotation. Growers should not assume that because a tree grew eight feet the first year and is healthy that it is the "super tree" for a given area (Hansen). Second, poplar clones should be selected based on their performance in plantations. Singular trees grown in an open field are not a good indicator of plantation performance (Hansen). Additional information on hybrid poplar performance can be found in the *USDA Research Paper NC-320 North Central United States in Field Performance of Populus in Short Rotation Intensive Culture Plantations in the North-Central U.S.* Some vendors offer cuttings in various lengths ranging from 8 to 36 inches or more. It is often possible to get volume discounts by ordering large quantities. Typically the longer the cutting the more expensive it is. Prices for Spring 2000 for 8-9 inch hybrid poplar cuttings were approximately $ 0.25 each for quantities of 25 to 100 to approximately $0.16 for orders of 5000 cuttings or more. Spring 2000 prices for 18 inch cuttings were about $0.30 and 36 inch cuttings were about $0.50. Shipping and handling charges are usually extra. Because of the relative inexpense of cuttings in the establishment of a plantation one should order more cuttings than one anticipates planting. When ordering cuttings, preference should be given to male clones which do not produce seeds. Female poplar trees can produce large amounts of small wind borne seeds. These seeds can clog air conditioner heat exchangers, cover outdoor pools, and create other maintenance roblems for people living near poplars (Baldridge). Vendors of hybrid poplars in the Pacific Northwest and North Central United States are listed at the end of this section.

Willows are another species that have potential as a short rotation woody crop. Willows are easy to propagate, resprout readily after cutting, and are not susceptible to *Septoria* canker (White). *Septoria* canker has caused serious damage to hybrid poplar planted in New York and harvested on 5-10 year rotations (White). The field trials of various willow clones for biomass production was initiated in 1987 in central New York State by the State University of New York College of Environmental Science and Forestry, the University of Toronto, and the Ontario Ministry of Natural Resources. The most promising clone, willow clone SV1, in ultra-short rotation was found to yield 16 oven dry tons per hectare per year during the fifth growing season (Kopp). White's group found that fertilization significantly increased the rate at which clones reached their maximum biomass production. Kopp also noted large clonal variation in biomass production and survival. For further information concerning the availability of specific clone willow cuttings contact Timothy Volk of the State University of New York College of Environmental Science and Forestry, One Forest Drive Syracuse, New York 13210 tavolk@mailbox.syr.edu. There are two commercial sources of non-proprietary eastern cottonwood cuttings for sale to the public. One is the Crown Vantage cottonwood clonal nursery at Fitler, Mississippi and the other is Ripley County Farms in Doniphan, Missouri. Additional information on specific eastern cottonwood clones can also be found at the end of this section.

Storage

Careful site preparation and selection of appropriate planting material can be compromised by several things. Perhaps the simplest is improper storage of cuttings. Dormant cuttings improperly stored often fail to grow. For best results cuttings must be protected from heating and moisture loss and should be stored in sealed double plastic bags in a cold room or refrigerator just above 0 degrees C or 32 degrees F

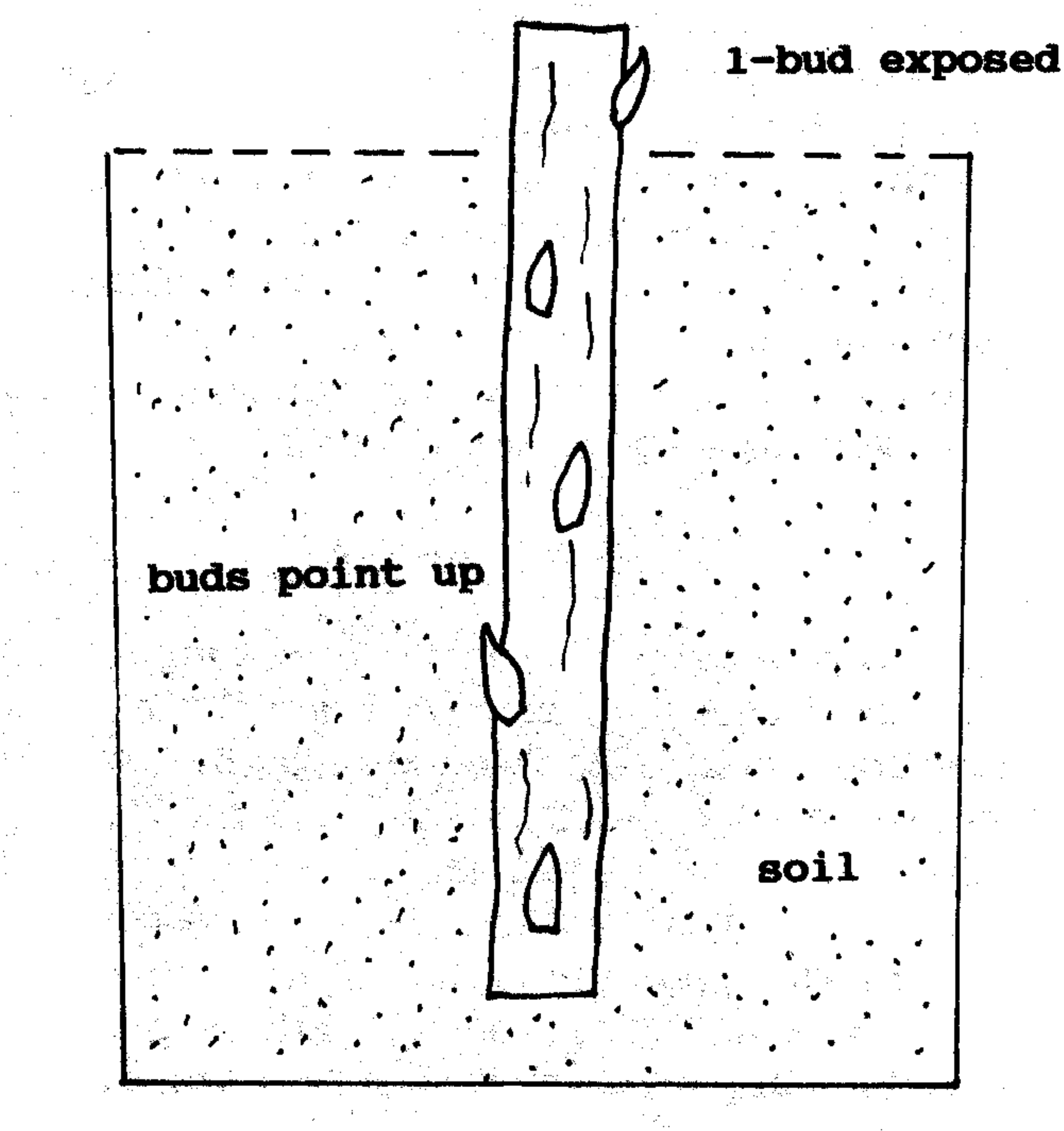
(Dickmann). It is important to warm cuttings slowly before they are planted (Dickmann). This is done by moving them to a room kept at 2 to 3 degrees C for a week or two prior to planting (Dickmann). Cuttings used for short rotation woody crop establishment in the North Central United States are usually 20 to 30 cm in length; 50 cm cuttings are the norm in the South and Pacific Northwest (Dickmann). Optimum diameters for cuttings range from 10-20 mm (Dickmann). On sites where moisture is limited in the upper most soil layer, the longer the cutting the better. Of course, it is seldom necessary to plant cuttings in excess of three feet long in the absence of hard pans. Cuttings should have numerous buds and be free of mechanical and insect damage (Dickmann). Cuttings that are spindly or have sprouted roots in storage should not be planted (Dickmann). For best results, cuttings should be warmed for 5-10 days prior to planting (Hansen) When soaking, it is important to make sure buds point up (Hansen).

Planting

The "best" time to plant cuttings is when soil temperature reach 50 degrees F (Hansen). In the North Central United States, planting usually occurs between mid April and early June (Hansen). In warmer places like the Carswell Site in Ft. Worth, Texas cuttings can be planted from late February to mid-May. Prior to planting, determine the location of above and below ground utilities, check if local ordinances prohibit some tree species, and decide if irrigation is necessary to supplement the natural soil moisture. Poplars and willows grow quickly and can obstruct the view of traffic if placed improperly. Special care should be exercised along roadways and intersections. Most cities encourage the planting of long-lived and low maintenance trees, but some local governments prohibit planting shorter-lived high maintenance trees. For example, the city of Ft. Worth prohibits planting hackberry, sycamore, silverleaf maple, mulberry, Arizona Ash, cottonwood, Siberan Elm and other high maintenance trees along city roadways. If a city prohibits a particular tree, a variance can often be obtained when there is an appropriate reason for using this type of tree.

Proper soil moisture and control of weeds are critical for a successful first year. The soil should be moist and the cuttings kept wet and protected from the sun while planting. Exposing cuttings to the sun for a prolonged period can significantly damage them prior to planting. It is important to remember to plant cuttings with their buds pointing up (Hansen). Buds must point up because this is the direction in which the tree will ultimately grow. Cuttings should also be oriented as close as possible to vertical (Dickmann). Cuttings must also have at least one bud exposed above ground (Hansen). Any air gaps around the cutting should be filled by pushing the soil against the cutting (Hansen). It is possible to plant cuttings by hand or to machine plant them. Usually small scale sites of a few acres are planted by hand and larger sites are planted by machine. Hand planting rates are reported by Hansen to be 3 acres/day/person and machine planting rates are 20 acres/day/three person crew. The trees at the Carswell Site were spaced at 8 by 8 feet in the five gallon bucket trees and 8 by 4 feet in the whip plantation. Spacing of the trees is often influenced by the number of years old they will be at harvest. The shorter the cutting cycle or rotation the closer the spacing of the trees. For poplars a cutting cycle of one to three years can have spacing of 2 by 2 to 4 by 4 feet. A rotation of 15 years can be spaced at 15 by 15 to 20 by 20 feet. For willows even closer spacing can be employed using the Swedish double row planting system. Keep in mind that closely spaced, genetically identical trees are prone to insect infestations and fungal diseases. Trees that are widely spaced apart, however, may take longer to root to the water table. A successful tree spacing design in phytoremediation achieves a balance where tree spacing promotes deep rooting without fostering conditions that encourage plant pathology problems.

Harvesting several rotations of a short rotation woody crop from a site can often result in a depletion of nutrients. Several different approaches to nutrient management for short rotation woody crops have been advocated (Heilman). The conservative approach is not overly concerned with the depletion of nutrients as long as production of above ground biomass is not significantly reduced (Heilman). The cost conservative school applies fertilizer only when soil fertility begins to impact growth. The other approach to fertilizing short rotation woody crops seeks to maintain fertility at a high steady state (Heilman). Here fertilizers are applied to not only supply nutrients but also to increase soil fertility (Heilman). The main drawback to this approach is the expense of maintaining high nitrogen levels and the risk of leaching nitrogen into the groundwater. Another drawback in phytoremediation applications of short rotation woody crops is that maintaining optimum levels of water and nutrients through irrigation and fertilization can decrease subsurface biomass (Dickmann). If trees are given optimum levels of nutrients and water it is unlikely that the tree will expend the resources to develop a large root system to explore the subsurface. Decreasing subsurface biomass may have an impact on the amount of carbon that is available for reductive dechlorination. Another problem with the liberal application of nutrients like nitrate is most studies show fertilizers are rarely 100% utilized by plants (Heilman). The liberal application of fertilizer in excess of what trees or other plants can use can cause leaching into the groundwater; this may impact the geochemistry of the groundwater making conditions unfavorable to reductive dechlorination. For these reasons, fertilizer applications to short rotation woody crops grown to phytoremediate shallow groundwater contaminated with halogenated solvents should only be done when foliar (leaf) level nitrogen levels fall below 3%. For further information about when to fertilize hybrid poplar platations obtain USDS Research Paper NC-319-A Guide to Determing When to Fertilize Hybrid Poplar Plantations.



Planted cutting.

Photo Courtesy of E. A. Hansen, et. al., 1992.

WEED CONTROL

Weed control is imperative during the establishment phase of a short rotation woody crop. The extensive experience of foresters throughout the world has shown that uncontrolled weeds can quickly compromise the success of a short rotation woody crop. Eliminating weeds reduces competition for light, water, and nutrient and also results in less cover for rodents (*Handbook of Short Rotation Woody Crops*). Omitting post planting weed control for hardwoods results in poor survival and growth and sometimes complete failure.
To insure a successful tree plantation, some short rotation woody crop foresters endeavor to have a 90% weed-free plantation in year one, 80% weed-free in year two, and 70% weed-free in year three. As the trees get bigger in the later years, they are better able to compete for light and water effectively, controlling the weeds.

There are a number of ways to control weeds by cultivation, mulching, and herbicides. One 1984 study by Edward Hansen *Research Note NC-317, Forest Service – U.S.P.A., titled, Weed Control for Establishing Intensively Cultured Hybrid Poplar Plantation* compared eight weed control methods that included cultivation, herbicides, and a legume cover by themselves or in various combinations. The weed control treatments were as follows:

- Glyphosate
- Linuron – Legume
- Linuron – Glyphosate
- Linuron – Cultivation
- Cultivation
- Legume
- Furrow Cultivation
- Furrow Cultivation

Hansen concluded that there was no difference in survival among poplar trees for six of the eight treatments. The weed control treatment significantly affected first year height. Hansen states that from the standpoint of tree survival and growth ,the pre-emergent herbicide lenuron applied alone or combined with other treatments gave consistently superior performance.

Glyphosate was found to be extremely difficult to apply after planting without damaging tree seedlings. Actively growing young hybrid poplars are easily damaged by even small amounts of glyphosate spray but are not affected through the soil (Hansen). Glyphosate damage is manifested in off color leaves and stunted growth.

Other researchers in Canada, Sweden, Italy, and the United Kingdom seem to agree that herbicides are consistently the most effective and cheapest means of providing the necessary degree of weed control. In contrast, mechanical cultivation must be done every 10-14 days to be effective. Manual weed control does not appear to be a viable economic option for large scale poplar plantations at this time. Manual weeding is labor intensive and is something to be avoided if possible even in small scale operations.

The actual choice of herbicide and application method chosen appears to depend chiefly on the nature of the weed problem and the timing of the application. Keep in mind that dry weather may render pre-emergent herbicides ineffective. A cautionary note is that laws regulating the use of herbicides differ from country to country. In America, regulations require the listing of a crop species on the herbicide label before it can be used legally on a commercial or private basis (*Handbook of Short Rotation Woody Crops*). Herbicide labels are constantly changing and one should also consult specific product labels and information before applying any herbicide. On smaller scale for plantings near wetlands or other sensitive areas, the use of plastic microfunnel mulches may be another option to consider. Ultimately, the level of weed control required will depend on the area to be planted, the time of year, and whether weeds are primarily annuals or perennials. A more in-depth review of weed management in short rotation woody crops is provided in a 1998 paper, "*Weed Management in Short Rotation Poplar and Herbaceous Perennial Crops Grown for Biofuel Products*" by Douglas Buhler.

Irrigation

The decision whether to irrigate or not can often be difficult. One must consider such factors as the depth to ground water, the amount of annual precipitation and the timing of this precipitation. Some places like Ft. Worth, Texas receive most of their precipitation in the spring and fall. Places with only sporadic, scattered rain in the summer can make the establishment of cuttings difficult because they lack an adequate root system. An understanding of historic weather patterns is required to make an informed decision on whether to install an irrigation system in a given area. Fortunately, free world-wide historical climate data can be obtained on-line from the Utah Climate Center at Utah State University at http://climate.usu.edu/free.

Supplemental water should be applied if soil moisture falls below 75 to 80 per cent of field capacity of below –0.05 to –0.1M Pa (0.5 to – 1.0 far) of tension (Dickman). Another approach is to irrigate whenever weekly precipitation fails to reach a certain minimum amount (Dickman). Tensiometers installed at a depth of 18 and 60 inches are a good way to assess the amount of available soil. There are numerous ways to apply supplemental water. Flood irrigation is the most economical but is restricted to level terrain and soil with high water holding capacity.

Large scale short rotation woody crop plantations in the Pacific Northwest employ drip irrigation systems that deliver millions of gallons of water per day derived from the Columbia River. Drip irrigation allows application of precise amounts of water to plant roots (New). This allows soil moisture in the area around the plant to be maintained at a uniform level throughout the growing period (New). Drip irrigation is used more often for orchard crops than for field crops (New). Drip irrigation was employed at the Carswell site during the first growing season. Without this irrigation system, the plantations at Carswell would have failed because the summer of 1996 was one of the driest summers on record in Texas.

Many planted trees are able to reach groundwater 3m below the surface when irrigated for the first two seasons after having been planted (Briggs). This was also our experience at the Carswell site. A root study conducted by the University of Georgia found that both plantations at the Carswell site had reached the saturated zone in September of 1997, seventeen months after planting (Hendrick). There are numerous ways to install an irrigation system at a site. Tree roots usually only explore moist soil so when the irrigation system is turned off roots can often be left high and dry above the water table or saturated zone. First plantings should be irrigated the first growing season. The length of irrigation and the amount depend on how long it takes tree roots to reach the saturated zone. Typically, young growing cottonwoods require 5-8 gallons a day per tree. (19-30 liters/day/tree) Experience in the restoration of riparian vegetation in the arid western United States has shown that the most reasonable irrigation strategy to give trees an over abundance of water so that soil is saturated to groundwater nearly constantly (Briggs).

The typical components of a drip irrigation system are a main pipeline which carries water to manifolds and lateral lines. Water flow is regulated using manual or automatic valves. Guidance on how to plan and operate an orchard drip irrigation system can be obtained in the *booklet Planning and Operating Orchard Drip Irrigation Systems B-1663* from the Texas Agricultural Extension Service at Texas A&M University System in College Station, Texas. This booklet addressees drip irrigation system layout, salinity management, emitter clogging control, fertilizer injection, and backflow prevention.

Salinity management is important because water from streams and aquifers usually contain dissolved salts. Application of groundwater can add salt to the soil where it will accumulate unless it is moved below the root zone by rainfall or excess irrigation water (New). When the amount of salt added exceeds the amount removed by leaching salts, the concentration in the soil can become harmful to trees and other plants (New). This process, called salinization, has caused the collapse of agriculture in many ancient and modern societies (Hillel). Irrigation water is considered poor quality when it contains moderate to large amounts of salt. Before irrigating a phytoremediation plantation with water from a contaminated deep aquifer it is important to know the amount of salts in this water (New). It is important not to guess about soil and water quality. It is advisable to have an annual salinity analysis of soil samples from the root zone to insure the long term productivity of a phytoremediation plantation irrigated with deep contaminated water.

Emitters employed in drip irrigation frequently clog from physical, biological, and chemical processes. Clogging reduces water emission rates and can cause stress to plants by non-uniform water distribution (New). Physical clogging is caused by soil, sand, pipe scale, and plant material and can be prevented by employing a filter system that is appropriate for the emitter type and size (New). Filters with multi-stage corrosion-resistant screens may be required when irrigation water contains large amounts of sand. Biological clogging is usually in the lateral lines and is caused by microorganisms and algae. Biological clogging is reduced by selecting emitters with large orifices and flushing the system with a chlorine concentration between 10-50 ppm (New). High concentrations and the precipitation of calcium, magnesium, and iron in irrigation water causes chemical clogging (New). Concentrations of calcium and magnesium greater than 50 ppm in irrigation water often requires periodic injections of hydrochloride solution throughout the growing season (New).

Back flow occurs when the flow of water is reversed from an irrigation system back into a potable water supply system. If contaminants are allowed to flow back into the potable water system it is possible to create a public health problem. The prevention of backflow in irrigation is very important. It is important to have an understanding of how to prevent backflow. Any connection between a potable water supply and a potential source of contamination is termed a cross-connection. Backflow or the reverse flow of liquids in a plumbing system is caused by two basic conditions backpressure or backsiphonage. The most likely causes of backpressure; are a booster pump designed without backflow prevention devices or interconnection with another system operated at a high pressure such as a fertigation injector system. When a change of system pressure causes the pressure at the supply point to become lower than the pressure at the point of use non-potable water can be backsiphoned into the main line. The main causes of backsiphonage are undersized piping, line repairs or breaks that are lower than a service point, lower main pressure from high water withdrawal rates and reduced supply main pressure on the suction side of a booster pump. Pollutants can be controlled at the cross-connection by one of several mechanical backflow preventers such as atmospheric or pressurized vacuum breakers, double check-valve assemblies, and a reduced pressure principle assembly. The type of backflow preventer required is based on the risks posed by the substance which may flow into the potable water supply system. Local and state regulations for codified construction requirements need to be checked. All backflow preventers should be inspected after installation and checked annually to insure their proper function and operation.

MONITORING LESSONS LEARNED

The monitoring of groundwater at the Carswell Site has produced several insights. The first is that traditional groundwater level measuring devices will likely cease to operate properly or give erroneous readings due to roots from the planted cuttings hanging them up. The iron in the steel float can interact with the groundwater to produce greatly elevated hydrogen levels. This is an artifact and doesn’t reflect the influence of the plantation subsurface biomass on the geochemistry of the groundwater. The problems with traditional floats were resolved at the Carswell Site by employing Design Analysis WATERLOG H310 pressure sensors. These cost approximately $1000 a piece and work by detecting changes in flow which correlate to changes in pressure. It is important that this pressure sensor be clamped or tied down to fixed location where there is no velocity flow. If the pressure is subject to open flow it is likely that the readings will be inconsistent (Rivers). This no flow condition is achieved by suspending the sensor from a stainless steel drop cable and using a weighted ballast or sinker (Rivers).

Where Can I Order Hybrid Poplar Cuttings?

Lee Wholesale Nursery Fertile, MN 56540 (218) 574-2237	Lincoln-Oaks Nurseries Box 1601 Bismark, ND 58501
Schumacher's Nursery & Berry Farm 711 Chapman Avenue Route 2 Box 10 Heron Lake, MN 56137 (507) 793-2288	Mike Hradel Cold Stream Farm 2030 Free Soil Road Free Soil, MI 49411 (616) 464-5809
Jamie DeRosier Route 1 Box 310A Red Lake Falls, MN 56750 (218) 253-2861	Insti Trees Nursery Box 1370 Rhinelander, WI 54501 (715) 365-8733
Hramor Nursery 515 9th Street Manistee, MI 49660 (616) 723-4846	Pope SWCD 24 First Avenue SE Glenwood, MN 56334 (320) 634-5326
East Otter Tail SWCD 655 3rd Avenue Southeast Perham, MN 56573 (218) 346-2050	MN Agro-Forestry Coop c/o WesMin RC&D Council 900 Robert Street, #104 Alexandria, MN 56308 (320) 763-4733
Mt Jefferson Farms, Inc. P.O. Box 12708 Salem, OR 97309 (503) 363-0467	Segal Ranches 2342 S. Euclid Road Grandview, WA 98930 (509) 882-2146

WHERE TO GET EASTERN COTTONWOOD CUTTINGS

Eastern Cottonwood (P. deltoides)

Non-Proprietary Planting Stock

- 110804
- 110610
- 110412
- 110226
- ST75
- ST72
- ST70
- ST66
- S7C20
- S7C15
- S7C8
- S7C1

CROWN VANTAGE
FOREST RESOURCES
5925 NORTH WASHINGTON STREET
VICKSBURG, MS 39183
OFFICE: (601) 630-9899
FAX: (601) 636-5865

NOTE: ST clones were developed by Stoneville Lab

S7C clones originated in Texas

110 clones originated from various sandbars along the Mississippi River

Non-Proprietary Cottonwood Cuttings

Harrison Wells

Ripley County Farms

P.O. Box 614

Doniphan, MO 63935

(573) 996-3449

rcf@semo.net

Forest Service Offices

Region 1 – Northern

USDA Forest Service
State & Private Forestry
Forest Pest Managaement
Federal Building
P.O. Box 7669
Missoula, MT 59807
(406) 329-3511
FTS 585-3511

Region 2 – Rocky Mountain

USDA Forest Service State & Private Forestry
Forest Pest Management
11177 W. 8th Ave.
Box 25127
Lakewood, CO 80225
(303) 236-3213
FTS 776-3213

Region 3 – Southwestern

USDA Forest Service
State & Private Forestry

Region 6 – Pacific Northwest

USDA Forest Service
State & Private Forestry
Forest Pest Management
319 S.W. Pine St.
P.O. Box 3623
Portland, OR 97208
(503) 221-2877
FTS 423-2727

Region 8 – Southern

USDA Forest Service
State & Private Forestry
Forest Pest Management
1720 Peachtree Road N.W.
Atlanta, GA 30367
(404) 347-2989
FTS 257-2989

USDA Forest Service
State & Private Forestry
Forest Pest Management
2500 Shreveport Hwy.
Pineville, LA 71360

Northeastern Area

USDA Forest Service
State & Private Forestry
Forest Pest Management
370 Reed Road
Broomall, PA 19008
(215) 461-3252
FTS 489-3252

USDA Forest Service
State & Private Forestry
Forest Pest Management
Louis C. Wyman For. Sci. Lab.
P.O. Box 640
Durham, NH 03842
(603) 868-5719
FTS 834-5765

USDA Forest Service
State & Private Forestry
Forest Pest Management
180 Canfield St.
P.O. Box 4360
Morgantown, WV 26505
(304) 291-4133

Forest Pest Management

Federal Building

517 Gold Ave. S.W.

Albuquerque, NM 87102

(505) 842-3292

FTS 476-3292

Region 4 – Intermountain

USDA Forest Service

State & Private Forestry

Forest Pest Management

Federal Building

324 25th St.

Ogden, UT 84401

(801) 625-5257

FTS 586-5257

Region 5 – Pacific Southwest

USDA Forest Service

State & Private Forestry

Forest Pest Management

630 Sansome St.

San Francisco, CA 94111

(415) 556-6520

FTS 556-6520

(318) 473-7160

FTS 497-7160

USDA Forest Service

State & Private Forestry

Forest Pest Management

200 Weaver Blvd.

Asheville, NC 28804

(704) 672-0625

FTS 672-0625

Region 10 – Alaska

USDA Forest Service

State & Private Forestry

Forest Pest Management

Federal Office Building

Box 1628

Juneau, AK 99802

(907) 261-2575

FTS 907-261-2575

FTS 923-4133

USDA Forest Service

State & Private Forestry

Forest Pest Management

1992 Folwell Ave.

St. Paul, MN 55108

(612) 649-5261

FTS 777-5261

REGIONAL BIOMASS ENERGY PROGRAM

The Regional Biomass Energy Program (RBEP) carries out activities related to technology transfer, industry support, resource assessment, and matches local resource to conversion technologies. Activities are conducted by five regional programs (Northwest, Western, Great Lakes, Southeast and Northeast) that promote development of biomass energy conversion technologies and feedstocks that are applicable to the region.

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Richard Handley **<u>Northeast Regional biomass Program</u>** Coalition of Northeastern Governors 400 North Capital St., NW Suite 382 Washington, D.C., 20001 (202) 624-8454 (phone), (202) 624-8463 (fax) nrbp@sso.org (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont)	**Jeff James** **Northwest Regional Biomass Energy Program** 800 5th Ave, Suite 3950 Seattle, WA 98104 (206) 553-2079 (phone), (206) 553-2200 (fax) jeffrey.james@hq.doe.gov (Alaska, Idaho, oregon, Montana, and Washington)
Phillip Badger **Southeast Regional Biomass Energy Program** P.O. Box 26 Florence, AL 35631 (256) 740-5634 (phone), (256) 740-5530 (fax) pcbadger@mindspring.com (Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, Missouri, North Carolina, South Carolina, Tennessee, Virginia, West Virginia, Washington, DC)	More RBEP information and reports are available at the Biomass Resource Information Clearinghouse.

REFERENCES for APPENDIX B

1. Briggs, Mark K., Riparian Ecosystem Recovery in Arid Lands. The University of Arizona Press, Tucson 1996.

2. Christersson, L., R Ramstedt, M., and Forsberg Pests, Diseases, and Injuries in Intensive Short Rotation Forestry. Chapter 7 in Ecophysiology of Short Rotation Forest Crops edited by C.P. Mitchell, J.B. Ford-Robertson, T. Hinckley, and L. Sennerby-Forsse, Elsevier Science Publishers, London, 1992 pp185-212.

3. Dickman, Donald and Stuart, Katherine W., The Culture of Poplars in Eastern North America, Michigan State University Publications, 1983.

4. Dickman, D. I. , and Pregitzer, K.S., The Structure and Dynamics of Woody Plant Systems. Chapter 4 in Ecophysiology of Short Rotation Forest Crops edited by C.P. Mitchell,J.B. Ford-Robertson, T. Hinckely and L.Sennerby-Forsse, Elsevier Science Publishers, London, 1992 pp95-115.

5. Hansen E.A., Ostry M.E., Johnson W.D., Tolsted, D.N., Netzer, D.A.,Berguson W.E., and Hall, R.B. Field Performance of Poplulus in Short Rotation Intensive Culture Plantations in the North-Central U.S., United States Department of Agriculture Forest Service, North-Central Experimental Station Research Paper NC-320.

6. Hansen E., Heilman, P., and Strobel, S., Clonal Testing and Selection for Field Plantations, Chapter 5 in Ecophysiology of Short Rotation Forest Crops edited by C.P. Mitchell, J.B. Ford-Robertson, T. Hinckley, and L. Sennerby-Forsse, Elsevier Science Publishers, London,1992 pp124-145.

7. Hansen E.A., Netzer D..A., and Tolsted D.N. Guidance for Establishing Poplar Plantations in the North-Central U.S., United States Department of Agriculture Forest Service, North Central Forest Experiment Station Research Note NC-363, 1993.

8. Hansen E.A., A Guide for Determining When to Fertilize Hybrid Poplar Plantations, United States Department of Agriculture Forest Service North-Central Forest Experiment Station, Research Paper NC-319, 1994.

9. Harrington, C.A., and DeBell D.S., Above and Below Ground Characteristics Associated with Wind Toppling in a Young Populus Plantation, Trees- Structure and Function 11 (2): 109-118.

10. Heilman P.E., Hinckley T.M., Roberts D.A., and Ceuleman R., Production Physiology Chapter 18 in Biology of Populus and its Implications for Management and Conservtion, edited by R.F. Stettler, H.D. Bradshaw Jr., P.E. Heilman, and T.M. Hincley Nation Research Council of Canada NRC Research Press Ottawa 1996 pp 459-489.

11. Kopp,R.F., Abrahamson, L.P., White E.H., Volk,T.A., Willow Biomass Producer's Handbook , State University of New York College of Environmental Science and Forestry, Syacuse, NY.

12. Neuman, D.S. Wagner, M., Braatne, J.H. and Howe, J., Stress physiology-abiotic. Chapter 17 Biology of Populus and its Implications for Management and Conservation. Edited by R.F. Stettler, H.D. Bradshaw Jr., P.E. Heilman, T.M. Hinckley. National Research Council of Canada, Ottawa, National Research Press, pp 423-458.

13. New, Leon and Fipps Guy, Planning and Operating Orchard Drip Irrigation Systems B-1663. Texas Agricultural Extension Service The Texas A&M University System, College Station, TX 1992.

14. Ostry, M.E., Wilson, L.F. McNabb, H.S. Moore,L.M., A Guide to Insect Disease , and Animal Pests of Poplars, United States Department of Agriculture Forest Service , Agriculture Handbook 677, 1989.

15. Portwood, Jeff, Crown Vantage Corporation , personal communication 22 March, 00 .

16. Pregitzer, K.S. The Structure and Function of Populus Root Systems, Chapter 14 in Biology of Populus and its Implications for Management and Conservation edited by R.F. Stettler, H.D. Bradshaw Jr., P.E. Heilman, and T,M. Hinckley, National Research Council of Canada, Ottawa National Research Press, 1996.

17. Telewski F.W. Wind –induced physiological and developmental responses in trees, chapter 14 in Wind and Trees edited by M.P.Coutts and J.Grace, Cambridge University Press 1995, pp237-259.

18. Tolbert, Viginia , Oak Ridge National Laboratory Biomass Biofuel Program , personal communication 3 February, 00.

19. Vogel, S., Blowing in the Wind: Storm –Resisting Feature of the Design of Trees in Storms, Journal of Arboriculture 22(2) March 1996, pp92-98.

20. Volk, Timothy, State University of New York College of Environmental Science and Forestry, personal communication 16 March 00.

21. Whitlow T.H. and Harris R.W. Flood Tolerance in Plants: A State of the Art Review Technical Report E-79-2. U.S. Army Engineer Waterways Experiment Station 1979.

22. Wood C.J. Understanding wind forces in trees, chapter 7 in Wind and Trees edited by M.P. Coutts and J.Grace Cambridge University Press, 1995 pp 133-163.

23. Ying C.C. and Bagley, W.T., Genetic Variation of Eastern Cottowood in an Eastern Nebraska Provence Study