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ANL/ES/RP-66172

317/319 Phytoremediation Site Monitoring Report - 2009 Growing Season

Energy Systems Division

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prepared by
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February 2, 2010

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By

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Project Sponsor: Argonne-ESQ

FINAL – February 2, 2010

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Abstract:

In 1999, Argonne National Laboratory (Argonne) designed and installed a series of engineered plantings consisting of a vegetative cover system and approximately 800 hybrid poplars and willows rooting at various predetermined depths. The plants were installed using various methods including Applied Natural Science's TreeWell® system. The goal of the installation was to protect downgradient surface and groundwater by intercepting the contaminated groundwater with the tree roots, removing moisture from the upgradient soil area, reducing water infiltration, preventing soil erosion, degrading and/or transpiring the residual volatile organic compounds (VOCs), and removing tritium from the subsoil and groundwater. This report presents the results of the monitoring activities conducted by Argonne's Energy Systems (ES) Division in the growing season of 2009.

Monitoring of the planted trees began soon after the trees were installed in 1999 and has been conducted every summer since then. As the trees grew and consolidated their growth into the contaminated soil and groundwater, their exposure to the contaminants was progressively shown through tissue sampling. During the 2009 sampling campaign, VOC concentrations found in the French Drain area were in general consistent with or slightly lower than the 2008 results. Additionally, closely repeated, stand wide analyses showed contaminant fluctuations that may indicate short-term contaminant depletion in the area of interest of roots. This data will be useful to determine short-term removal rate by the trees. As in previous years, levels in the Hydraulic Control Area were close to background levels except for a few exceptions.

Introduction:

The 317/319 Area at Argonne (approximately 2 hectares of surface) contains several release sites used in the past to dispose of solid and liquid waste from various laboratory activities. Because of these past activities, VOCs and tritium have been released in the groundwater at depths of approximately 6-9 m and have been detected in groundwater offsite. The U.S. Department of Energy (DOE) has funded Argonne to deploy a phytoremediation system as it was deemed more cost effective and better suited to achieve project goals than current baseline technologies (mechanical extraction wells, currently removing groundwater as an interim measure, and an asphalt cap).

As part of the deployment efforts, approximately 800 hybrid poplars and willows were planted in the summer of 1999 in the 317/319 Area at varying, predetermined depths as an engineered plantation (see Figure 1). An additional 142 trees were planted in 2003 in areas that were not accessible in 1999. All trees were planted so that root development targets the areas of soil and groundwater contamination, using methods that include the TreeWell® and TreeMediation® system patented by Applied Natural Sciences, Inc. In addition, a vegetative cover of herbaceous plants was seeded among the trees to control soil erosion and minimize water infiltration. In the upgradient VOC source area French Drain (FD) hybrid willow trees were planted so that their roots could freely explore the contaminated soil from the surface throughout the 9 m depth and take up excess water and entrained chemicals. A few TreeWell® poplars were also planted at the southernmost edge of the FD area to contain the contaminated groundwater. In the downgradient area of groundwater contamination (hydraulic control area, or HC), hybrid poplars were planted using the TreeWell® technology so that their roots were isolated from clean surficial aquifers and forced to extend downwards to the deeper, contaminated groundwater. Background control cells have been set up at the Argonne greenhouse area (a clean area on site nearby) to represent clean groundwater/soil conditions.

The 2009 monitoring efforts conducted by ES Division personnel had the purpose of contributing to the determination the system's effectiveness in achieving the remediation objectives. Activities involved:

- Determining the uptake of the volatile contaminants in tree tissue to document source reduction and contact with groundwater.
- Determining tree water uptake and movement within the tree by measuring sap flow at two different depths of wood.
- Determining temporal variations on contaminant concentrations in tree tissue and groundwater over a six-day time period.

Monitoring Protocols:

1) Site-wide VOC monitoring::

Site-wide monitoring conducted in years past presented a valuable picture of the contaminant plume in the phytoremediation system. In 2009 we monitored contaminant levels in the tree tissue following methods established in previous years. As branch concentrations typically begin to be reliably measurable after mid-June, we performed the 2009 field campaign on July 7th, 9th and the 13th. The purpose of the repeated sampling was to determine stand-wide concentration fluctuations over a short time interval. These, in turn, would be useful to determine any localized contaminant removals that are not noticeable in longer timeframes and/or when monitoring groundwater. Because of the presence of a contaminant source, any removal by the trees is masked by continuous redissolution of contaminants from the source into the soil water/groundwater. Based on results from years past, we hypothesized that the short-term fluctuations we found in tree concentrations could signal a temporary depletion of contaminants due to strong water use. This year we tested this hypothesis on a stand-basis (i.e., across the entire tree stand).

Plant tissue from the study area was sampled to determine the presence of VOCs. Finding VOCs above background levels in leaf and/or branch tissue, sap or wood cores provides a clear indication that the trees are taking up the contaminants from soil or groundwater and translocating it to the aboveground tissues. In principle, by multiplying contaminant concentrations in the sap (ng/mL) by sap flow (L/day), a quantitative measure of contaminant removal by plant uptake can be obtained. Plant uptake of contaminants from the soil solution and the resulting concentration in tissue are dependent on many factors, including soil properties, the contaminant distribution coefficient between soil and soil water, its octanol-water partitioning coefficient (K_{ow}, a measure of a chemical's lipophilicity, and indirectly of its ability to be taken up by plants); the rate of microbial degradation in the rhizosphere, the contaminant's transpiration stream concentration factor (TSCF, or the ratio of the concentration in the transpiration stream of the plant to the concentration in soil water – empirically related to the log K_{ow}), and the rate of diffusion of the contaminant from the plant tissue to the air. In order to properly predict plant uptake and its spatial and temporal variations, these factors need to be properly understood.

Sampling and analytical methods were described in previous years' reports. In 2009 analytes were trichloroethene (TCE), tetrachloroethene (PCE), carbon tetrachloride (CT) and chloroform (CF). Detection limits were 3 ng/g for chloroform and TCE, 0.04 ng/g for PCE, and 2.6 ng/g for CT. Monitoring of 1,1,1, trichloroethane (TCA) was discontinued due to its very limited detection in tree tissue in past years. Trichloroacetic acid (TCAA, a degradation product of TCE, PCE) is measured as chloroform after thermal decarboxylation and thus is not distinguishable from it.

Samples were collected from approximately every sixth tree (willows and poplars) at the 317 FD area, and downgradient hydraulic control area, starting with tree A10W and through row V. A total of 81 trees/day were sampled during the main campaign, for a total of three different days. In most cases, two branch samples were collected from each sampled tree. Two samples of leaves growing on the sampled branch were also collected from selected trees. While the current SOP calls for sampling the lowest available branch, low branches suitable for sampling have become limited in recent years, thus our samples had to be collected either from branches at a higher insertion point in the main trunk, or from the distal portion of large, low branches, which may have contributed to overall concentrations differences compared to the first growth years. Repeated sampling over the three-day period was done on branches from the same height and orientation of each tree. To ensure that the samples from each tree were as similar as possible, three contiguous branches of similar height and orientation were pre-selected and marked with field ribbon before starting the sample collection on the first day. Samples on all three days were collected at approximately the same time each day in the late morning period (between 10am and noon).

2) Sap Flow Measurements:

Since sap flow remains the best estimate of tree water uptake, measurement of sap flow using the thermal dissipation method is commonly used on trees due to its ease and relatively low cost to set up. The thermal dissipation method described by Granier (1985, 1987) utilizes two needles (probes) imbedded in sapwood, one pulse-heated and the other a reference, spaced at a known vertical distance. The reference needle gives a baseline temperature to compare with the heated needle's temperature dissipation caused by sap flow. When sap flow increases, the difference in temperature between the two probes decreases. The maximum temperature difference is at little to no flow. By measuring the difference in temperature between the heated and reference needle (via differences in voltage between thermocouples in each needle), sap velocity can be measured.

$$dT\ (°C) = \text{thermocouple differential voltage (in mV)} * 25$$

Where dT is the differential temperature between heated and reference needle.

Using the differential temperature (**dT**) and the maximum differential temperature (**dTM**) when there is no sap flow, Granier defined a dimensionless constant, **K** as:

$$K = (dTM – dT) / dT$$

When dT = 0, K = ∞. If dT = dTM (no sap flow), then K = 0.

Granier found that average sap flow velocity (**V**, in cm/sec) could be related to K by the following relationship:

$$V = 0.0119 * K^{1.231}$$

Furthermore, sap flow rate (**F**, in cm^3/hour or grams/hour) can be derived from the following equation:

$$F = A * V * 3600$$

Where **A** is the sapwood area (cm^2).

The sap flow monitoring system (Dynamax, Inc., Houston, TX) acquired in August of 2007 was used again this year and installed on thirteen poplar trees by ES personnel in the vicinity of MW 319171 in the Spring of 2009. New to this monitoring season was the use of longer (80 mm) probes to ascertain the sap flow within the more water-saturated heartwood of the trees. These two different types of thermal dissipation probes (TDP-30 and TDP-80) were installed on each tree again at breast height. Data from the probes were averaged to estimate total sap flow for sapwood area measured, assuming that flow is homogeneous. Data was recorded by a CR1000 datalogger in a weather-resistant housing. The sap flow system was powered by a solar panel with marine battery backup. This year, two batteries were used to help supply power to the more demanding long probes. Data collection ran from the period of May 8 to July 9, 2009, a similar period as in 2008. Four newly purchased TDP-80 probes, in addition to two from late last year, were installed on June 5 on five trees. One tree (S392P) was replicated with four 30 mm probes and two 80 mm probes to assess validity of the sap flow data being collected.

Tree diameters were taken for determination of basal area within the stand where sap flow was measured. Due to the relative genetic uniformity of trees planted, reasonably accurate stand level estimates of water use could be made for this season. Currently there are 542 poplar trees in the 317 and 319 Areas, covering approximately 1.15 hectares. Live stem counts, average diameter at breast height (DBH) and health of the willows in the 317 FD Area were not determined this year. Also, annual and perennial weed growth was excessive again this year especially within the willow stand of the 317 FD Area.

Results:

1) Site-wide VOC monitoring:

Figure 2 presents the contaminant plume map drawn using the tree branch samples collected during the years 2007 through 2009. The VOC tissue analysis results for contaminants in the hotspot near the vault area were compared for three years and the results are presented in Table 1. The full set of data collected from field sampling is reported in Appendix 1.

VOC concentration levels in leaf samples are also presented in Appendix 1. Once again overall leaf contaminant levels in both areas were very close to background levels (i.e., collected in the clean groundwater/soil background cells near Bldg. 485) further indicating that leaf data are primarily driven by background levels and not by uptake from soil or groundwater.

VOC data in branch tissue followed the established trend of being highest in the French Drain area and near the storage vaults (the source area), and decreasing as distance from the source area increased. This trend was similar for all years as seen from the contaminant maps.

The hydraulic control areas showed some non-detects but in general results in this area were in the 2-digit ppb range, with a few notable exceptions, such as those found in the north-eastern portion of the M row in the HC area within the fence. Results for PCE found in trees M296P (a new sampling point within the suspected hot spot) and M312P were in the 1000 ppb range this year. Carbon tetrachloride levels were almost twice as high near this hot spot this year than last year as well, whereas PCE levels were only slightly lower. In addition, higher levels of PCE than before were found in the O and P row trees near these two trees. This data further reinforces the probability of a nearby presence of a DNAPL pool.

During the sampling period, the ESQ Long-Term Stewardship program was operating pumps in the wells within the French drain area. These pumps removed between 500 and 1600 gallons of groundwater from each of the four wells. This groundwater extraction should have depressed the groundwater elevation near the wells, which may have changed the distribution of soil moisture and contaminants within the root zones of some of the trees, with some influence on the uptake of contaminants in 2009. During late 2008 similar pumps were installed on two of the four wells.

As previously discussed, many factors could contribute to the low values of VOCs found in the HC: low contamination levels in the groundwater, retardation by the backfill medium, and possibly biodegradation in the rhizosphere. None of these possible explanations has been thoroughly studied at this time. Because VOCs may be adsorbed and/or degraded in the organic-richer backfill rhizosphere of the TreeWell® trees before they actually reach the roots, non-detects do not necessarily imply that the roots have not reached the groundwater. Likewise, some of the low levels found do not necessarily prove contact with groundwater as they are not different from background concentrations. Background concentrations of TCE, PCE and CCl_4 were notably high on a few days this year in both leaf and branch samples, possibly leading to further confounding of estimation of the phytoremediation system's soil decontamination.

Differences in branch VOC concentrations may have many reasons. Since the height of sample collection influences contaminant concentrations (the lower the branch, the higher the concentration), and since with time low branches have become scarcer, samples collected in recent years may not compare well with those collected in earlier years when low branches were almost exclusively sampled. Other differences in branch concentrations may be caused by dilution and diffusion (as the trees grow larger, the contaminants may be diluted in the larger biomass volume. In addition, as branches grow large, samples must be taken from distal branch portions, where there are more opportunities for VOCs to escape by diffusion). An additional possible reason for differences in branch concentration is the temporal variability in soil and groundwater concentrations (supply and equilibrium), resulting in different concentrations in the tree branches depending on the day when samples were collected. Finally, phytotoxicity may locally depress transpiration rates and thus uptake. This may play a role locally, considering that many French Drain Area willow trees have appeared to become quite stressed and unhealthy in recent years as the summer progressed. Without soil and root samples being collected, reasons for the willow trees' midsummer decline are debatable.

The site-wide temporal series analysis provided interesting results: a high level of variability was found in the branch concentrations within a few days. This short-term variability was most pronounced in the hotspots where levels can fluctuate by an order of magnitude (see Figure 3). Where the concentrations were low, the variability was present but it was within sampling and analytical error. This seems to tell us that the interactions between soil processes for the contaminants (TCE, PCE and CCl_4) and plant root interactions are the primary factors responsible for the fluctuation.

Because of the close similarity among the three samples from each tree, and in light of our greenhouse and hydroponic experiments in previous years, we hypothesize that the primary reason for the variability is the partitioning, desorption and uptake processes between the soil water and the roots. Under this hypothesis, it would appear that the trees are drawing out the soil water faster than the lag between the desorption of the TCE in the soil particles and the replenishment of the soil water. How that affects the rhizospheric bacteria and the degradation of TCE in the soil is an open question. Importantly however, these concentration fluctuations point at a localized, short-term depletion of contaminants in the area of interest of tree roots. This data is important as it may allow us to estimate how much contaminant the trees are capable of removing – which, in turn, will give us an estimate of the performance of the phytoremediation system. In short, the short-term variability will let us know how much of a slug of TCE/PCE is being removed within a couple of days by the trees. Coupled with the sap flow rates data, it will allow us to calculate stand-wide removal rates.

2) Sap Flow Measurements:

Since measuring sap flow is currently the best estimate of tree water usage, it is commonly used to estimate hydraulic control by a phytoremediation installation. For 2009, sap flow was measured on many of the same poplar trees in the vicinity of MW 319171 as the previous two years. Sap flow data in the 319 Area is of interest because this site has the greatest number of trees of the largest diameter, hence should exact the greatest hydraulic control.

For the 319 Area, thirteen hybrid poplar trees in the vicinity of MW 319171 were monitored from May 8 to July 9, 2009, from the beginning to the height of the transpirative period. All of these trees were the same used in 2008, but several of them had multiple probes installed at varying heights and orientation to test system accuracy**.** Sap flow data was quite similar on trees with multiple probes mounted at varying heights and direction (see Figure 5). Trees measured for sap flow in this area had aDBH of 23 cm, four cm larger compared to 2008, which was only one cm greater than 2007. Average monthly temperatures for May and June were respectively 1.6°C and 5°C higher than last year. Monthly total precipitation for May and June was -3 and +5 mm respectively for 2009 compared to 2008.

The health of the trees has not changed significantly since last year, although many of the HP 510 (=NE 41) variety in the 317 HC area are more greatly affected by canker and winter-kill. For the HP 308 (=NE 308) variety, most of the trees have canker-killed lower branches. Several of the trees also have broken tops from wind damage of canker-weakened wood. The prevalence of dead branches from disease and/or shading only increases disease reinoculation within the site and may ultimately affect long-term performance. Generally the trees that have shown the lowest sap flow and flux have had the most canker and dead branches around the area probed as well as being the smallest DBH.

Collecting sap flow measurements in the 319 Area for 2009 offered perhaps more accurate data compared to previous years', because we were able to measure heartwood sap flow. Average sap flow, flux and tree diameters for the thirteen trees measured in the 319 Area for 2008-09 are shown in Table 2. A few cores were taken again this year to ascertain the extent of the sapwood area. In the six samples taken, all the trees showed active, moist live wood inside the bark layer to the center. Four of the six trees cored actively hissed and dripped copious amounts of sap when the sapwood-heartwood boundary was reached. The outer, drier sapwood comprises roughly 76% of the total wood area (minus bark). Analyzing data collected this year, this sapwood has an average flow of 42% greater and an average flux of 60% greater than that of the inner, more saturated heartwood

The inner heartwood has been shown in the past to hold roughly twice as much water by weight via oven drying cores. Since previously we did not have the ability to measure sap flow within this deeper wood, we had either estimated assuming it had sap velocity equal to that of the outer sap wood, or assumed it was not actively transporting any significant amount of water, but rather just storing it. The data collected this year confirmed that the inner sapwood is less actively transporting water.

Comparing diurnal sap flow between the two different depths of wood measured (see Table 3), mean sap flow at 15 mm deep (from bark face) generally peaked at about 2 to 3 pm and was minimal at 1 to 2 am. Maximum sap flow was recorded by the 70mm deep probes a few hours later (5 to 6 pm), the minimum at 3 to 8 am (see Figure 6). This lag time between the two different depths may partly be explained by the tree's roots not being able to take up water fast enough during peak daytime transpiration. Therefore the tree may be radially redistributing water from the deeper, wetter heartwood outwards to keep up with transpiration, as this water may be more easily accessible than vadose water (via shallow roots) or groundwater (via sinker roots). In other words, during the day, the trees may not be able to meet all transpiration demand via direct root uptake of water but rather may be taking excess water stored in the deeper xylem. This deeper xylem may be recharged at night then (as shown by sapflow data) restoring water potential gradients. Poplars in this setting would not be significantly closing stomata at night (a typical dark response) nor during the day (typical drought response) ensuring that the tree is always removing water from the ground. Note that tree night transpiration may actually be quite high, from of 5-30% of total transpiration (from other studies).

Interestingly, on a 24 hour basis sap never completely ceased flowing in the heartwood. Nighttime flow in the heartwood suggests a cyclic recharge of this deeper wood occurring, regardless of decreases in vapor pressure deficit and transpiration during the night. Similar tree sap flow studies have shown water recharge of deeper xylem to occur during the night (Fischer et al 2007). Hydraulic redistribution may also be an indirect contribution to nighttime sap flow, but the marked decrease in outer wood sap flow during the night may contradict this, unless the trees are separating xylem water dynamics around the soil line.

In 2008 we assumed that the total stem area minus bark was actively moving water, therefore a typical poplar tree in the site transpired 108 L/day on average, to a maximum of 176 L/day. This was calculated by using the measured sap flux multiplied by total wood area (not including bark). In 2009, using combined measured sap flow from sapwood (outer xylem) and heartwood (inner xylem) we estimate that each tree transpired an average of 163 L/day up to a maximum of 253 L/day. The last two days of sap flow data collection (July 8-9) yielded the highest daily total flows of the season: 176 and 186 L/day/tree average up to a maximum of 327 and 348 L/day/tree respectively.

For the 319 HC Area as a whole, the ca. 160 poplar trees therefore removed an average of 26 kL/day up to a maximum of 46.5 kL/day for this 62 day period. For a stand estimation, assuming a 200 day growing season (April 20 – Nov 6) and a stand density of 472 trees/ha, poplars in the 319 HC Area may have removed an average of 600 mm/yr, up to a maximum of 1.7 m/yr.

For the 317 HC Area the ca. 382 trees removed an average of 62.1 kL/day up to a maximum of almost 96.6 kL/day. Again, assuming a 200 day growing season and above stand density, the 317 HC poplars may have removed an average of 1.4 m/yr up to a maximum of 2.2 m/yr. High variability in measured sap flow, low sample size and lack of tree data, especially for willows (stem count, DBH, health) in the FD Area prevents accurate stand estimations for water removal at this time.

Using extrapolated poplar data, the entire installation of 542 poplar trees in both the 317 and 319 HC Areas may have transpired an approximate average of 88.2 kL/day, up to a maximum of 137kL/day. Again assuming a 200 day growing season, the poplar stands in the 317 and 319 HC Areas combined may have transpired an average of 2.0 m/year, up to a maximum of 3.1 m/yr

Conclusions:

As the 317 and 391 Area trees completed their tenth growing season in the field, a significant amount of information has been collected to assess their performance at achieving the remedial objectives. From this data, the trees appear to be influencing the cleanup area. Quantitative assessments of this influence need to be evaluated in concert with other parts of the monitoring efforts.

Based on this year's monitoring results, the following conclusions can be drawn:

- VOC data in branch tissue during the 2009 season tended to be comparable or slightly lower than data from 2008. The only exception for 2009 is an overall increase in average CCl_4. VOCs were highest in the French Drain (source) area, and decreased as distance from the source area increased. VOC leaf data once again was very close to background, further indicating that leaf uptake is data are primarily driven by background levels and not by uptake from soil or groundwater.
- Over a period of only six days, branch concentrations of VOCs showed marked fluctuations in the trees sampled. This short-term variability was found to be most pronounced in the hotspots where levels fluctuated by an order of magnitude. Where the concentrations were low, the variability was still present but within sampling and analytical error. This seems to tell us that the interactions between soil processes for TCE and plant root interactions are the primary factors responsible for the fluctuations recorded.
- Most of the willow trees once again have grown poorly this year, with more decline and death, for reasons still uninvestigated. Whether it is from lack of water, direct soil toxicity from VOC's or VOC breakdown by-products is unknown.
- Poplars grew on average four cm DBH since last year in the 319 Area, compared to one cm between 2007 and 2008. Higher monthly average temperatures, solar radiation and precipitation for both May and June 2009 are most likely the cause.
- Measured sap flow (of outer wood) in the 319 HC Area was 47% higher in 2009 than 2008 for the period June 4 to July 9. For 2009, measured whole tree flow (all wood) was 34% higher than the 2008 whole tree estimate. Sap flow was 53% greater at 15mm depth than at the 70mm depth, and sap flux was 75% greater at 15mm than 70mm with only a 24% difference in wood area. Mean daily sap flow generally peaked at 2-3 pm at 15mm depth probe and peaked at 5-6 pm for the 70mm deep probe. Sap flow in the deeper wood occurred around the clock, possibly indicating that the trees are continually depleting and recharging this water-saturated wood. How much this flow may be affected by night transpiration or soil hydraulic redistribution is unknown.

Acknowledgements:

We gratefully acknowledge Norbert Golchert, Larry Moos, Rob Piorkowski, of Argonne/ESQ for the support, and Sabeen Ahmad of ES for the invaluable laboratory help.

References:

Fisher, J., Baldocchi, D., Misson, L., Dawson, T. and Goldstein, A. (2007) *What the towers don't see at night: nocturnal sap flow in trees and shrubs at two AmeriFlux sites in Calfifornia.* Tree Phys., 27:597-610.

Gopalakrishnan G, M.C. Negri, B.S. Minsker and C.J. Werth (2007). *Monitoring Subsurface Contamination Using Tree Branches.* Groundwater Monitoring and Remediation 27 (1) pp. 65-74.

Granier, A. (1985) Une nouvelle méthode pour la mesure du flux de sève brute dans le tronc des arbres. Annal. Sci. Forest. 42, 193–200.

Granier, A. 1987. *Evaluation of transpiration in a Douglas fir stand by means of sap flow measurements.* Tree Phys., 3:309-320.

Hinckley, T., Brooks, J., Cermak, J., Ceulemans, R., Kucera, J., Meinzer, F., *et al*. (1994) *Water flux in a hybrid poplar stand*. Tree Physiology 14:1005-18.

Howard, A., Iersel, M., Richards, J. and Donovan, L. (2009) *Night-time transpiration can decrease hydraulic redistribution.* Pl. Cell & Env. 32:1060-1070.

Ma, X., and J.C. Burken (2003), *TCE Diffusion to the Atmosphere in Phytoremediation Applications.* Environ. Sci. Technol. 37, 2534-2539.

Newman L.A., X. Wang, I.A. Muiznieks, G. Ekuan, M. Ruszaj, R. Cortellucci, D. Domroes, G. Karescig, T. Newman, R.S. Crampton, R.A. Hashmonay, M.G. Yost, P.E Heilman, J. Duffy, M. Gordon, and S.E. Strand (1999), *Remediation of Trichloroethylene in an Artificial Aquifer with Trees: A Controlled Field Study*, Environ. Sci Technol. 33:2257-2265.

Newman, L.A., S.E. Strand, N. Choe, J. Duffy, G. Ekuan, M. Ruszaj, B.B. Shurtleff, J. Wilmoth, P. Heilman, and M. Gordon (1997), *Uptake and Transformation of Trichloroethylene by Hybrid Poplars*, Env. Sci. Technol. 31, 4:1062:1067.

Nietch C.T., J.T. Morris, and D.A. Vroblesky (1999) *Biophysical Mechanisms of Trichloroethene Uptake and Loss in Baldcypress Growing in Shallow Contaminated Groundwater*, Environ. Sci. Technol. 33:2899-2904.

Nzengung, V.A. (2001), *Sequestration, Phytoreduction, and Phytooxidation of Halogenated Organic Chemicals by Aquatic and Terrestrial Plants*, Int. J. of Phyto. 3, 1:13-40.

Phillips, N., Oren, R. and Zimmermann, R. (1996) *Radial patterns of xylem sap flow in non-, diffuse- and ring-porous tree species.* Pl. Cell Env. 19:983-990.

Schroth, G. & F.L. Sinclair, Eds. (2003) *Trees, Crops and Soil Fertility: Concepts and Research Methods.* CABI Publishing, Wallingford.

Vroblesky D.A., C.T. Nietch, and J.T. Morris (1999), *Chlorinated Ethenes from Groundwater in Tree Trunks*, Environ. Sci Technol. 33:510-515.

Vose, J., Swank, W., Harvey, G., Clinton, B. and Sobek, C. (2000) *Leaf water relations and sap flow in Eastern cottonwood (P. deltoides) Trees planted for phytoremediation of a groundwater pollutant.* Int. J. Phytorem. 2, 1: 53-73.

Vose, J., Harvey, G., Elliott, K. and Clinton, B. (2003) *Measuring and modeling tree and stand level transpiration.* In: McCutcheon & Schnoor, eds. Phytoremediation: transformation and control of contaminants. Wiley, New York.

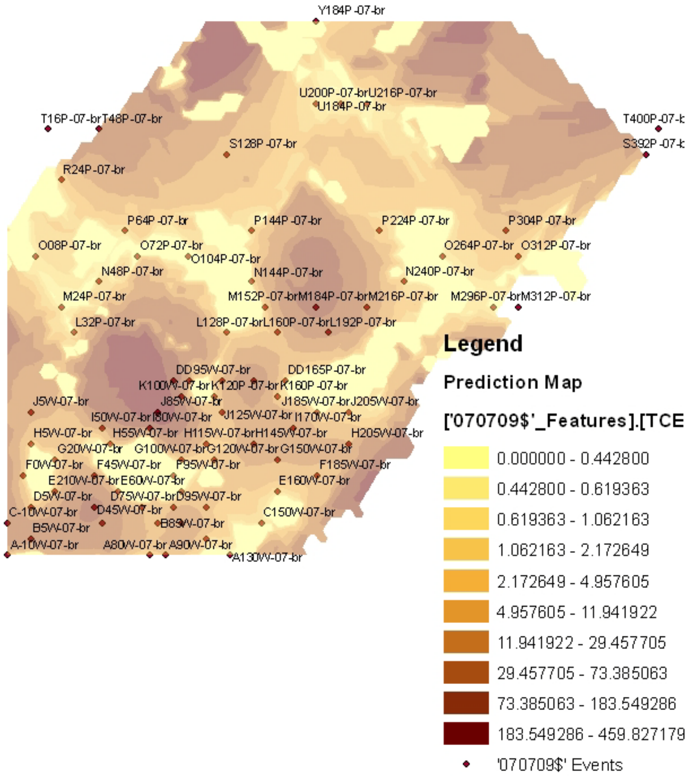
Wullschleger, S. and King, A. (2000) *Radial variation in sap velocity as a function of stem diameter and sapwood thickness in yellow-poplar trees.* Tree Phys. 20: 511-518.

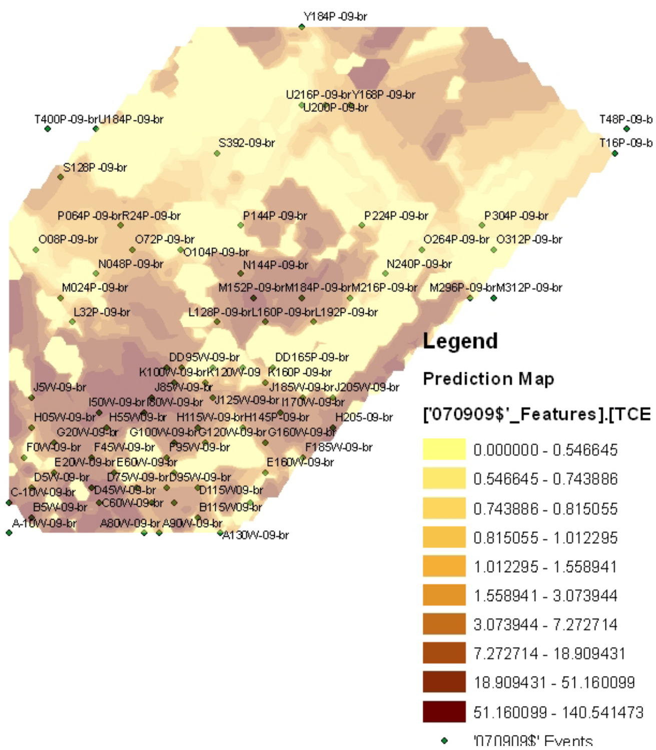
Zalesny, R.A. Jr, Wiese, A.H, Bauer, E.O. and Riemenschneider, D.E. (2006) *Sap flow of hybrid poplar (Populus nigra L.×P. maximowiczii A. Henry 'NM6') during phytoremediation of landfill leachate.* Biomass and Bioenergy**.** 30, 8-9: 784-793.

Figure 1: Aerial Pictures of the 317/319 Area, 2001 and 2006. Each tree in this area was given a specific coordinate number composed of row lettering and a numbering. Row lettering start from top row (N) and numbering increases from left to right (W to E).

Figure 2: TCE and PCE Contaminant plume maps from tree branch tissue in the 317 Area for 2009.

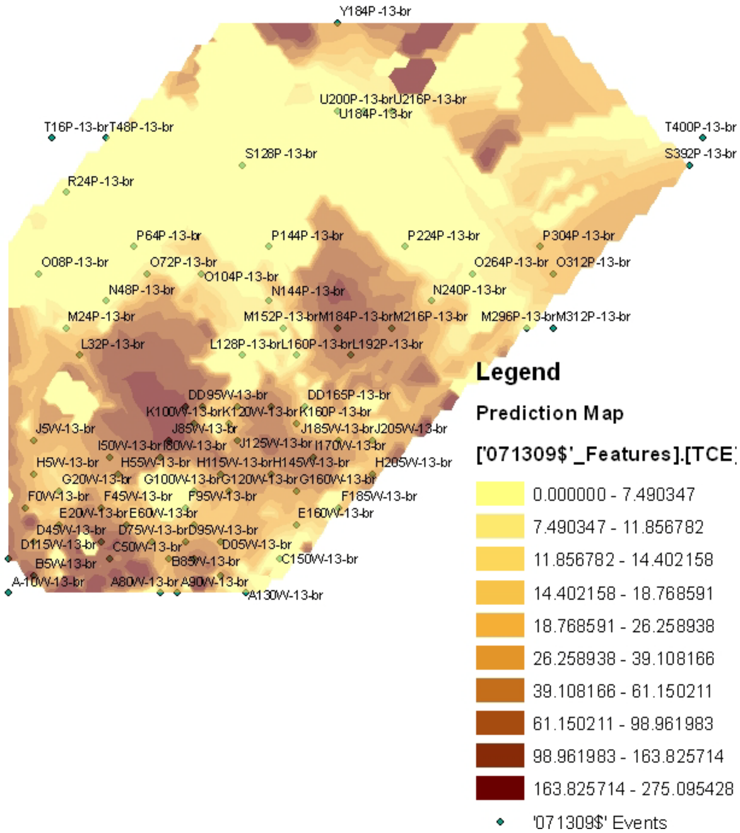
TCE plume map for 7/7/09

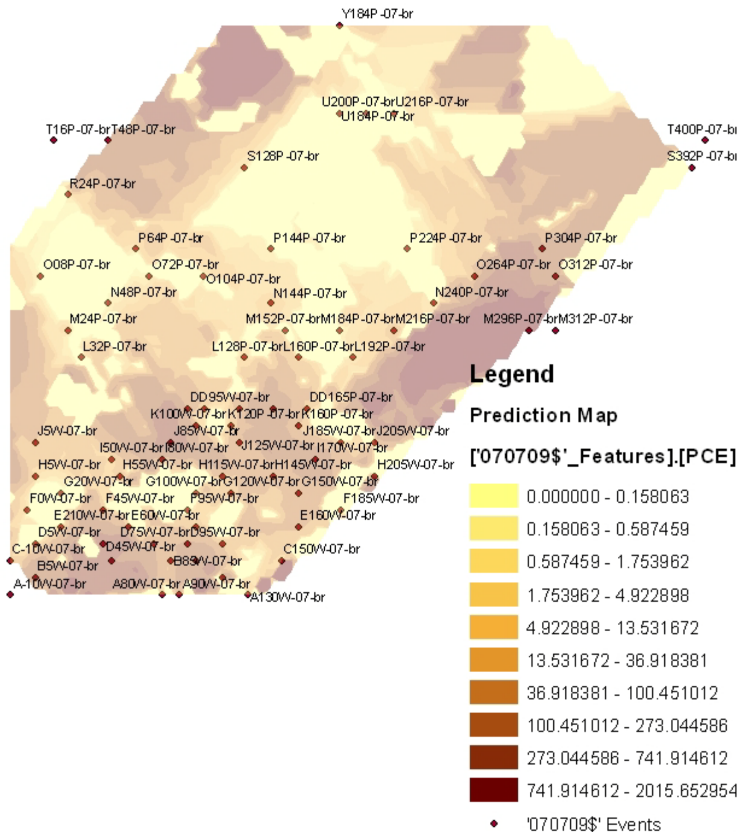




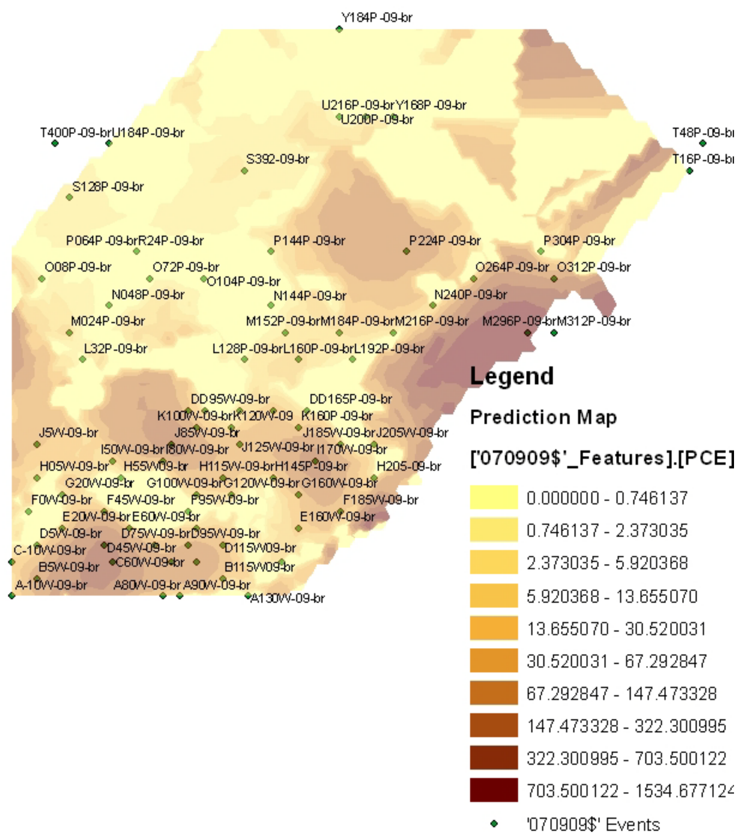
TCE plume map 7/9/09

TCE plume map 7/13/09

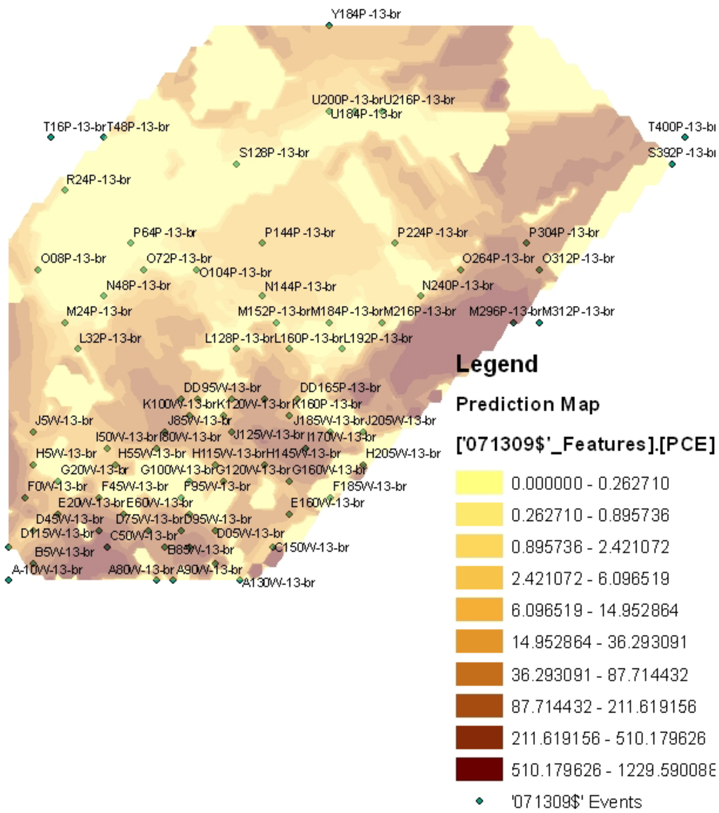




PCE plume map 7/7/09



PCE plume map 7/9/09



PCE plume map 7/13/09

Figure 3 a,b,c: Mean VOC branch levels of trees growing in hot spots near 317 vaults on three vegetation sampling dates in July 2009.

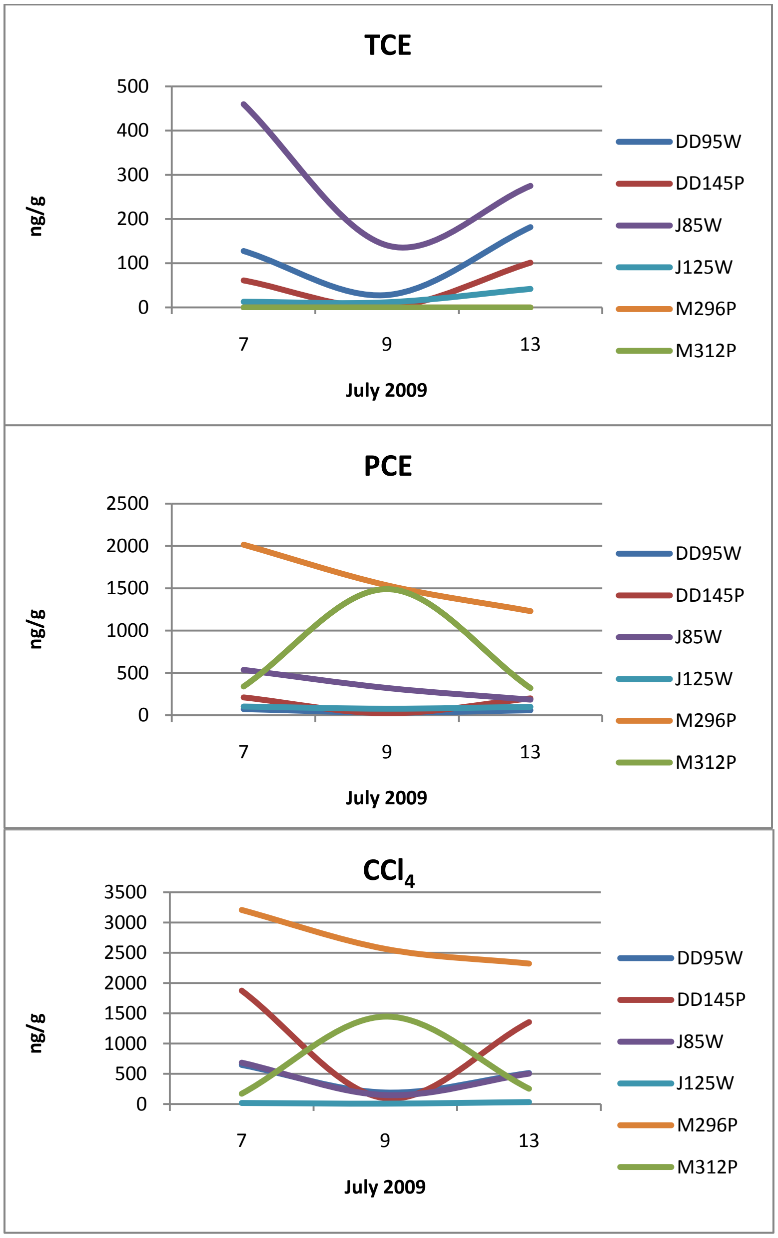


Figure 4. Selected daily average meteorological data from Argonne weather station for July 1 - 13, 2009.

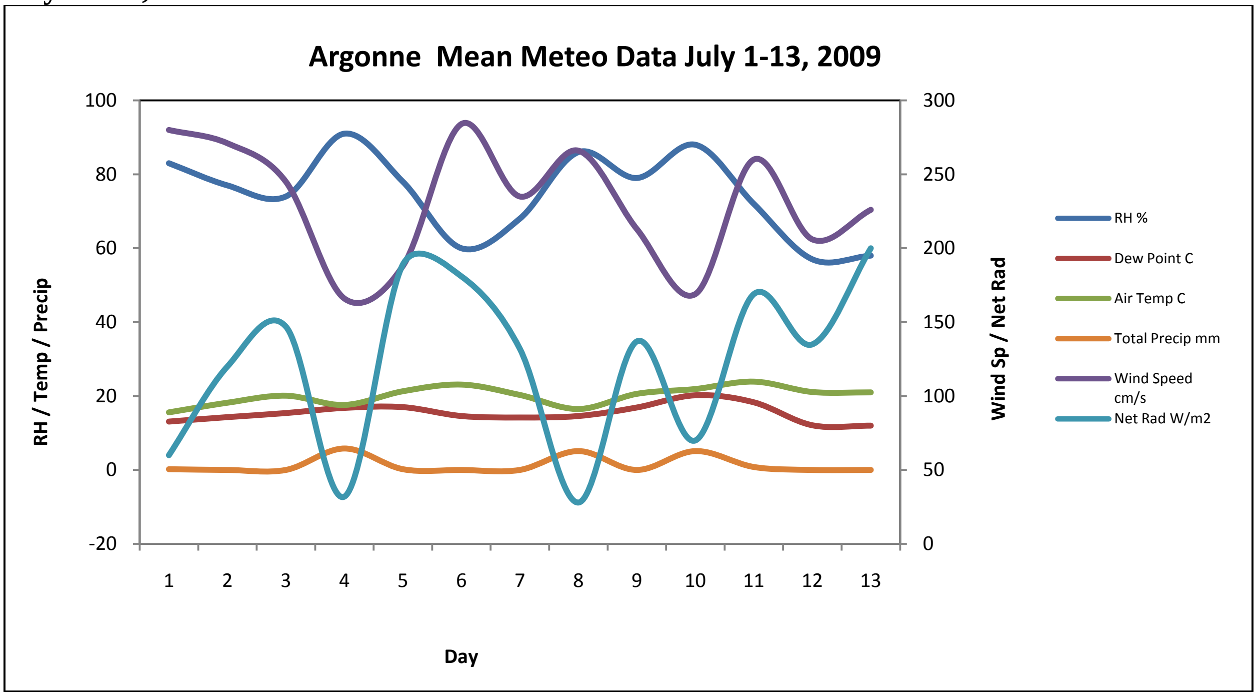


Figure 5: Comparison of diurnal sap flow over eight days for three TDP30 probes (15mm depth) mounted at three different heights and orientation on hybrid poplar tree in 319 HC Area. Time period is June 4-11, 2009.

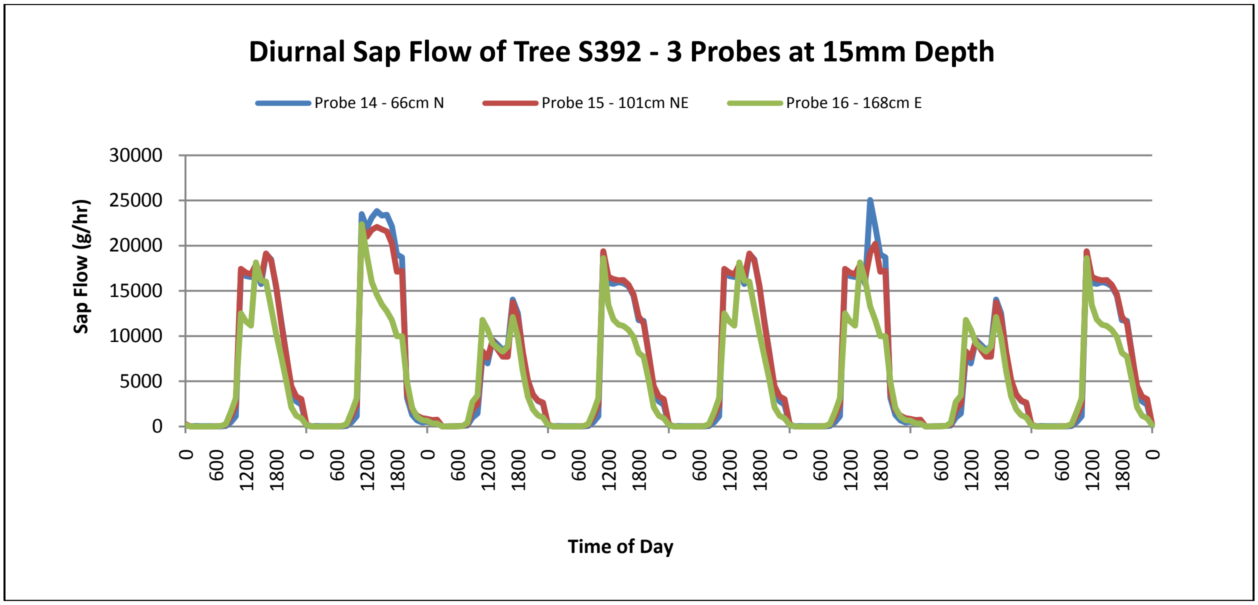


Figure 6: Typical diurnal sap flow showing difference in flow and timing between shallower and deeper woods of a hybrid poplar in 319 HC Area. Time period is June 4-11, 2009.

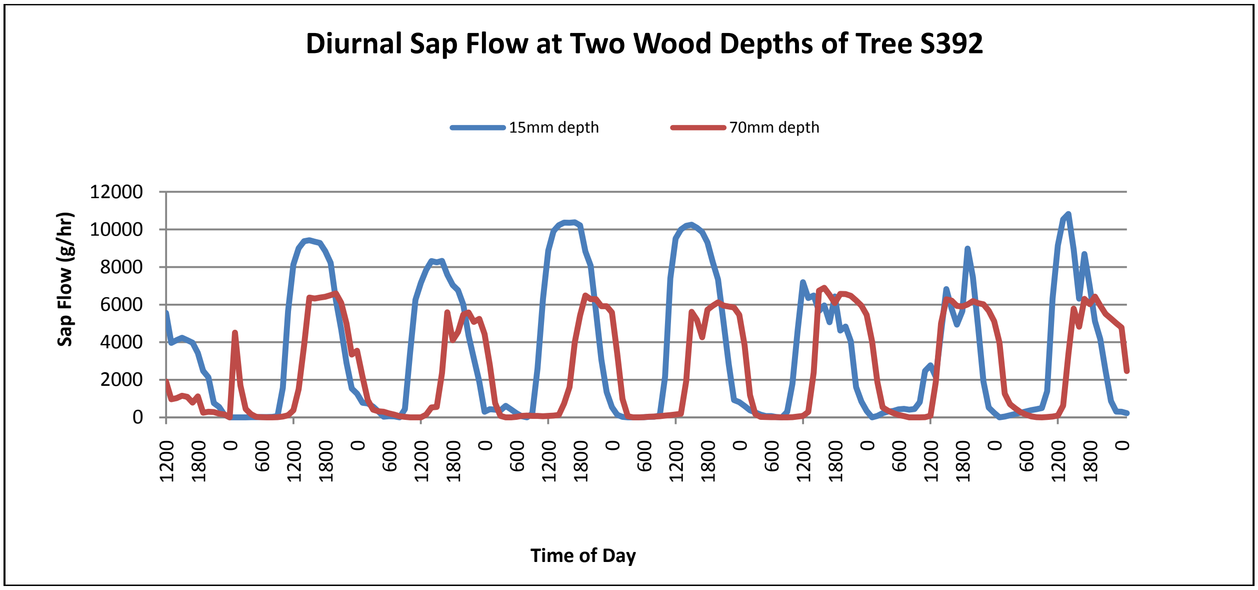


Table 1: Mean VOC concentrations in branch samples collected from trees in two hot spots in the 317 Area. Control is in vicinity of Bldg 485*.

Year	2007 (ng/g)				2008 (ng/g)				2009 (ng/g)			
Sample ID	TCE	PCE	1,1,1 TCA	CCl4	TCE	PCE	1,1,1 TCA	CCl4	TCE	PCE	1,1,1 TCA	CCl4
DD145W	7	7	0	0	92	249	0	301	54	144	0	1109
DD95W	106	35	0	123	250	98	0	85	112	54	0	452
J85W	81	20	0	56	108	229	0	211	292	347	0	445
K100W	36	17	0	15	53	83	0	68	32	32	0	13
K120W	9	4	0	3	0	2	0	0	8	4	0	9
M296P	-	-	-	-	-	-	-	-	0	1593	0	2698
M312P	3	125	0	145	8	1940	0	1473	0	716	0	625
Control	*4*	*0*	*0*	*2*	*0*	*1*	*0*	*0*	*13*	*73*	*0*	*6*

*As seen from the biomaps in Figure 2, there are significant differences between contaminant concentrations based on the day that the samples were collected. Thus, this table illustrates the areas where the contaminant hotspots are present; values of contaminant concentrations are inherently uncertain as a result of the temporal variability and may differ significantly from year-to-year.

Table 2: DBH, mean sap flows and sap flux for thirteen hybrid poplar trees in the 319 Area sampled from June 4-July 9, 2008 and 2009.

	2008			2009		
Tree	**DBH (cm)**	**Total Wood Sap Flow (L/day)**	**Sap Flux (g/d-cm^2)**	**DBH (cm)**	**Total Wood Sap Flow (L/day)**	**Sap Flux (g/d-cm^2)**
Q392	18.2	70.1	12.6	21.6	156.7	19.6
Q408	15.9	109.5	26.2	18.4	181.1	31.7
R384	20.6	156.2	21.6	23.5	192.4	20.2
R400	18.8	51.8	8.7	22.0	123.8	14.9
R416	22.9	131.2	14.5	29.3	216.7	14.4
S360	17.3	57.3	11.4	19.0	76.8	12.6
S376	18.5	188.3	32.6	21.5	248.8	31.4
S392	19.8	188.4	28.3	22.8	183.6	20.5
S408	20.1	91.6	13.3	26.2	203.7	22.3
S424	20.6	193.5	26.7	23.0	181.0	15.1
T400	21.0	82.3	10.9	22.0	148.6	17.9
T416	18.3	82.6	14.6	22.2	142.6	16.8
T432	17.3	144.5	28.9	21.0	203.1	26.9
Mean	**19.2**	**121.7**	**19.6**	**23.2**	**173.7**	**20.3**
Min	**15.9**	**34.4**	**6.2**	**18.4**	**76.8**	**12.6**
Max	**22.9**	**219.8**	**32.7**	**29.3**	**248.4**	**31.7**
StDev	*3.5*	*57.5*	*9.0*	*2.7*	*44.3*	*6.3*

Note: Total wood sap flow is estimated sap flow for whole tree diameter minus bark. Sap flux is mean measured flux by probes. For 2008, total sap flow was estimated using total wood area and measured flux; for 2009 total sap flow is sum of outer and inner woods' flows.

Table 3: Comparison of mean daily sap flow and sap flux at two different wood depths, June 4-July 9, 2009.

	15 mm depth (n=25)			70 mm depth (n=5)		
	Wood Area (cm2)	**Mean Sap Flow (L/day)**	**Sap Flux (g/cm^2-hr**	**Wood Area (cm2)**	**Mean Sap Flow (L/day)**	**Sap Flux (g/cm^2-hr)**
Mean	244.1	114.8	20.1	181.2	48.0	12.2
Min	152.2	42.3	10.2	127.1	34.3	11.2
Max	402.6	174.8	34.5	238.9	78.0	14.4
StDev	*62.6*	*34.9*	*6.6*	*51.2*	*18.4*	*1.3*

Appendix 1 - Summer 2009 Field Data: VOCs in plant tissue from field samples (ng/g dry weight).

Branch Samples Tree ID	**Date**	**TCAA+ $CHCl_3$**	**TCE**	**PCE**	**CCl4**
A-10W-07-br	7/7/2009	7	1	5	2
A-10W-09-br	7/9/2009	2	0	4	1
A-10W-13-br	7/13/2009	0	17	3	21
A130W-07-br	7/7/2009	5	1	1	2
A130W-09-br	7/9/2009	17	1	0	3
A130W-13-br	7/13/2009	0	11	1	16
A80W-07-br	7/7/2009	9	1	4	3
A80W-09-br	7/9/2009	8	1	2	3
A80W-13-br	7/13/2009	0	18	3	13
A90W-07-br	7/7/2009	11	5	9	2
A90W-09-br	7/9/2009	8	1	2	2
A90W-13-br	7/13/2009	0	21	4	23
B115W-07-br	7/7/2009	3	0	10	1
B115W09-br	7/9/2009	10	1	8	1
B115W-13-br	7/13/2009	0	20	17	17
B5W-07-br	*7/7/2009*	*13*	*47*	*123*	*1*
B5W-09-br	*7/9/2009*	*7*	*41*	*104*	*1*
B5W-13-br	*7/13/2009*	*82*	*74*	*120*	*21*
B85W-07-br	7/7/2009	10	4	38	2
B85W-09-br	7/9/2009	8	7	73	13
B85W-13-br	7/13/2009	64	28	80	18
C100W-07-br	*7/7/2009*	*14*	*36*	*324*	*1*
C100W-09-br	*7/9/2009*	*12*	*20*	*189*	*2*
C100W-13-br	*7/13/2009*	*82*	*88*	*490*	*17*
C-10W-07-br	7/7/2009	52	69	17	1
C-10W-09-br	7/9/2009	34	65	18	1
C-10W-13-br	7/13/2009	163	135	21	21
C150W-07-br	7/7/2009	16	1	5	2
C150W-09-br	7/9/2009	13	1	2	2
C150W-13-br	7/13/2009	171	0	3	25
C50W-07-0br	*7/7/2009*	*21*	*50*	*477*	*2*
C50W-09-br	*7/9/2009*	*7*	*36*	*386*	*2*
C50W-13-br	*7/13/2009*	*74*	*122*	*742*	*20*
D115W-07-br	7/7/2009	14	7	30	2
D115W09-br	7/9/2009	12	8	40	2
D115W-13-br	7/13/2009	81	36	68	20
D45W-07-br	*7/7/2009*	*22*	*115*	*473*	*1*
D45W-09-br	*7/9/2009*	*12*	*83*	*422*	*3*

Branch Samples Tree ID	**Date**	**TCAA+ $CHCl_3$**	**TCE**	**PCE**	**CCl4**
D45W-13-br	*7/13/2009*	*82*	*169*	*521*	*16*
D5W-07-br	7/7/2009	9	1	1	2
D5W-09-br	7/9/2009	10	1	0	2
D5W-13-br	7/13/2009	68	22	2	24
D75W-07-br	*7/7/2009*	*17*	*13*	*104*	*2*
D75W-09-br	*7/9/2009*	*16*	*4*	*52*	*5*
D75W-13-br	*7/13/2009*	*72*	*40*	*120*	*22*
D95W-07-br	*7/7/2009*	*16*	*11*	*99*	*3*
D95W-09-br	*7/9/2009*	*7*	*6*	*83*	*1*
D95W-13-br	*7/13/2009*	*60*	*35*	*127*	*23*
DD105P-07-br	7/7/2009	62	6	6	8
DD105P-09-br	7/9/2009	37	3	4	5
DD105P-13-br	7/13/2009	150	33	5	27
DD125P-09-br	7/9/2009	343	1	10	30
DD125P-07-br	7/7/2009	2304	16	45	271
DD125P-13-br	7/13/2009	690	25	17	80
DD145P-07-br	*7/7/2009*	*6352*	*61*	*210*	*1876*
DD145P-09-br	*7/9/2009*	*473*	*1*	*22*	*96*
DD145P-13-br	*7/13/2009*	*6183*	*101*	*199*	*1355*
DD165P-07-br	7/7/2009	307	0	14	174
DD165P-09-br	7/9/2009	69	1	2	9
DD165P-13-br	7/13/2009	882	818	11	830
DD95W-07-br	7/7/2009	1429	128	72	649
DD95W-09-br	7/9/2009	485	28	32	192
DD95W-13-br	7/13/2009	1337	182	58	514
E100W-07-br	7/7/2009	10	1	24	2
E100W-09-br	7/9/2009	8	1	8	3
E100W-13-br	7/13/2009	68	25	12	25
E160W-07-br	7/7/2009	3	0	42	1
E160W-09-br	7/9/2009	13	1	22	3
E160W-13-br	7/13/2009	0	16	41	26
E20W-07-br	7/7/2009	9	1	0	2
E20W-09-br	7/9/2009	11	1	0	1
E20W-13-br	7/13/2009	62	35	40	7
E60W-07-br	7/7/2009	0	1	7	4
E60W-09-br	7/9/2009	11	4	7	4
E60W-13-br	7/13/2009	0	29	12	26
F0W-07-br	7/7/2009	11	1	0	2
F0W-09-br	7/9/2009	11	1	0	1
F0W-13-br	7/13/2009	69	41	74	22
F185W-07-br	7/7/2009	23	8	26	8

Branch Samples Tree ID	**Date**	**TCAA+ $CHCl_3$**	**TCE**	**PCE**	**CCl4**
F185W-09-br	7/9/2009	30	10	41	6
F185W-13-br	7/13/2009	73	21	15	17
F45W-07-br	7/7/2009	17	26	24	3
F45W-09-br	7/9/2009	1260	19	25	6
F45W-13-br	7/13/2009	54	45	14	19
F95W-07-br	7/7/2009	0	1	0	3
F95W-09-br	7/9/2009	18	8	4	2
F95W-13-br	7/13/2009	12	11	2	11
G100W-07-br	7/7/2009	14	1	6	1
G100W-09-br	7/9/2009	0	24	2	25
G100W-13-br	7/13/2009	0	15	1	16
G120W-07-br	7/7/2009	13	7	34	1
G120W-09-br	7/9/2009	14	1	7	3
G120W-13-br	7/13/2009	44	34	19	28
G160W-07-br	7/7/2009	103	12	47	13
G160W-09-br	7/9/2009	65	7	31	12
G160W-13-br	7/13/2009	0	33	34	35
G20W-07-br	7/7/2009	11	1	0	1
G20W-09-br	7/9/2009	22	15	1	23
G20W-13-br	7/13/2009	0	14	0	20
H115W-07-br	7/7/2009	14	1	7	0
H115W-09-br	7/9/2009	9	0	3	1
H115W-13-br	7/13/2009	69	35	3	24
H145P-09-br	7/9/2009	8	18	42	0
H145W-07-br	7/7/2009	12	20	47	13
H145W-13-br	7/13/2009	59	49	69	0
H205-09-br	7/9/2009	0	1	0	2
H205W-07-br	7/7/2009	6	13	29	2
H205W-13-br	7/13/2009	349	37	27	0
H55W-07-br	7/7/2009	10	4	8	2
H55W09-br	7/9/2009	113	56	4	32
H55W-13-br	7/13/2009	0	33	13	28
H5W-07-br	7/7/2009	9	1	3	2
H5W-09-br	7/9/2009	61	24	1	28
H5W-13-br	7/13/2009	0	25	1	30
I170W-07-br	*7/7/2009*	*39*	*34*	*185*	*2*
I170W-09-br	*7/9/2009*	*32*	*32*	*247*	*3*
I170W-13-br	*7/13/2009*	*129*	*104*	*550*	*17*
I50W-07-br	7/7/2009	12	11	7	3
I50W-09-br	7/9/2009	83	62	10	25
I50W-13-br	7/13/2009	77	46	4	14

Branch Samples Tree ID	**Date**	**TCAA+ $CHCl_3$**	**TCE**	**PCE**	**CCl4**
I80W-07-br	7/7/2009	8	5	6	2
I80W-09-br	7/9/2009	84	35	5	17
I80W-13-br	7/13/2009	0	34	3	19
J125W-07-br	*7/7/2009*	*1653*	*13*	*102*	*18*
J125W-09-br	*7/9/2009*	*920*	*12*	*77*	*8*
J125W-13-br	*7/13/2009*	*976*	*42*	*99*	*33*
J185W-07-br	7/7/2009	13	1	5	2
J185W-09-br	7/9/2009	8	1	3	2
J185W-13-br	7/13/2009	27	21	1	13
J205W-07-br	7/7/2009	16	1	4	3
J205W-09-br	7/9/2009	9	1	4	2
J205W-13-br	7/13/2009	52	21	3	13
J5W-07-br	7/7/2009	20	18	35	5
J5W-09-br	7/9/2009	9	14	34	1
J5W-13-br	7/13/2009	66	28	19	11
J85W-07-br	*7/7/2009*	*3686*	*460*	*536*	*685*
J85W-09-br	*7/9/2009*	*798*	*141*	*322*	*148*
J85W-13-br	*7/13/2009*	*3194*	*275*	*184*	*503*
K100W-07-br	7/7/2009	106	19	29	2
K100W-09-br	7/9/2009	84	19	40	2
K100W-13-br	7/13/2009	237	58	26	35
K120P-07-br	7/7/2009	21	1	9	3
K120W-09-br	7/9/2009	7	1	0	2
K120W-13-br	7/13/2009	74	22	2	23
K160P-07-br	7/7/2009	347	1	38	45
K160P-09-br	7/9/2009	208	2	28	23
K160P-13-br	7/13/2009	370	27	26	57
L128P-07-br	7/7/2009	1	2	5	7
L128P-09-br	7/9/2009	7	1	1	2
L128P-13-br	7/13/2009	0	0	2	77
L160P-07-br	7/7/2009	0	3	0	23
L160P-09-br	7/9/2009	0	6	8	169
L160P-13-br	7/13/2009	0	0	1	16
L192P-07-br	7/7/2009	0	35	0	3
L192P-09-br	7/9/2009	7	3	0	1
L192P-13-br	7/13/2009	42	76	0	7
L32P-07-br	7/7/2009	0	1	0	7
L32P-09-br	7/9/2009	18	1	0	8
L32P-13-br	7/13/2009	42	28	3	36
M152P-07-br	7/7/2009	3	1	2	2
M152P-09-br	7/9/2009	11	1	3	3

Branch Samples Tree ID	**Date**	**TCAA+ $CHCl_3$**	**TCE**	**PCE**	**CCl4**
M152P-13-br	7/13/2009	0	0	1	13
M184P-07-br	*7/7/2009*	*46*	*103*	*0*	*9*
M184P-09-br	*7/9/2009*	*46*	*97*	*2*	*5*
M184P-13-br	*7/13/2009*	*70*	*133*	*1*	*18*
M216P-07-br	7/7/2009	0	23	19	3
M216P-09-br	7/9/2009	6	43	5	2
M216P-13-br	7/13/2009	66	89	1	48
M24P-07-br	7/7/2009	0	0	0	2
M24P-09-br	7/9/2009	9	1	0	2
M24P-13-br	7/13/2009	31	17	1	22
M296P-07-br	*7/7/2009*	*1275*	*0*	*2016*	*3208*
M296P-09-br	*7/9/2009*	*1314*	*0*	*1535*	*2564*
M296P-13-br	*7/13/2009*	*1184*	*0*	*1230*	*2321*
M312P-07-br	*7/7/2009*	*95*	*0*	*339*	*172*
M312P-09-br	*7/9/2009*	*480*	*0*	*1489*	*1447*
M312P-13-br	*7/13/2009*	*232*	*0*	*320*	*255*
N144P-07-br	7/7/2009	1	1	8	4
N144P-09-br	7/9/2009	4	0	0	0
N144P-13-br	7/13/2009	29	13	2	27
N240P-07-br	7/7/2009	6	1	0	5
N240P-09-br	7/9/2009	4	1	0	5
N240P-13-br	7/13/2009	66	8	2	16
N48P-07-br	7/7/2009	6	1	0	2
N48P-09-br	7/9/2009	9	1	0	1
N48P-13-br	7/13/2009	21	0	0	21
O08P-07-br	7/7/2009	1	1	0	3
O08P-09-br	7/9/2009	4	0	0	1
O08P-13-br	7/13/2009	0	0	0	19
O104P-07-br	7/7/2009	0	0	2	16
O104P-09-br	7/9/2009	9	1	0	4
O104P-13-br	7/13/2009	73	14	1	23
O264P-07-br	7/7/2009	2	1	12	4
O264P-09-br	7/9/2009	10	0	6	1
O264P-13-br	7/13/2009	60	6	5	29
O312P-07-br	*7/7/2009*	*52*	*3*	*126*	*21*
O312P-09-br	*7/9/2009*	*51*	*1*	*114*	*25*
O312P-13-br	*7/13/2009*	*139*	*23*	*111*	*50*
O72P-07-br	7/7/2009	0	0	1	5
O72P-09-br	7/9/2009	26	3	0	11
O72P-13-br	7/13/2009	47	14	1	20
P144P-07-br	7/7/2009	1	1	0	3

Branch Samples Tree ID	**Date**	**TCAA+ $CHCl_3$**	**TCE**	**PCE**	**CCl4**
P144P-09-br	7/9/2009	15	4	0	9
P144P-13-br	7/13/2009	278	0	6	80
P224P-07-br	7/7/2009	0	3	0	14
P224P-09-br	7/9/2009	5	1	0	1
P224P-13-br	7/13/2009	61	0	3	86
P304P-07-br	*7/7/2009*	*0*	*7*	*107*	*36*
P304P-09-br	*7/9/2009*	*46*	*0*	*93*	*17*
P304P-13-br	*7/13/2009*	*539*	*22*	*114*	*34*
P64P-07-br	7/7/2009	7	1	0	1
P64P-09-br	7/9/2009	8	1	0	2
P64P-13-br	7/13/2009	0	0	0	22
R24P-07-br	7/7/2009	15	3	1	15
R24P-09-br	7/9/2009	11	0	0	1
R24P-13-br	7/13/2009	0	0	0	76
S128P-07-br	7/7/2009	20	9	0	20
S128P-09-br	7/9/2009	6	3	2	6
S128P-13-br	7/13/2009	31	0	0	65
S392-09-br	7/9/2009	7	1	2	2
S392P-07-br	7/7/2009	5	1	0	3
S392P-13-br	7/13/2009	44	24	0	12
T16P-07-br	7/7/2009	5	1	3	4
T16P-09-br	7/9/2009	5	1	0	3
T16P-13-br	7/13/2009	58	14	11	13
T400P-07-br	7/7/2009	0	32	0	13
T400P-09-br	7/9/2009	25	5	0	13
T400P-13-br	7/13/2009	22	10	0	20
T48P-07-br	7/7/2009	26	34	151	5
T48P-09-br	7/9/2009	10	1	0	3
T48P-13-br	7/13/2009	43	0	0	32
U184P-07-br	7/7/2009	56	1	0	4
U184P-09-br	7/9/2009	3	1	0	2
U184P-13-br	7/13/2009	62	0	0	26
U200P-07-br	7/7/2009	7	1	0	3
U200P-09-br	7/9/2009	11	0	0	2
U200P-13-br	7/13/2009	49	0	0	11
U216P-07-br	7/7/2009	5	0	0	1
U216P-09-br	7/9/2009	10	1	0	0
U216P-13-br	7/13/2009	43	9	0	10
Y168P-09-br	7/9/2009	42	2	0	5
Y184P-07-br	7/7/2009	10	0	3	4
Y184P-09-br	7/9/2009	8	1	0	1

Branch Samples Tree ID	**Date**	**TCAA+ $CHCl_3$**	**TCE**	**PCE**	**CCl4**
Y184P-13-br	7/13/2009	83	34	32	14
GHCP-07-br	7/7/2009	9	0	5	2
GHCP-09-0br	7/9/2009	42	23	94	4
GHCP-13-br	7/13/2009	117	15	121	12
Leaf Samples Tree ID	**Date**	**TCAA**	**TCE**	**PCE**	**CCl4**
B5W-lf	7/13/2009	138	0	0	21
DD95W-lf	7/13/2009	371	75	0	48
DD105P-lf	7/13/2009	274	45	0	27
K100W-lf	7/13/2009	242	53	0	31
L32P-lf	7/13/2009	0	37	0	24
GHCP-lf	7/13/2009	107	41	12	31

Samples highlighted in italics represent the samples taken in areas of higher concentration

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