Center for Watershed Science and Education

University of Wisconsin-Stevens Point and University of Wisconsin Extension

University of Wisconsin-Stevens Point
College of Natural Resources
1900 Franklin St. · Stevens Point, WI USA 54481

Sand Creek Consultants

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MONITORING THE EFFECTIVENESS OF PHYTOREMEDIATION AND HYDROGEOLOGIC RESPONSE AT AN AGRICULTURAL CHEMICAL FACILITY

William M. DeVita — Water and Environmental Analysis Laboratory
Center for Watershed Science and Education
University of Wisconsin – Stevens Point
Stevens Point, WI

Mark Dawson — Sand Creek Consultants, Inc. and Hyde Environmental Inc.
Amherst, WI

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WRI#: R/UW-REM-009, GCC#:03-REM-06

William M. DeVita, Laboratory Manager, Water and Environmental Analysis Laboratory, College of Natural Resources, University of Wisconsin – Stevens Point

Mark Dawson, Environmental Engineer, Sand Creek Consultants, Inc. and Hyde Environmental, Inc., Amherst, Wisconsin

July 1, 2002 – June 30, 2004

Background - Phytoremediation offers the prospect of using biotechnology to degrade or sequester contaminants from soil and groundwater, and/or slow the movement of shallow groundwater. Sequestration of heavy metals and degradation of petroleum hydrocarbons and volatile organic compounds is well documented; however, the fate of many pesticides is unclear. If groundwater movement can be slowed, possibly so will the movement of contaminants off-site, and therefore, a greater likelihood they will be degraded by biotic or abiotic processes, or be sequestered by plants.

The study site, located near Bancroft, Wisconsin, has a history of soil and groundwater degradation. Dinoseb (2, sec-butyl-4,6-dinitrophenol) is the primary contaminant of concern and this soil is unacceptable for conventional landfill disposal or landspreading. Sandy soil, shallow groundwater, and other factors make this a prime site to study the effects of phytoremediation. In June 2000, a mixture of 834 hybrid poplars, willows, and cottonwoods were planted in an effort to degrade and/or retard the movement of pesticides.

Objectives - The objectives of this research were:

1) Assess mortality and biomass production of the established trees at the site as they begin tapping into the capillary fringe of groundwater.
2) Correlate hydrologic response to transpiration rates at various times through the project duration (both daily and seasonal changes). Calculate radius of influence based on water table observations and correlate the results with a capture-zone model.
3) Determine changes in groundwater contaminant profile through the plots. Perform biannual testing on select monitoring wells (12 from the current project and three from the ACCP). Analyze a total of 32 samples per year on selected wells and piezometers. Install three to four piezometers with 2-foot screens to help assess the vertical extent of contamination.

Methods - Mortality is assessed in the fall by visual inspection of the tree and evidence of viable leaves or leaf buds. Occasionally, determination of a viable tree is difficult as they may appear dead in the fall (as evident by a dried main stem, lack of leaves and buds) then resprout from the base the following spring.

Biomass is estimated through direct measurement of trunk diameter and height as recommended by U.S. Forest Service North Central Experimental Station. The equation for this estimation is d^2*h where d = diameter breast height and h = total tree height.

Hydrologic response is monitored with the use of groundwater elevation dataloggers (Aquarod – Sequoia Scientific) in three areas of the property. Elevation is logged once every 30 minutes with 1 mm of accuracy. Transpiration is determined with the use of thermal dissipation probes (Dynamax, Inc.). These probes are inserted into the tree and sap velocity is determined as first proposed by Granier. Volume of sap is determined and assumed to be equal to water transpired. Transpiration is correlated to weather station (Davis Instruments) data and groundwater elevation.

Groundwater modeling was performed using WELFLO and Visual MODFLOW. Hydrogeologic conditions such as hydraulic conductivity, specific yield and saturated thickness were determined in previous studies. WELFLO uses analytical equations to predict drawdown near pumping wells. Visual MODFLOW is a numeric model used to predict groundwater contours in 2 or 3 dimensions.

Three monitoring well nests with 1-foot screens were replaced with 5-foot well screens. Four piezometers were installed at select points in the site to determine vertical extent of contamination. Groundwater samples were analyzed by EPA Method 8270 which utilizes gas chromatography/mass spectrometry.

Results and discussion - Dinoseb concentrations in groundwater continue to fluctuate widely. Slugs of dissolved contaminants are believed to be released during changing water table elevations and large rainfall events. The steady drop in groundwater elevation throughout the summers of 2003 and 2004 is believed to be the result of extensive pumping from high capacity wells and groundwater discharge to drainage ditches in the area. Sharp rises are associated with rainfall events and correlate with rainfall data collected at the site.

Diurnal fluctuations were observed to varying degrees beginning in July 2002 and throughout 2003, but were not observed in 2004. The maximum diurnal fluctuation observed was 10 mm. Diurnal fluctuations correlate with sap flow and evapotranspiration (as determined from weather station data), suggesting the diurnal fluctuations are the result of the trees extracting groundwater. Tree sap flow is affected by humidity, solar radiation, temperature and wind. Thermal dissipation probes determined that seven to 28 liters of groundwater per day are being transpired by each of the hybrid poplars during the time period measured (Sept. 30-Oct. 10). Assuming an average sap flow of 10 liters per day (lpd), 650 trees will transpire 6,500 liters per day, or 4.5 liters per minute, of groundwater removal. Subsequent measurements in the summer of 2004 have determined up to 100 liters per day with an average within 16 measured trees of 50 lpd.

Within the hydrogeologic assumptions made, WELFLO predicts that the drawdown observed with the AquaRods could be due to trees pumping at the transpiration rate observed. The use of MODFLOW showed only a very slight effect in the water table contours near the phytoremediation plot, which suggests that the trees are not capturing the groundwater that flows beneath the plot.

Conclusions - Fluctuations in groundwater contaminant concentrations indicate a source of dinoseb in the upgradient zone or possibly in the zone where containers were excavated. This makes it difficult to assess the impact hybrid poplars have on degradation of the contaminant. A separate study will evaluate tree tissue to determine the presence of dinoseb and dinoseb metabolites. It is evident that the trees are utilizing groundwater, and it is expected that retardation of groundwater flow will require more time.

Groundwater modeling portrays that the effect of the trees on groundwater flow becomes significant once the rate of evapotranspiration is increased by a factor of 10, which is expected in another two to three years.

Key words - dinoseb, phytoremediation, poplars, groundwater

Funding - Water Resources Institute, University of Wisconsin, McIntire-Stennis Cooperative Forestry Research Program.

Introduction

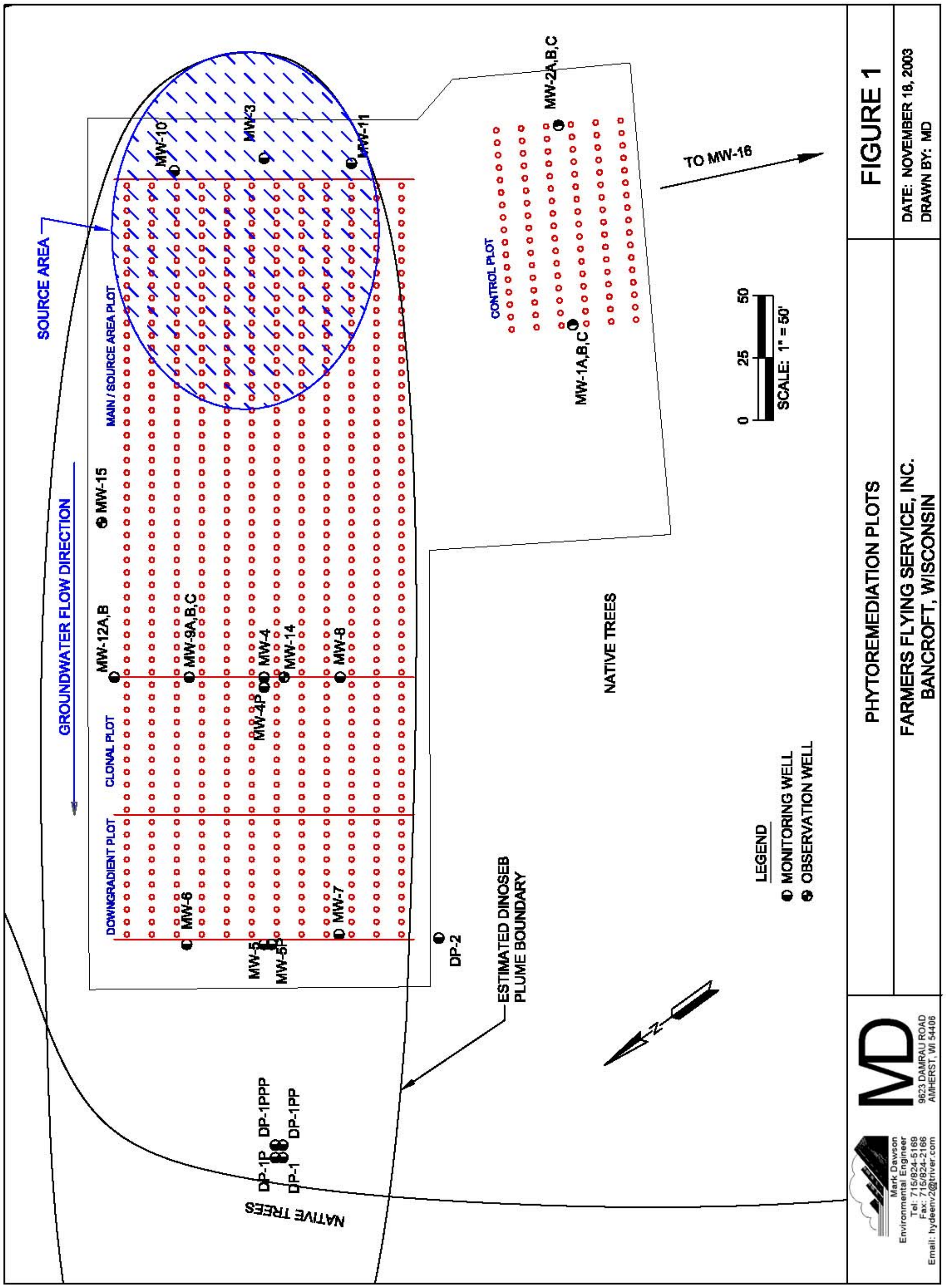
Improper handling of agricultural chemicals has resulted in contaminated soil and groundwater at countless areas around the state of Wisconsin and nationwide. Cleanup of these sites is often an expensive proposition that is burdensome to the responsible party, users of the agricultural chemicals, and residents of the state who inevitably pay for remediation. Phytoremediation has been recognized as a viable technology for restoration of contaminated soils and groundwater. Its effectiveness has been demonstrated for the remediation of volatile organic compounds (1), metals (2), petroleum hydrocarbons (3), and a wide array of industrial compounds (4). With the myriad of agricultural chemicals used past and present, there is insufficient evidence in literature reviews to endorse the effectiveness of phytoremediation on each pesticide, pesticide metabolites, or combinations thereof.

The study site (Figure 1) is located in Bancroft, Wisconsin, in the Central Sands region and provides a nearly ideal aquifer for hydrogeologic investigations because of the shallow depth to groundwater and sandy soil. The site is an aerial pesticide application service that has a long history of environmental contamination due to handling and improper disposal of agricultural chemicals. Spent chemical containers were buried from one to two meters deep while the water table exists at two meters. Also, testing of spray nozzles on the planes resulted in highly localized areas of soil and groundwater contamination. The main chemical of concern is dinoseb (2, sec-butyl-4,6-dinitrophenol), which has been found in groundwater at this site at concentrations as high as 6600 µg/L, or nearly 1000 times the State of Wisconsin (NR 140) Enforcement Standard. As part of an ongoing investigation through DATCP, it was determined that conventional cleanup methods would require thousands of cubic yards of contaminated soil be placed in a hazardous waste landfill. This could cost several million dollars and this does not account for any groundwater treatment system.

In preparation for implementing this phytoremediation study, buried pesticide containers located in an area west of the north-south runway were excavated. This area was graded and the remaining vegetated area was treated with Roundup to reduce competition for the trees. In June 2000, a mixture of 834 hybrid poplars, willows, and cottonwoods were planted as 20 cm cuttings in an effort to degrade and/or retard the movement of pesticides. Trees were planted by drilling a 1-meter x 5-cm hole with a power auger, then backfilling the hole with loose native soil. This technique was used to encourage root growth through the loosened soil toward the water table. Trees were planted in four plots (see Figure 1): the source area was planted with two types of hybrid poplars (DN-34 and NM-6); the clonal test plot was planted with 2 species of willows (SX-61 and SV-1), an additional hybrid poplar (DN-17), and a cottonwood (D-105); the downgradient plot was planted with the same two species of hybrid poplars as in the source area; and the control plot also receiving the same poplars as in the source area. The trees were planted on a 1.5-meter x 3-meter spacing. An electric fence surrounds the 2-acre site to deter deer and a drip irrigation system was installed to help establish the trees during dry periods.

There are 17 monitoring wells on site. Groundwater samples are collected each May and October and analyzed for dinoseb and other pesticides. Dinoseb concentrations vary widely across the site and fluctuate seasonally. In addition, three water table observation wells are present that contain groundwater elevation dataloggers (AquaRods, Sequoia Scientific). Groundwater elevation is measured every 30 minutes with an accuracy of 1 mm. A weather station (Davis Instruments) is also present on site with capabilities to record basic weather data along with solar radiation for evapotranspiration calculation.

Hydraulic control is key to the success of any remediation effort. It is often desirable to contain contaminated groundwater to keep it from sensitive receptors such as private and municipal wells, wetlands, and surface waters. Studies conducted by Newman et. al (1) suggest a 5-year old poplar will transpire 100 to 200 liters of water per day while Hinckley et. al (5) report values for a 4-year old poplar of 20 to 51 liters per day. It is desirable for the trees to directly metabolize the contaminants, however, if


SOURCE AREA
GROUNDWATER FLOW DIRECTION
MAIN / SOURCE AREA PLOT
CLONAL PLOT
DOWNGRADIENT PLOT
CONTROL PLOT
MW-10
MW-3
MW-11
MW-2A,B,C
MW-1A,B,C
MW-15
MW-12A,B
MW-9A,B,C
MW-4
MW-4P
MW-14
MW-8
MW-6
MW-7
MW-5
MW-5P
DP-2
DP-1P
DP-1
DP-1PPP
DP-1PP
ESTIMATED DINOSEB PLUME BOUNDARY
NATIVE TREES
NATIVE TREES
TO MW-16
0
25
50
SCALE: 1" = 50'
LEGEND
MONITORING WELL
OBSERVATION WELL
N
FIGURE 1
PHYTOREMEDIATION PLOTS
FARMERS FLYING SERVICE, INC.
BANCROFT, WISCONSIN
DATE: NOVEMBER 18, 2003
DRAWN BY: MD
MD
Mark Dawson
Environmental Engineer
Tel: 715/824-5169
Fax: 715/824-2166
Email: hydeenv2@tnver.com
9623 DAMRAU ROAD
AMHERST, WI 54406

they are unable, slowing the flow of groundwater may offer more time for other processes, biotic or abiotic, to degrade the substances of concern.

Procedures and Methods - Mortality is assessed each autumn by visual inspection of the tree and evidence of viable leaves or leaf buds. Occasionally, determination of a viable tree is difficult as they may appear dead in the fall (as evident by a dried main stem, lack of leaves and buds) then resprout from the base the following spring. Trees on the site often grow to a height of 1 to 3 meters, then suddenly die only to resprout from the base the following years. These are counted as mortalities as the assessment is performed in the fall when they appear dead.

Biomass is estimated through direct measurement of trunk diameter and height as recommended by U.S. Forest Service North Central Experimental Station (6). The equation for this estimation is d^2*h where d = diameter breast height and h = total tree height. While this method lacks the accuracy of harvesting methods, it provides a generalized representation of differences between the poplar clones, as well as differences in zones within the site.

The transpiration rate of trees is estimated by the sap flow rate in the trunk. Sixteen thermal dissipation probes were used to determine sap flow velocity in the sapwood of two poplar clones in the source area. Sapwood constitutes nearly all of the wood of a poplar, and there is very little if any heartwood in young poplars. Granier (7) first proposed the use of thermal dissipation probes to determine sap velocity. The commercially available probes are produced by Dynamax, Inc. (Houston, TX) and are a variation of Granier's original design. Thermal dissipation probes (Figure 2) consist of two small needles that are inserted into the tree trunk. The lower probe consists of a thermocouple and the upper probe consists of a thermocouple and a heat source. The difference in temperature between these two probes is relative to sap flow. A large difference in temperature is indicative of little sap flow (low heat dissipation), while a small difference in the sensors represents a greater flow (high heat dissipation).

Figure 2. Diagram of thermal dissipation probe (Dynamax, Inc) and insertion into hybrid poplar.

The thermal dissipation probes are insulated with Styrofoam and an insulated blanket (not pictured) to prevent temperature changes occurring from incident sunlight. Data are recorded on a Campbell Scientific CR10X data logger and downloaded weekly.

A multifunction weather station (Davis Instruments, Hayward, CA) was located on-site to record temperature, rainfall, wind speed and direction, relative humidity, ultra violet and solar radiation. The instrument calculates evapotranspiration potential using the Pennman-Montieth equation. Data from the weather station are downloaded monthly.

Changes in groundwater elevation are monitored with the use of AquaRods (Sequoia Scientific) in 5 cm PVC monitoring wells with 150 cm well screens that intersect the water table. These data loggers are programmed to record groundwater elevation every 30 minutes with an accuracy of 1 mm. Three AquaRods are used for this study: MW14 is located near the center of the plot, MW-15 is located on the north side edge of the plot and MW-16 is the off-site control. Data are downloaded on a monthly basis.

Groundwater quality monitoring was evaluated by collecting samples from 17 monitoring wells. Previous sampling efforts resulted in large fluctuations in dinoseb concentrations between sample intervals believed to be associated with changing water table elevations and "slugs" of dissolved dinoseb thought to be flushed from the soil during large rainfall events. In an attempt to diminish these fluctuations, three well nests (MW-3, MW-4, and MW-5) were replaced. Each nest originally consisted of three, PCV monitoring wells with 30 cm screens. They were replaced with one 150 cm long screen at each location. In addition, four piezometers were installed as follows; MW-4P, 3.7 meters below ground surface (bgs), MW-5P, 5.2 meters bgs, DP-1PP, 6.8 meters bgs, and DP1-PPP, 7.7 meters bgs. Piezometers were installed to evaluate the depth of the dinoseb plume in the aquifer.

Groundwater samples from these monitoring wells were analyzed semiannually (spring and fall). Sampling was conducted in accordance NR 700 Wisconsin Administrative Code and analyzed at the University of Wisconsin – Stevens Point Water and Environmental Analysis Laboratory (WDNR Laboratory Certification #750040280). Using a peristaltic pump, wells are purged to replace a minimum of three standing volumes of water, then collected in one liter, amber glass bottles and placed on ice. Samples are extracted and analyzed using EPA Method 8021. A Varian Saturn 2000 gas chromatograph/mass spectrometer (Varian Analytical Instruments, Walnut Creek, CA) was used for this analysis. The instrument is equipped with a 30 meter capillary column and operated in the full-scan mode monitoring 65- 450 amu.

Two methods (analytical and numerical) of groundwater modeling were conducted to model the effect that the trees are having on the groundwater elevations and thereby evaluate whether the plantation is currently, or would in the future, provide groundwater capture.

The analytical method used WELFLO (8), a software program that uses analytical equations to predict drawdown near pumping wells. To simulate the site conditions, the following assumptions were made:

- *Hydraulic conductivity:* Slug tests performed in MW-14, MW-15, and MW-16 (conducted previously) revealed that the hydraulic conductivity of near-surface glacial deposits ranges from 0.015 to 0.019 cm/sec. A uniform value of 0.018 cm/sec was used in the model for horizontal hydraulic conductivity.

- *Specific Yield:* Based on the type of subsurface materials present and the measured values of hydraulic conductivity, the specific yield was assumed to be 0.2.

- *Saturated Thickness:* Based on the data that are available from this area, the bottom of the sand aquifer was assumed to be 19.8 meters below land surface; however, only the upper 3 meters of saturated thickness was assumed to be affected by the trees. Therefore, the transmissivity of the aquifer was assumed to be 46.5 meters^2/day.

- *Phytoremediation Plot:* The trees were simulated by a grid of pumping wells spaced 1.5 meters x 3 meters apart over an area measuring 36.6 by 91.4 meters. Each "well" (tree) was assigned a discharge rate of 0.023 lpm and assumed to pump for a period of 12 hours (to simulate an average discharge of 15.1 liters per day per tree during sunlight hours).

The numerical modeling method used Visual MODFLOW (9). To simulate the site conditions, the following assumptions were made:

- *Hydraulic conductivity:* Slug tests performed in MW-14, MW-15, and MW-16 revealed that the hydraulic conductivity of near-surface glacial deposits ranges from 0.015 to 0.019 cm/sec. A uniform value of 0.018 cm/sec was used in the model for horizontal hydraulic conductivity, and the vertical hydraulic conductivity was assumed to be 0.008 cm/sec.

- *Specific Yield:* Based on the type of subsurface materials present and the measured values of hydraulic conductivity, the specific yield was assumed to be 0.2 across the model domain.

- *Saturated Thickness:* Based on the data that are available from this area, the bottom of the sand aquifer was assumed to be 19.8 meters below land surface.

- *Model Boundaries:* Drainage ditches are located across the agricultural fields in this area to lower the water table. A drainage ditch located roughly 244 meters west of the phytoremediation plot was assumed to be a constant head boundary. Recharge rates were then varied until the resulting water table gradient in the model output matched the apparent steady state gradient of 0.0025 meter/meter that has been measured repeatedly beneath the site over several years. The recharge rate required to achieve this match was 56 centimeters/year, a substantially higher value than what is normally assigned to the Central Sands region (24 to 38 centimeters/year is more typical). This suggests that the one or more of the model assumptions is/are not valid (e.g., it is possible that hydraulic conductivity varies significantly from the assumed average value in areas where no testing has been done).

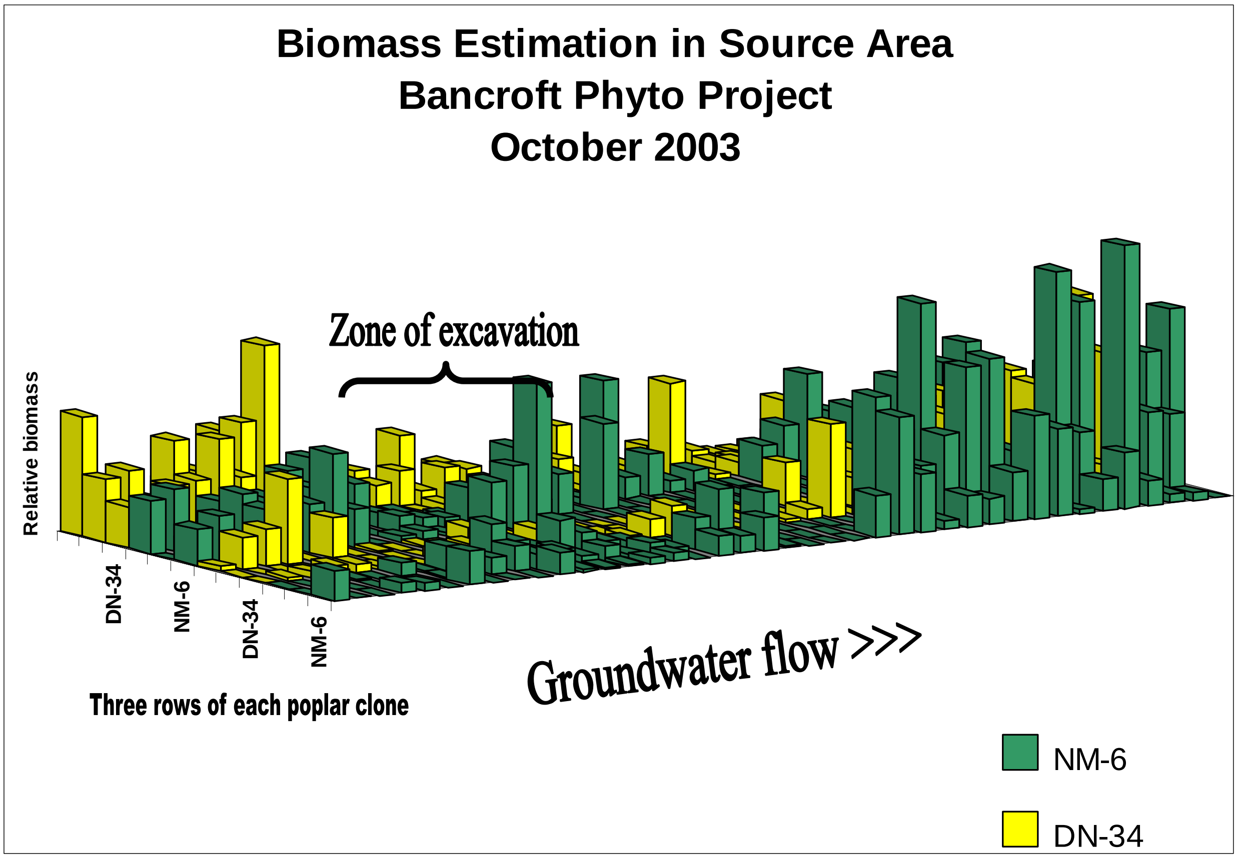
- *Phytoremediation Plot:* The plot of trees planted in the source area was treated as a zone of evapotranspiration, using measured sap flow values to estimate an annual evapotranspiration rate for the plot. At the present rates, evapotranspiration from this area is roughly 117 cm/year for 5 months, or about 48 centimeters/year. The trees were assumed to affect only the upper 1.5 meters of saturated thickness.

Results and discussion – Numerous variables will affect survival and estimated biomass production of these new trees. With the limited resources available, it is not reasonable to assess all possible variables. Differences in soil conditions, for example, texture, nutrient content, and contaminant concentration exist within the study site. Random differences also exist from weed growth, damage from deer browsing, girdling by rabbits and other small mammals, and damage from site maintenance equipment. Examination of the control plot as well as the downgradient plot facilitates the interpretation of mortality and estimated biomass production throughout the study site. There have been several replantings to achieve the overall goals of phytoremediation of this site. For this study, mortality and biomass was assessed considering only those trees from the original planting in June 2000.

Mortality is greater in the source area which constitutes the easternmost 480 trees (laid out in 12 rows), as compared to the downgradient area which consists of 120 of the same trees (in the westernmost same 12 rows). Mortality in the source area is 32% as compared to 10% in the downgradient area and 18% in the control area. The source area was excavated in May 2000 to remove buried containers. Residual chemicals were spilled, and top soil was mixed with the nutrient poor sands when replaced. It appears trees in the source area are more apt to grow and appear relatively healthy, then suddenly die. It is assumed that the contaminants in the soil are not thoroughly mixed and may decimate a healthy tree as roots encounter a pocket of contaminated soil, or it is possible a slug of contaminated groundwater moves into the root zone. There is no appreciable difference in mortality between the DN-34 and NM-6 clones (31.7% and 32.1% respectively) in the source area.

Biomass production will also vary according to site specific variables. Biomass is important as it is considered evidence of relative water usage. The biomass estimation used was provided by personnel at the U.S. Forest Service North Central Experimental Station. As displayed graphically in figure 3, the NM-6 clone produced on average 1.7 times the biomass of DN-34 in the source area.

Figure 3. Biomass produced from two poplar clones in contaminated source area.



Groundwater elevations changed throughout the 2003 and 2004 growing seasons due to precipitation and pumping from adjacent high capacity irrigation wells (Figures 4 and 5). Sharp rises are associated with rainfall events and correlate with rainfall data collected at the site. For example, the sharpest rises in June 2004 occurred when a series of short, intense rainfall events during which 1 to 2 inches of rain fell.

A lack of precipitation and resulting dry conditions in 2003 appears to have encouraged poplars to utilize groundwater. This is evident in the diurnal fluctuations in groundwater elevation (Figure 6). While is not likely roots from poplars will penetrate the saturated zone, it is evident from excavation that the roots penetrate into the capillary fringe. If the capillary fringe is depleted, water will be drawn from the saturated zone and eventually utilized by the tree.

Figure 4. Water Table Elevations Summer 2003; MW-14 and MW-15.

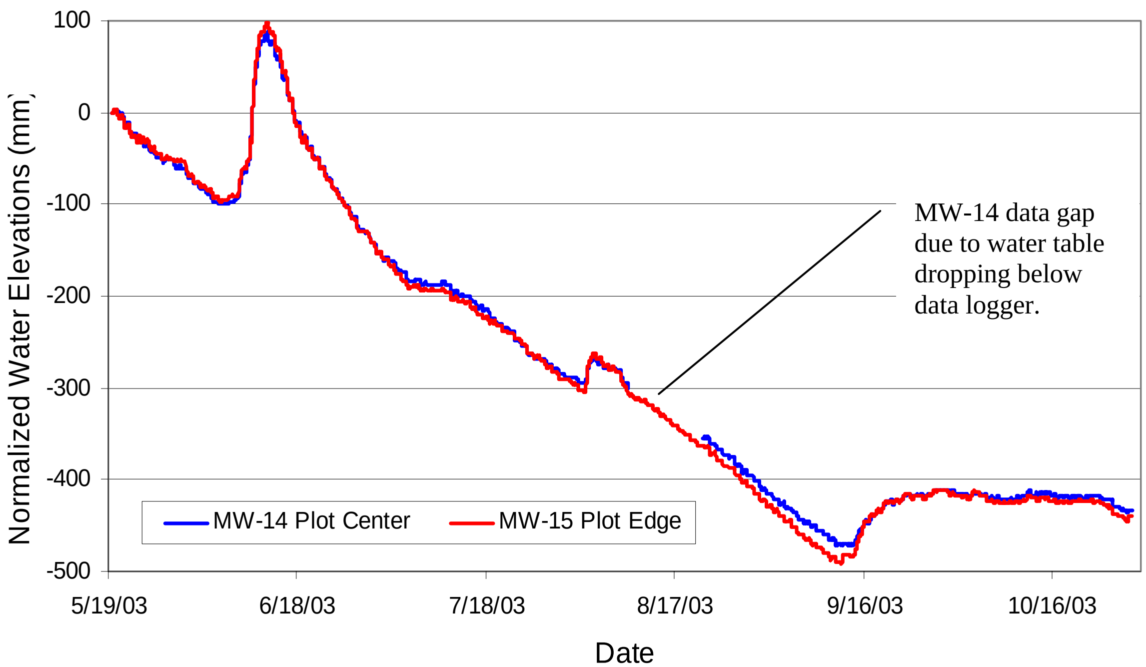
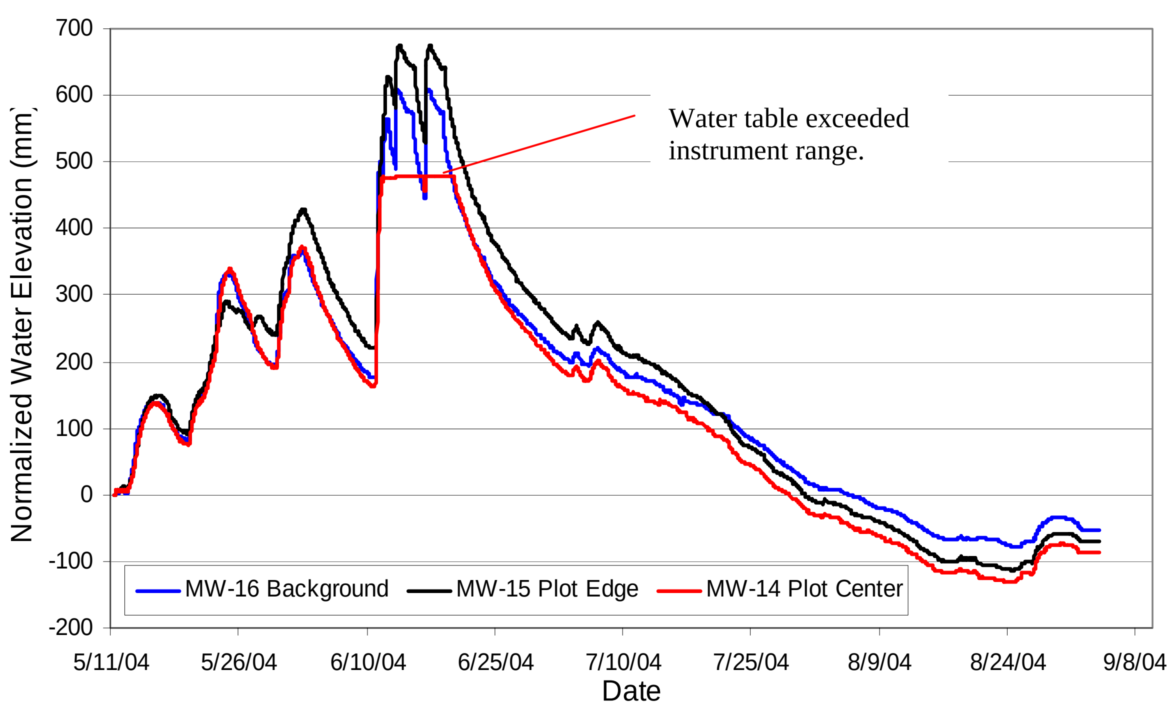
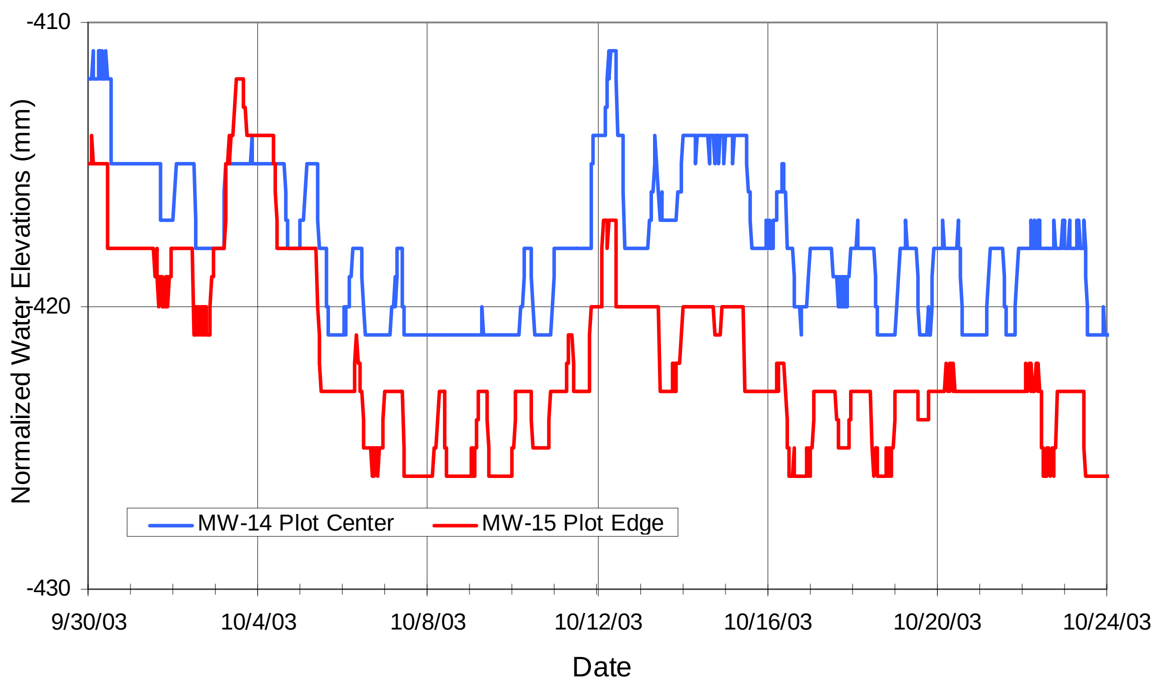


Figure 5. Water Table Elevations Summer 2004; MW-14, MW-15 and MW-16.



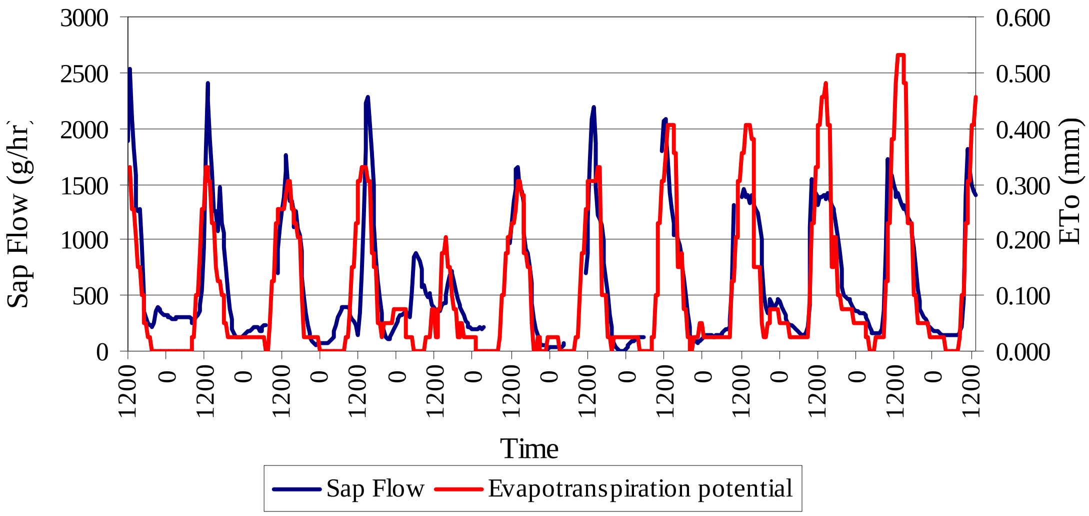
The diurnal fluctuations were observed beginning in July 2002 and throughout 2003. The maximum diurnal fluctuation observed was 10 mm. An example of the diurnal fluctuations is shown on Figure 6. These diurnal fluctuations were not observed in 2004, most likely due to the cool weather (low ET rates) and large and frequent rainfall events that provided the trees with soil moisture. Diurnal fluctuations of groundwater elevation in 2003 correlate with sap flow and evapotranspiration data, suggesting the diurnal fluctuations may be the result of the trees extracting groundwater. Sap flow is affected by humidity, solar radiation, temperature and wind. Thermal dissipation probes determined that 7 to 28 liters of groundwater per day are being transpired by each of the hybrid poplars during the time period measured (Sept. 30-Oct. 10, 2003). An average sap flow of 10 liters per day for 650 trees results in 6,500 liters per day, or 4.5 liters per minute, of groundwater removal. When the trees mature, it is reasonable to average 100 liters or more of sap flow per day per tree (5), resulting in a groundwater extraction rate of 45 liters per minute for 650 surviving trees on days with good evapotranspiration. Subsequent measurements in the summer of 2004 have shown the 16 measured trees to have an averaged transpiration rate of 50 lpd from June through the end of August 2004. A maximum sap flow of 215 lpd was recorded on one tree on a hot, dry summer day in 2004.

Figure 7. Diurnal fluctuations of groundwater observed 09/30-03 – 10/24/03.



Sap flow was plotted with evapotranspiration potential (Eto) as determined by a Davis Instruments weather station that uses the Pennman-Montieth equation (Figure 7). This equation determines ETo based upon temperature, humidity, barometric pressure, wind speed, and solar radiation. As might be expected, these independent measurements are synchronous with each other.

Figure 7. Sap Flow vs. Evapotranspiration Potential



The correlation between sap flow rates and groundwater elevations measured in monitoring wells located within or adjacent to the phytoremediation plot suggest that the trees are having an effect on the water table beneath the plot. To test this hypothesis, the plot of trees were treated as a grid of pumping wells, each discharging at an average rate of 0.023 liters per minute for a duration of 12 hours (a value inferred from the sap flow measurements).

Using an analytical model known as WELFLO (8), the drawdown caused by this grid of trees was shown to be on the order of what was actually measured in the field (e.g., 5 mm of drawdown in an observation well located 3 meters from the plot). The proof of this relationship would presumably come from larger diurnal changes in water table elevations as the trees grow larger and produce more transpiration.

Because drawdown alone does not demonstrate groundwater "capture", the effect that this plot has on groundwater was also modeled using Visual MODFLOW (9). Although it is difficult to validate the results of the model with the data currently available, the output suggests that groundwater beneath the plot is not being captured under the present evapotranspiration rates. However, the model also shows that as the trees grow larger, it is possible to achieve effective capture of the groundwater. This would likely occur when the transpiration rate reaches 10 times the measured rate (October 2003), a rate that is expected to occur across the plantation within the next two to three years. Sap flow monitoring shows the larger trees to have approached this pumping rate during summer 2004. It should be noted that the model has not been verified by any field data other than the water table gradient measured between onsite wells.

Dinoseb concentrations in groundwater continue to fluctuate (see Table 1). Installation of longer-screened monitoring wells at MW-3, MW-4 and MW-5 did not appear to reduce the large fluctuations in dinoseb groundwater concentrations. The fluctuations are believed to be slugs of dinoseb released during changing water table elevations and large rainfall events that flush contaminants from the soil into the groundwater. Downward trends in dinoseb concentrations are not obvious in any of the wells with the exception of downgradient piezometer DP-1P where dinoseb has steadily decreased since June 2002. Due to the variability in dinoseb concentrations across the site and the lack of groundwater quality data before the trees were planted, no conclusions can yet be drawn regarding the influence the trees are having on the dinoseb plume.

Table 1. Dinoseb groundwater concentration summary.

Monitoring Well	Oct. 00	May 01	Oct. 01	June 02	Oct. 02	June 03*	Oct. 03	May 04
MW-1	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
MW-2A	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
MW-3	1300	180	860	610	600	160	5.9	260
MW-4	740	7.4	49	230	570	<5.0	160	860
MW-4P 12' bgs						<5.0	<5.0	<5.0
MW-5	800	<5.0	<5.0	<5.0	5	26	120	240
MW-5P 17' bgs						9.1	<5.0	<5.0
MW-6	<5.0	5.0	<5.0	<5.0	110	540	480	77
MW-7	<5.0	65	<5.0	<5.0	<5.0	<5.0	13	64
MW-8	<5.0	150	<5.0	<5.0	5.2	140	22	20
MW-9	140	<5.0	18	<5.0	690	260	410	79
MW-10	700	<5.0	1900	570	72	97	420	3600
MW-11	2100	550	880	3400	74	6600	39	1500
DP-1	<5.0	17	<5.0	<5.0	no water	no water	no water	<5.0
DP-1P 17' bgs	<5.0	280	<5.0	1500	310	77	7.9	6.5
DP-1PP 22' bgs						<5.0	<5.0	<5.0
DP-1PPP 25' bgs						<5.0	<5.0	<5.0
MW-12A			<5.0		<5.0	<5.0	21	27
MW-15					170			

All values reported in parts per billion (µg/L).
*In June 2003, well nests, MW3 A, B and C, MW4 A, B and C, and MW5 A, B and C, were replaced with wells with a 1.5 meter screen in each location.

Conclusions
Mortality between the two hybrid poplar clonal varieties is nearly identical; however the NM-6 clone produced 1.7 times more biomass.

Fluctuating groundwater dinoseb concentrations indicate that the contaminant source area in the upgradient zone continues to act as an ongoing source of dinoseb in the groundwater. Fluctuations are believed to be the result of large rainfall events and fluctuating water table. These fluctuations make it difficult to assess the impact hybrid poplars have on degradation or sequestration of dinoseb. A separate study will evaluate tree tissue to determine the presence of dinoseb and dinoseb metabolites.

Diurnal fluctuations in the water table elevation suggest that the trees are utilizing groundwater; however, it is expected that greater tree growth will be required before retardation of groundwater flow can be confirmed.

Water usage by the trees, as determined through the use of thermal dissipation probes, is consistent with what has been discussed in the literature.

Groundwater modeling portrays effect of the trees on groundwater flow becomes significant once the rate of transpiration is increased to approximately 150 lpd. This suggests that hydraulic influence on the groundwater can be achieved. Agrochemical facilities (and other industrial sites) located in areas with shallow groundwater that have the potential for low-level and long-term chemical releases, could reduce groundwater contamination through hydrologic control. If an adequately sized group of trees can be planted downgradient of a chemical handling area, a reduction in offsite migration of chemicals could be realized.

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