REVISED
Work Plan for Small-Scale Field Pilot and Landfill Suitability Determination for the Upland Phytoremediation System

at the Former Seaboard Chemical Corporation Facility and
City of High Point Landfill, Jamestown, North Carolina

FINAL

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1.0 OVERVIEW

A small-scale field trial is proposed at the City of High Point Landfill. The trial would commence in November 2004 and continue through until the end of 2005, with additional data collection through 2006 and early 2007. The trial is part of the pre-design data acquisition activities for the proposed full-scale upland phytoremediation system to treat recovered groundwater and leachate. Groundwater extraction is required to hydraulically contain a contaminant plume that originates near the Former Seaboard Chemical Corporation Facility site. The groundwater also contains contaminants derived from the City of High Point Landfill leachate. The primary constituent of concern for treatment by the phytoremediation system is 1,4-dioxane. VOCs will be treated by constructed wetlands and/or a HiPOx ozone oxidation system prior to irrigation of the tree stands. While this proposed pilot study includes a schedule into 2007, sufficient data will be obtained by the late fall of 2005 to prepare and implement a full-scale system in early 2006.

The proposed full-scale phytoremediation system would consist of large stands of trees located on the City of High Point Landfill that would be subirrigated with the moderately saline pre-treated groundwater/leachate ("recovered groundwater") (ENSR and Phytokinetics, 2003a). The tree stands would use all of the recovered groundwater via transpiration and 1,4-dioxane would be effectively removed from the groundwater through phytovolatilization. Any VOCs not removable by pretreatment would be biodegraded in the oxidized plant rhizosphere. The full-scale phytoremediation system would consist of two different types of tree stands (ENSR, 2004): *a*) a stand of deciduous trees including poplars that would be subirrigated with recovered groundwater from April through October; and *b*) conifer stands that would be subirrigated recovered groundwater in the winter months (November through March). The conifers are naturally slower growing and have lower rates of water use than the deciduous trees. The conifer stand would be much larger than the deciduous stand because it would be designed to transpire the flow of recovered groundwater during the winter months when evapotranspiration rates are low. During the winter months, rains would leach the salts from the root zone of the deciduous stand, and during the summer months (when the deciduous stand is being subirrigated with recovered groundwater) rains would leach the salts from the root zone of the conifer stand. The size of the tree stands would depend upon the following factors: *a*) the rate of groundwater recovery; *b*) estimates of the rates of water use for specific types of mature tree stands; and *c*) the growing conditions under which the tree stands develop.

In order for the proposed full-scale system to be a viable remediation option on the landfill, the following performance criteria must be met: *a*) the annual volume of landfill leachate produced with the mature phytoremediation stands in place must be equal to or less than that currently produced; and *b*) the contaminants introduced to the phytoremediation stands via the subirrigation water must be removed by the stands (*i.e*. not contribute to the contaminant mass that currently exists in the landfill leachate).

1.1 Phytoremediation System Study Areas

To assess the feasibility of an upland phytoremediation system, we propose to install four adjacent plots measuring 864 ft^2 each (Plots A to D) on the western portion of the landfill (Figures 1, 2 and 3):

- ***Plot A*** would be planted with 24 hybrid poplar trees (*Populus deltoides x nigra*; DN-34). The trees would be planted directly into the existing 2 ft thick soil cap. The existing vegetation growing on the cap would be removed.
- ***Plot B*** would be planted with 24 hybrid poplar trees (DN-34). The trees would be planted on a 1.5 ft thick layer of soil spread over the top of the existing soil cap. The existing vegetation would be removed.
- ***Plot C*** would be planted with 24 large containerized Japanese black pine trees (*Pinus thunbergii*). The trees would be planted on a 1.5 ft thick layer of soil spread over the top of the existing soil cap. The entire 864-ft^2 Plot C would be covered with an impermeable membrane to prevent the infiltration of rainwater.
- ***Plot D*** would be undisturbed and serve as the experimental control. It would not be planted with trees and the existing vegetative cover of grasses and forbs would remain undisturbed.

1.1.1 Study Plot Set-up

The trees in Plots A through C would be planted in four rows with six trees per row (the rows and the trees within a row would be planted on 6 ft centers). Subsurface drip emitters would be installed at the base of each tree (two 0.5 gph emitters per tree, located 6 in. below ground surface). Note that Plot D would not be irrigated. The trees would be subirrigated as needed with groundwater/leachate recovered from PW-DR1 and the trees in Plots A and B would also obtain moisture from infiltrated precipitation. The groundwater/leachate used in the pilot study will not be pre-treated prior to irrigation of the tree stands, because the constructed wetland and ozone oxidation systems are not yet in place. The following instruments would be installed in the test plots:

- Two (duplicate) Drain Gauges, set at 3 ft below ground surface (bgs) to measure the volume of water that is moving downward in Plots A to D (Figure 2);

- Soil-water content meters set at 1 ft, 2 ft, and 3 ft bgs at each of two locations in Plots A to D (Figure 3);
- Water meter, installed in each planted plot to monitor the total volume of recovered groundwater delivered to the trees via the subirrigation system;
- One rain gauge, installed at the site to monitor precipitation in the area of the test plots; and
- Thermal dissipation probes (TDPs) would be installed for 3 trees per plot during the second growing season (total of 9 TDPs). The TDPs measure sap flow and can be used to estimate transpiration rates.

Using this instrumentation, a water balance would be maintained for each of the four plots. For the poplar Plots A and B, the total volume of input water (subirrigation plus precipitation) would be measured by the water meter and the rain gauge. The TDPs would be used to estimate the total rate of transpirational water use by the stands of trees in each plot (V_T), and the Drain Gauges would measure the volume of water moving downward. The subirrigation drip emitters would be controlled by soil moisture probes set at 1 ft bgs. Thus, the soil moisture would be maintained at levels that are optimal for the trees (less than 80 centibars of soil suction). For the 864-ft^2 plots, average growing season precipitation is approximately 60 gallons per day.

1.2 Tests with the Poplar Plots

If the growing conditions for the poplar trees in Plots A and B were optimal, it is expected that the total rate of transpirational water use (V_T) would be approximately 150 gal/day per stand by the end of the second growing season. Optimal growing conditions are those in which the trees are minimally stressed. Any type of stress (*e.g.* phytotoxic chemicals, saline conditions, inadequate rooting zone) would reduce V_T. For a stand growing under optimal conditions, greater than 95% of the roots would likely be in the top 3 ft of the soil profile.

The main objective of this component of the field trial is to compare the rate of drainage in Plots A, B and D by assessing the data from the duplicate sets of Drain Gauges. For the unplanted control Plot D, the rate will be assessed at which rainwater percolates into the waste layer in this portion of the landfill, presumably creating leachate ("baseline" drainage). The poplar Plots A and B would receive subirrigation water at a specific rate as well as rain water. Maintaining a favorable water balance in the poplar systems (*i.e.* obtaining less than "baseline" drainage) would require that the total rate of water added to the root zone is $\leq V_T$ (approximately 150 gal/day by the end of the second growing season). Plant available water would be derived from precipitation (approximately 60 gal/day) and from subirrigation water. Thus, the rate of subirrigation in the latter part of the second growing season should be less than or equal to 90 gal/day. However, maintaining a favorable water balance in the

planted systems also would require that the trees could extract the subirrigation water (plus precipitation) at a fast enough rate to prevent the water from draining below the root zone. This condition would exist provided that: *a*) the matrix in which the trees are planted has an adequate water holding capacity; and *b*) the trees have deep, well-developed root systems.

For Plot A, one potentially limiting factor may be that the soil layer on the landfill is only 2 ft thick (Figure 3). This depth of soil is marginal both for water holding capacity and for the development of an extensive root system. [The natural rooting depth for different species of trees was recently reviewed (Ferro et al., 2003).] Thus, to maintain a favorable water balance it may be necessary that the tree roots be able, at least to some extent, to colonize the waste layer. In addition, it is important that the waste layer have an adequate water holding capacity, and that this water is available for uptake by the trees. However, if the roots cannot develop into the waste layer or if the waste has limited water-holding capacity, then it may be difficult to maintain drainage at less than "baseline" levels.

Plot B is included in the field trial to evaluate a system in which the thickness of the soil layer is increased by a 1.5-ft thick layer of additional soil (Figures 2 and 3). This added thickness would optimize both the water holding capacity of the matrix and the development of deep extensive roots. Comparing V_T for Plots A and B (*i.e*. by analyzing TDP data) would indicate whether the added thickness of soil in Plot B results in the development of a tree stand with higher transpiration rates (and by inference, a better developed root system).

1.3 Tests with the Pine Plots

Plot C would contain a stand of 24 Japanese black pine trees planted on a 1.5-ft thick layer of soil spread over the existing cap (*i.e*. Plot C would be a raised plot similar to Plot B). The objective in this part of the field trial is to test the ability of the trees to use the recovered groundwater (provided via the subirrigation system) and remove the 1,4-dioxane during the winter months. The length of the field trial is short relative to the growth rate of the trees, and even if the growing conditions for the pine trees in Plot C were optimal, it would be expected that V_T would be approximately 60 gal/day by the end of the trial (winter 2007). However, the rate of precipitation is about 60 gal/day and, therefore, it is proposed that the area between the trees in Plot C be covered with an impermeable membrane that excludes infiltration of rainwater. A perforated horizontal drainpipe would be installed at the toe of the Plot C slope to divert runoff onto the surrounding vegetated landfill.

It is expected that a densely planted pine tree stand would obtain maximal V_T in about 7 years. Hypothetically wintertime V_T for the mature Plot C would be approximately 120 gal/day and it would then be possible to subirrigate the stand with recovered groundwater at the rate of 60 gal/day and still maintain a rate of drainage less than or equal to "baseline" drainage.

1.4 Location of the Study Area

The waste layer on the western portion of the landfill is at least 25 years old and may have degraded and settled sufficiently that it would be an adequate rooting medium. It is the oldest part of the City of High Point Landfill. This western portion is approximately 50 acres and, depending on the rate of groundwater pumping that is required to hydraulically contain the plume, may be a sufficient area for the full-scale upland phytoremediation system. It is proposed that the small-scale field trial be located in this area and that the groundwater leachate used to subirrigate the stand be obtained from well PW-DR1 (Figure 1).

1.5 Data Collection

Data that would be collected in the field trial are listed below:

- *Drainage rates*. The duplicate Drain Gauges in Plots A to D would measure flux rates for down-welling water in the four plots (Figure 2 and 3).
- *Contaminant concentrations in drainage water*. Based on the results of the greenhouse study, it is expected that the DN-34 hybrid poplar trees, as well as the Japanese black pine, can efficiently phytovolatilize dioxane (ENSR and Phytokinetics, 2003b; 2004). For the planted plots, if down-welling water is collected in the drain gauges following the normal subirrigation protocol, then the drainage water would be analyzed for dioxane as well as for chlorinated aliphatics. If down-welling water is not produced following the normal subirrigation regime, then the tree stand would be "flushed" with clean tap water (not recovered groundwater) until down-welling water is recovered in the drain gauges. The drainage water then would be analyzed for contaminants. In an optimal planted system, it is expected that the concentration of dioxane and other contaminants in the drainage water would be minimal or below detection limits.
- *Rooting depth*. The data from the soil-water content meters would be used to evaluate rooting depth for the trees in the planted Plots A to C (Figure 3). For example, if the majority of the tree roots are 2.5 ft deep, then the soil-water content meters set at 1 ft and 2 ft bgs would show readings that fluctuate in synchrony with the subirrigation cycles (*i.e*. water uptake by the trees would readily dry out the top 2.5 ft of the landfill matrix in between the subirrigation cycles). On the other hand, the water content meter set at 3 ft bgs would not fluctuate in the same manner as the upper meters.
- *Metals uptake and accumulation*. The recovered groundwater contains approximately 7 mg/L Mn and certain sensitive plant species can take up and accumulate toxic levels of the metal in the leaves. Based on the results of the greenhouse study, DN-34 hybrid poplar and Japanese

black pine were tolerant of the groundwater and did not accumulate Mn (ENSR and Phytokinetics, 2004). This observation would be confirmed in the longer-term field trial by analyzing samples of leaf tissue for Mn and other metals.

- *Transpiration rates*. Data from the TDPs would be used to calculate transpiration rates for individual trees. In each of the planted plots (A to C), three trees would be instrumented with TDPs. Based on the correlation between basal area and transpiration rates (*i.e*. water uptake), V_T for each of the three stands of 24 trees could be calculated.

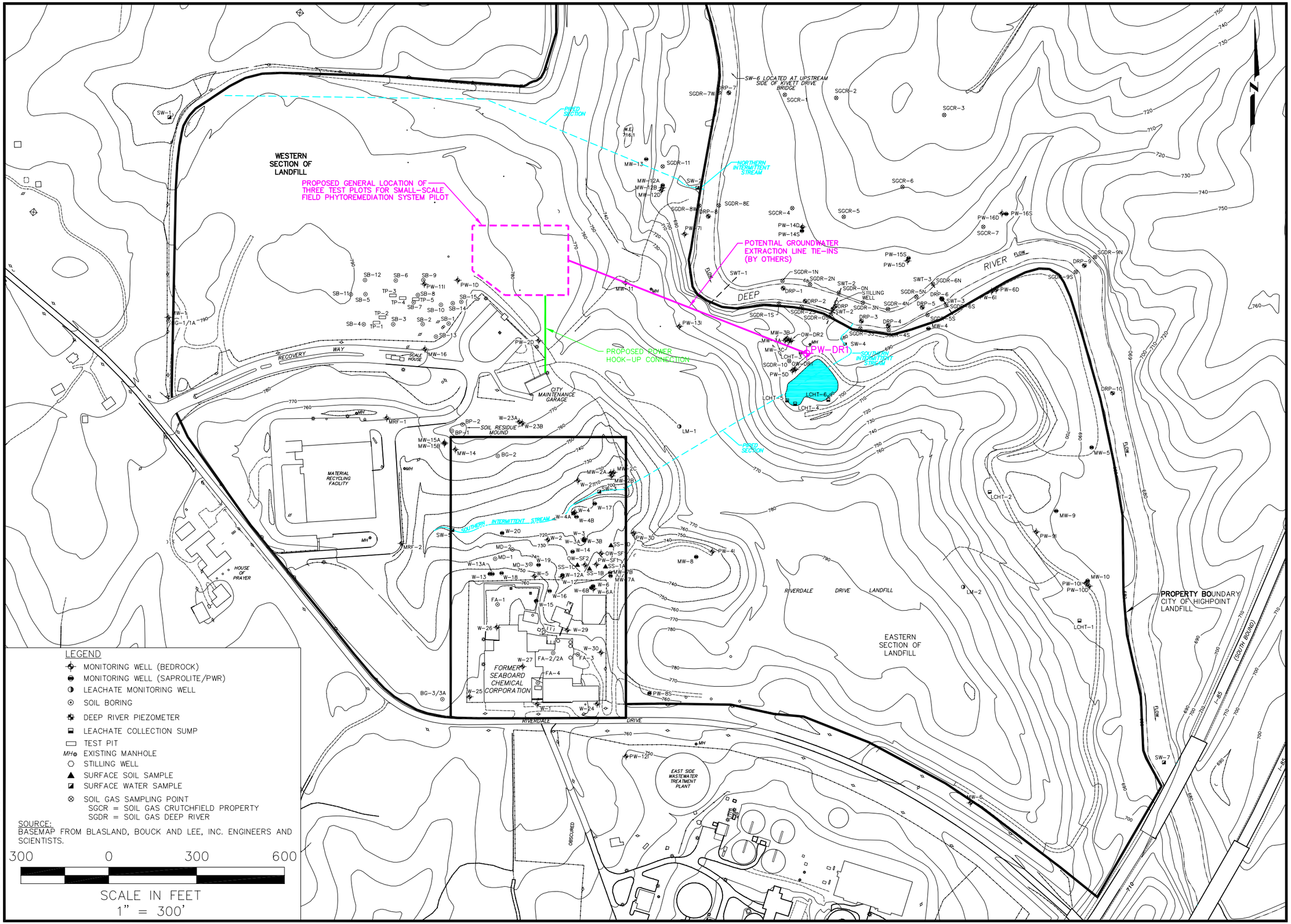
- *Salt accumulation in the soil and drainage water*. Soil samples would be taken at regular intervals for Plots A to C and analyzed for salinity. Samples of drainage water from the Drain Gauges would be analyzed for salinity at the same intervals. It is expected that, for example in Plots A and B, that salts would accumulate in the soil throughout the summer, and would be leached by rainwater below the root zone of the trees during the winter months.

- *Dioxane mass accounting*. In order to assess the fate of dioxane, the following accounting would be maintained:
  - *a*) The mass of dioxane added to each planted plot via the subirrigation water. This value could be calculated by analyzing the dioxane concentration in the recovered groundwater (sampled at regular intervals) and the volume of groundwater used to subirrigate the trees (data from the water meters);
  - *b*) The mass of dioxane in the drainage water in Plots A to C. This value could be calculated by analyzing the dioxane concentrations in the drainage water (sampled at regular intervals; *see above*) and the volume of drainage water (data from the Drain Gauges; *see above*);
  - *c*) The mass of dioxane phytovolatilized in Plots A to C. This value could be calculated by analyzing the dioxane concentration in samples of xylem sap and the TDP data. Xylem core samples would be taken at intervals during the second growing season (from trees instrumented with TDPs) and analyzed using the same methods as reported in the greenhouse study (ENSR and Phytokinetics 2003b, 2004). Data from the TDPs would be used to calculate the seasonal V_T by the stand. Thus, assuming that the mass of dioxane moving to the leaves with the xylem sap is quantitatively lost to the atmosphere in the transpiration gas:

$$\left(\frac{mg\ dioxane}{L\ sap}\right)\left(\frac{L\ transpired}{season}\right) = \ mg\ dioxane\ phytovolatilized\ \ per\ growing\ season$$

  - *d*) The mass of dioxane in the soil. In December 2005 and at the end of the study dioxane would be analyzed in composite soil samples taken from each of the three planted plots. The mass of dioxane that accumulates in the root zone of the plants could be calculated from these data plus data for the bulk density of the soil. It is expected that the dioxane concentrations in the root zone soil would be minimal or below the detection limit because the dioxane would be efficiently phytovolatilized.

A monitoring program is briefly outlined. Data would be collected that would enable us to assess the pilot system in terms of the study objectives.



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ENSR AND PHYTOKINETICS PROPOSED PHYTOREMEDIATION PILOT SYSTEM: LANDFILL SUITABILITY STUDY SEABOARD GROUP II AND CITY OF HIGHPOINT SITE

PROJECT NUMBER: 08734-679-460
DATE: 9/04
SCALE: 1" = 300'

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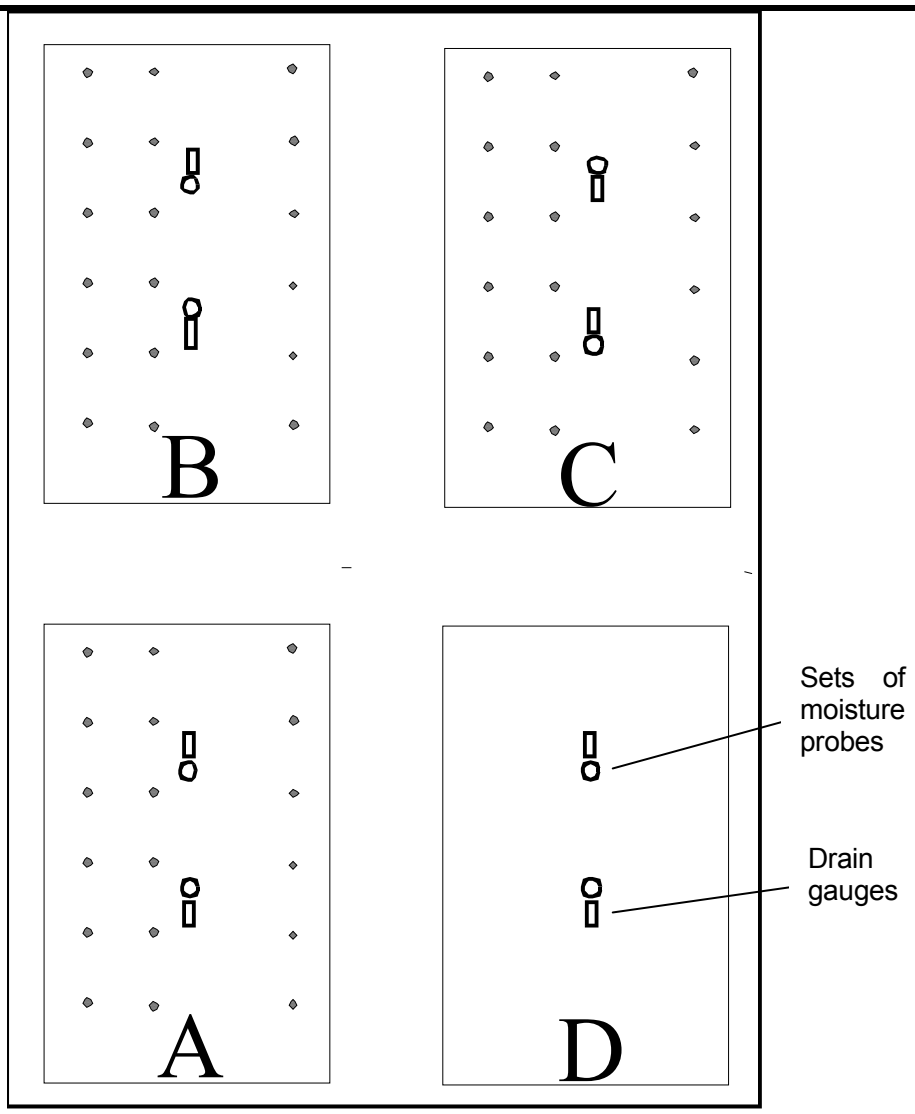

Figure 2. The four test plots at the study site. The dimensions of the plots (Plots A to D) would be 24 ft x 36 ft. The study plots would be located side by side with a 10 ft wide buffer between the plots. The trees in the planted plots (Plots A to C) would be planted in four rows with six trees per row. Plot D would be undisturbed. A 1.5-ft thick layer of soil would be spread on Plots B and C. The edges of the raised plot would be gradually slopped to the grade of the landfill An impermeable membrane would be used to cover Plot C and a perforated drainpipe would be installed at the toe of the Plot C slope to divert runoff onto the surrounding landfill. For raised Plot B, rainwater would probably infiltrate the soil layer and runoff would be minimal.

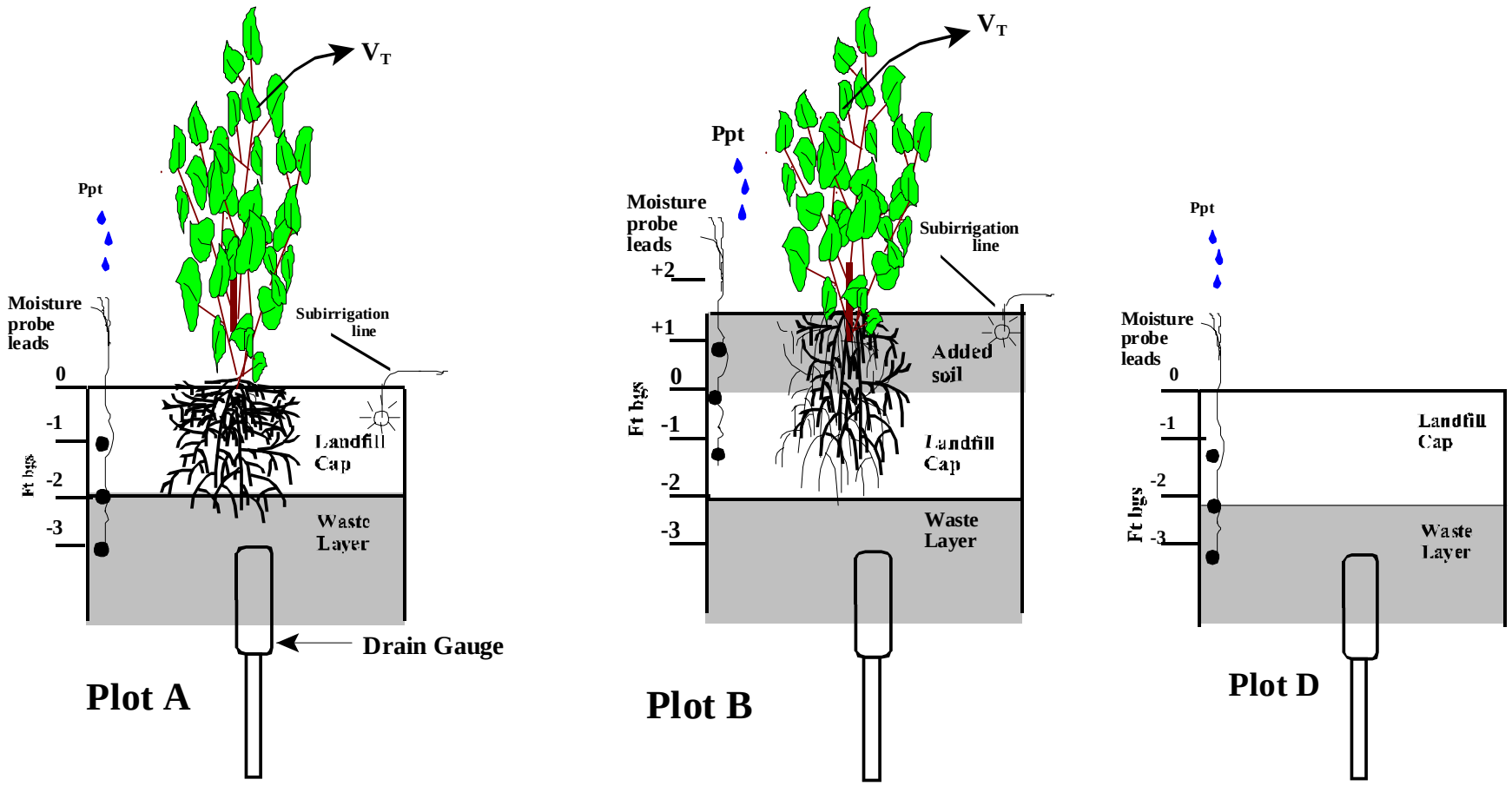

Figure 3. Cross-section of study plots. Plots A and B would be planted with poplar trees and Plot D would be unplanted. Plot C (not shown) would be the same as Plot B, but planted with pines, not poplars, and covered with an impermeable membrane.

2.0 WATER BALANCE: CALCULATIONS/INSTRUMENTATION

This section reviews the calculations used to estimate the water balance for the deciduous and coniferous tree stands and also provides background information for the water balance instrumentation.

2.1 Estimates of Water Use for Stands of Poplar Trees

The rate of transpirational water use for a stand of trees during a given time period can be estimated using the following equation (Ferro et al., 2003):

$$V_T = ET * \theta * LAI * A, \text{ where} \qquad \text{[Eq. 1]}$$

V_T = transpirational water use by the stand,

ET_0 = reference evapotranspiration during the given time period,

θ = the water use multiplier for a tree within a stand, which is equivalent to the rate of water use per leaf as a percentage of ET_0,

LAI = leaf area index (the leaf area per unit area of ground surface),

A = the total area of the stand.

Monthly estimates for ET_0 for the City of High Point area are presented in Table 1. During the growing season (April through October), the average ET/precipitation ratio is 1.3. In the winter months the ratio is 0.63.

Values for θ and LAI are species-specific and depend on planting density and stand maturity. Rough estimates for θ and LAI for a stand of hybrid poplar trees planted on 7 ft centers (approximately 850 trees/acre) growing in the High Point area are shown in Table 2. Note that the LAI increases gradually and would probably reach a plateau (at canopy closure) during the third to fourth growing season, and at this time V_T reaches a maximal value. Mean values for transpirational water use by the stand during the growing season (V_T; gpm/acre) estimated using Equation 1 are shown in Table 2. For a mature (3 to 4 year-old) stand of poplars, the average rate of water use in April through October is estimated to be 11.5 gpm/acre.

Equation 1 can give reasonably accurate estimates of V_T, although another key factor in estimating transpiration is potential plant stresses. The equation assumes that the trees are freely transpiring, and any kind of stress – water, nutritional, toxic substances, etc. - can reduce photosynthesis and stomatal conductance. If the stomates close, the transpiration rate is reduced.

The rate at which a stand of poplars could be subirrigated with recovered groundwater without producing excess drainage is approximately equal to V_T minus the rate of soaking precipitation (*i.e*. the precipitation that infiltrates the soil). As the stand of trees matures and V_T increases, the rate that irrigation water could be added also increases. The expected rate at which a mature 1-acre stand of poplar trees could be irrigated is approximately 9.4 gpm/acre (Table 3).

Table 1. Climate data. Precipitation data is for the City of High Point (monthly averages from *weather.com*). ET_0 is calculated from the pan evaporation data for Greensboro, NC (the weather station nearest to High Point collecting pan data). Precipitation is corrected for interception by the trees. Daily precipitation less than 0.2 inches is assumed to be intercepted by the stand of trees and evaporated before it reaches the soil (calculated as 15% of precipitation). It is assumed that precipitation greater than 0.2 in/day infiltrates the soil (*i.e*. "soaking" precipitation referred to in the text).

	Pan Evaporation (in.)	ET_0 (=Pan Evap*0.8)	Total Precip. (in.)	Interception (in.)	Corrected Precip. (in.)	ET_0/Precip
Jan	1.8	1.5	4.1	0.6	3.5	0.4
Feb	2.2	1.8	3.5	0.5	2.9	0.6
Mar	4.0	3.2	4.3	0.6	3.6	0.9
Apr	5.3	4.2	3.7	0.6	3.2	1.3
May	6.4	5.1	4.2	0.6	3.6	1.4
June	6.7	5.4	3.9	0.6	3.3	1.6
July	6.7	5.4	4.3	0.6	3.6	1.5
Aug	6.2	5.0	4.2	0.6	3.6	1.4
Sept	4.6	3.7	3.9	0.6	3.3	1.1
Oct	3.5	2.8	3.5	0.5	3.0	0.9
Nov	2.5	2.0	3.2	0.5	2.8	0.7
Dec	1.9	1.5	3.4	0.5	2.9	0.5
Total	51.7	41.4	46.2	6.9	39.3	
Growing season (Apr to Oct)		31.5	27.7	4.2	23.6	9.3
Winter (Nov to March)		9.9	18.5	2.8	15.7	3.1

Table 2. Estimation of average seasonal V_T for a 1-acre stand of poplar trees at High Point NC. The growing season is April though October. Estimates are given for years 1 to 7.

Year	ET_O (in)	LAI	θ	V_T (gal/min)
1	31.5	0.10	2	0.6
2	31.5	0.60	3.8	6.4
3	31.5	0.70	5.8	11.5
4	31.5	0.68	6.0	11.6
5	31.5	0.68	6.0	11.5
6	31.5	0.67	6.0	11.4
7	31.5	0.66	6.0	11.2

2.2 Estimates of Water Use for Stands of Conifers

Equation 1 was used to estimate V_T for a 1-acre stand of conifers growing at High Point NC (Table 4). Values for V_T are estimated for a 1-acre stand at different stages of maturity both in summer (Table 4A) and winter when ET_0 is low (Table 4B). The values for θ and LAI for the conifer stand are different from those for the poplar stand (specifically θ is lower and LAI is higher) and the time required for the stand to reach maturity (canopy closure) is longer (7 years). For a mature stand of conifers, it is estimated that the average rate of water use in the winter (November through March) is 4.8 gpm/acre. The rate at which a mature stand of conifers could be subirrigated without producing excess drainage (V_T minus soaking precipitation) is approximately 2.9 gpm/acre (Table 5).

2.3 Measurements of Sap Flow

TDPs will be installed on a sub-sample of trees in each of Plots A to C. Thermal dissipation probes are widely used to measure sap flow velocity through a cross-section of a tree trunk. The measurements are then used to quantify the rate of water use by the tree. Each probe consists of two needles containing chromel-constantan thermocouples. One needle contains a fine-wire resistance element heated with a constant voltage. The needles are inserted into holes drilled into the tree, with the heated needle closer to the top of the tree. Under high flow conditions the heat input into the upper needle is dissipated by sap flow, and the temperature difference (ΔT) between the upper and lower

needle is reduced. Values for ΔT and sap velocity are related empirically (Granier, 1985).[1] The product of sap velocity (V) and average trunk cross-sectional area between the two thermocouples yields the rate ($cm^3\ h^{-1}$) of sap flow.

The relationship between ΔT data obtained from TDPs and actual transpirational water use from containerized poplar trees has been investigated (Ferro, et al, 2001). Preliminary results indicated that the empirical relationship yielded sap flow values that were approximately 45% of the actual volumetric water use. This corrected value for the relationship between V and K in poplar trees would be used in the proposed project. Thus, transpirational water use will be measured directly, and these data will be compared with the estimates presented in Sections 2.1 and 2.2.

2.4 Water Balance Instrumentation

The Drain Gauge is designed for long-term monitoring of soil-water drainage and also has a collection system that allows for rapid sampling of drainage water (Decagon Devices, 2001; Gee et al., 2002; 2004). The instrument is installed below the root zone. Water infiltrates down to the "divergence control tube" (DCT; Figure 4) and then down a fiberglass wick into a collector. The wick creates a suction that overcomes the boundary layer at the bottom of the divergence control tube and facilitates the water movement down into the reservoir. As collected water fills the measurement reservoir, the water level is monitored by a sensor. When the water level reaches the top of the siphon, the water is emptied and the event is recorded by a datalogger. Samples can be withdrawn from the reservoir with a syringe, and excess water drains out of the instrument.

The soil water content ECH_2O probe is a sensor for measuring volumetric water content of soil (Decagon Devices, 2002). The probe measures the dielectric permittivity of the soil, which is directly

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[1] A dimensionless flow index, *K*, is calculated for a specific time period according to the relationship: $K = \frac{\Delta T_{Max} - \Delta T}{\Delta T}$, where ΔT_{Max} is the value in a given time period (e.g., the pre-dawn hours) where ΔT is the greatest (zero set point). A value for sap velocity, V ($cm\ s^{-1}$), is then estimated using the following empirical relationship developed by Granier [1985]: $V = 0.0119 * K^{1.231}$. Sap velocity is multiplied by the cross-sectional area of the tree (basal area) at the location of the probe (As) to yield Fs ($cm^3\ h^{-1}$), the rate of sap flow, using the following equation: $Fs = As * V * 3600\ s\ h^{-1}$. Thus, the parameter, Fs, represents the volume of water transpired per unit time.

related to water content.[2] The voltage output on the probe is proportional to the volumetric water content in the soil. The data can be stored with a datalogger that is compatible with the sensors.

Table 3. **V_T and expected irrigation rates for a 1-acre stand of poplars.** Estimates are for the growing season (April through October) for the first 7 years after planting.

Year	ET_o	V_T (gal/min/acre)	Corrected Precipitation (gal/min/acre)	Irrigation Rate (gal/min/acre)
1	31.5	0.5	2.1	-1.6
2	31.5	6.4	2.1	4.3
3	31.5	11.5	2.1	9.4
4	31.5	11.6	2.1	9.4
5	31.5	11.5	2.1	9.4
6	31.5	11.4	2.1	9.3
7	31.5	11.2	2.1	9.1

Table 4. Estimation of average seasonal VT for a 1-acre stand of conifers at High Point NC. ***A***, summer (April through October) ***B***, winter (November to March).

	A.				B.			
	SUMMER				WINTER			
Year	ETo (in)	LAI	θ	V_T (gal/min)	ETo (in)	LAI	θ	V_T (gal/min)
1	31.5	0.1	0.1	0.03	9.9	0.1	0.1	0.01
2	31.5	1	0.15	0.4	9.9	1	0.15	0.2
3	31.5	2	0.2	1.3	9.9	2	0.2	0.5
4	31.5	4	0.25	2.8	9.9	4	0.25	1.2
5	31.5	7	0.3	6.0	9.9	7	0.3	2.5
6	31.5	9	0.35	8.9	9.9	9	0.35	3.8
7	31.5	10	0.4	11.3	9.9	10	0.4	4.8

[2] The ECH_2O probe measures the charge time of a capacitor in the medium. A TDR probe (time domain reflectometry) measures the time it takes for an electromagnetic wave to propagate along a transmission line. Both types of probes measure dielectric permittivity of the medium to obtain volumetric water content and can provide accurate measurements if the probes are correctly installed. However, the capacitance probe (e.g. ECH_2O) is less expensive.

Table 5. **V_T and expected irrigation rates for a 1-acre stand of conifers.** Estimates are for the winter (November through March) for the first 7 years after planting.

Year	ET_o	V_T (gal/min/acre)	Soaking Precipitation (gal/min/acre)	Irrigation Rate (gal/min/acre)
1	9.9	0.01	1.9	-1.9
2	9.9	0.2	1.9	-1.7
3	9.9	0.5	1.9	-1.4
4	9.9	1.2	1.9	-0.7
5	9.9	2.5	1.9	0.6
6	9.9	3.8	1.9	1.9
7	9.9	4.8	1.9	2.9

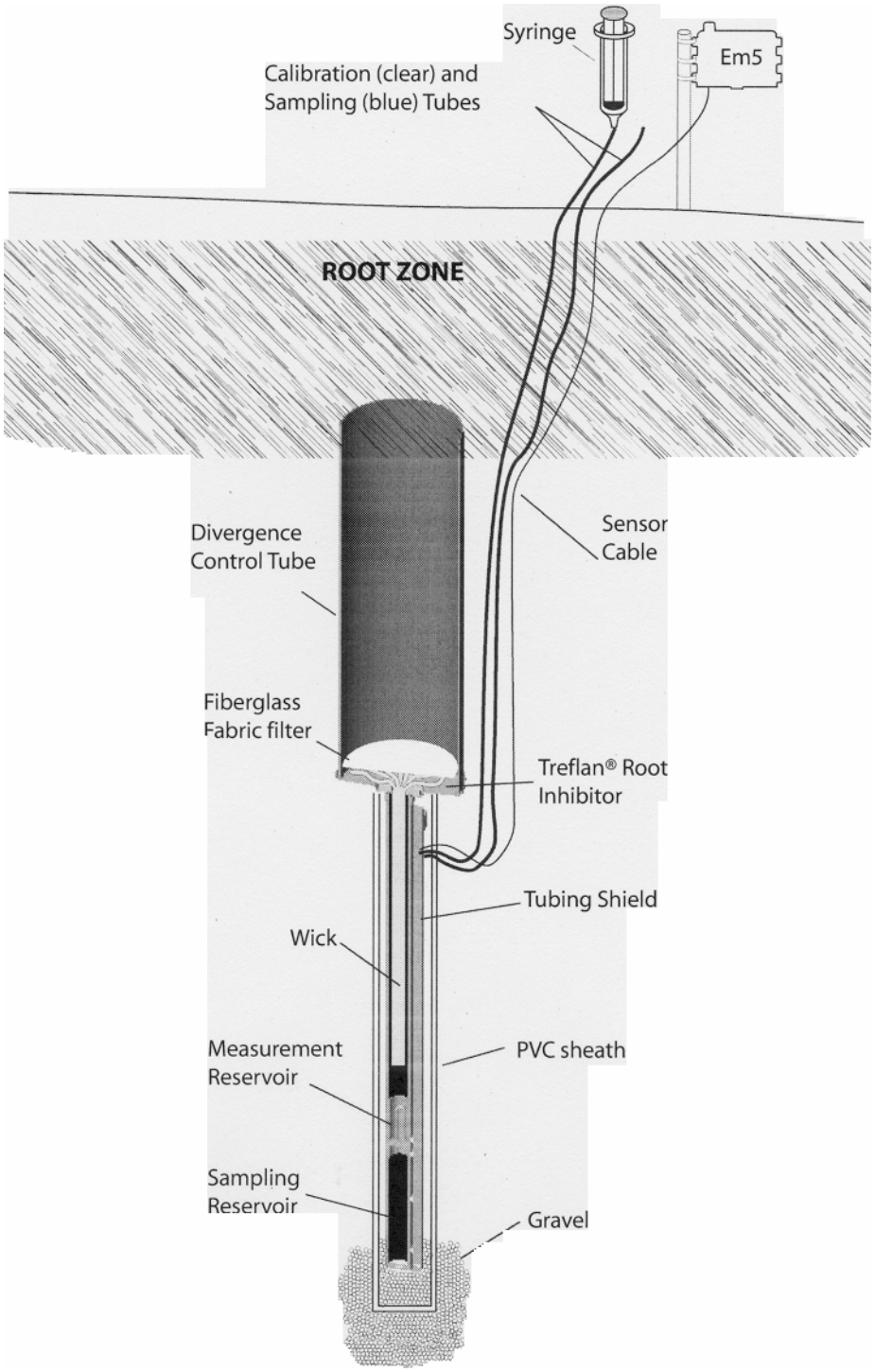


Figure 4. Drain Gauge. Gee Passive Capillary Lysimeter.

3.0 INSTALLATION PLAN

This section outlines all of the steps that would be carried out in Fall 2004 and Spring 2005 for the installation of the small-scale field trial. Maintenance and monitoring protocols for the project are briefly discussed in Section 5.0.

3.1 Overview

The project tasks are listed below in the sequence in which they would be carried out.

- *Utilities hook up*. The project would require water and electrical hookups, tasks that would be carried out by licensed contractors. Specifically for the water hook-ups, a plumber would be contracted to run a 1-in main water line from the City Maintenance Garage to the study site. The main line (>30 psi water pressure) would terminate in a utility box located adjacent to the study site and would contain a hose spigot, pressure reducer, and a pressure gauge all supplied by the contractor. The electrical hookups (several standard 120 V AC electrical outlets) would be located in an outdoor box mounted near the water supply box.
- *Study site mark out*. The four study plots (Plots A to D) each measure 24 ft x 36 ft and would be located side by side with a 10 ft wide buffer between the plots (Figure 2). Therefore, an area of approximately 4700 ft^2 would be required for the field trial. Criteria for choosing the site in the western part of the landfill are: *a*) that it is clear of underground utilities; and *b*) that it is reasonably close to PW-DR1. A potential location is shown in Figure 1.
- *Site preparation*. The existing vegetation in Plots A to C (and the buffer zones) would be sprayed with Roundup herbicide, and the next day it would be mowed and removed from the plots. The soil would be tilled (4 to 6 in. deep) using a standard rototiller. Plot D would be left undisturbed.
- *Planting location mark out*. The planting locations for individual trees within each of the plots would be marked (Figure 2).
- *Installation of water balance monitoring instruments*. The two Drain Gauges and two sets of soil-water content meters would be installed between the planting locations in the central portion of each of the four plots (Figure 2). Note that in Plots A and D, the duplicate Drain Gauges would be installed 3 ft bgs, while in Plots B and C (the raised plots) the Drain Gauges would be set 1.5 ft bgs.
- *Soil layer*. A 1.5 ft thick layer of minimally compacted soil would be spread on Plots B and C (Figures 2 and 3). The first 1 ft of soil would probably be comprised of a fill material, which would be covered with 0.5 ft of a better quality topsoil. The 1.5 ft thick layer of soil would be spread in even 0.5-ft lifts to help minimize preferential flow pathways of infiltrated precipitation. The edges of the plots receiving the soil layer would be gradually sloped to the grade of the landfill.
- *Planting holes for the conifers*. Planting holes would be dug for the 24 containerized trees in Plot C (4 rows, 6 holes per row). The soil would be stockpiled adjacent to Plot C.
- *Installation of subsurface irrigation system*. Each study plot would be a single irrigation zone (24 trees per zone) and contain a solenoid valve and a water meter (Figure 5). The three plots

would be regulated by a multi-station irrigation timer. Water lines that supply the subsurface drip emitters would be installed in trenches.

- *Impermeable membrane*. An impermeable membrane would be installed over the entire Plot C and the 24 planting holes would be cut out in the membrane.
- *Planting of pine trees*. Containerized Japanese black pine trees would be planted through the membrane in the pre-dug holes. Additional soil would be transferred from the stockpile with a wheelbarrow. The pine trees would be planted in Plot C in late fall 2004.
- *Installation of Plot C drainpipe*. A perforated PVC drainpipe would be installed around the toe of the Plot C slope to divert runoff onto the adjacent vegetated landfill.
- *Installation of data loggers and other instruments*. The electrical leads from the Drain Gauges (8), soil-water content meters (24), rain gauge (1), and water meters (3) would be connected to a multiplexer and datalogger in a waterproof enclosure.
- *Fencing*. In order to prevent damage to the trees by animals, the study area (Plots A to D) would be fenced using T-base posts and field fence. A simple gate would be installed.
- *Planting of poplars*. The poplars would be planted (as unrooted hardwood cuttings), in 3 ft deep, 3-in. diameter boreholes in early spring 2005.

3.2 Equipment, Materials and Contractor

The main equipment and materials needed for the field trial are listed in this section. This list does not include the materials needed for the installation (by other contractors) of the electrical and water hookups.

- Water balance instrumentation:
  - Drain Gauge – Gee Passive Capillary Lysimeters (x8); Decagon
  - CR10X data loggers (x1); Campbell Scientific (CSI)
  - AM 16/32 Multiplexer (CSI)
  - Soil water content capacitance probes (x24); Decagon and Dynamax
  - Power supply (CSI)
  - Rain gauge (CSI)
  - TDPs (x9); Dynamax
- Plants: Twenty-four containerized Japanese black pine trees (8-ft). Unrooted hardwood cuttings (3/4-in diameter) of Imperial Carolina poplar (*Populus deltoids x nigra*; DN-34).
- Irrigation supplies:
  - Sprinkler system timer (x1)
  - Solenoid valves (x3)
  - Aqua-Pro moisture sensor with irrigation control

  - PVC pipe, 1 in.
  - GeoFlow 16 mm supply line, pressure compensated drip emitters, 0.5 gph
  - Filters
- Water meter with contact switches (0.025 to 10 gpm); DL Jerman
- Equipment (rented):
  - Trencher
  - Tiller
  - Mower or weed eater
- Impermeable membrane, 12-mil polyethylene
- Drilling and earth moving would be carried out by Parratt Wolff Inc., Hillsborough, NC

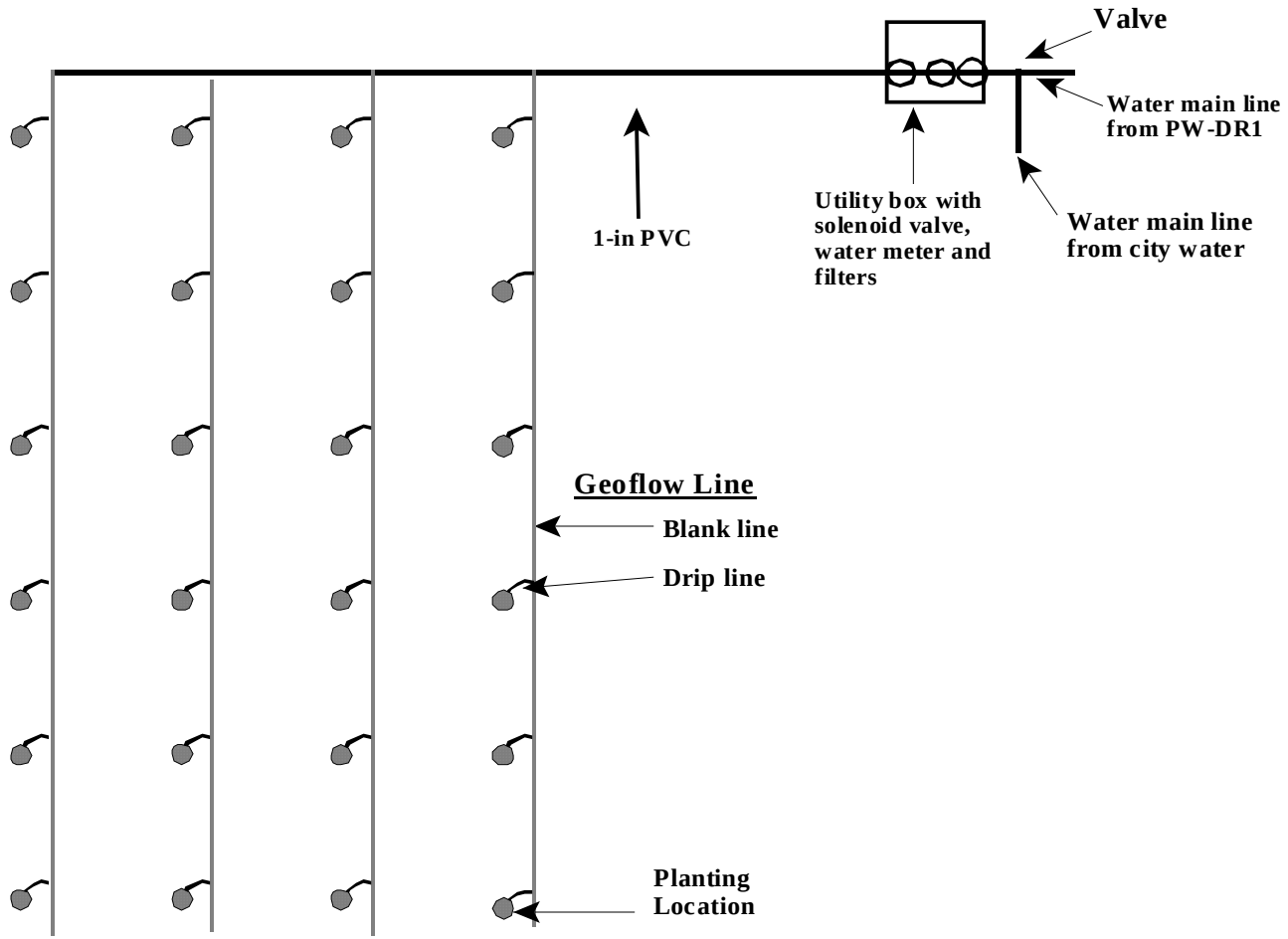


Figure 5. Sketch of the Irrigation System. The system would be the same for Plots A, B and C. Note that there are alternate sources of water, either groundwater leachate from PW-DR1 or City water from the City maintenance garage. City water would be routed to the study area via a I in main line installed in a 18 in deep trench. The main line would terminate in a large utility box installed next to the study area that would contain a hose spigot, pressure reducer and pressure gauge. All of these items would be supplied and installed by a plumber. ENSR/Phytokinetics would supply and install the solenoid valve, water meter, and filters.

3.3 Installation of Subsurface Monitoring Equipment

This section outlines the tasks involved for the installation of the Drain Gauges and the soil-water content probes.

3.3.1 Drain Gauge

The overall length of the Drain Gauge is 6 ft 1 in. (the DCT is 2 ft 2 in. in length and the wick section is 3 ft 11 in. in length; Figure 4). The top of the DCT would be set at 3 ft bgs (Figure 3). A backhoe (Parratt Wolff) would be used to dig a trench three ft deep. The horizons, including the waste layer dug from the trench, would be set aside in separate piles. A truck-mounted auger (Parratt Wolff) would be used to drill a 8-in. diameter hole that is 26 in. deep. The top of this hole would be at the bottom of the 3 ft deep trench. A 4-in. diameter auger would then be used to extend the length of the 8-in. diameter hole by an addition of 3 ft 11 in. The DCT would be used to make a monolith of the soil in a location adjacent to the augered hole (see below). The PVC tube that houses the wick section of the Drain Gauge would be inserted into the 4-in. diameter hole (Figure 4). A soil slurry would be made and poured around the outside of PVC pipe to assure a tight fit. Gravel would be poured into the bottom of the PVC tube to create a 1 ft thick layer, and the wick section of the Drain Gauge would be lowered into the PVC pipe. The upper plate of the wick section (Figure 4) would rest on the PVC pipe flush with the top of the 4-in. diameter hole. Diatomaceous earth would be packed around the fiberglass wick to enhance the contact between the wick and the soil in the DCT. The DCT monolith mentioned above would then be inserted into the 8 in. hole so that it fits over the upper plate of the wick section. The soil and waste horizons would be replaced in the order that they were removed. A valve box would be installed next to the Drain Gauge to provide access to and protection of the calibration and sampling tubes. Conduit would be used to protect the monitoring wires and tubes.

3.3.1.1 Calibration and Testing of the Drain Gauge

At different steps in the installation, the various components of the Drain Gauge would be tested as per Decagon's instructions (Decagon, 2001; Gee et al., 2002; 2004). For example, before the DCT is installed, the function of the reservoir's depth gauge would be tested using the CR10X data logger.

3.3.2 Soil-Water Content Probes

The soil moisture probes would be set at 1 ft, 2 ft, and 3 ft bgs (Figure 3). Note that the probes at 2 ft and 3 ft bgs may be in waste material in Plots A and D, a matrix that has an unknown consistency. Probes would be placed in the trench along with the drain gauge. The probes would be installed at their respective depths at the same time that the trench used to install the Drain Gauge is backfilled. Care would be taken to assure thorough soil contact with the probe. The probe is most sensitive at the surface, and even small air gaps would interfere with the function. Conduit would be used to protect the wires and link them to the Drain Gauge valve box.

3.4 Irrigation Systems

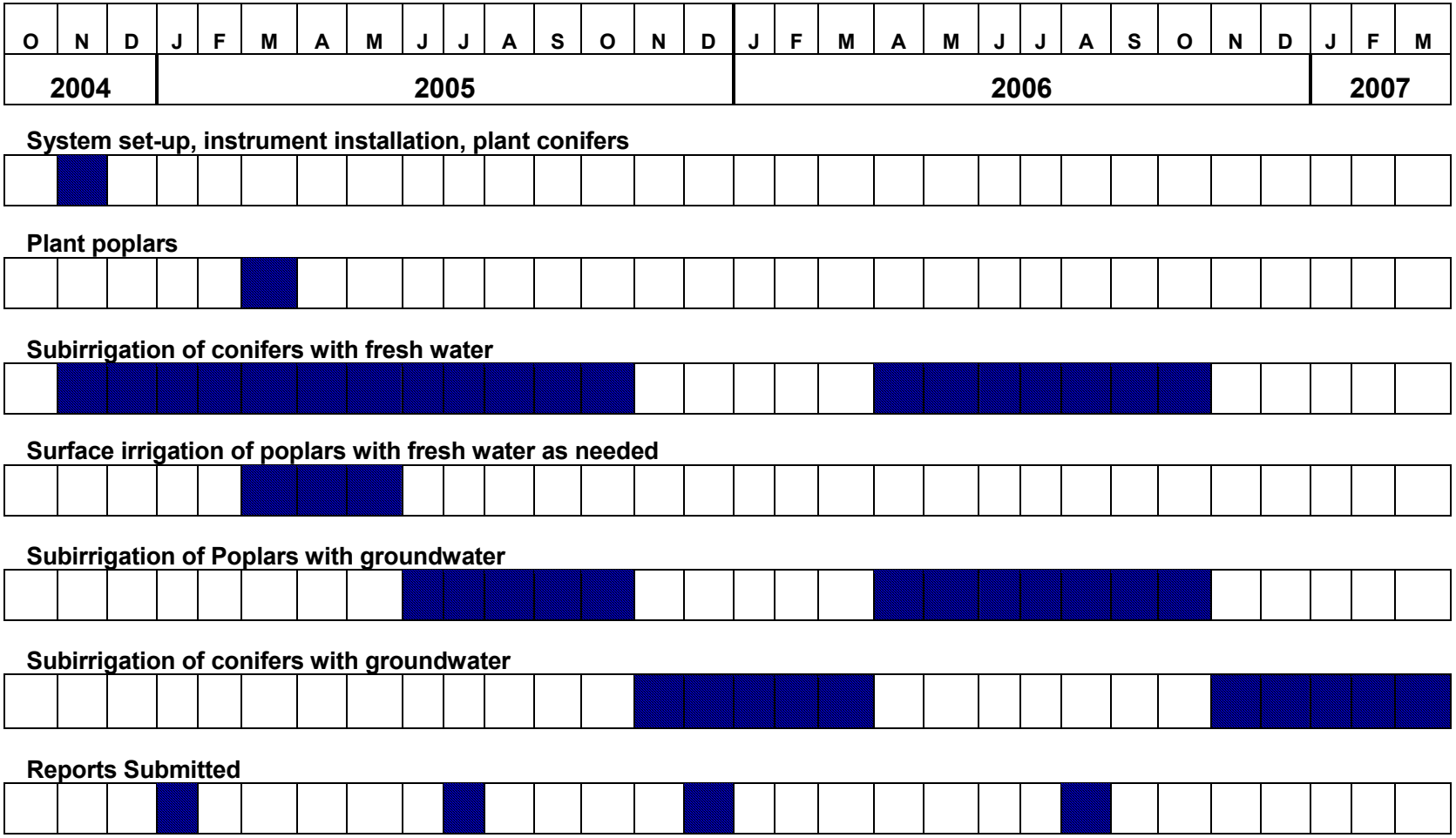
A sketch of the irrigation system is shown in Figure 5. There would be three zones, one each for Plots A, B and C. Each tree would be supplied by two pressure-compensated subsurface drip emitters (0.5 gpm each) set at 6 in. bgs. The supply lines for the emitters would be installed in trenches (1 ft deep) running along side each of the tree rows. The subirrigation drip emitters would be controlled by an irrigation controller. A moisture sensor would be wired to the irrigation controller to override the watering system when the soil is already wet (> 80 centibars). The sprinkler system timer would be set for short run-times with several different start times each day. A water meter would be installed in the water supply line to provide an ongoing record of water use.

4.0 SCHEDULE FOR PLANTING AND IRRIGATION

The schedule is summarized in Table 6. The conifers would be planted in late Fall 2004 and irrigated as needed with fresh water from the time of planting through September 2005. The established conifers would be subirrigated with recovered groundwater from October 2005 through March 2006 and from November 2006 through March 2007. From April through October 2006 the conifers would be subirrigated with fresh water.

The poplars would be planted in March 2005 and surface irrigated with fresh water until they become well established (through May 2005). The poplars would be subirrigated with recovered groundwater from June through October 2005 and again from April through October 2006.

Table 6. Proposed Schedule for Small-Scale Field Pilot



5.0 MAINTENANCE AND MONITORING

5.1 Maintenance.

Miscellaneous maintenance tasks are listed below (the irrigation schedule was described in Section 4), The routine maintenance would be carried out by ENSR personnel:

- Pelletized slow-release fertilizer (macro and micro nutrients) would be worked into the soil at the base of each tree in April 2005 and April 2006;
- The drip irrigation system would be checked on a bi-monthly basis (*i.e*. water line pressure, and solenoids). Water filters for the drip system would be inspected on a bi-monthly basis and be cleaned/replaced as necessary;
- Trees would be inspected monthly for insect damage, and sprayed as needed; and
- The current vegetation on Plots A to C would be removed at the time of installation. It is expected that the trees will grow quickly and shade the area between the trees. However, during the first growing season the area between the trees (as well as the 10-ft wide buffer between the plots) would be kept weed-free to discourage mice.

5.2 Monitoring.

Monitoring tasks, listed below, would start in November 2004. Certain data would be collected on a twice-monthly basis, and data would be analyzed at 6-week intervals. Routine monitoring would be carried out by ENSR.

- The water meter readings would be taken bi-monthly.
- The datalogger would continuously collect data from the Drain Gauges, soil-water content meters and the rain gauge. The water balance data would be analyzed and evaluated based on the objectives of the field trial outlined in Section 1.0.
- For Plots A and B the Drain Gauges would be sampled in August and September of 2005 and 2006 and the water analyzed for dioxane and CVOCs (4 sampling events x 4 drain gauges x 2 analytical procedures = 32 samples total). For Plot C, the Drain Gauges would be sampled in December and March of 2006 and in February and March of 2007, and the water analyzed for dioxane and CVOCs (16 samples). At the same intervals, the recovered groundwater (subirrigation water) would also be analyzed for dioxane and CVOCs (16 samples total).
- The salinity of the soil would be analyzed in samples taken 1 ft bgs at 3 random locations within each of the four plots. Soil would be sampled at the following times: November 2004, April 2005, November 2005, April 2006, November 2006, and March 2007. Samples of water from each of the two drain gauges would be collected at the same sampling times and analyzed for electrical conductivity.

- The dioxane concentration would be analyzed in composite soil samples in December 2005 and in March 2007. Each composite sample would be a mixture of 0 to 2-ft core samples taken from four locations in each plot.
- Separate sap flow measurement systems would be installed in Plots A to C in Spring 2006. Rate of transpirational water use would be measured for three trees per plot using TDPs connected to the dataloggers.

5.3 Reporting

Progress reports would be submitted in January, July and December 2005; August 2006 and April 2007 (see Table 6). The first report (January 2005) would summarize the installation of the water balance instrumentation and the planting of conifers in late fall 2004. Initial soil salinity values would be reported. Some baseline data from the drain gauges/soil moisture content meters may be available at that time. The second report (July 2005) would describe the establishment phase for the conifers and poplars and the initial phase of subirrigation of the poplar stands with pre-treated groundwater leachate. Water balance data from the Drain Gauges, soil-water content meters and rain gauge would be analyzed. Results from the analysis of salinity in soils and drainage water would be reported. The third report (December 2005) would be an update from the second report but would also contain results for dioxane analysis in samples of the groundwater leachate and drainage water, as well as initial results from the subirrigation of the conifer stands with groundwater leachate. This report would contain sufficient data to prepare the full-scale implementation plan in early 2006. The fourth report (August 2006) would contain an analysis of TDP data, plus an update of analyses fro the third report. Therefore, in this report a dioxane mass accounting would be possible (see Section 1.5). The fifth and final report would be submitted in April 2007. This report would summarize all of the water balance and dioxane accounting data, data for the water and soil samples, an evaluation of performance vs. objectives, site photos and recommendations.

6.0 REFERENCES

Decagon Devices, Inc., Pullman, WA, 2001. Drain Gauge, Gee Passive Capillary Lysimeter, User's Manual, Version 1.2. (www.decagon.com/draingauge).

Decagon Devices, Inc., Pullman WA, 2002. ECH_2O Probes Dielectric Aquameter, User's Manual for Models EC-20 and EC-10, Version 1.4. (www.decagon.com/echo).

ENSR and Phytokinetics, 2003 (a) *Conceptual Design and Pilot Study Workplan for a Phytoremediation and Constructed Treatment Wetlands System*, at the Former Seaboard Chemical Corporation Facility and City of High Point Landfill, Jamestown, North Carolina. January 2003.

ENSR and Phytokinetics, 2003 (b) *Work Plan for a Greenhouse Study to Test the Feasibility of the Conceptual Design for an Upland Phytoremediation System*. Addendum to the Work Plan for a Phytoremediation and Constructed Treatment Wetland System at the Former Seaboard Chemical Corporation Facility and City of High Point Landfill, Jamestown, North Carolina. September 12, 2003.

ENSR and Phytokinetics, 2004 Greenhouse Pilot Study to Test the Feasibility of the Conceptual Design for an Upland Phytoremediation System for the Former Seaboard Chemical Corporation Facility and City of High Point Landfill, Jamestown, North Carolina, *Final Report*. Prepared for The Seaboard Group II and the City of High Point, NC, April 30, 2004.

ENSR, 2004. ENSR Letter Proposal and Scope of Work for Supplemental Phytoremediation Technical Support in Relation to Remedy Recommendation Report and Remedy Design Implementation, Seaboard Group II/City of High Point, Letter to James LaRue Seaboard Group II Project Contact from Carl Tammi ENSR, May 7, 2004.

Ferro, A., Chard, J., Kjelgren, R., Chard, B., Turner, D., and Montague, T. 2001. Groundwater capture using hybrid poplar trees: Evaluation of a system in Ogden, Utah. *Int. J. Phyto*. 3;87-104.

Ferro, A., M. Gefell, R. Kjelgren, D.S. Lipson, N. Zollinger, S. Jackson. 2003. Maintaining hydraulic control using deep-rooted tree systems. In: *Advances in Biochemical Engineering Biotechnology, Special Volume: Phytoremediation*, G.T. Tsao and D. Tsao (eds.). Spring-Verlag, Neidelberg, Germany, Vol. 78. 125-156.

Gee, G.W. et al., 2002. A vadose zone water fluxmeter with divergence control. *Water Resources Research*, vol. 38, No. 8, 1029/2001 WR 000816, 2002.

Gee, G.W., A.L. Ward, Z.F. Zhang and A. Anandacoomaraswamy. 2004. Use of water flux meters to measure drainage. Pp. 321-331. In: R.A. Cooke (ed.) *Drainage VIII. Proceedings of the Eighth*

International Drainage Symposium. 21-24 Mar. 2004, Sacramento, CA., Am. Soc. Ag. Engr., St. Joseph, MI.

Granier, A. 1985. Une novella methode pour la mesure du flux de seve brute dans le tronc des arbres. *Ann. Sci*. For. 42;193-200.