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MEMORANDUM

Date: July 28, 2006

To: Jim LaRue / Southwest Environmental

From: Carl Tammi, P.W.S. and Ari Ferro, Ph.D./ENSR

Subject: **Summary Report to the NCDENR on Small-Scale Phytoremediation Field Pilot Studies on the City of High Point Landfill for the Seaboard Group II and the City of High Point.**

1.0 PURPOSE

The purpose of this memo is to (1) present information on the status of the two pilot-scale phytoremediation systems at the City of High Point Landfill in North Carolina, and (2) respond to questions posed by the North Carolina Department of Natural Resources (DENR) regarding system-monitoring as the source of irrigation water is transitioned from city-supplied water to the contaminated groundwater extracted from a recovery well (PW-DR1).

This memo provides a detailed technical summary of the two pilot-scale phytoremediation systems and provides answers to DENR's questions (6/28/06 email from Robert Glaser), specifically:

(1) Where the monitoring will occur;

(2) The planned frequency of monitoring;

(3) How the flow of extracted groundwater will be regulated;

(4) The proposed irrigation flow rate (i.e., contaminated water volume / unit time); and

(5) How water uptake by the trees will be monitored

2.0 PROJECT OVERVIEW

Two pilot-scale projects are being conducted on the landfill with the objective of testing the operational feasibility of the eventual full-scale upland phytoremediation system. The full-

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scale system, consisting of 35 acres of coniferous and deciduous trees, will be irrigated with treated effluent from the constructed wetland (see discussion in reference 5). This effluent, produced at the rate of 50 gallons per minute (gpm) year-round, will contain low levels of 1, 4-dioxane and is moderately saline (2) due primarily to the presence of bicarbonate salts (EC = 2,000 µhos/cm; TDS = 1,200 mg/L; bicarbonate = 1,000 mg/L). Moreover, the treated effluent received from the wetland will contain elevated concentrations of Manganese (Mn) (approximately7mg/L), which is a chemical element that can cause chlorosis in sensitive tree species. The function of the full-scale phytoremediation system will be for the trees to use the treated groundwater effluent from the constructed wetland via root uptake and transpiration, and to phytovolatilize the dioxane present in the water. Reports in the literature, and the results of our greenhouse studies (2), indicate that dioxane is readily taken up by a variety of the tree species. Uptake is indicated by a high transpiration stream concentration factor (TSCF) for dioxane. After uptake, dioxane exits the leaves via the stomata (phytovolatilization). The compound does not tend to accumulate in the plant tissue.

Previous greenhouse studies have indicated that the recovered groundwater contained sufficiently high concentrations of Mn to cause chlorosis in poplar trees and other sensitive tree species (2). The chlorosis is apparently a result of the inhibition of iron (Fe) uptake by the Mn. Greenhouse studies indicated that the chlorosis could be prevented if chelated Fe (Fe-EDDHA) was added to the groundwater used as irrigant. Other data obtained in the preliminary greenhouse studies indicated the following: a) loblolly pine, western red cedar, and Chinese elm are tolerant of the groundwater (i.e. they do not develop chlorosis); b) the TSCF for dioxane is approximately 0.70 in hybrid poplar (DN-34), 0.47 in Japanese black pine, 0.76 in loblolly pine , 0.70 in western red cedar.

The management practices used for the full-scale system must be compatible with the following performance objectives (5):

- *Zero-discharge.* The irrigation will be carried out in such a way that the leaching of dioxane-containing water below the root-zone of the trees will be minimal. The irrigation water will either be immediately transpired by the trees, or temporarily stored in the "sponge" layer of the landfill. The "sponge" layer is the zone of soil material colonized by the tree roots. This layer will hold water during cool, wet periods in winter, and during the warm dry weather of the growing season the water will be taken up by the trees. It is important that the sponge layer be as thick as possible in order for it to have maximal water holding capacity. It is therefore important that the management practices for full-scale phytoremediation system promote the development of deeply rooted trees.

- *Long term viability.* The accumulation of salts in the root-zone of the trees will be prevented by seasonal leaching (with low EC water). Plants will be employed that are Mn-tolerant (or for sensitive species, chelated Fe will be added to the irrigation water), and relatively saline-tolerant.

The objective of the two pilot projects is to test the feasibility of the full-scale upland phytoremediation system. The pilot projects must therefore confirm that stands of trees can be irrigated with recovered groundwater without resulting in percolation of water below the root zone. [In the full-scale system, the recovered groundwater will be pre-treated by a constructed wetland system. Because the treatment wetland is not yet functional, the trees in the pilot stands will receive groundwater directly with no pre-treatment.] The pilot projects must also

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confirm that salts accumulating in the root-zone soil can be leached and that the trees will remain viable.

During the 2006 growing season, we plan to discontinue irrigating the trees in the pilot projects with city-supplied water and begin irrigation with groundwater recovered from PW-DR1. Prior to the use of this groundwater, we must be able to demonstrate that a water balance can be maintained in order to minimize percolation of moisture below the root-zone of the trees. Input water comes from irrigation plus precipitation. The input water must be either taken up and transpired by the trees or held in storage by the "sponge" layer of the landfill.

2.1 The 2004 Pilot Study

The study area is divided into four plots (1). Hybrid poplars are established on Plots A and B; Japanese black pine are established on Plot C. The three plots each have 24 trees, planted on 6-foot centers. Plot D is the experimental control in which the original landfill vegetation, consisting of herbaceous vegetation) is maintained. We did not know the thickness of the landfill cap when the study was started. Therefore, in order to ensure that the trees had an adequate thickness of soil, a 1.5-foot layer of fill was placed on Plots B and C. Plots A and D, in contrast, were installed directly on the landfill cap.

Each plot is instrumented with drain gauges and soil moisture probes. Plots A to C have independently-regulated (and metered) automatic drip-irrigation systems that deliver 3.6 gpm (28.8 ft^3/h) of water to each of the 24 ft x 36 ft (864 ft^2) plots. This equates to roughly 0.4 inches per hour. Plot D does not have an irrigation system. The drain gauges measure percolation of water below the root-zone of the trees. The face of the drain gauge that collects drainage water is 1.5 feet below ground surface (bgs). The moisture probes are set at 1, 2, and 3 ft bgs. A rain bucket has also been installed at the site to measure precipitation. Values for soil moisture, drainage, precipitation, and irrigation rate are continuously collected by a datalogger and this data can be remotely accessed via a modem. All of the instrumentation and systems were installed in 2004 at the beginning of the study.

By July of 2006, the poplar trees had attained a height of 10 to 15 ft (Figure 1) and transpiration rates were at sufficient levels that daily changes in soil moisture could be noted. The popular trees in Plot A (planted directly in the landfill cap) have out-performed the poplars in Plot B, probably because of the poor quality of the fill material used on Plots B and C. The poplars in Plot B, however, are now catching up to those in Plot A. The Japanese black pines in Plot C are also thriving and are 5 to 7 ft in height (Figure 2). The trees are being irrigated with city-supplied water to maintain adequate soil moisture.

The next step in the 2004 Pilot is to irrigate the poplar trees in Plots A and B, and the pine trees in Plot C with extracted groundwater. A nutrient injector has already been installed on the supply lines for the drip-irrigation system for the poplars and a solution of Fe-EDHA (1.2 mg Fe/L) will be added to the irrigation water (2). The objectives in this phase of the study for the 2004 Pilot are listed below (1):

- To maintain adequate soil moisture via irrigation with groundwater in a controlled fashion, without creating excessive drainage. Irrigation cycles will be deep and infrequent in order to encourage the formation of deep roots and therefore a thick sponge layer.

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- To monitor the accumulation of soil salinity in the root-zone of the trees (as measured by EC).
- To maintain a mass balance for 1, 4-dioxane on a per plot basis. For a given time interval, the following data will be collected:
    - the volume of groundwater irrigant, the mass of root-zone soil (upper 1.5 ft of the soil profile), and the volume of drainage water will be estimated,
    - the concentration of dioxane will be measured in groundwater, root-zone soil, and drainage water at specific time intervals.
- To test the leachability of the accumulated salts from the root-zone soils. After the poplar trees in Plots A and B become dormant in November 2006, we will monitor the reduction in the soil salinity that results as winter rains percolate through the soil profile. Predictably, water with high EC will be detected in the drain gauges.

2.2 The Plant Suitability Demonstration (PSD) Pilot

A second pilot project was started on the landfill in spring 2006 (3). Large containerized trees were planted in May (Figure 3). The main objective of the PSD Pilot is to test in the field a variety of deciduous and coniferous tree species for their suitability for the eventual full-scale upland phytoremediation system. The study area is divided into two plots: In Plot I, loblolly pine, Virginia pine, and western red cedar are becoming established (two trees of each species); In Plot II, willow oak and Chinese elm are becoming established (two trees of each species). Each plot is instrumented with soil moisture probes, including a single PR 2/6 Soil Moisture Probe that can be moved from Plot I to Plot II. This probe can simultaneously measure water content at 100, 200, 300, 400, 600 and 1000 mm bgs. Plots I and II also have independently regulated (and metered) automatic drip-irrigation systems. As shown in Figure 3, at the base of each tree four drip emitters deliver 2.4 gph. One tree of each species is instrumented with thermal dissipation probes (TDPs). The use of TDPs to monitor plant water use is outlined in Section 1.4. Soil moisture, irrigation rate, and transpirational water use (TDP data) are continuously datalogged. Furthermore, two suction lysimeters have been installed in Plot I. The lysimeters are installed at 0.5 ft and 3 ft bgs at the base of a loblolly pine tree. The trees are currently being irrigated with city water.

The next step for the PSD Pilot is to irrigate the trees in Plots I and II with recovered groundwater. Chelated iron will not be added to the irrigation water. Previous greenhouse studies (2) indicated that loblolly pine, western red cedar, and Chinese elm are tolerant of the groundwater, but the tolerance of Virginia pine and willow oak to groundwater will be evaluated for the first time in the PSD Pilot. Starting in 2007 (after the plant establishment phase in the 2006 growing season), deep, infrequent irrigation cycles will be used to encourage the development of deep-rooted trees and therefore a thick sponge layer.

Tree health will be monitored after the irrigation of the plots with groundwater is initiated. The appearance of the trees will be monitored, especially any tendency to develop chlorosis. As noted above, the tolerance of Virginia pine and willow oak to the groundwater is still unknown.

One objective for the project is to demonstrate that adequate plant-available moisture can be maintained without creating excessive drainage. The PSD Pilot plots do not contain drain

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gauges (as do the 2004 Pilot plots). The purpose of the "suction lysimeters" will be to monitor the potential infiltration of dioxane containing water below the root-zone of the trees. Water samples can be collected from the vadose-zone soil by creating a vacuum inside the suction lysimeter that is greater than the soil suction holding the water in the capillary space. Samples of soil water will be taken at 0.5 ft and 3 ft bgs, and analyzed for dioxane. Comparisons of the dioxane concentrations at these two depths will indicate the effectiveness of dioxane phytovolatilization: The dioxane concentration of the soil water at 0.5 bgs would presumably be the same as that in the irrigation water; the concentration at 3 ft bgs would be the concentration in water that had passed through the root zone of the trees.

The suction lysimeters also will be used to monitor the accumulation of salt in the root-zone soil. The lysimeters are installed within the root-zone of a loblolly pine in Plot I. As this tree is irrigated, soil water will be taken up from the root-zone, assumed to be mostly within the upper 2 ft of the soil profile. This uptake of water will result in salt accumulation, reflected by a gradual increase in the EC of the water collected in the lysimeter at 0.5 ft bgs. Predictably, there would be less increase in EC in water samples at 3 ft bgs. On the other hand, when the salts are leached from the soil by excess irrigation with city water a decrease in EC would be observed at 0.5 ft bgs and an increase at 3 ft bgs.

2.3 Data Input from the Landfill Suitability Assessment (LSA)

The data from the LSA are helpful in developing a rational approach to managing the water balance for the pilot projects (4). For example, the estimated mean value for field capacity in the upper 3 ft layer of the landfill was 28.5% by volume. The estimated mean permanent wilting point (-15 bars soil suction) was 8.5% by volume.

In the LSA project, the test plots were irrigated with sufficient water to bring the various soil strata to a moisture content that was at or above field capacity. Drip irrigation was then stopped, and the measurement of the soil water content (at 100, 200, 300, 600, and 1000 mm bgs using the PR2/6 Moisture Probe) was continued for several days to obtain an estimate of field capacity for the various strata.

For many of the plots (plot A12 for example) the water content in the various strata after irrigation ceased, and the content after several days of drainage, was approximately the same. These data suggested that the drainage of gravitational water was fairly rapid.

2.4 Thermal Dissipation Probes

Thermal dissipation probes are widely used to measure sap 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 needle-like sensors with a pair of thermo junctions in each sensor. The upper needle in the pair contains a heating element. The thermocouples are differentially wired to determine temperature differences between the heated needle and the non-heated (reference) needle. The needles are inserted into holes drilled into the xylem of 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. As described below, values for ΔT and sap velocity are related empirically. The product of sap velocity and average trunk cross-sectional area (basal area) between the two thermocouples yields the rate (cm^3/h) of sap flow.

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A dimensionless flow index, K, is calculated for a specific time period according to the relationship: $K = (\Delta T_{max} - \Delta T)/ \Delta T$, where ΔT_{max} is the value in a given time period where ΔT is the greatest (e.g., the pre-dawn hours). A value for sap velocity, V (cm/s), is then estimated using the following empirical relationship development by Granier: $V=0.0119 \times K^{1.231}$ (8).

3.0 RESULTS OF THE 2004 PILOT STUDY

3.1 Estimation of Field Capacity

The same approach as used for the Landfill Suitability Analysis (LSA) was used to assess the hydrologic characteristics of Plots A, B, C, and D. Access tubes for the PR2/6 Probe were installed in each of the four plots. The existing drip-irrigation system was used on 6/6/06 for Plots A, B, and C to deliver sufficient city water (1 to 2 inches) to bring the various strata to field capacity. For Plot D, the network of drip emitters used in the LSA was employed (the system delivered water at 2.14 in/h over a 90 ft^2 area). Allowing the strata to drain for several days to estimate field capacity, as was done in the LSA, was not feasible in this study. As pointed out in the next section, at least for Plots A and B, the poplar trees are now rapidly taking up water from the top 3 ft of the soil profile. However, a fairly good estimation of field capacity can be made immediately after ceasing irrigation (see the discussion of the apparently rapid drainage of gravitational water in Section 1.3).

Data for Plots A through D are presented in Figure 4, and are compared to similar data from the LSA test plots A12 and E2. These test plots in the LSA were nearest to the 2004 Pilot (4). The estimated field capacity values for the upper soil layer for Plots A to D are shown in Table 1. Mean "low end" values for the 2004 Pilot (26% by volume) and "high end" values (40% by volume) were used to calculate a grand mean for field capacity of 33% by volume (25.4% by mass). This value is slightly higher than the grand mean for the 18 LSA plots (28.5%; Ref. 4) and is a field capacity characteristic of silt loam soils. For such soils, the corresponding moisture content at the permanent wilting point is approximately 10.5% by volume (8% by mass).

3.2 Data Analysis

The data from March through mid-July for Plots A through D are shown in Figures 5 to 8. For each Figure, the top panel shows the values for soil moisture (% by volume) obtained by probes installed at 1, 2, and 3 ft bgs, and drainage (in inches) as measured by the drain gauges. The bottom panel shows water input into the specific plot from irrigation and precipitation, as measured by the water meters and rain bucket. Water exiting the plots is from plant transpiration and drainage.

As discussed in Section 2.1, a very rough value for field capacity for the plots is 33% by volume. When soil moisture exceeds this value, drainage would be expected. The rate of transpirational water use by the poplars is high enough in Plots A and B, that fluctuations in soil moisture can be observed. Following irrigation or precipitation, soil moisture levels increase, and during intervals with no input of water, the soils quickly dry out. Whenever soil moisture exceeds about 33% by volume (within the upper 3 ft of the soil profile) the rate of drainage increased. Drainage slowed or stopped when soil moisture decreased. In Plot D for example, from 5/10 to 6/5 soil moisture at all depths was <33% by volume and drainage ceased. Once soil moisture increased in Plot D, especially after 6/5, drainage increased.

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The poplar trees in Plots A and B were able to take up moisture from the entire 3 ft thickness of the soil profile. This observation suggests that the landfill matrix is conducive to the development of trees with deep roots, given optimal cultural practices (e.g. deep infrequent irrigation cycles). For trees in both Plot A and B, there are wet and dry cycles (Figures 5 and 6): The wet cycles resulted from irrigation or precipitation; water uptake by the trees dried the soil profile, as measured by probes at 1, 2, and 3 ft bgs, reducing moisture to a minimum of about 15% by volume (11.5% by mass). This level of soil moisture corresponds to about 7 bars of soil suction (Figure 11). Very little plant-available moisture remains at this moisture content (the permanent wilting point for this soil is ~10% by mass, 13% by volume). Prolonged periods of such dry soil would result in plant stress.

The rate of transpiration by the poplar stands can be very roughly estimated from the data. For example, in Plot A on 6/15 soil moisture held in storage (0 to 3 ft bgs) is approximately 10.3 in. By 6/22, this value is 6.4 in. Drainage during this time period is 0.08 inches. These data suggest, therefore, that the poplars transpired 3.3 in. per week or 15.5 in. per mo. Comparable data for poplars in Plot B during this same time interval (soil storage 6/15, 11.6 in; soil storage 6/22, 6.0 in; drainage, 0.8 in) is 4.8 in per week or 19.2 in per mo. For both Plots A and B, rates of drainage were relatively rapid on 6/15 and was much less by 6/22.

The rapid rate of transpiration by the poplars in Plot A was further indicated by the step-like patterns in reduction of soil moisture at 1, 2, and 3 ft bgs (Figure 9). These patterns are evidently due to diurnal changes in the rate of transpiration (i.e. that the trees transpire rapidly during the day, with peak water use occurring at about noon, and cease transpiration at night).

The data for soil moisture for Plot C suggests that the Japanese black pines, at this stage in their development, are relatively shallow rooted: marked fluctuations in soil moisture were evident only at 1 ft bgs (Figure 7). However, the pines transpired 4.5 to 5.0 in/mo and could effectively reduce the water content of the upper 1 ft of the soil profile.

Although there were no marked fluctuations of soil moisture at Plot D containing relatively shallow rooted grass, the 0 to 3 ft soil profile tended to dry out. Figure 8 shows the gradual decline in soil moisture in Plot D between 5/10 and 6/5. The grass stand apparently transpired between 2.5 to 3.0 in/mo.

A relatively long-term water balance was estimated for the month of June (6/6 to 7/4). This was a period in which the plots were extensively irrigated in order to perform the study discussed in Section 2.1. Also, the month of June had unusually high precipitation (7.6 in, normally 3.9 in). As shown in Table 2, the estimation for the water balance includes water input from precipitation and irrigation, and changes in soil storage and drainage. Based on the data, estimates were made for transpiration. The estimate for transpiration by the grass in Plot D (3.0 in) is lower than average ET_o for June (5.4 in; Ref. 5). ET_o is "reference evapotranspiration", the rate of water use for a well-watered 6 in fescue turf. The estimates for poplar transpiration for this longer time interval are lower than those mentioned above for the week of 6/15 to 6/22. The basis for these differences are probably due to sampling error (i.e. scatter and error in the data collected by the instruments) and well as real fluctuations in rates of transpiration from week to week.

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4.0 RESULTS FROM THE PSD

The large containerized trees transplanted into the PSD Plots are now becoming established. During the plant establishment phase, growth rates will be slow, and rates of water use will be low. The TDP data indicated that sap velocity is still relatively low (Figure 10). For example, the sap velocity measured for the loblolly pine (P*inus taeda*) was 5 to 6 cm/h (corresponding to a transpiration rate of approx 3.5 L/d). By comparison, literature values (7) for other pine species are about double that value (8 to 13 cm/h for *Pinus pinaster*; 13 to 15 cm/h for *Pinus radiata*). During the establishment phase, the trees have been provided with adequate water via the drip irrigation system. Soil moisture a 1 ft bgs has been maintained at 19 to 23% by volume, based on moisture probes set at 1 ft bgs in Plots I and II (see below).

5.0 IRRIGATION OF THE PILOT PLOTS WITH RECOVERED GROUNDWATER

The next step in the pilot projects, as discussed in Section 1.0, is to discontinue irrigation with city water, and initiate irrigation with groundwater recovered from PW-DR1. The objective is to demonstrate that the tree stands can be irrigated with recovered groundwater without producing drainage (percolation of water below the root-zone).

To prevent shocking the trees with the moderately saline groundwater, the trees in both pilot plots will be irrigated initially with a city water/groundwater blend. The percent groundwater used will be increased in a step-wise fashion: week 1, 25%; week 2, 50%; week 3, 75%; week 4, full strength groundwater. The current irrigation system will be retro-fitted with flow regulators and an in-line mixer to make the appropriate water blends.

In order to maintain the deep roots for the poplars in Plots A and B, and stimulate the development of deep roots for the pines in Plot C, the irrigation cycles will be deep and infrequent. The following protocols assume that there is no rain fall. If rain occurs, the irrigation schedules will be changed to take precipitation into account. Plots A and B will be irrigated once per week for 6.9 hours (four 1 h. and 40 min. run times, to deliver 2.8 inches of water). The average soil moisture in the top 3 ft of the soil profile should cycle between approximately 21.5 % and 29.5 % by volume. This input of water is based on estimates of water use by the poplars in Plots A and B of about 12 in. /mo. The 6.9 h. irrigation is split into four 1 h. and 40 min. cycles to allow for infiltration.. During these irrigation cycles, drainage and soil moisture will be continuously monitored as shown in Figures 5 and 6.

Although the Japanese black pine in Plot C are well established, the data suggest that the roots are less than 2 ft bgs (Figure 7). The trees appear to dry out the soil at 1 ft bgs, but reductions in soil moisture at 2 ft bgs are minimal. Plot C will be irrigated twice per week for 1 h. and 22 min. (two 41 min. run times, total 0.55 inches of water on each of two days of each week). Soil moisture in the top 1 ft of the soil profile should cycle between approximately 23 % and 28 %. This input of water is based on estimates of water used by the pine of about 4.8 in./mo. The 1 h. 22 min. irrigation is split into two 41 min. cycles to allow for infiltration. .

During the 2006 growing season, as the PSD Pilot stand is becoming established, each tree will be irrigated 1h/d (2.4 gal/d), which is about twice the transpiration rate of the loblolly pines (Figure 10). The PR2/6 moisture probe will be used to monitor soil moisture at 2 to 3 ft bgs and the irrigation will be reduced if moisture at these depths becomes excessive (> 33%). The

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infiltration of dioxane containing water at 3 ft bgs will be monitored using the suction lysimeters (Section 1.2). As the plants are becoming established this year, it is important that adequate moisture be provide, and no attempt will be made to stimulate deep roots by using deep infrequent watering cycles, as described above for the 2004 Pilot. Soil moisture at 1 ft bgs will be maintained at 25% to 30% by volume. Irrigation with recovered groundwater will be started in 2006, and therefore we will evaluate the tolerance of the various species to groundwater under field conditions.

6.0 SUMMARY / CONCLUSIONS

This memo provides information on how the pilot stands (the 2004 Pilot plot and the PSD) will be monitored during the transition from irrigating with city water to irrigating with groundwater recovered from PW-DR1. Specifically, the memo addresses the following questions posed by DENR: 1) Where will the monitoring occur ?; 2) What will be the frequency of the monitoring ?; 3) How will the flow of contaminated water (groundwater recovered from PW–DR1) we regulated ?; 4) What is the volume of contaminated water dispensed to the pilot plots per unit time ?; and 5) How will water uptake by the trees be monitored ?

The responses to questions 1, 2 and 3 are the same for the 2004 Pilot and the PSD: Data from the instruments will be continuously transmitted to data loggers, and these data transmitted to ENSR's Raleigh office either continuously (via modem) or at weekly intervals (via manual down-load by field personnel and e-mail transmissions). The instruments include soil moisture probes, water meters, rain bucket, drain gauges (for the 2004 Pilot) and TDPs (for the PSD). The flow of contaminated water will be regulated using irrigation timers that control solenoid valves. Data from the soil moisture probes, the drain gauges and the water meters will be evaluated to confirm that the timers/valves work as intended.

The volume of contaminated water dispensed will be different for the two pilot plots. For the 2004 Pilot, we estimate that the poplars in Plots A and B (24 trees/plot) use approximately 12 inches per month (approximately 8.8 gal/d/tree; 1490 gal/week/plot). Once per week, the drip irrigation system will deliver 1490 gallons of recovered groundwater to each of the poplar plots. This volume of water (delivered in four 1 h. and 40 min. intervals within a single day) will be sufficient to increase the soil moisture in the upper 3 ft of the soil profile from about 21.5 % to 29.5 % by volume. The deep, infrequent irrigation cycles will encourage deep roots.

The pines in Plot C of the 2004 Pilot use an estimated 4.8 inches per month (3.5 gal/d/tree; 595 gal/week/plot). Twice per week, the drip irrigation system will deliver 298 gal of recovered groundwater to the pines. This volume of water (delivered in two 41 min. intervals within a single day) will be sufficient to increase the soil moisture in the top 1 ft of the soil profile from 23 % to 28 %.

During the 2006 growing season, the trees in the PSD plot will be irrigated 1 hour per day (2.4 gal/d/tree). The PR2/6 moisture probe will be used to monitor soil moisture a 2 to 3 ft below ground surface, and the rate of irrigation will be reduced if moisture at these depths becomes greater than 33%. Soil moisture a 1 ft bgs will be maintained at 25 % to 30 % by volume.

Water uptake by the trees in the 2004 Pilot plot will be estimated indirectly by monitoring from the water meters, rain bucket, soil moisture probes and drain gauges: After moisture input,

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there will be a spike in the moisture content in the soil profile. Assuming that the rate of drainage is minimal, the rate of change in soil moisture will be due to water uptake by the trees. Water uptake by the trees in the PSD plot will be monitored using TDPs.

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Table 1 Field capacity values for the upper soil layer in the 2004 Pilot plots and from selected LSA test plots. The ranges shown correspond to the "low end" and "high end" estimates for field capacity for the various strata.

Study	Plot	Field Capacity	
		% vol	% mass
2004 Pilot	A	24-36	18-28
2004 Pilot	B*	38-44	29-34
2004 Pilot	C	27-42	21-32
2004 Pilot	D	15-38	12-29
2004 Pilot	Mean	26-40	20-31
LSA	A12	26-43	20-33
LSA	E2	26-35	20-27
LSA	Mean**	20.7-36.2	16-27

*data for the sandy upper layer was not included in the range of values
*mean for all LSA test plots (n=18)

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Table 2 Water balance estimations for 2004 Pilot Plots from 6/6/06 to 25/4/06.

Plot	Input			Soil Storage			Drainage	Transpiration	
	Precip (in)	Irrig (in)	Total (in)	6/6/06 (in)	7/4/06 (in)	Net (in)	(in)	(in)	(in/mo)
A	7.6	1.7	9.3	6.0	8.6	+2.6	0.76	5.9	6.3
B	7.6	1.1	8.7	5.9	6.3	+0.4	4.0	4.3	4.6
C	7.6	0.58	8.2	10.2	8.9	-1.3	4.8	4.7	5.0
D	7.6	4.25	11.8	5.6	10.1	+4.5	4.5	2.8	3.0