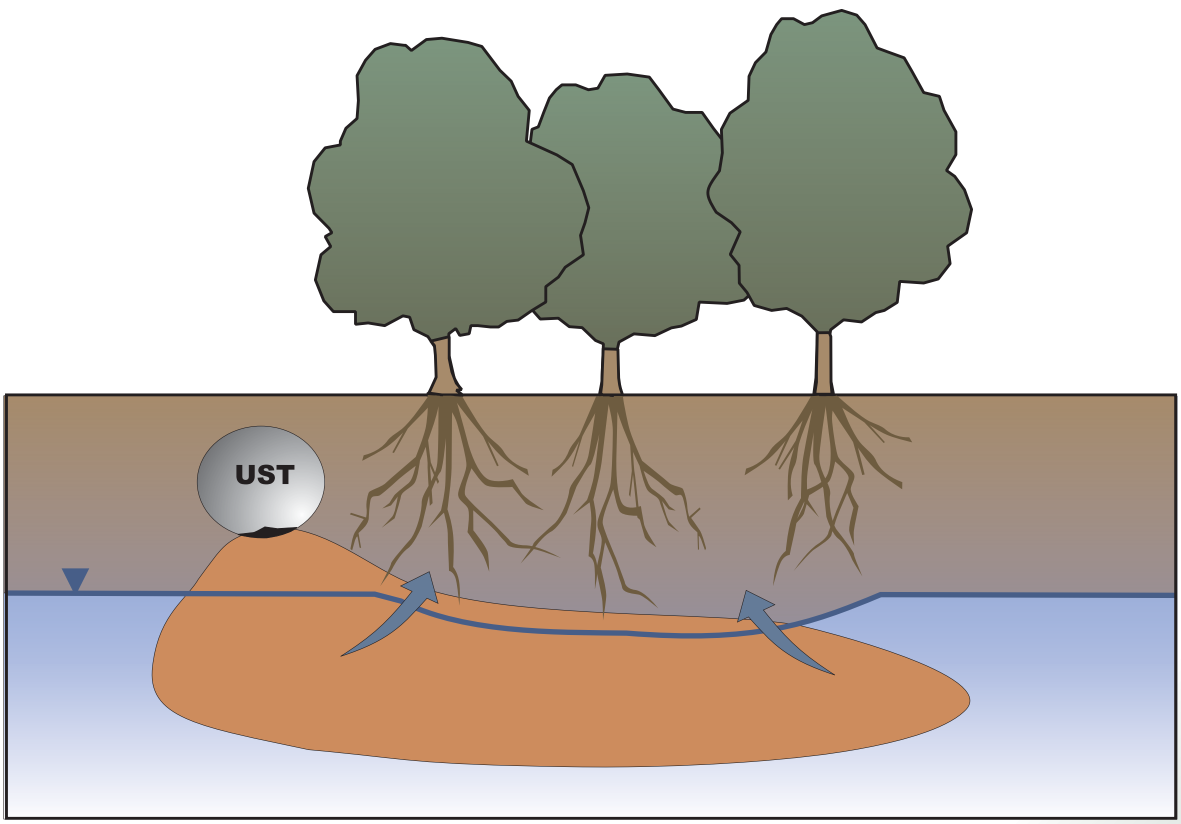
Demonstration of Phytostabilization of Shallow Contaminated Groundwater Using Tree Plantings at Travis Air Force Base, California

Addendum Report No.3
to the
Interim Technical Report
Interim Cost and Performance Report



Final
September 2005

Air Force Center
for Environmental Excellence

FINAL

ADDENDUM REPORT NO. 3

TO THE

INTERIM TECHNICAL REPORT FOR THE DEMONSTRATION OF PHYTOSTABILIZATION OF SHALLOW CONTAMINATED GROUNDWATER USING TREE PLANTINGS AT TRAVIS AIR FORCE BASE, CALIFORNIA

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ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
AFCEE/TDE	Air Force Center for Environmental Excellence Environmental Science Division
amsl	above mean sea level
bgs	below ground surface
^{o}C	degrees Celsius
CAH	chlorinated aliphatic hydrocarbons
cbars	centibars
cm	centimeters
DCAA	dichloroacetic acid
DCE	dichloroethene
DO	dissolved oxygen
^{o}F	degrees Fahrenheit
gal/day	gallons per day
gpm	gallons per minute
K_c	crop coefficient
K_L	landscape coefficient
LAI	leaf area index
L/day	liters per day
m^2	square meters
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
mL	milliliter
mm	millimeter
mm/day	millimeter per day
mS/cm	millisiemens per centimeter
mV	millivolt
ND	non-detect
OM&M	operations, maintenance, and monitoring
Parsons	Parsons Infrastructure and Technology Group, Inc.
PCE	tetrachloroethene
PET	potential evapotranspiration
pg/L	picograms per liter
PVC	polyvinyl chloride
redox	reduction/oxidation potential
SMOW	standard mean ocean water
SU	standard units
TCAA	trichloroacetic acid
TCE	trichloroethene
TCEt	trichloroethanol
TSC	transpiration stream concentration
TSCF	transpiration stream concentration factor

ACRONYMS AND ABBREVIATIONS (CONTINUED)

USEPA	United States Environmental Protection Agency
VOC	volatile organic compound
WABOU	West/Annexes/Basewide Operable Unit

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INTERIM TECHNICAL REPORT
FOR THE DEMONSTRATION OF PHYTOSTABILIZATION
OF SHALLOW CONTAMINATED GROUNDWATER
USING TREE PLANTINGS AT
TRAVIS AIR FORCE BASE, CALIFORNIA

1.0 INTRODUCTION

The phytostabilization demonstration at Travis Air Force Base (AFB) is part of an initiative being conducted by the Air Force Center for Environmental Excellence Environmental Science Division (AFCEE/TDE) in conjunction with Parsons Infrastructure and Technology Group, Inc. (Parsons). AFCEE/TDE has implemented a multi-site program to independently evaluate phytostabilization of contaminated groundwater. The purpose of this demonstration project is to test the ability of selected plants to remove groundwater through uptake and consumption in order to contain or control the migration of dissolved contaminants. Travis AFB is one of six Air Force bases that is taking part in this demonstration.

The phytostabilization demonstration site at Travis AFB (approximately 0.91 hectares [2.24 acres] in size) is located southeast of Building 755 (Figure 1.1) in an area that is part of the West/Annexes/Basewide Operable Unit (WABOU). Building 755 is a Battery and Electric Shop with a former acid neutralization sump. Groundwater below and immediately downgradient of this former sump is contaminated with chlorinated aliphatic hydrocarbons (CAHs); including tetrachloroethene (PCE), trichloroethene (TCE), cis-1,2-dichloroethene (DCE), trans-1,2-DCE, and vinyl chloride. Contaminated groundwater exists approximately 5 meters below ground surface (bgs) and extends approximately 650 meters downgradient of the source area (Figure 1.2).

The plantings at Travis AFB took place in two stages: 1) an initial 100 trees (red bark eucalyptus; 15-gallon size) were planted in the fall of 1998 using planting pit/root ball techniques with an aggressive engineered approach (i.e., augured 12-inch diameter holes to the groundwater table with the addition of a vent tube); and 2) a supplemental planting of 380 trees (red bark eucalyptus; 1-gallon size) was completed in the summer of 2000 using the planting pit/root ball technique without any engineered approach.

The *Final Interim Technical Report for the Demonstration of Phytostabilization of Shallow Contaminated Groundwater Using Tree Plantings at Multiple Air Force Demonstration Sites* (Parsons, 2003a) was submitted to AFCEE/TDE in January 2003 and describes the progress of the Travis AFB phytostabilization project from 1998 through 2001. The *Final Demonstration of Phytostabilization of Shallow Contaminated Groundwater Using Tree Plantings at Travis AFB, California, Addendum Report No. 1 to the Interim Technical Report; Interim Cost and Performance Report* was submitted to AFCEE in July 2003 and describes the progress of the Travis AFB demonstration site in 2002 (Parsons, 2003b). The *Final Demonstration of Phytostabilization of Shallow Contaminated Groundwater Using Tree Plantings at Travis AFB, California, Addendum Report No. 2 to the Interim Technical Report; Interim Cost and Performance Report* was submitted to AFCEE in August 2004 and describes the progress of the Travis AFB demonstration site in 2003 (Parsons, 2004). The three reports identified above are provided for reference in electronic format on a CD-ROM at the back of this document.

This Addendum Report No. 3 summarizes the operations, maintenance, and monitoring (OM&M) activities and additional data collected at the Travis AFB demonstration site during 2004 (the sixth growing season for the initial planting and fifth growing season for the supplemental planting), as well as a summary of the entire demonstration project. The OM&M activities are outlined in the OM&M work plan (Parsons, 2002).

This report consists of seven sections and four attachments. Section 1 provides an introduction to this demonstration project. Section 2 summarizes the 2004 plant observations. Section 3 describes the maintenance activities, and Section 4 summarizes the monitoring activities. Section 5 summarizes the results of the demonstration to date, and Section 6 provides a plan for future activities. Section 7 presents references used in preparing this report. Appendix A includes the data acquisition system calibration report. Appendix B presents the results from the performance of the on-site data acquisition system. Appendix C provides a summary of groundwater data collected by CH2M HILL, Inc. Appendix D contains the phytovolatilization report from Utah State University. Appendix E contains the cost and performance report.

2.0 TREE OBSERVATIONS

This subsection provides a summary of tree observation results from the sixth growing season (2004). Observations of the trees (e.g., growth, trunk circumference, and mortality) were made in September 2004. Individual trees are referenced by the row and tree number (Figure 2.1). Figure 2.2 contains photographs that show the actual growth of the trees.

2.1 Mortality

Tree mortality rates have been fairly low. Of the 100 trees that were planted in 1998, six trees (6 percent) were replaced after the first growing season because of freeze damage. From the second to fifth growing season, there was no additional mortality of the initial plantings. In 2000 and 2001, 20 (5 percent) of the 380 supplemental trees died and were either replaced or removed. During the third year (2002) of growth, another 9 supplemental (2 percent mortality) trees died. In 2003, 25 additional trees died or were nearly dead (7 percent mortality of the remaining trees). In 2004, an additional 7 supplemental trees (2 percent) died or fell over. Most of the dead trees were in the easternmost portion of the site in a shallow depression filled with water. The other mortalities occurred adjacent to the ponded area on the south end of the site. Trees that were lost from 2002 to 2004 were not replaced. All 100 trees from the initial planting and 342 trees (90 percent) from the supplemental planting remain as of September 2004 (Figure 2.1).

2.2 Plant Growth

The success of the tree plantings is measured by the health and growth characteristics of the vegetation planted. Tree growth characteristics including tree height and trunk circumference were recorded in September 2004 for 51 trees, which represented a subset (12 percent) of the healthy trees in the entire plant stand. Table 2.1 shows the heights and circumference of selected initial trees that were planted in 1998. After six years, the initial trees ranged in heights from 5.5 to 7.6 meters or an average of 7.0 meters (a 7-percent increase from 2003). The circumference of the initial trees at approximately 1 meter above the ground surface had increased from an average of 42 centimeters (cm) in 2003 to an average of 44 cm in 2004 (a 5 percent increase).

Table 2.2 shows the heights of 41 selected supplemental trees that were planted in 2000. The heights of the selected trees averaged 2.0 meters in 2001; 2.4 meters in 2002; and 3.2 meters in 2003. In 2004, the average height of the supplemental trees was 3.7 meters (a 14 percent increase from 2003). The average circumference of the trees was 4.4 cm in 2001; 7.7 cm in 2002; and 11.5 cm in 2003. In 2004, the average circumference increased to 15.6 cm (a 26 percent increase from 2003).

Tree roots continued to grow rapidly in 2004, to the point where they invaded the monitoring wells through the well screens. Photographs of roots in two of the wells are shown on Figure 2.3. Wells 755PHYTO27 and 755PHYTO28 had root blockages that occurred from 5.5 to 6.4 meters bgs. Both of these wells are approximately 9 meters deep. Well 755PHYTO31 had root blockages from 4.3 to 5.0 meters bgs; the well is 8 meters deep. It appeared the roots were above the water table but within the zone where groundwater fluctuates seasonally. The wells located in the secondary tree planting area have yet to be impacted by root intrusion.

In June 2004, the intrusive roots were removed from the wells, so that the groundwater levels could be measured and wells could be sampled. Root removal was carried out by assembling up to 24 feet of fiberglass chimney cleaning rods (4-foot rods that screw together) and attaching a 3/8-inch sharp steel hollow bit to the end. A T-bar was placed at the other end to push and twist the rods through the root mass. The steel bit was pushed down to the root blockage and a chopping motion was used to cut the roots next to the polyvinyl chloride (PVC) screen. Once the bit was full of roots, the rods were pulled up, and the bit was cleaned out. In some cases, a hollow auger bit was placed on the end of the fiberglass rods and drilled down through the tough root mass.

3.0 MAINTENANCE ACTIVITIES

Site maintenance is the responsibility of Parsons and the landscape contractor (Ad Land Venture, Inc.). In 2004, routine maintenance was completed as described below.

3.1 Site Inspections

The landscape contractor and Parsons personnel conducted periodic site inspections to observe the general condition of the demonstration site, plant material, irrigation system, and monitoring equipment. The landscape contractor noted concerns and relayed them to Parsons regarding the general condition or status of plant materials and stressed trees. During the site inspections, necessary weed control was completed.

3.2 Equipment Calibrations

MeasureTek, Inc. calibrated the weather station in February 2004. The calibration report is provided in Attachment A. The relative humidity sensor was reading 15 percent high, so the relative humidity chip was replaced and the readings were corrected to within specifications (2 percent). The solar radiation sensor was initially reading 3 percent low, so it was cleaned and corrected to within 1 percent. The rain gauge was reading 14 percent low, so it was recalibrated back to within 1 percent. The air temperature sensor and wind speed anemometer were operating within specifications.

MeasureTek also checked the data acquisition system in the center of the planting area and the connected sensors. The two Druck® pressure transducers were cleaned and placed back in their respective wells. The calibration of one of the transducers was off and was corrected to within standards. The soil water content and soil moisture sensors were working well and appeared responsive. One of the reflectometers had been malfunctioning for some time, which appears to be due to underground wire damage that cannot be fixed.

To test the accuracy of the weather station, temperature and relative humidity were recorded with a hand-held digital psychrometer (Model No. DP-122 from A.W. Sperry Instruments, Inc.) by Parsons personnel on 8 and 9 September 2004. Figures 3.1 and 3.2 show the comparison of the weather station and psychrometer readings of temperature and relative humidity, respectively. For the temperature comparison, the digital psychrometer's average readings were approximately 1 to 2 degrees Celsius (ºC) higher than the average readings for the weather station. The relative humidity readings were 2 percent above to 13 percent below the weather station readings, with an average difference of approximately 3 percent. The accuracy of the digital psychrometer is ± 1 ºC for temperature and ± 3 percent for relative humidity.

3.3 Equipment Repairs

The wires attached to the poles of both the weather station and data acquisition system had some minor damage due to landscape weed whips cutting the wires. Foam insulation was placed around the wires on the poles to protect the wires from future damage.

3.4 Landscape Maintenance

The landscape contractor visited the demonstration site once in May 2004. The following landscape maintenance activities occurred.

3.4.1 Irrigation

The irrigation system was not turned on in 2004.

3.4.2 Fertilization

No fertilizing activities occurred during the 2004 growing season.

3.4.3 Pest Control

No rodent control measures or insecticides were used at the site in 2004.

3.4.4 Weed Control

The landscape contractor carried out minimal weed control (mowing) within the planting area.

3.4.5 Pruning

The trees were pruned to trim broken branches and create one main stem on the smaller trees. The debris was removed from the site.

4.0 MONITORING ACTIVITIES

4.1 Automated Monitoring Activities

A large portion of the OM&M activities are automated at the planting site using the weather station and data acquisition system. The following provides a summary of some of the monitoring activities. A more detailed description of the automated monitoring activities and equipment is provided in Section 4 of the Interim Technical Report (Parsons, 2003a).

4.1.1 Meteorological Conditions

Meteorological conditions were continually monitored in 2004. The automated weather station collected data for temperature, wind speed, relative humidity, and solar radiation and recorded hourly average, maximum, and minimum readings. Results of the data collection are shown graphically in Attachment B (Figures B-1 through B-4).

4.1.1.1 General Conditions

In general, 2004 was an average year in terms of temperatures at the planting area. The average temperatures at the site ranged from 2.5ºC to 27.0ºC. Historical average temperatures (based on 51 years of data) in Fairfield, California range from 8ºC to 23ºC. Figure B.1 in Attachment B shows the maximum and minimum air temperatures for 2004.

4.1.1.2 Precipitation

Precipitation at the planting site for the year 2004 is shown on Figure 4.1. The total precipitation at the site in 2004 was 473 millimeters (mm) (18.6 inches) of rain; below average for the area. The average historical rainfall for the Fairfield, California area is 570 mm (22 inches).

Precipitation for the past three years has been below average. In 2001, total precipitation was 838 mm (33 inches); well above average. However in 2002 and 2003, total precipitation was well below-average at 363 mm (14 inches) and 293 mm (11 inches), respectively. The trees have responded well to the below average rainfall in the years where little or no irrigation water was added to the site.

4.1.1.3 Potential Evapotranspiration

Potential evapotranspiration (PET) is calculated by the monitoring station by using the meteorological readings for air temperature, relative humidity, solar radiation, and wind speed in conjunction with the Penman-Monteith equation. Attachment B (Figures B.1 through B.4) provides the meteorological readings.

PET in 2004 is shown on Figure 4.2. The cumulative PET for 2004 was 1,301 mm of water. The 2004 PET was slightly higher than the cumulative PET in 2002 (1,271 mm of water) and 2003 (1,227 mm of water). For the Suisun Valley area, the total yearly average PET (a ten-year reporting span) is 1,225 mm (California Department of Water Resources, 2005). In 2004, higher temperatures were recorded over the average and that may have contributed to the higher PET in 2004.

Figure 4.3 illustrates the potential water use at the demonstration site for 2004. The bar chart shows the total PET for each month compared to the total amount of rain and irrigation water that entered the site. In 2004, no irrigation water was introduced at the site. The amount of water added to the system (through precipitation) was significantly less than what was potentially removed by the plant stand (as determined through PET) in the spring, summer, and autumn months (March through September), which increases the chances of the tree stand using groundwater. During the winter months (October through

February) precipitation increased and PET decreased, therefore decreasing the potential need of groundwater by the tree stand.

4.1.2 Soil Temperature

Soil temperature readings for 2004 are presented on Figure 4.4. The average annual soil temperature for 2004 was 20^{o}C with an annual range of 9^{o}C to 30^{o}C. The soil temperature changes are similar to those recorded in 2002 and 2003.

4.1.3 Soil Moisture

Potentiometric soil moisture data in 2004 are presented on Figure 4.5. The locations of the sensors are shown on Figure 4.1 in the Interim Technical Report (Parsons, 2003a). In 2004, potentiometric soil moisture for the deep sensors (2.4 to 2.5 meters bgs) was generally between 0 and 100 centibars (cbars) from January to May and late October through December. For the shallow sensors, the potentiometric soil moisture was between 0 and 100 cbars from February to May and again in December. Potentiometric soil moisture increased to above 100 cbars for both shallow and deep sensors from May to November (deep sensors) and May to December (shallow sensors). Several sensors reached the 200 cbars sensor limit, between the months of June and October, indicating less soil moisture availability. Individual soil sensor readings are located in Attachment B, Figure B.5 through B.10.

This increased soil water suction (cbars) indicates that the soil was significantly drier in the summer months, correlating with the decreased precipitation and increased water use by the plant stand. Although water potentials of 200 cbars may slow plant growth, it is not critically limiting for the trees chosen at this phytoremediation site.

The monitoring station software automatically adjusted the Watermark® sensor data according to the soil temperature reading at 0.3 meter. The deeper soil sensors (2.4 to 2.5 meters) were adjusted using the same soil temperature as the shallow soil sensors. The adjustment factor may slightly affect the actual soil moisture reading at the greater depth.

Volumetric soil moisture in 2004 is presented on Figure 4.6. Reflectometer RF02 had been at the limit of the sensor for the entire year, which may indicate that the underground sensor wire may be damaged. On average, the volumetric soil moisture across the site was 54 percent, an increase of 2003 (47 percent). The deeper soils had higher volumetric soil moisture contents ranging from 42 to 100 percent (77 percent average). The 100 percent soil moisture in the deep sensor occurred in March 2004 and corresponds with increased precipitation. The shallow soils had lower volumetric soil moisture contents ranging from 16 to 68 percent (32 percent average). This decrease in soil moisture in shallow soils in the summer corresponds with the decreased precipitation and increased use by the plant stand.

4.1.4 Sap Flow

No sap flow readings were collected in 2004.

4.1.5 Groundwater Level Fluctuations

Groundwater level measurements were collected in June and September 2004 at a total of 22 piezometers (Table 4.1). Figures 4.7 through 4.11 illustrate the groundwater elevations in 2001, 2002, 2003, June 2004, and September 2004, respectively. Tree root obstructions prevented water levels from being collected in one well in September 2004.

Groundwater elevations were high in June 2004 as compared to previous years, but returned to normal levels by September 2004. Groundwater elevations across the site ranged from 11.48 to 12.49 meters above mean sea level (amsl) or 5.72 to 6.02 meters bgs. The southeast direction of groundwater flow remained constant from 2001 to 2004.

There are currently two Druck® pressure transducers and four In-Situ® pressure transducers that are automatically collecting groundwater level data. The sensor locations are shown on Figure 4.12. Figure 4.13 presents the groundwater level fluctuations at 755PHYTO30 and 755PHYTO32 from the Druck® sensors in 2004. As shown on the figure, the groundwater level is consistent for most of the year at 755PHYTO30. The 755PHYTO32 sensor appears to be malfunctioning, because the water level increases of over two feet were recorded during the summer months, which was not seen in the other sensors. Both of these sensors were recalibrated on 6 February 2004.

In January 2004, four In-Situ® water level sensors started to collect data in the monitoring wells. These sensors were installed in January 2004 because they have a higher accuracy (±0.05 percent of full-scale or 0.005 meter) than the Druck® sensors (approximately 0.035 meter). One of the In-Situ® sensors is located upgradient of the planting area at 755PHYTO43, two are located within the planting area at 755PHYTO25 and 755PHYTO29, and one is located downgradient of the planting area at 755PHYTO45 (Figure 4.12). Figure 4.14 shows the diurnal effects that occurred within the planting area in a three-day period in July 2004. The groundwater levels in the upgradient well stayed steady through the three-day period. The well in the center of the planting area had very small (0.01 meter) diurnal fluctuations and the wells in the northeast corner of the planting area and downstream of the planting area had diurnal fluctuations of 0.028 and 0.026 meter, respectively. It appeared that the trees were having minimal diurnal effects on the groundwater beneath the site in 2004.

4.2 Manual Monitoring Activities

Groundwater samples were collected in June 2004. Plant tissue was analyzed in September 2004. No soil samples were collected in 2004.

4.2.1 Groundwater Investigation

Groundwater samples were collected by CH2M HILL, Inc. from 8 to 21 June 2004. Most of the piezometers went dry during the low flow micro-purging process and were sampled the following day after water levels recovered. Figure 4.15 shows the locations of the piezometers and TCE results from the 2004 sampling event. The sampling/analysis methods and results of the groundwater investigation are summarized and discussed in the following subsections.

4.2.1.1 Analyses

Groundwater samples were analyzed for various organic, inorganic, and geochemical indicators to evaluate natural chemical and physical attenuation processes at the site.

Table 4.2 lists the analyses completed and the number of piezometers at which each analysis was completed. Historical field and laboratory analyses for groundwater sampling are summarized in Tables 4.3 and 4.4.

4.2.1.2 Methods

Methods used for collecting groundwater samples at Travis AFB are discussed in detail in the Interim Technical Report (Parsons, 2003a). Travis AFB and their consultant, CH2M HILL, collected groundwater samples in June 2004 as part of a Remedial Process Optimization effort for the Dual-Phase Extraction system at Building 755. Because Travis AFB collected the groundwater data in 2004 for the demonstration project, AFCEE/TDE was able to proceed with phytovolatilization sampling at the site, which is discussed in Section 4.2.3.

4.2.1.3 Groundwater Investigation Results

The sampling objectives were to measure the current volatile organic compound (VOC) concentrations in groundwater and to collect the appropriate chemical and geochemical data to evaluate the occurrence and significance of phytostabilization/ natural attenuation processes. VOC analysis results are presented in Table 4.3. Geochemical, electron acceptors, and metabolic by-products analysis results are presented in Table 4.4.

Volatile Organic Compounds

Chlorinated solvents were the predominant compounds detected by method SW8260 during the 2004 sampling events. Table 4.3 lists concentrations of TCE and 1,1-DCE detected during each sampling event at the demonstration site since July 1998. These two chlorinated solvents had the highest concentrations in the groundwater at the demonstration site.

TCE concentrations in 2004 ranged from 1.4 to 21,600 micrograms per liter (μg/L) and DCE concentrations ranged from 0.12 to 700 μg/L. A total of 26 piezometers and wells were sampled in 2004, and 20 of the piezometers can be compared to data taken from 1998 to 2002. Of the 20 piezometers, 16 had increased TCE concentrations in 2004 compared to historical values, and four had decreased TCE concentrations compared to historical values. The piezometers with decreasing concentrations are located on the eastern portion of the tree stand (755PHTYO37 and 755PHYTO39) and north of the tree stand (755PHTYO33 and 755PHYTO47). The increased TCE concentrations (sampled in June) correspond to and may be related to increased groundwater elevations. Previous groundwater samples were collected in the late fall.

To provide additional data for the demonstration project, Travis AFB and CH2M Hill, Inc. installed five 4-inch-diameter PVC monitoring wells in the vicinity of the demonstration site (three upgradient of the trees, one in the middle of the large trees, and one downgradient of the trees) in November 2004 (Figure 4.15). Groundwater samples collected from wells MW778x39 and MW777x39 in November 2004 correlated with samples collected from piezometer 755PHYTO29 in December 2002. However, adjacent wells MW777x39 and 755PHYTO43 did not correlate. The 755PHYTO43 piezometer demonstrated an extremely slow recharge rate after its installation in December 2002, which may have affected its TCE analytical results. The five new monitoring wells will benefit the demonstration site by validating future results from the smaller piezometers.

The 1,1-DCE concentrations also are increasing across the site with 16 of 20 comparable piezometers increasing, three decreasing, and one remaining the same. The decreasing concentrations occurred at piezometers located on the southern portion of the tree stand (755PHTYO37 and 755PHYTO39) and at piezometers downstream of the tree stand (755PHYTO47).

Geochemistry

During the June 2004 sampling event, 14 of the 21 piezometers were purged dry prior to completing the sampling. The piezometers that were purged dry were allowed to recharge and sampled when a sufficient volume of water was present to fill the sample bottles. At eight of the piezometers, it was not possible to record stabilization parameters (dissolved oxygen [DO], pH, temperature, conductivity, and reduction/oxidation [redox] potential). Additionally, at some piezometers, not all field-geochemical analyses could be completed. Geochemical parameter results of the November 2004 sampling event have also been included (Table 4.4).

The geochemistry from 2001 to 2004 at the site indicates that the groundwater beneath the site is exhibiting a Type 3 behavior as described by the United States Environmental Protection Agency (USEPA) (1998). Type 3 behavior is characterized by very low concentrations of native and/or anthropogenic carbon as well as dissolved oxygen concentrations greater than 1.0 milligram per liter (mg/L). In Type 3 behavior, the highly-oxidized compounds PCE, TCE, and DCE cannot be transformed by reductive dechlorination. The evidence supporting Type 3 behavior is summarized below.

Reduction/Oxidation Potential. Reduction/Oxydation Potential (Redox) was measured at 13 piezometers and the five new wells June (Table 4.4). Redox potential ranged from -126 to 278 millivolts (mV), however, only three of the readings were below zero, indicating a reducing environment. In general, the site had oxidizing redox potential readings. The redox potential readings may not be representative of the true groundwater conditions, because many of the piezometers were purged dry and sampled at a later time without re-recording stabilization parameters. In general, the oxidizing environment found throughout the majority of the site is not favorable for biodegradation of CAHs by the anaerobic processes of oxygen reduction, denitrifiation, and manganese reduction.

Dissolved Oxygen. Dissolved Oxygen (DO) measurements were taken at 12 piezometers in June 2004 and the five new wells in November 2004. The DO measurements ranged from 0.1 to 9.9 mg/L. The lowest DO measurements are found at the southern end of the tree stand and downgradient of the tree stand, corresponding to lower CAH concentrations. The relatively high concentrations of DO across the site indicate that the anaerobic conditions required for reductive dehalogenation of CAHs are not present. However, similar to redox potential, some of the DO measurements may not be representative of actual groundwater conditions, because the measurements did not stabilize prior to the piezometers purging dry.

Nitrate and Nitrite. In June 2004, nitrate and nitrite (as nitrogen) concentrations ranged from 0.54 to 8.4 mg/L. In November 2004, the three new wells had slightly higher nitrate/nitrite concentrations ranging from 5.9 to 9.9 mg/L. The relatively low concentrations of nitrate and nitrite at some piezometers indicate that microbes may be utilizing nitrate as an electron acceptor for degradation of organic material in limited portions at the site.

Ferrous Iron. In June 2004, samples from 17 piezometers were analyzed for ferrous iron using a CHEMetrics field test kit, and detections occurred in concentrations ranging from non-detect (ND) to 17 mg/L. Ferrous iron concentrations were ND at 13 of the 17 piezometers and between 0.3 mg/L and 1.0 mg/L for 3 piezometers (755PHYTO45, 755PHYTO28, and 755PHYTO30). Piezometer 755PHYTO32 had a ferrous iron concentration of 17 mg/L but the CH2M Hill field notes indicated that a 5 to 1 dilution occurred, which may have interfered with the results. Typically, dilutions are not done with the field test kits. Previously, ferrous iron concentrations in 2000 and 2001were ND at this location; therefore, the 17 mg/L concentration is suspect.

Manganese. In June 2004, samples from 15 piezometers were analyzed for dissolved manganese. Thirteen of the 15 samples were ND, while piezometers 755PHYTO28 and 755PHYTO30 had detections at 1.5 and 1.0 mg/L, respectively. The lack of detections and low concentrations of manganese are consistent with the aerobic and oxidizing condition in groundwater beneath the plant stand.

Sulfate and Hydrogen Sulfide. Sulfate concentrations were measured at 19 piezometers in June 2004, and detections ranged from 3.5 mg/L to 16.5 mg/L. Sulfate concentrations at the three new wells measured in November 2004 ranged from 4.7 mg/L to 13 mg/L. Hydrogen sulfide concentrations were measured in 18 piezometers, and concentrations ranged from ND to 0.3 mg/L. Thirteen of the 18 results were ND, while the five detections ranged from 0.1 mg/L to 0.3 mg/L. This distribution does not indicate that reduced sulfate concentrations or elevated hydrogen sulfide concentrations are present at the site; therefore, it is unlikely that sulfate reduction is occurring.

Methane, Ethane, and Ethene. Methane was detected at low concentrations ranging from 0.00012 mg/L to 0.27 mg/L at 24 piezometers in 2004 (Table 4.4). Ethene was detected at 20 of the 24 piezometers ranging from 0.000023 to 0.001 mg/L. Ethane was detected at 15 of the 24 piezometers sampled ranging from 0.000024 mg/L to 0.00465 mg/L. Because of the aerobic conditions present in groundwater at this site, methanogenesis is not expected to be a significant process in biodegradation. The low concentrations of methane, ethane, and ethene across the site support this expectation.

Alkalinity, Carbon Dioxide, and pH. In 2004, alkalinity concentrations measured at the site ranged from 168 mg/L to 305 mg/L (Table 4.4). Carbon dioxide was measured at concentrations ranging from 35 mg/L to 110 mg/L. There was a general increase in alkalinity and carbon dioxide during the 2002 sampling event. The pH at the site ranged from 7.1 Standard Units (SU) to 8.1 SU in 2004. The optimal pH range for VOC-degrading microbes is between 6 SU and 8 SU. The pH that was measured at each piezometer was within the optimal pH range for VOC-degrading microbes.

Dissolved gasses such as carbon dioxide in groundwater are the result of three things (1) exposure to the atmosphere prior to infiltration into the subsurface, (2) contact with soil gas during infiltration to the water table, and (3) gas production below the water table by chemical or biochemical reactions involving the groundwater, minerals, organic material, and bacterial activity (Freeze and Cherry, 1979). Carbon dioxide dissolution in water produces carbonic acid, which lowers the pH and increases the weathering capacity of groundwater (Clark and Fritz, 1997). In aquifers that have carbonate minerals as part of the soil matrix, increases in carbon dioxide concentration causes an increase in groundwater alkalinity.

Dissolved Organic Carbon. In 2004, dissolved organic carbon concentrations ranged from 1.2 mg/L to 12 mg/L. In general, the organic carbon concentrations detected at the site are lower than the 20 mg/L that is considered desirable to drive reductive dechlorination reactions.

Temperature. Temperature was measured during well purging and stabilization in 13 of the 21 piezometers sampled in June 2004 and the five new wells in November 2004. The temperatures ranged from 17.5 to 26.1 ^{o}C. Temperature affects the type and growth rates of bacteria that can be supported in the groundwater environment. The groundwater temperatures beneath the site are within the optimal range for psychrophilic (0 to 20 ^{o}C) and mesophilic microorganisms (20 to 40 ^{o}C) (Chapelle, 1993).

4.2.2 Plant Tissue Investigation

Plant tissue samples were collected at the demonstration site to evaluate the potential for trees to take up and translocate contaminants (namely TCE) from the groundwater system. Initial samples were collected in December 2002 to use as a "baseline" for comparison purposes in future growing seasons. Samples were collected again in September 2004.

The target analyte to establish the potential for uptake/translocation is TCE. TCE metabolites (2,2,2-trichloroethanol [TCEt]; 2,2,2-trichloroacetic acid [TCAA]; 2,2-dichloroacetic acid [DCAA]) also were analyzed to determine the potential for the vegetation to break down TCE upon uptake.

4.2.2.1 Collection Procedures and Locations

Leaf, stem cores, and root tissue samples were collected for TCE analysis from four separate trees [R3T4 (row 3 tree 4), R1T4, R7T3, and a background area tree]. The locations of the tissue samples are shown on Figure 4.16. Refer to the *Final Addendum Report No. 1 to the Interim Technical Report for the Demonstration of Phytostabilization of Shallow Contaminated Groundwater Using Tree Plantings at Travis Air Force Base, California* (Parsons, 2003b) for a discussion of the tissue collection procedures.

4.2.2.2 Tissue Analysis Procedures

Plant tissue samples were analyzed by Utah State University for TCE, TCEt, TCAA, and DCAA. Refer to the *Final Addendum Report No. 1 to the Interim Technical Report for the Demonstration of Phytostabilization of Shallow Contaminated Groundwater*

Using Tree Plantings at Travis Air Force Base, California (Parsons, 2003b) for a discussion of the tissue analysis procedures.

4.2.2.3 Plant Tissue Investigation Results

In September 2004, 12 plant tissue samples (including one duplicate) were collected from trees within the plant stand and analyzed for the presence of TCE and TCE metabolites. Additionally, three samples were collected from a background tree located approximately 0.5 mile north of the site. The tree locations are shown on Figure 4.16. The results of these analyses are presented in Table 4.5.

TCE was detected in 9 of the 12 tissue samples collected from the planted trees in 2004. In comparison, in 2003, all 12 samples had TCE detections. In 2004, TCE concentrations were greatest in the roots and trunk (core) of the trees and lower in the leaves and stems. The highest TCE concentration was in the roots of tree R3T4 at 273 micrograms per kilogram (µg/kg) wet weight. The core TCE concentrations ranged from 19 µg/kg to 136 µg/kg wet weight. Concentrations in the leaves and stems ranged from below detection limits to 13 µg/kg wet weight. As illustrated in Figure 4.17, TCE concentrations in the roots have increased since 2003, while TCE concentrations in the core and leaves have decreased from 2003 to 2004.

Tissue samples were also collected at various heights in one tree (R3T4) to determine if the TCE levels decrease or stay the same as the contaminant moves up the tree. Figure 4.18 presents the results of this fieldwork, which indicates that the TCE levels in the tree decrease in the direction from the roots to the leaves. TCE concentrations were below method detection limits in most of leaf samples (Table 4.5). This may indicate that the tree is either metabolizing the TCE before it reaches the leaves or it is volatilizing/diffusing more TCE through the lower trunk of the tree. Per William Doucette of Utah State University (Doucette, 2005), research indicates that volatilization/diffusion from the lower trunk of the tree through the bark does occur. TCE concentrations reaching the leaves would be quickly volatilized into the air.

The metabolite TCEt was detected in the trunk (core) of one tree (R7T3) at 87.14 µg/kg wet weight (Table 4.5). All other samples for metabolites were below method detection limits. For comparison, no TCE metabolites were detected in any of the tissue samples in 2003. This may indicate that the trees are mostly volatilizing the TCE rather than metabolizing it.

TCE levels detected at the Travis AFB site are an order of magnitude higher than have been detected at the phytostabilization demonstrations at the other five Air Force bases. At Vandenberg and Fairchild AFB, non-detect to low TCE levels (less than 8.5 µg/kg wet weight) were detected in their tree tissues.

In 1999, Utah State University conducted tissue sampling in mature trees growing above contaminated groundwater at Hill AFB.. Groundwater depth is 2.3 meters bgs, and the TCE concentrations in tissues from older, established trees growing above the contaminant plume ranged from 150 µg/kg to 8,100 µg/kg on a dry weight basis. TCE concentrations in groundwater at the Hill AFB site ranged from 1 to 10 mg/L, similar to those at the Travis AFB phytostabilization site. Concentrations in the stems were an order of magnitude greater than that found in the leaves, and stem TCE concentrations correlated with the concentration of TCE in the local groundwater. Metabolite concentrations in leaves ranged from method detection limits to 740 µg/kg (Doucette *et al*., 2003).

These data suggest that there is some limited exposure of the trees to TCE resulting in contaminant uptake/translocation at this time. Exposure can occur through direct uptake of contaminated groundwater or could occur through soil vapor diffusion through the root system. Tissue samples from the background tree that was not exposed to TCE-contaminated groundwater or subsurface vapor had no TCE detections. However, the TCE concentrations within the plant tissue of the Travis AFB trees are well below those observed at the more established Hill AFB site with mature trees that are assumed to be greater than 10 years in age. These data from different demonstration sites will allow annual comparisons to be made, possibly showing increased concentrations corresponding with increased groundwater usage (as determined by groundwater level fluctuations, isotope analysis, etc.).

4.2.3 Isotope Analysis

Stable isotopes are used to understand the source of water or processes that have affected the water since it entered an aquifer (Drever, 1988). To identify the sources (e.g., irrigation water, groundwater, precipitation) of water that is taken up by the trees, isotope analyses were conducted on tree cores from one of the initial trees and compared to the isotopes in the various water sources. The two stable isotopes that were analyzed included oxygen with an atomic weight of 18 (^{18}O) and hydrogen (H^1 and H^2, commonly written D from the name deuterium). In depth reviews of isotope chemistry, analysis, and use can be found in Faure (1986), Drever (1988), and Dawson (1993 and 1995).

4.2.3.1 Collection Procedures and Locations

Two stable isotope samples were collected from groundwater and tree sap in September 2004. No irrigation sample was collected, because no irrigation water was applied to the site in 2004. No precipitation samples were collected, because it did not rain at the time of the sampling event. The tree sap sample was collected from tree R1T3, and the groundwater sample was collected from piezometer 755PHYTO26.

The groundwater sample was collected in two 40-milliliter (mL) glass vials equipped with Teflon®-lined-rubber septa. During water sample collection, all head space or bubbles were removed from the 40-mL glass vials. While collecting isotope samples, care was taken so that water samples were not collected from locations where prolonged evaporation has occurred. Tree sap samples were collected as cores (5 mm x 15 cm) taken from the trunk using a hand driven, 5.15-mm increment borer. The stems were placed directly in 40-mL vials and sealed immediately. Samples were then placed on ice and shipped to the laboratory. The isotope samples were analyzed within 30 days of sample collection.

4.2.3.2 Isotope Analysis Results

Results of the isotope analysis conducted in September 2004 are presented in Table 4.6. The δ (delta) notation is used to represent the relative difference in parts per thousand [called per mil (‰) by analogy with percent (%)] between the ratio in a sample and the ratio in some standard. For oxygen and hydrogen isotopes, the universally-used reference standard is Vienna Standard Mean Ocean Water (SMOW) (Faure, 1986).

Positive values of $\delta^{18}O$ and δD indicate enrichment in a sample compared to SMOW. Negative values imply depletion of those isotopes in the sample relative to the standard. When water evaporates from the surface of an ocean, the $\delta^{18}O$ and δD values of water vapor in the atmosphere are both negative. Therefore, freshwater and snow have negative $\delta^{18}O$ and δD values. The enrichment in the isotopes increases with decreasing air temperature. Therefore, the isotope values vary seasonally and in terms of latitude and elevation (Faure, 1986). There is no fractionation of isotopes by plant roots during water uptake. Therefore, isotope analysis of xylem sap should reflect the water sources used in the plants (Dawson and Ehleringer, 1991).

It is possible to compare isotope values of the various sources to assess where plants are obtaining their water. Ideally, the isotope values of the different sources (precipitation and groundwater) would be significantly different allowing for a clear comparison with sap flow values. If the sap flow values are closer to one source than the other, than it is reasonable to conclude that the tree is getting a majority of the water from that source. However, if the isotope values for the different water sources are not significantly different, it becomes increasingly difficult to distinguish between water sources using this method.

Tree sap samples indicate slightly depleted $\delta^{18}O$ (-4.2‰ to -5.9‰) and slightly enriched δD values (-58‰ to -59‰) when compared to groundwater (-6.1‰ to -7.0‰ and -45‰ to -51‰, respectively) and precipitation (-5.5‰ to -6.4‰ and -32‰ to -75‰, respectively). Precipitation isotope results from previous years were used for comparison purposes because no samples were collected in 2004. The data does not suggest a clear or predominant water source for the trees and it is likely a combination of groundwater, precipitation, and soil moisture reserves.

The total precipitation in 2004 at the site was 473 mm (approximately 19 inches); therefore, the trees need to obtain water from either soil moisture reserves (previous precipitation that has accumulated in the soil pores during the rainy seasons) or groundwater.

4.2.4 Phytovolatilization Results

Utah State University, Utah Water Research Laboratory conducted a phytovolatilization sampling and analysis survey at Travis AFB on 7 and 8 September 2004. The purpose of the survey was to determine if the trees are phytovolatilizing (transpiring volatile organic compounds along with water) measurable amounts of TCE. The locations of the trees sampled are shown on Figure 4.16. The report from Utah State University is provided in Attachment D. The report contains collection and analysis procedures for the survey. This was the second survey that Utah State University conducted on Travis AFB; the first survey took place in December 2003.

The results of the second phytovolatilization survey confirm that the trees are being exposed to TCE in the underlying groundwater/soil vapor and are able to absorb this chlorinated compound through their root structures. This determination is important to the evaluation of this potential groundwater cleanup approach, because it is unlikely that any chemical processes outside of the rhysosphere would contribute to effective plume management. The results also show that the trees are able to release chlorinated solvents into the air via transpiration. Along with incorporation into their cellular structure, the trees will be able to use phytovolatilization to remove contaminant mass from the subsurface and improve their ability to stabilize the plume.

The amount of phytovolatilized TCE is expressed in terms of transpiration stream concentrations (TSC) which is defined as mg TCE per liter of water expired. Assuming that the TSC values measured in the field are representative of all the eucalyptus trees in the area, they can be used along with transpiration measurements to estimate the amount of TCE phytovolatilized at the site.

TCE was detected in the transpiration stream of the six trees sampled during September 2004 with TSC values ranging from 3 to 250 mg TCE per liter of transpired water collected. This is significantly different than the results obtained during the initial December 2003 sampling event when no significant volatilization of TCE was observed. The difference in the results from 2003 and 2004 can be explained by seasonal differences. The December 2003 event took place when meteorological conditions included low solar intensity (cloudy), intermittent rain, high humidity (near 100 percent), and low temperatures (~10˚C); these conditions minimize water transpiration and TCE phytovolatilization. The September 2004 sampling event took place during an unexpected period of high solar intensity, high temperatures (greater than 38˚C), and relatively low humidity (15 to 25 percent).

The results of the 2004 sampling event show that the trees are removing TCE from the subsurface soil and groundwater through phytovolitization (Table 4.7). However, it is not recommended that the September 2004 results be used to predict annual TCE phytovolatilization, because the results are thought to be artificially high. The extremely high temperatures and dry mid-day conditions likely restricted normal water transpiration but not the short-term TCE volatilization as it continued to diffuse through the leaf cuticle because of its higher lipophilicity. Given more time, the TCE flux from the leaves would also decrease, because less TCE would be moved into the leaf cuticles via sap flow.

An estimate of TCE being removed from the site can be obtained by using laboratory-derived transpiration stream concentration factors (TSCF) of 0.1 and 0.75, groundwater TCE concentrations (0.1 to 15 mg/L), and yearly water transpiration rates (6.3×10^6 L). Using these numbers, TCE could be removed from the site at a rate of 63 to 69,300 grams per year or 0.14 to 152 pounds per year (0.0004 to 0.42 pounds per day) through phytovolatilization (Doucette, 2005). This estimate makes certain assumptions that could prove to be inaccurate. Additional sampling events will be needed to better quantify actual removal rates.

4.2.5 Soil Investigation

No soil samples were collected in 2004.

5.0 SUMMARY OF 2004 RESULTS

5.1 Impact on Groundwater Elevation

Groundwater level measurements were collected continuously (once per hour) from six wells (using two Druck® and four In-Situ® pressure transducers) and collected manually from various piezometers in June and September 2004 using a mini water-level indicator.

As discussed in Section 4.1.5, groundwater elevations were elevated in June 2004 as compared to previous years, but returned to normal levels by September 2004. The southeast direction of groundwater flow has remained constant from 2001 to 2004. It was also observed that diurnal fluctuations were observed within the plant stand, albeit minimal.

Water usage by the trees was estimated as part of the demonstration project to determine any effects to groundwater elevation. The following subsections focus on the water use of the initial trees, which were planted in November 1998.

5.1.1 Estimated Water Use

The estimated water use by the initial plant stand was completed for years 2000 through 2004 (Table 5.1). The estimated water use by the secondary tree stand was completed for 2001 through 2004 (Table 5.2). No sap flow readings were collected in 2004, so measured water use could not be calculated. A detailed discussion of the methods used for the comparison is located in Section 5 of the Interim Technical Report (Parsons, 2003a).

The estimated water use was calculated by using site-specific PET, a landscape coefficient (K_L), leaf area index (LAI), and area of the plant stand (Tables 5.1 and 5.2). In the past demonstration addendum reports, a crop coefficient (K_c) from a study conducted by Worledge *et al*. (1998) was used to estimate water use in the initial tree stand. However, those K_c values appeared too high for the existing site conditions. Research conducted in California (California Department of Water Resources, 2000) suggests that K_L values are better estimates for determining water losses from trees. The K_L was calculated from three variables: species (specifically eucalyptus), density, and microclimate (increased evaporative conditions at the site due to wind and heat).

The LAI was estimated based on a phytoremediation study in Utah for hybrid poplar trees that were similar in size to the site eucalyptus trees. Dividing the leaf area of an entire tree by the ground covered by the tree canopy yielded the LAI for two to five-year-old poplar trees (Ferro *et al*., 2001). For determining the area of the plant stand, it was assumed that each of the 100 larger trees had a canopy coverage (i.e., basal area) in 2004 of 114 square feet; resulting in a total coverage of 14,400 square feet or 1,135 square meters. The 342 secondary trees each had a canopy coverage in 2004 of 36 square feet; resulting in a total coverage of 12,312 square feet or 1,144 square meters.

The average water used by the initial tree stand in 2000 was estimated to be 0.4 millimeters per day (mm/day), which converts to 24 gallons per day (gal/day). Water use was converted from mm/day to gal/day by multiplying it by the canopy area of the plant stand (e.g., 232 square meters) and utilizing appropriate conversion factors. This value has steadily increased over the years as the trees grow, with an average water usage of 1.9 mm/day (2,132 liters per day [L/day] or 563 gal/day) in 2004. Similarly, the average water used by an individual initial tree had increased yearly to 0.02 mm/day (24 L/day or 6 gal/day) in 2004 (Table 5.1). In comparison, the average water used by the secondary tree stand in 2004 was estimated to be 0.7 mm/day (813 L/day or 215 gal/day) in 2004. The average water used by an individual secondary tree has increased yearly to 0.002 mm/day (3 L/day or 0.8 gal/day) in 2004 (Table 5.2).

The estimated average water use in 2004 by the initial and secondary tree stands was a total of 2,945 L/day (778 gal/day) or about 907 mm per year (35 inches per year). This equates to 1 million liters per year (approximately 300,000 gallons per year) of potential water use by the trees. The total precipitation in 2004 at the site was 473 mm (approximately 19 inches); therefore, the trees need to obtain water from either soil moisture reserves (previous precipitation that has accumulated in the soil pores during the rainy seasons) or groundwater.

5.1.2 Water Balance

If the transpired water can be proportioned between surface water sources (precipitation and/or irrigation) and a subsurface source (soil moisture and/or groundwater), estimates of tree water use (Section 5.1.1) can be used to quantify potential volume of groundwater being removed by a plant stand. Another way of determining the extent of groundwater uptake by the plant stand is to complete a simple water balance. Table 5.3 presents the water balance for each month in the second through sixth growing seasons within the initial plant stand and Table 5.4 presents the water balance in the remaining secondary trees. The estimated total volume of water the plant stand transpired was subtracted from the total added water value to determine a net water balance. Positive water balance values indicate an excess of water is being applied to the site, while negative values indicate a water deficit. When a water deficit occurs, it can be assumed that the trees have to be using soil moisture reserves that have been stored during the rainy season and/or groundwater to make up for the water deficit.

During 2000 and 2001, positive water balances occurred over the entire site, because the irrigation system was applying water to all the trees. In 2002, irrigation water was discontinued for the initial trees which resulted in a negative water balance for the larger trees; however, irrigation water was still being applied to the secondary trees which resulted in a positive water balance for the new trees. Therefore, if you add the initial and secondary tree water balances together, you get an overall positive water balance for 2002. In 2003 and 2004, the irrigation system was not used and the water balance remained negative for the initial trees. The water balance has remained positive through 2004 for the secondary trees, indicating that precipitation is adequate to sustain the trees at this point. It should be noted that negative water balance in the secondary trees does occur during the dry months of the year. It is expected that the water balance will become negative for the secondary trees as the plant stand matures.

In 2004, the water deficit was estimated at 200,000 liters per year (53,000 gallons per year) for the initial trees. Each year, the water deficit has been getting larger as the trees grow and require more water; therefore, extracting more water from the groundwater and soil moisture. This trend will continue as the trees grow larger and increase their canopy area.

5.2 Impact on Groundwater Quality

Chlorinated solvents were the predominant compounds in groundwater at the site from 1998 through 2004. Overall, across the site, TCE and DCE concentrations have increased in 2004 compared to historical data recorded since 1998. Decreasing concentrations were found at 4 of the 20 piezometers sampled; however the piezometers were located in two specific areas, the southern portion of the tree stand and downgradient of the tree stand.

The increased TCE concentrations in 2004 correspond to and may be related to increased groundwater elevations. However, TCE concentrations have been historically high and increasing since 2000, therefore the influence of the groundwater elevations may not be significant.

The geochemistry of the groundwater beneath the tree stand was characterized from 2000 to 2004. During each of the sampling events, the majority of the piezometers purged dry prior to completing the sampling and were resampled once the water levels had recharged, therefore the geochemical field data (pH, temperature, DO, conductivity, and redox potential) are not completely reliable.

In general, groundwater temperature and pH ranges have been historically within the optimal ranges for VOC-degrading microbes. However, the geochemical conditions beneath the site are and have historically been oxidizing and aerobic; therefore, not favorable for biodegradation of CAHs by the anaerobic processes of oxygen reduction, denitrification, manganese reduction, iron reduction, sulfate reduction, or methanogenesis.

Since 2000, field and laboratory analyses have been completed for nitrate and nitrite, ferrous iron, manganese, sulfate, hydrogen sulfide, methane, ethane, and ethene. The results have consistently shown non-detect to low levels of ferrous iron, manganese, sulfate, methane, ethane, or ethene. The low to non-detect concentrations are consistent with the aerobic and oxidizing condition in groundwater beneath the plant stand that is not favorable for microbial-mediated degradation of CAHs. Nitrate and nitrite concentrations have been reported at slightly elevated levels in limited portions of the site indicating that microbes may be utilizing nitrate as an electron acceptor for degradation of CAHs.

5.3 Impact on Soil Quality

No soil sampling was conducted in 2004.

5.4 Conclusions

This addendum report updates the Interim Technical Report (Parsons, 2003a) by describing the OM&M activities that occurred in 2004 and provides an overall summary of the Travis AFB phytostabilization site. OM&M activities included plant growth observations, equipment and landscape maintenance activities, automated data collection, and groundwater and tissue sampling.

A summary of conclusions from the sixth growing season are as follows:

- Tree growth and plant stand health has increased steadily since the initial planting in 1998 and the supplemental planting in 2000. In 2004, the average initial tree height was 7.0 meters, a 118-percent increase since 1998. In 2004, the average initial tree circumference was 43.6 cm, a 665-percent increase since 1998. For the supplemental trees, in 2004 the average tree height was 3.7 meters, a 300 percent increase since 2001 when the average height was 0.9 meters. Also for the supplemental trees, in 2004 the average tree circumference was 15.6 cm, a 262-percent increase since 2001 when the average circumference was 4.3 cm. The trees have established themselves quickly and are in good health.

- Irrigation water was applied to the site in the first, second, and third growing seasons, however, from the third season on, no irrigation water has been applied, with little impact on tree health or growth. In 2000 and 2001, positive water balances occurred at the site due to the use of the irrigation system. From 2002 through 2004, the irrigation system was not utilized resulting in an overall negative water balance for the plant stand, indicating that the trees are probably obtaining water from the soil and groundwater.

- The data acquisition system continues to operate well. Monitoring activities consisted of collecting data automatically from the data acquisition system. Data was collected remotely approximately every two weeks throughout 2004. One of the Druck pressure transducers may be malfunctioning, but sufficient information is being gained from the five other transducers on-site to evaluate potential water table influence by the plant stand. There are no current plans to replace the sensor.

- Analysis of plant tissue samples indicates that the trees at Travis AFB are being exposed to TCE via direct uptake of groundwater or subsurface vapor. TCE concentrations in plant tissues at Travis AFB have been monitored since 2002 and have been significantly higher (an order of magnitude) than the demonstration sites at other bases, but less than what were found during a mature tree study.

- Phytovolatilization sampling completed in December 2003 did not detect a significant amount of TCE being translocated to the atmosphere. In 2004, the sampling detected high TCE concentrations in the transpiration stream of all trees sampled. The trees are removing TCE from the subsurface soil and/or groundwater through phytovolitization. The significant difference in the results from 2003 and 2004 can be explained by meteorological conditions during sampling. TCE could be removed from the site at a rate of 0.14 to 152 pounds per year (0.0004 to 0.42 pounds per day) through phytovolatilization. This estimate makes certain assumptions that could prove to be inaccurate.

Additional sampling events will be needed to better quantify actual removal rates.

- There is no evidence to date that the plant stand is significantly impacting the groundwater system. Groundwater level fluctuations within the planting area have been measured since 1999, both daily by the automated sensors and during groundwater sampling events. No significant changes have occurred over time that can be correlated to the tree stand uptake. Also, minimal diurnal fluctuations have occurred throughout the years. However, the increasing negative water balance calculated for 2002 through 2004 and the phytovolatilization results suggest that the trees have the potential to effectively remediate the solvent contaminated groundwater as they mature.

6.0 FUTURE FIELD ACTIVITIES

In spite of the short time that they have been growing, the eucalyptus trees at site DP039 on Travis AFB have demonstrated that they can provide a means to remove contaminant mass from the solvent plume. Additional fieldwork is needed to determine whether the rates of water extraction and contaminant mass removal can increase with tree growth to the point where the solvent plume is no longer able to migrate. Travis AFB believes that phytostabilization offers a more technically-effective groundwater remedy than engineered groundwater extraction and treatment. The completion of the following tasks for continued monitoring and maintenance of the planting area would support the technical validation of this treatment strategy.

- Groundwater levels need to be measured on a quarterly basis for all appropriate piezometers and monitoring wells to track the changes in groundwater fluctuations that may be attributable to the trees' water use. A significant drawdown of the water table underneath the planting area would indicate the water uptake into the trees has significantly increased.

- Groundwater and tissue sample collection and analysis are needed in order to support the evaluation of contaminant mass removal and plume containment as the trees grow larger. Initially, groundwater samples could be collected on a quarterly basis to determine seasonal groundwater VOC concentration fluctuations. This sampling could be changed to an annual event once a solid baseline has been established. Tissue and isotope samples could be collected on a semi-annual (late spring and early fall) basis on a representative portion of the planting area to evaluate potential seasonal effects, followed by an annual frequency.

- The data acquisition system and weather station need to be maintained to continue the collection of relevant data, such as evapotranspiration rates, soil moisture, and water use. These data are used to update water balance models and mass quantity removal rates. The onsite equipment needs to be calibrated yearly to maintain accurate results.

- Field activities such as sap flow readings and transpiration sampling would be useful in quantifying the potential TCE mass removal rates for the plant stand. Transpiration sampling is used to determine the amount of water the trees are actually transpiring. Transpiration can be estimated by measuring the rate of water movement through the tree trunks. The data acquisition system at the site can connect two sap flow sensors to two separate trees, to monitor the water movement in the trunks.

- Phytovolatilization sampling and analysis would be useful for directly quantifying the amounts of TCE that volatilize (transpiring solvents along with water) from their leaves. To more accurately estimate the potential phytovolatilization that is representative at this site, this fieldwork should take place at a variety of times, seasons, and meteorological conditions. In addition, this task requires a specific type of monitoring that is not available with most environmental consulting firms. Utah State University provided the tissue analysis and phytovolatilization sampling and analysis for this demonstration project.

- The plant stand is relatively maintenance-free with respect to weeds and native grass. Currently, the landscape contractor mows the site once a year (after April 15th, the end of the rainy season) to clear the tall grass and weeds that had grown through the winter months. Once the trees become larger, they may need to be thinned to maintain healthy tree growth.

- The placement of the plant stand covers most but not the entire central portion of the solvent plume that originated from Building 755. To transition from a demonstration project to a selected groundwater remedy, Travis AFB will have to expand the planting area to cover more of the groundwater plume. Additional trees can be planted north of Ellis Drive and west of the current plant stand to obtain complete coverage (Figure 6.1). The irrigation system can be modified to provide water for new trees as their new root systems are being established. To accelerate the growth of the roots toward the water table, the aggressive engineered approach described in Section 1.0 should be used during the tree planting. Since eucalyptus trees do not have a tap root, this approach provides a preferential pathway for the roots to reach the water table and to expand out in all directions. Nutrients can be added to promote tree growth, and air vent tubes create an oxygenated environment to promote root growth. Parsons will work with the Base on future expansion opportunities for the plant stand.

Overall, the phytostabilization demonstration project at Travis AFB has shown positive results in the potential uptake of contaminants in the Building 755 solvent plume. As the plant stand grows in size to close the canopy and increase its root mass, increased water uptake will result. Actual stabilization of the groundwater plume to keep it from migrating downgradient of the plant stand is probable, but yet to be proven to a high degree of certainty. More fieldwork is necessary to support the use of this cleanup strategy as a selected remedy and to determine the timeframe after which plume stabilization is achieved. Most of this fieldwork can be accomplished as part of the

Travis AFB Groundwater Sampling and Analysis Program, but some of the more unique sampling techniques can only be carried out by qualified specialists.

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FIGURES

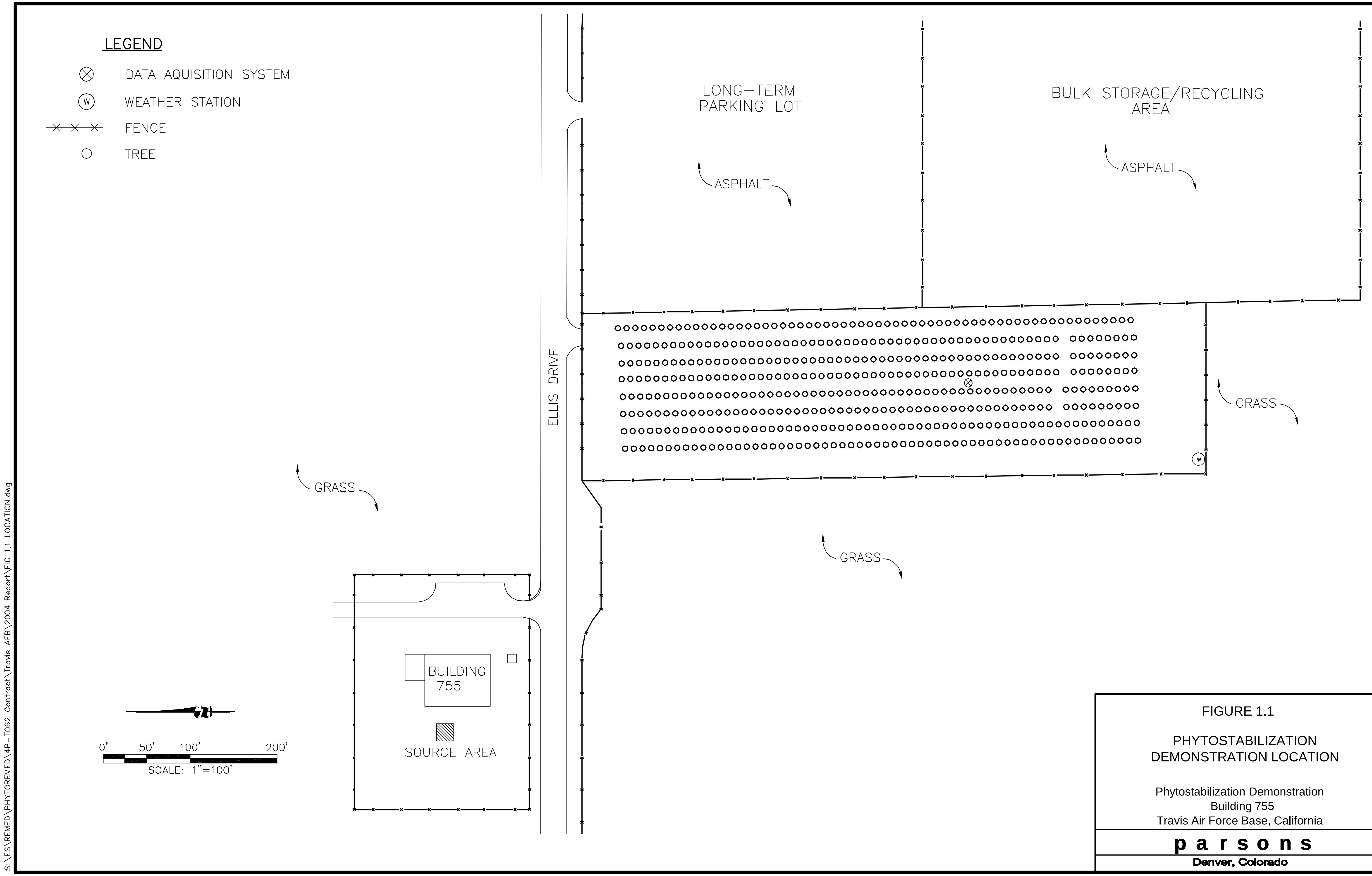


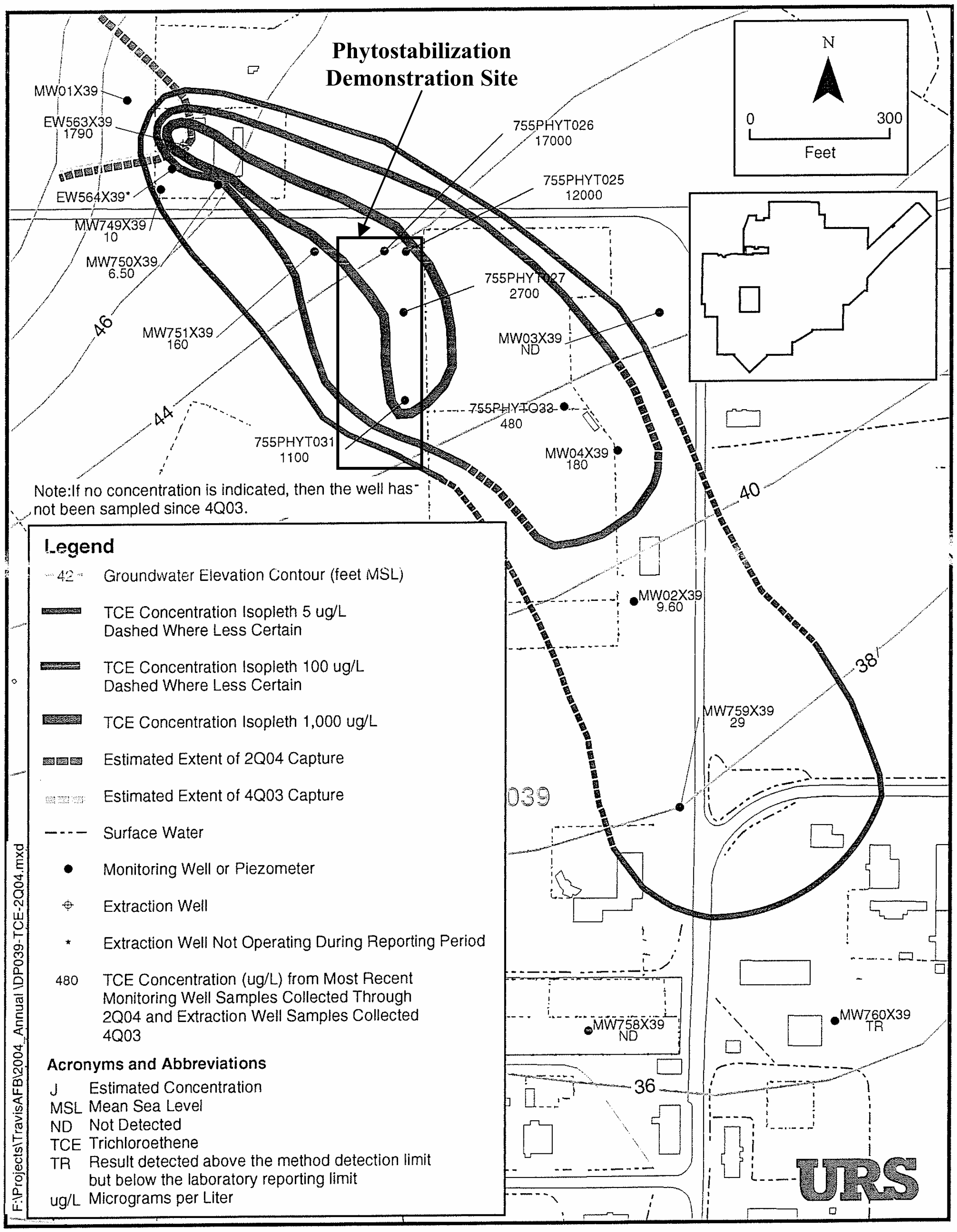
FIGURE 1.1

PHYTOSTABILIZATION DEMONSTRATION LOCATION

Phytostabilization Demonstration
Building 755
Travis Air Force Base, California

parsons
Denver, Colorado

FIGURE 1.2
GROUNDWATER PLUME LOCATION
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AFB, CALIFORNIA



Source: URS, 2004. *Travis AFB 2003-2004 Annual GSAP Report.*

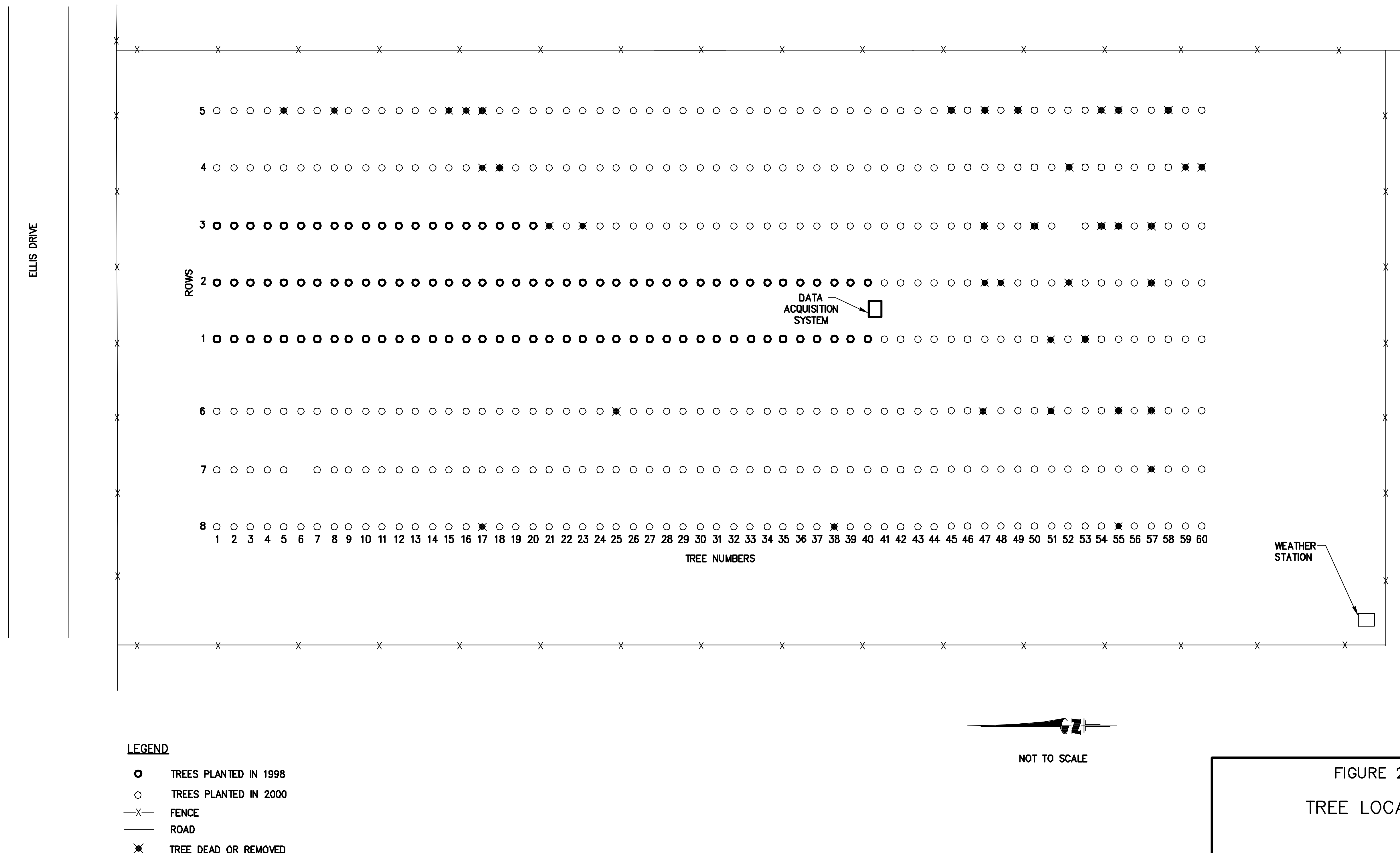


FIGURE 2.1

TREE LOCATION

Phytostabilization Demonstration
Building 755
Travis Air Force Base, California

PARSONS

Denver, Colorado

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FIGURE 2.2
TREE GROWTH PHOTOGRAPHS
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AFB, CALIFORNIA

February 1999
Initial Planting

December 2003

September 2004

February 2005

January 2002
Secondary Planting

Secondary Trees
Initial Trees

December 2002

Secondary Trees
Initial Trees

December 2003

Initial Trees
Secondary Trees

February 2005

fig2.2.doc

FIGURE 2.3
TREE ROOTS IN MONITORING WELLS
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AFB, CALIFORNIA

Photograph taken February 2004 at monitoring well 755PHYTO32, which contains a Druck® pressure transducer. This shows the roots that were pulled up when the sensor was removed from the well.

Photograph taken February 2005 at monitoring well 755PHYTO25, which contains an In-Situ® pressure transducer. This shows the roots that were pulled up when the sensor was removed from the well. The roots consisted of tough/woody red roots at the top (above the water table) and wet/smooth white roots that were in the groundwater.

FIGURE 3.1
TEMPERATURE DATA COMPARISON
WEATHER STATION VS. PSYCHROMETER READINGS
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

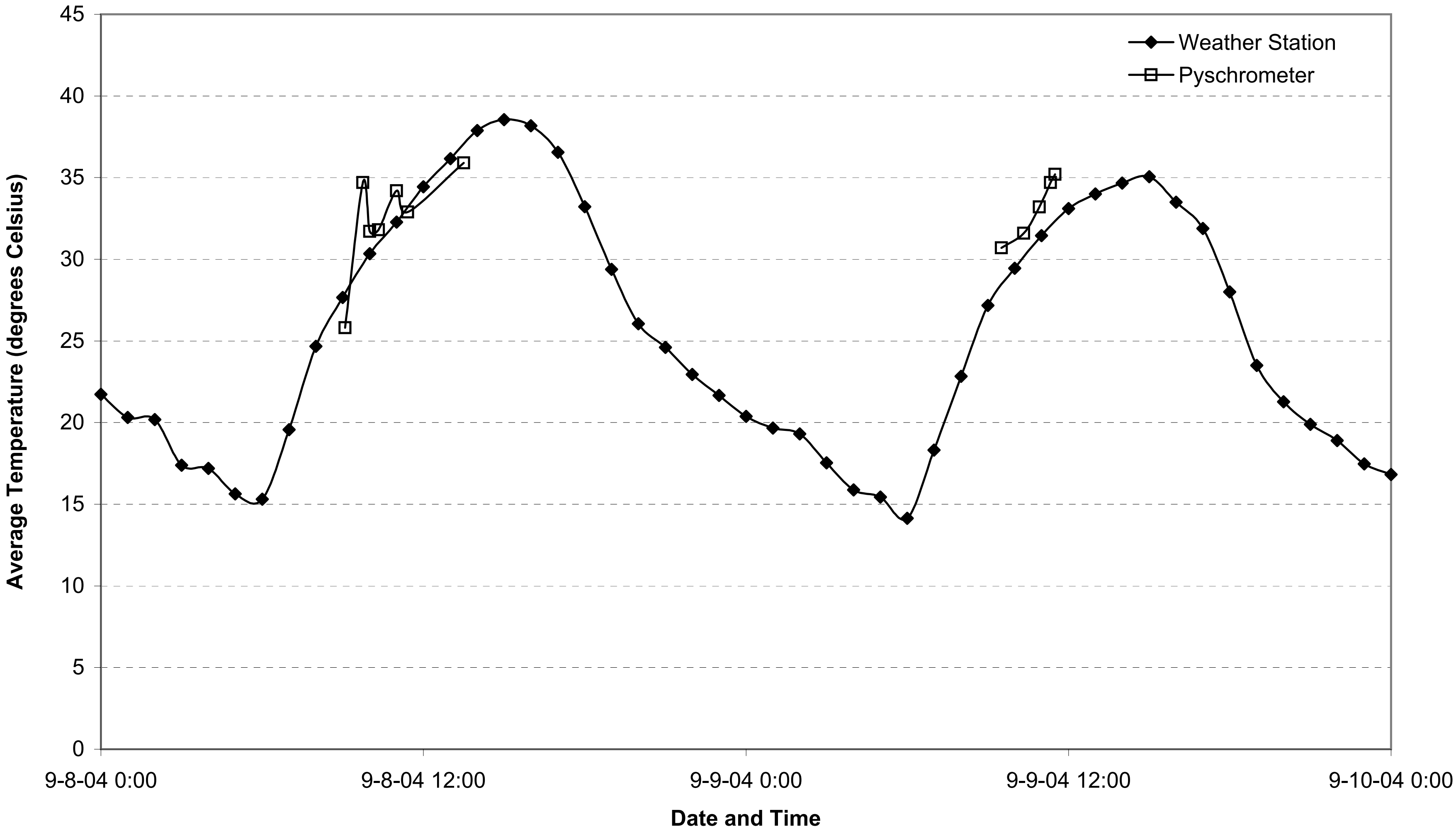


Fig 3.1 and 3.2.xls

FIGURE 3.2
HUMIDITY DATA COMPARISON
WEATHER STATION VS. PSYCHROMETER READINGS
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

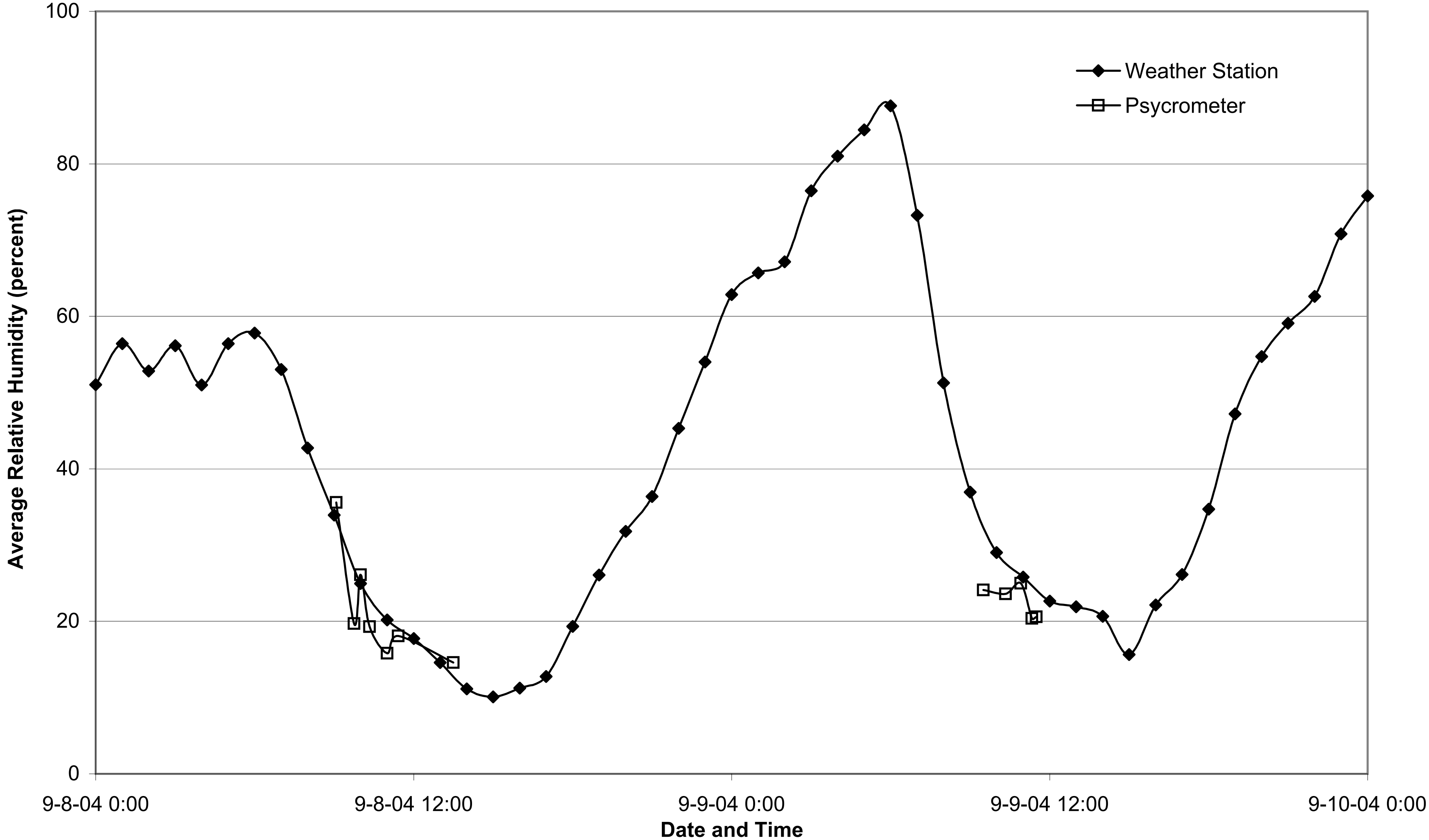
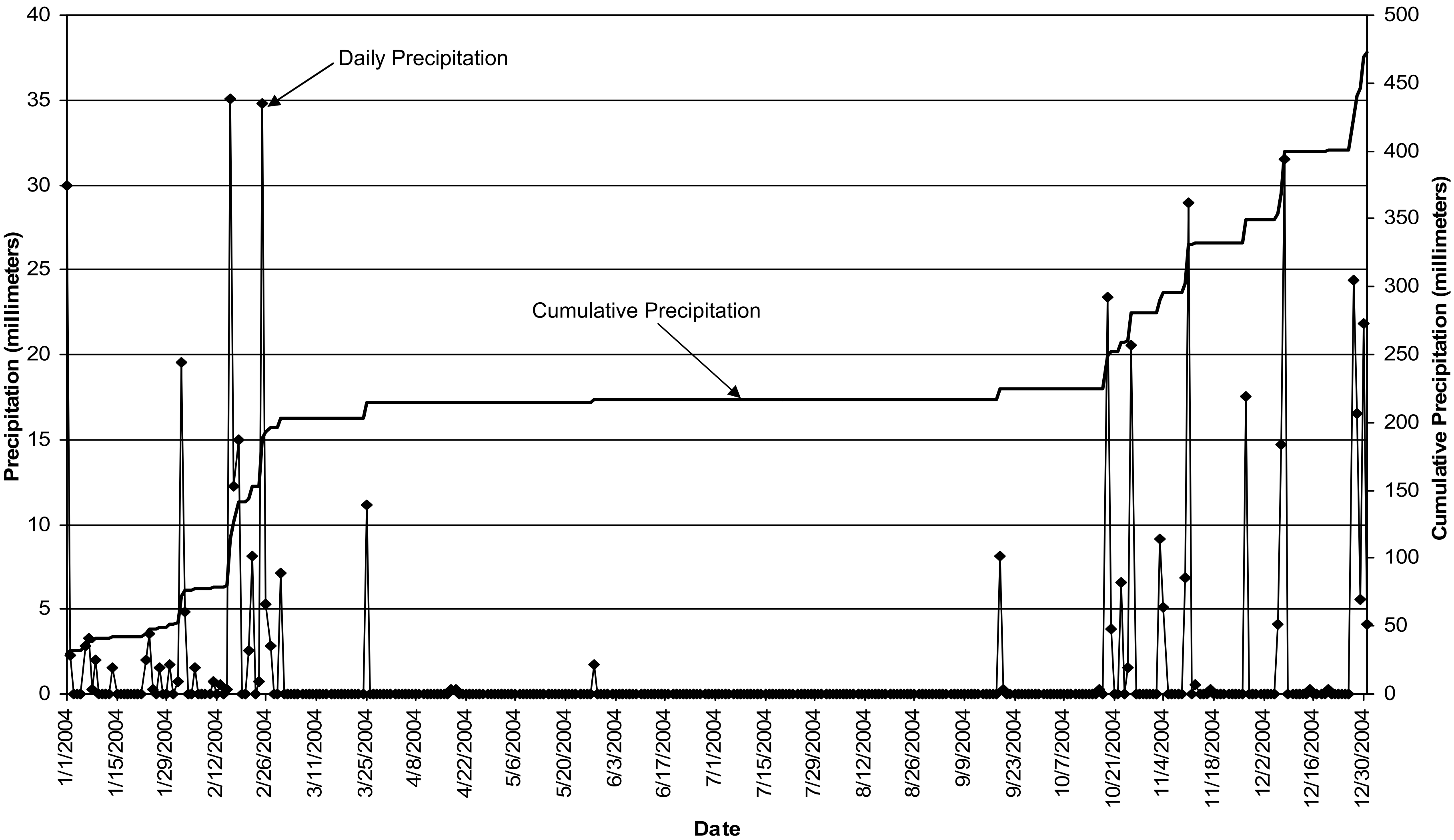


Fig 3.1 and 3.2.xls

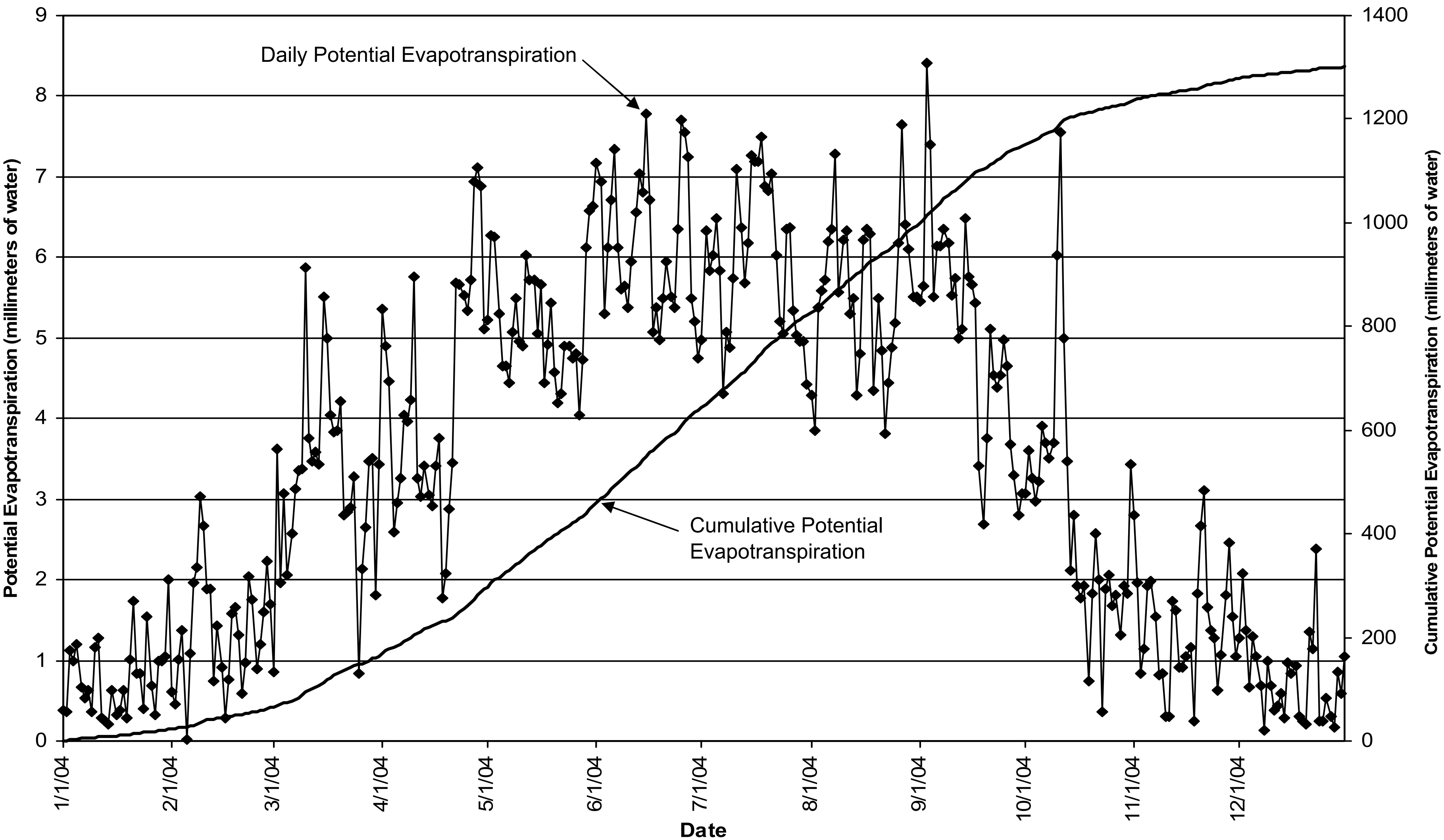
FIGURE 4.1
MEASURED PRECIPITATION IN 2004
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA



Travis-Figs-2004.xls

FIGURE 4.2
CALCULATED POTENTIAL EVAPOTRANSPIRATION IN 2004

PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA



Travis-Figs-2004.xls

FIGURE 4.3
POTENTIAL WATER USE IN 2004
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

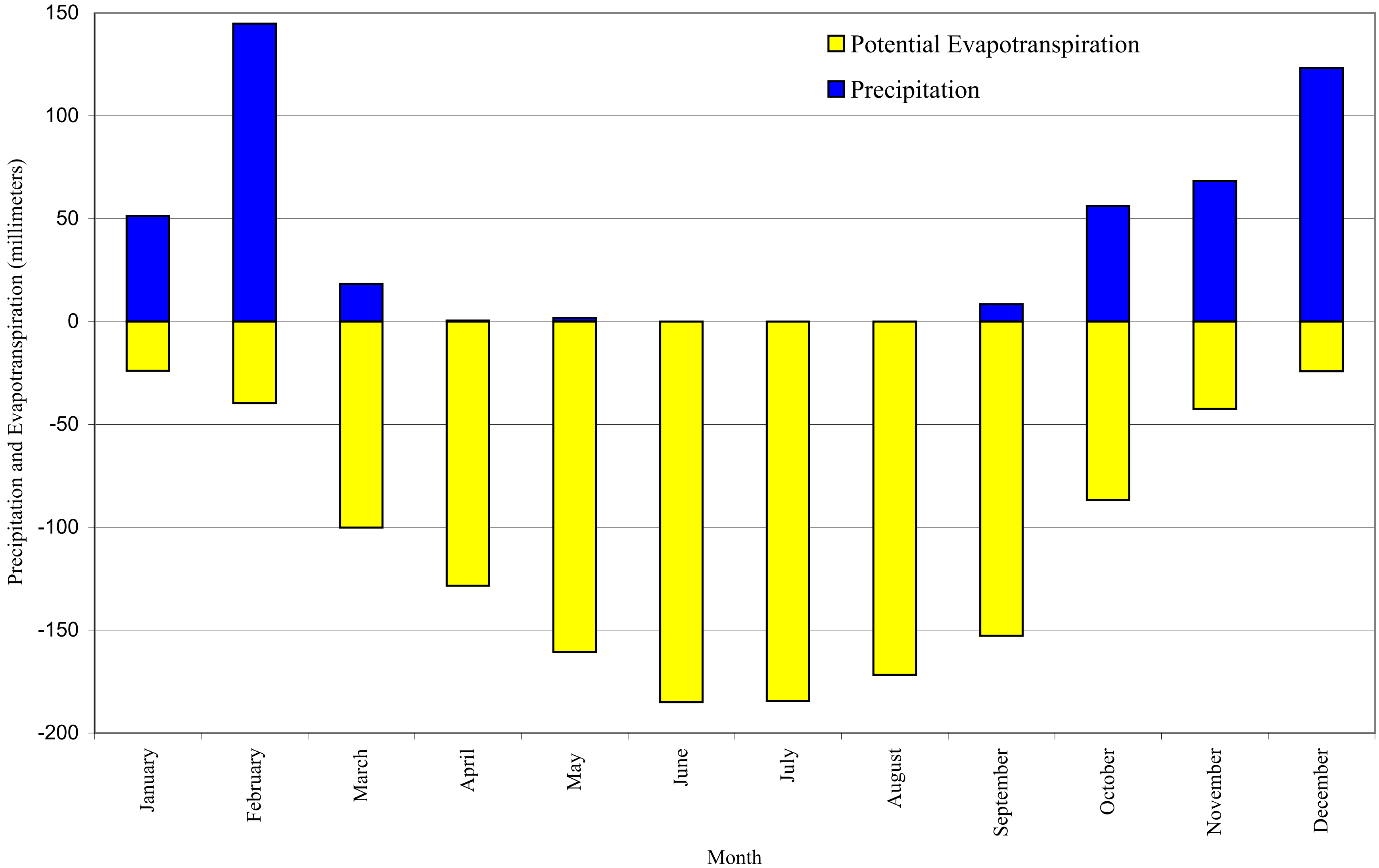


Fig4-3.xls

FIGURE 4.4
AVERAGE DAILY SOIL TEMPERATURE IN 2004
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

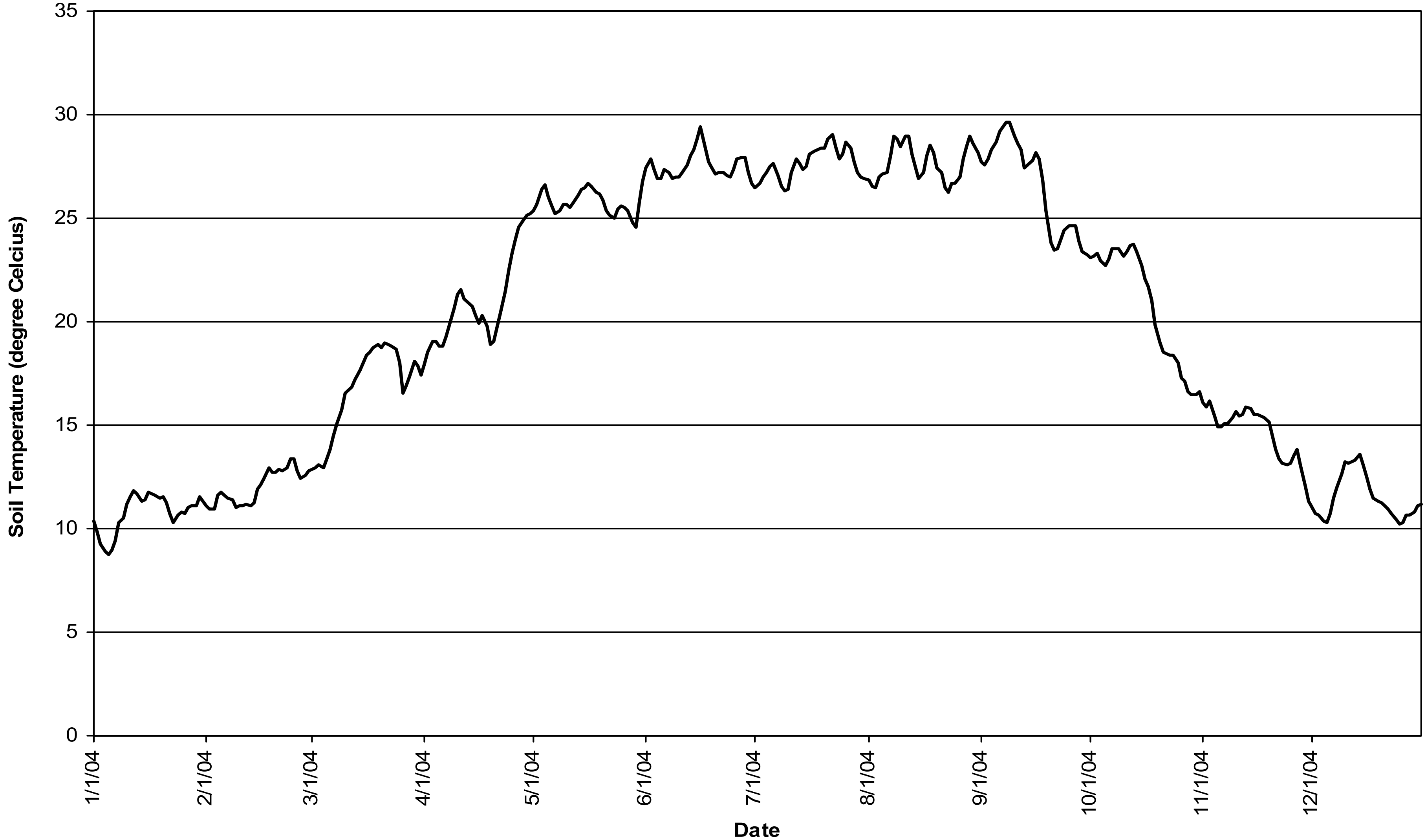
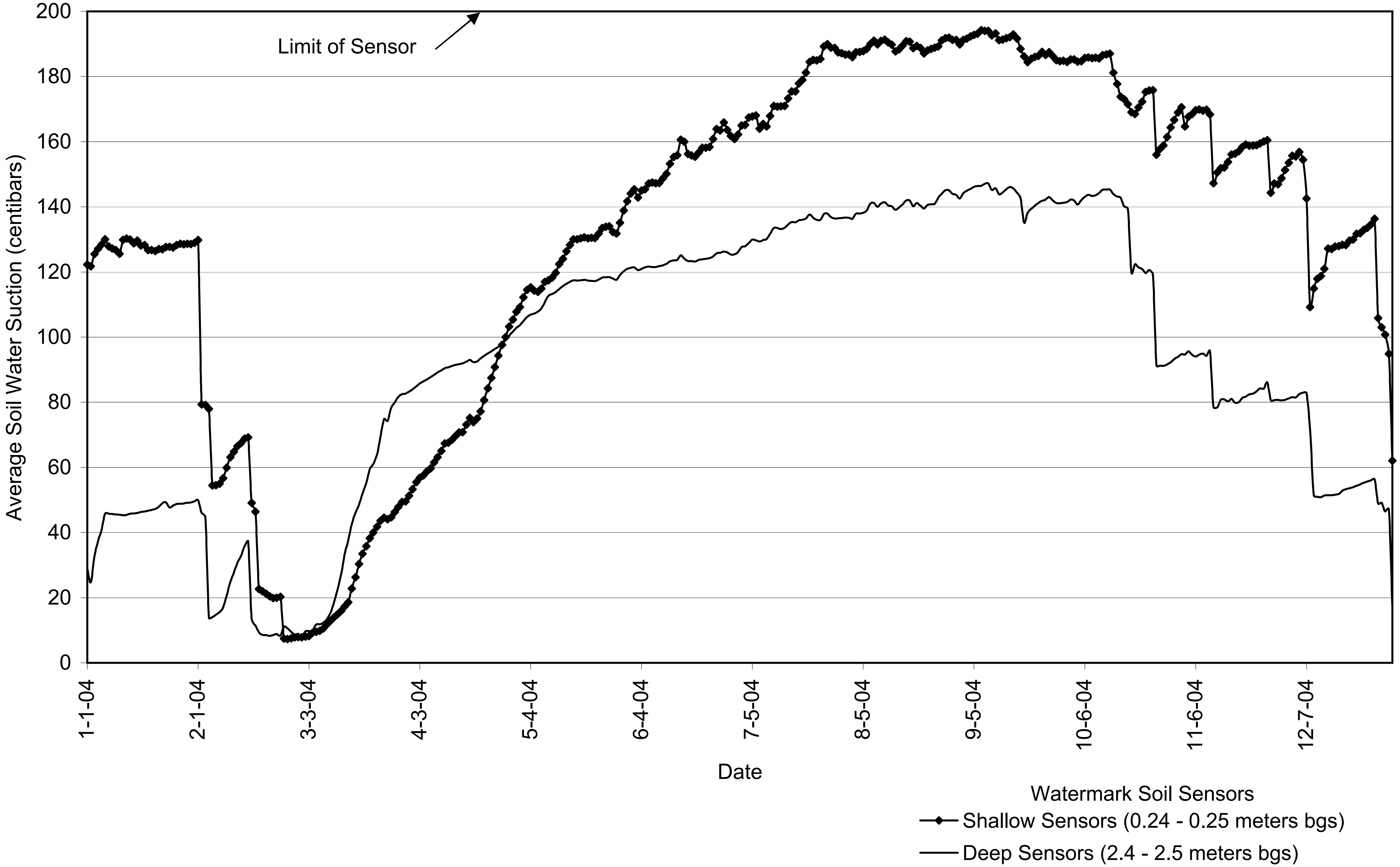


FIGURE 4.5
AVERAGE POTENTIOMETRIC SOIL MOISTURE IN 2004

PHYTOSTABILIZATION DEMONSTRATION

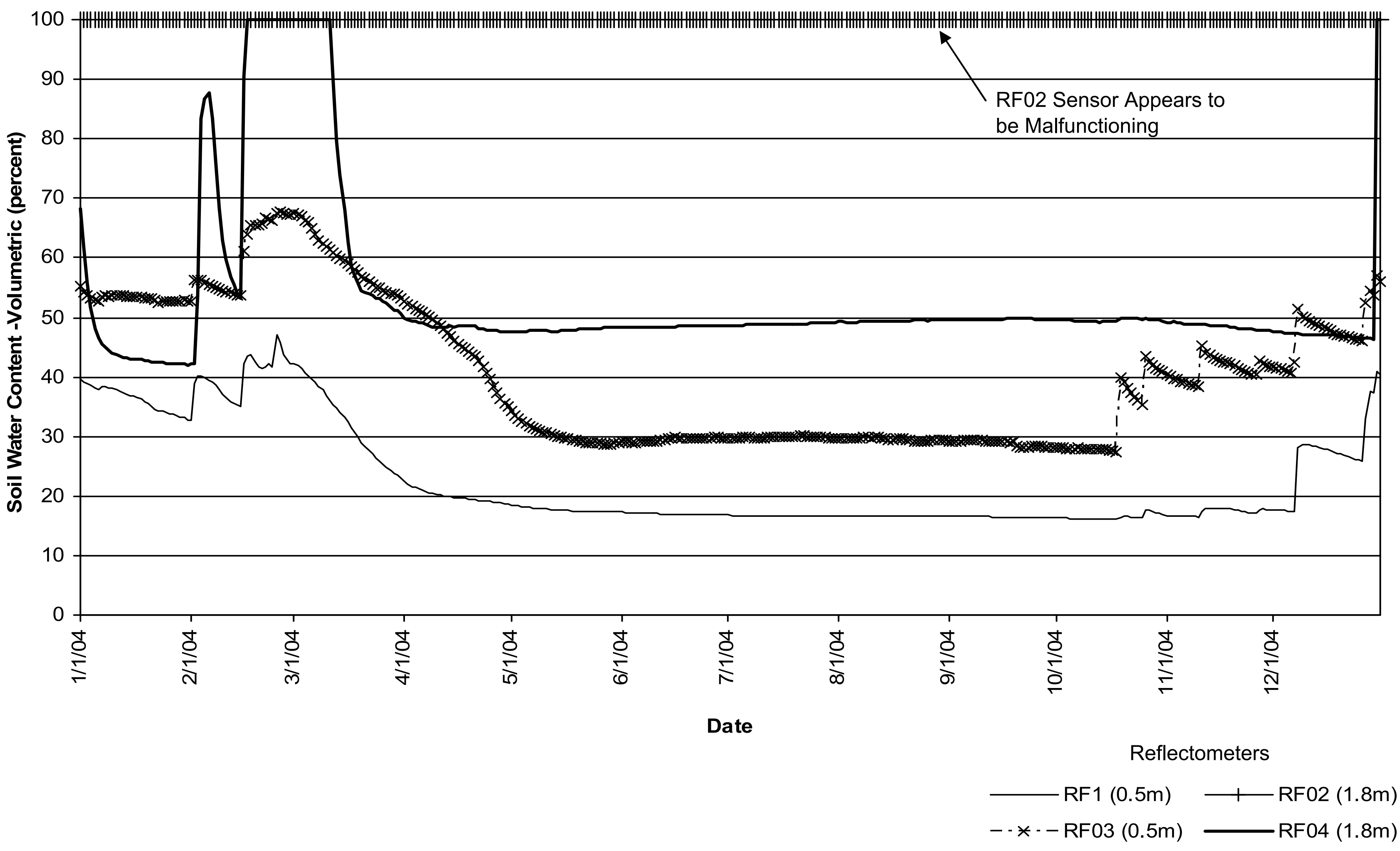
BUILDING 755

TRAVIS AIR FORCE BASE, CALIFORNIA



Travis-Figs-2004.xls

FIGURE 4.6
VOLUMETRIC SOIL MOISTURE IN 2004
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA



Travis-Figs-2004.xls

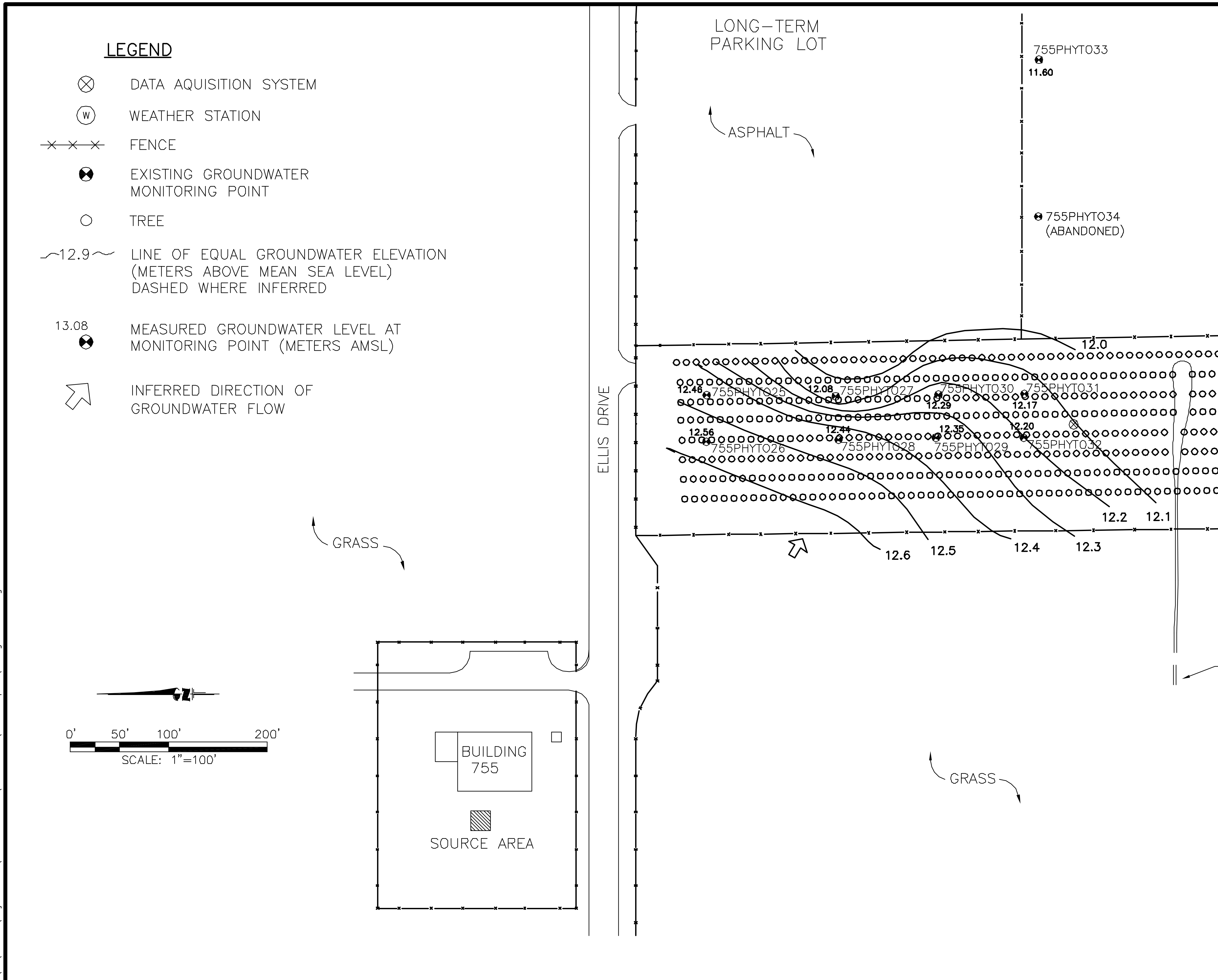


FIGURE 4.7

GROUNDWATER ELEVATIONS
SEPTEMBER 2001

Phytostabilization Demonstration
Building 755
Travis Air Force Base, California

parsons
Denver, Colorado

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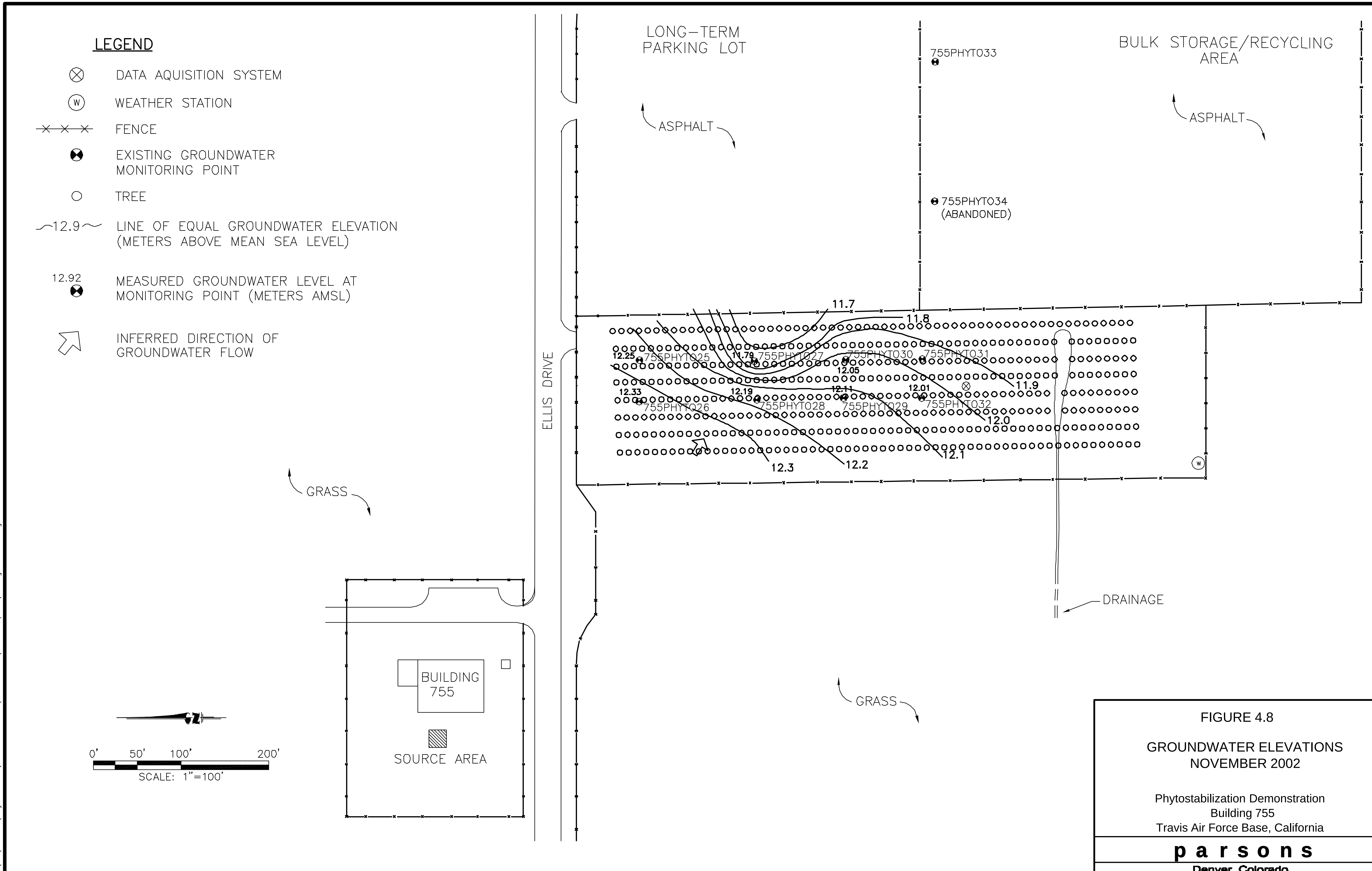

FIGURE 4.8

GROUNDWATER ELEVATIONS
NOVEMBER 2002

Phytostabilization Demonstration
Building 755
Travis Air Force Base, California

parsons
Denver, Colorado

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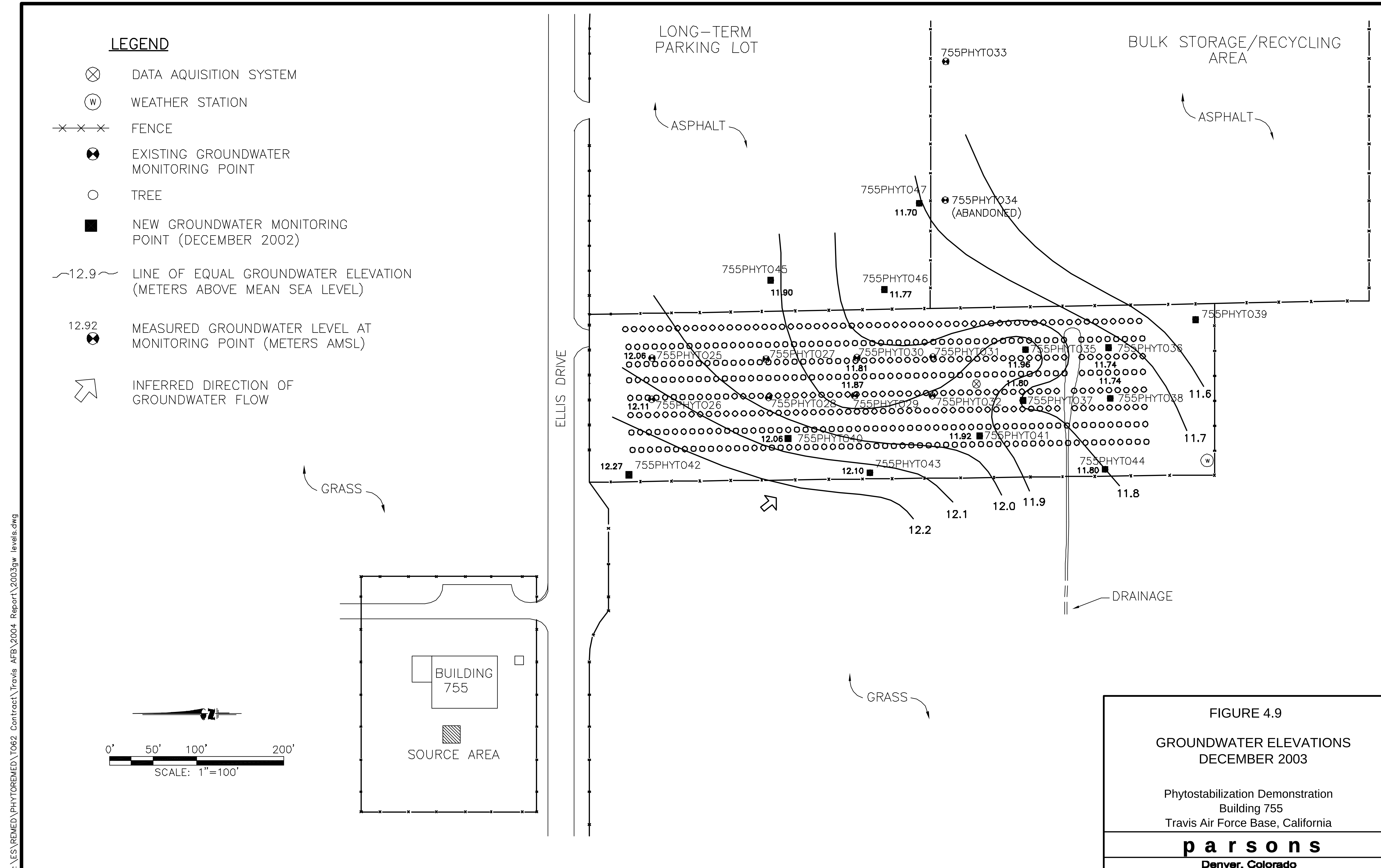

FIGURE 4.9

GROUNDWATER ELEVATIONS
DECEMBER 2003

Phytostabilization Demonstration
Building 755
Travis Air Force Base, California

parsons
Denver, Colorado

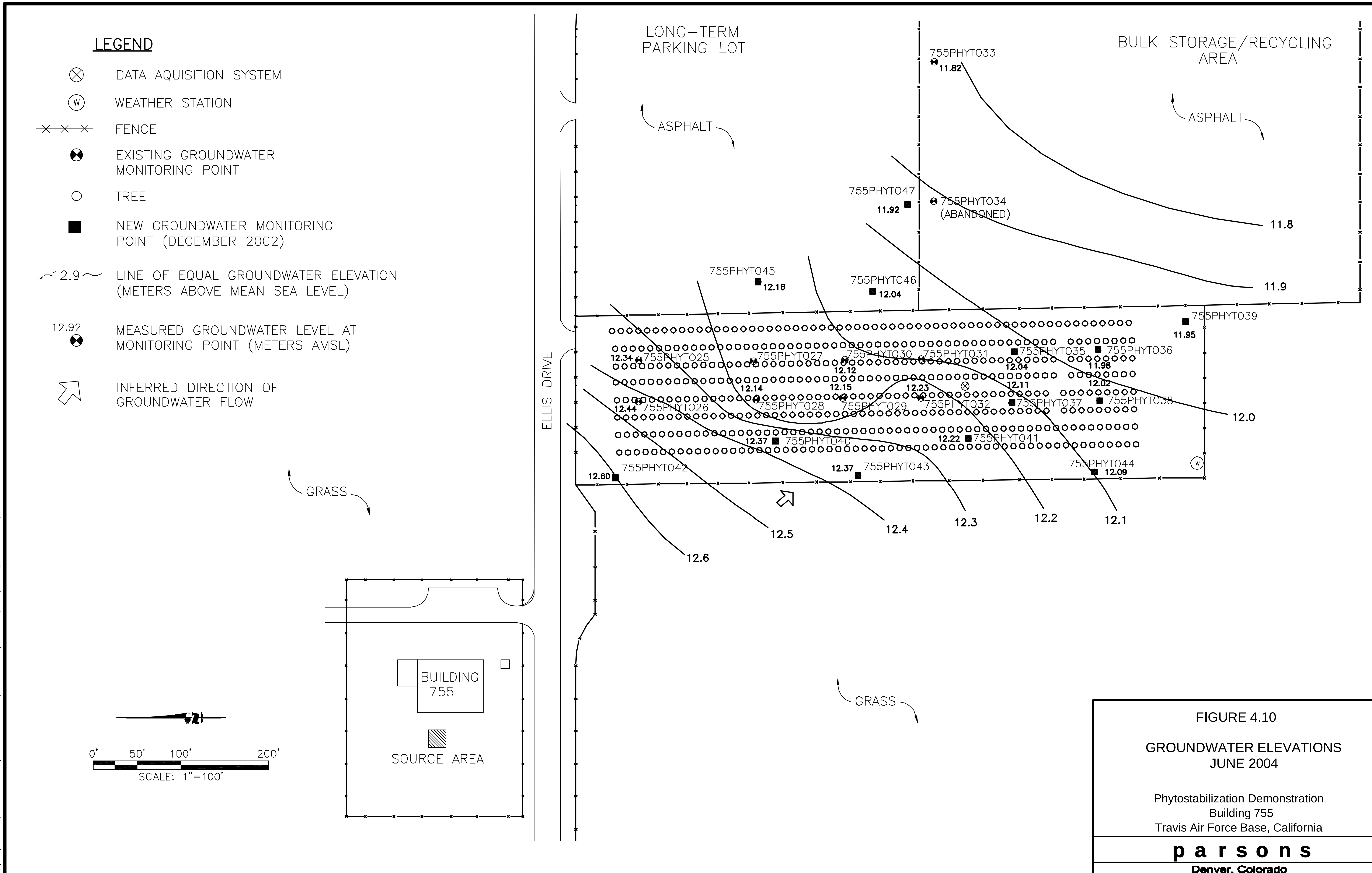

FIGURE 4.10

GROUNDWATER ELEVATIONS
JUNE 2004

Phytostabilization Demonstration
Building 755
Travis Air Force Base, California

parsons
Denver, Colorado

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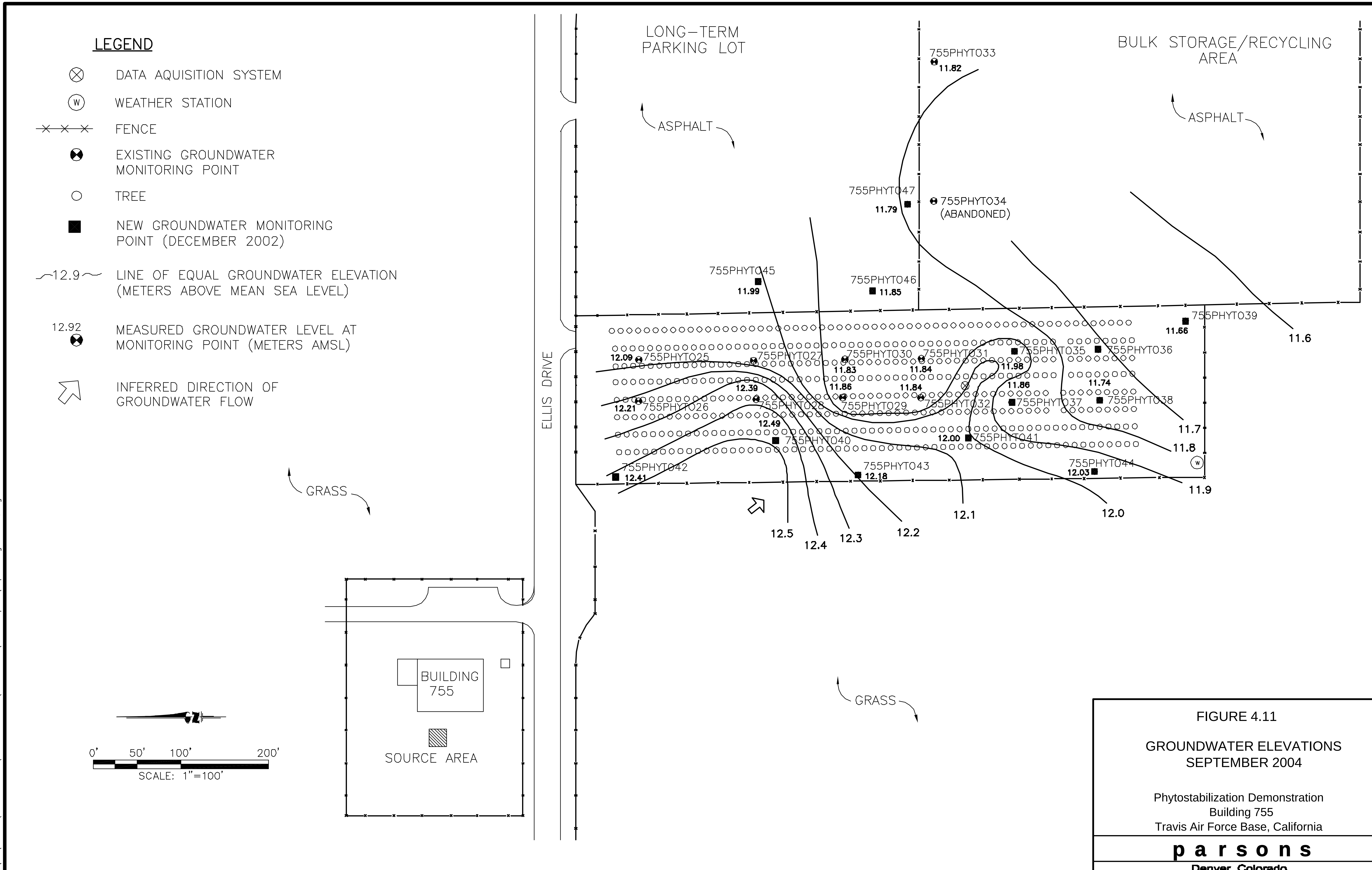

FIGURE 4.11

GROUNDWATER ELEVATIONS
SEPTEMBER 2004

Phytostabilization Demonstration
Building 755
Travis Air Force Base, California

parsons
Denver, Colorado

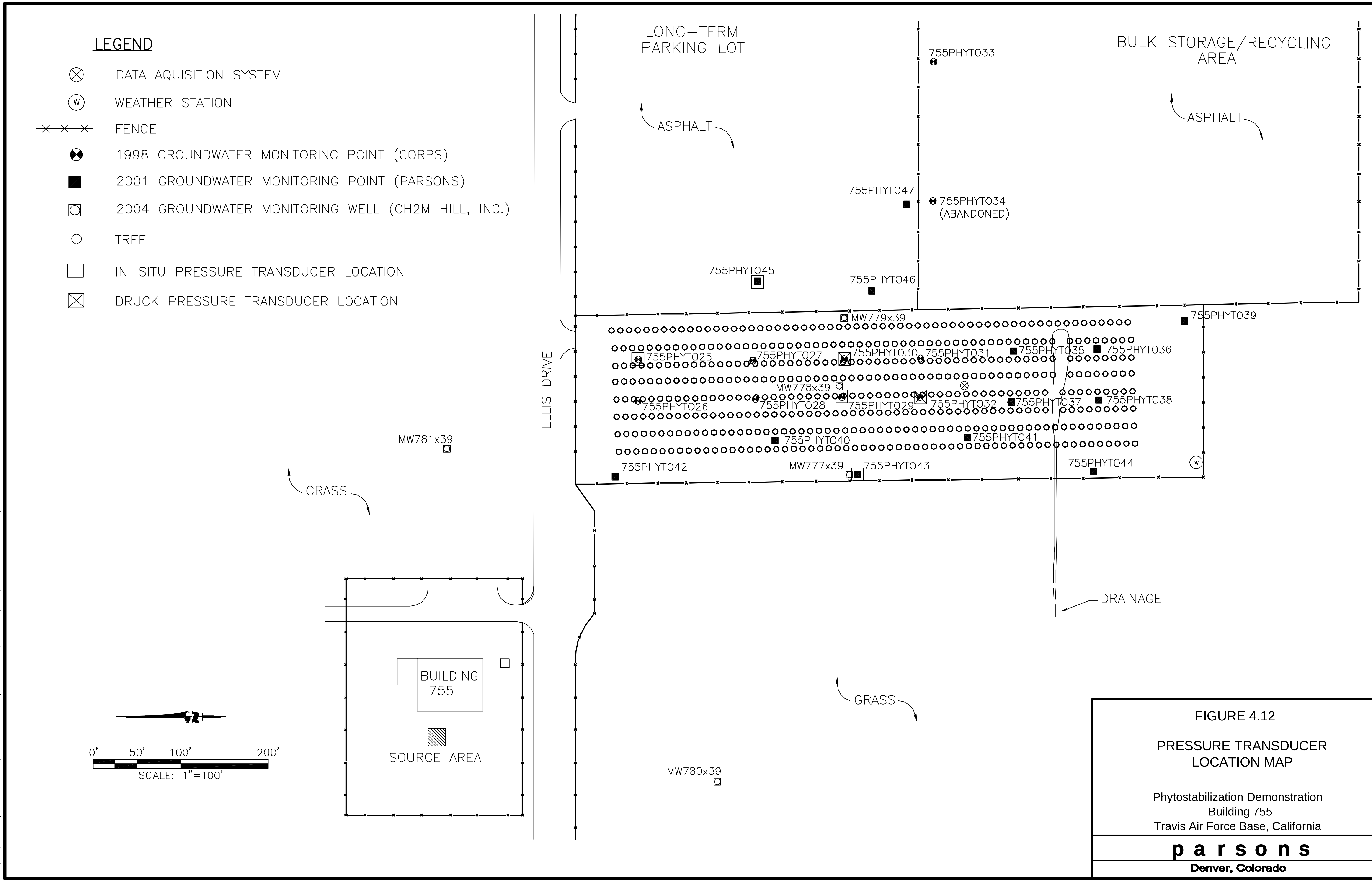

FIGURE 4.12

PRESSURE TRANSDUCER LOCATION MAP

Phytostabilization Demonstration
Building 755
Travis Air Force Base, California

parsons
Denver, Colorado

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FIGURE 4.13
GROUNDWATER LEVEL FLUCTUATIONS IN 2004 FOR DRUCK® PRESSURE TRANSDUCERS

PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

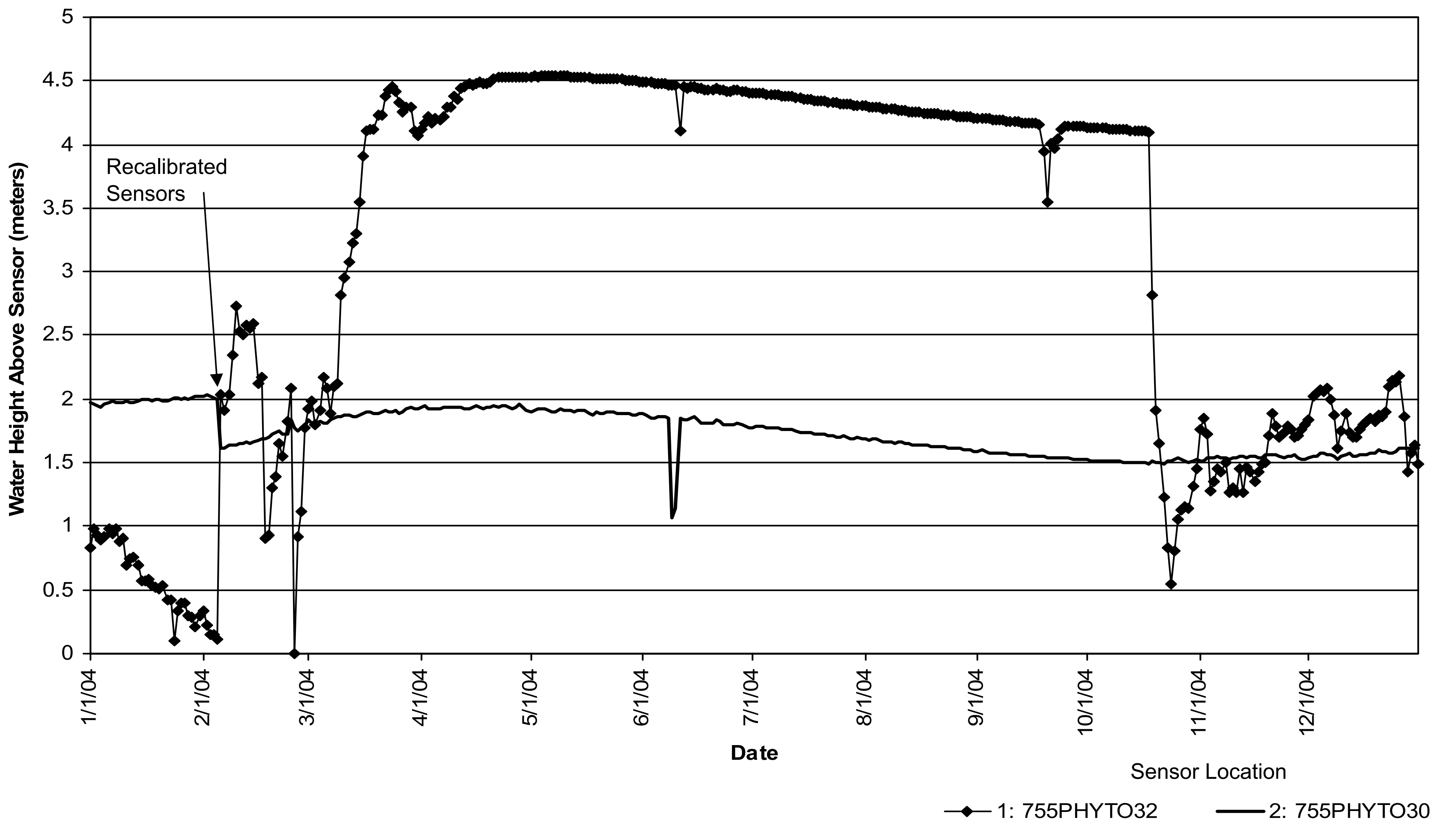


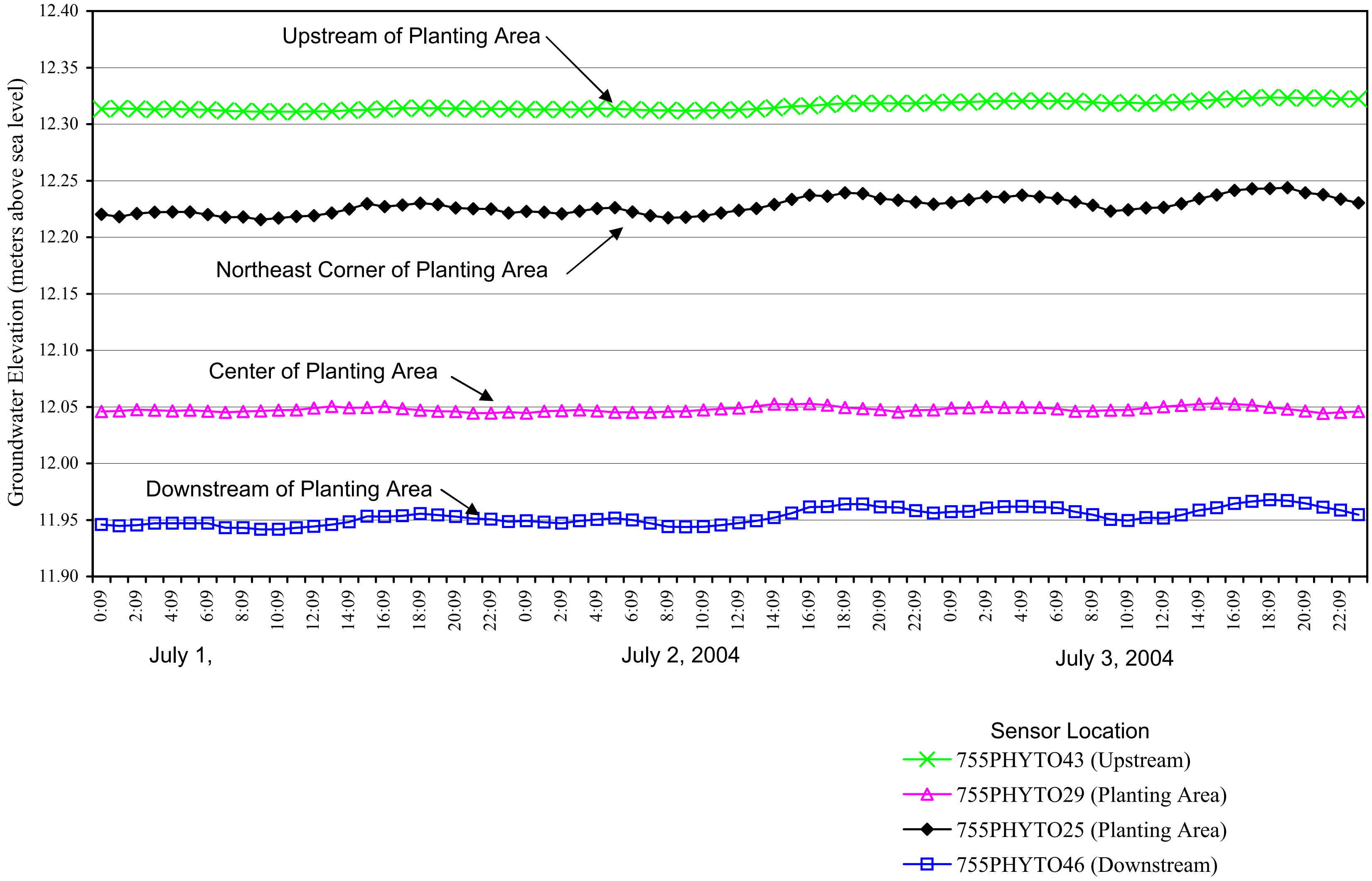
FIGURE 4.14

TYPICAL HOURLY GROUNDWATER LEVEL FLUCTUATIONS IN JULY 2004 FOR IN-SITU® PRESSURE TRANSDUCERS

PHYTOSTABILIZATION DEMONSTRATION

BUILDING 755

TRAVIS AIR FORCE BASE, CALIFORNIA



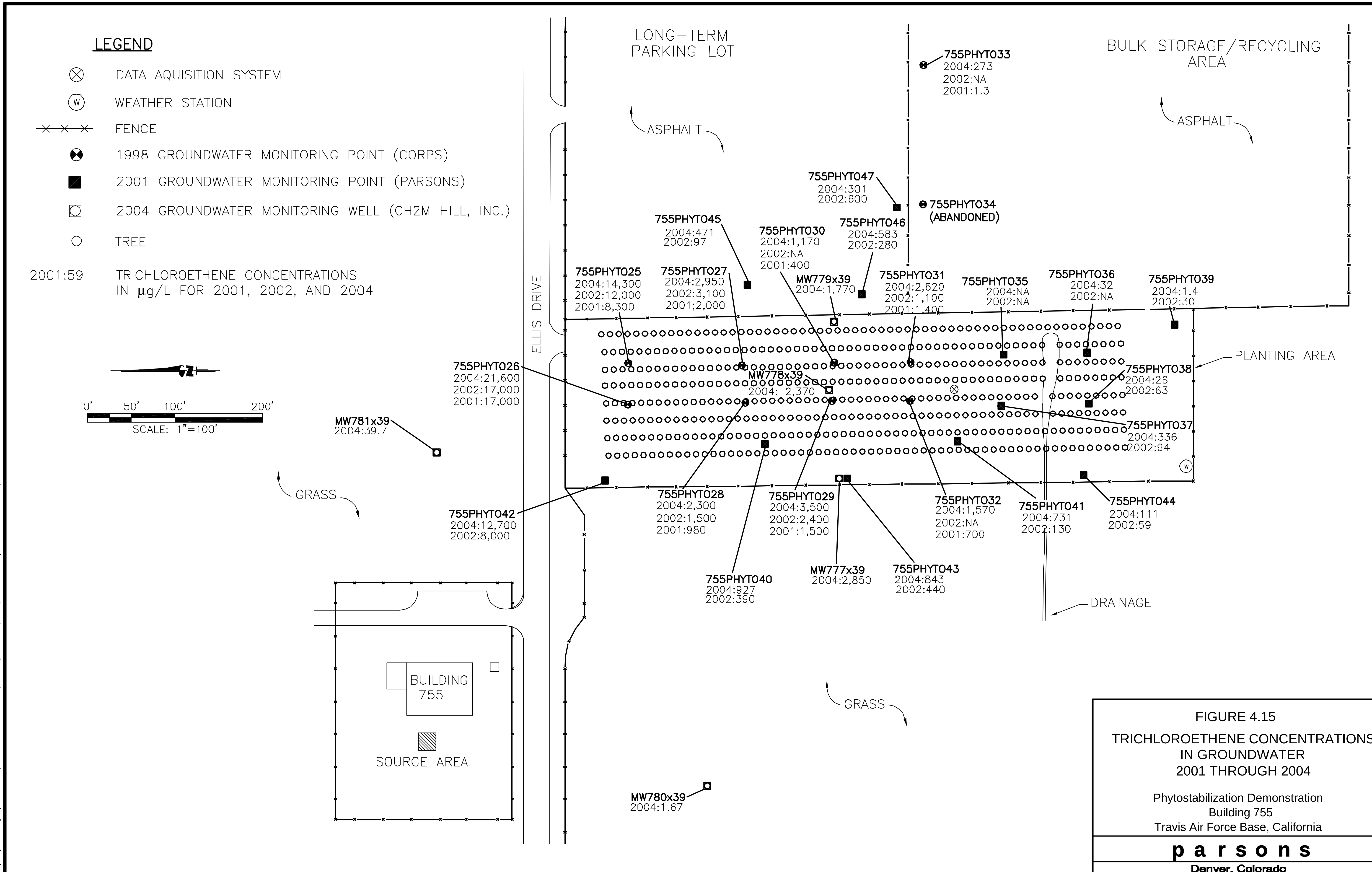


FIGURE 4.15

TRICHLOROETHENE CONCENTRATIONS IN GROUNDWATER 2001 THROUGH 2004

Phytostabilization Demonstration
Building 755
Travis Air Force Base, California

parsons

Denver, Colorado

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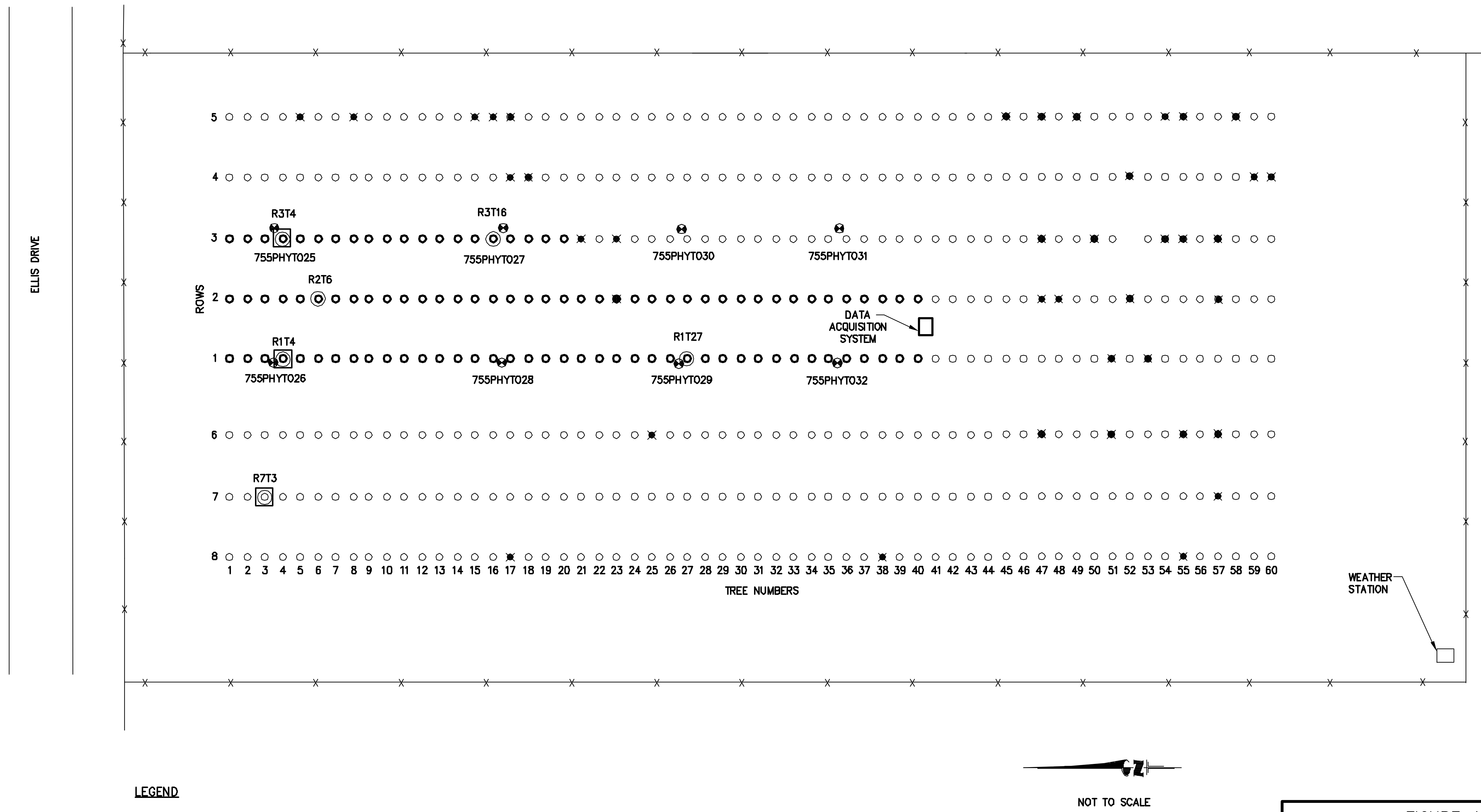


LEGEND

- TREES PLANTED IN 1998
- TREES PLANTED IN 2000
- MONITORING POINT
- FENCE
- ROAD
- TREE DEAD OR REMOVED
- PHYTOVOLATILIZATION SAMPLE LOCATION
- PLANT TISSUE SAMPLE LOCATION

FIGURE 4.16

TISSUE SAMPLE LOCATIONS SEPTEMBER 2004

Phytostabilization Demonstration
Building 755
Travis Air Force Base, California

PARSONS
Denver, Colorado

s:\es\remed\phytoremed\4P-T062 Contract\Travis\2004 Report\Tissue-sample-locations.dwg

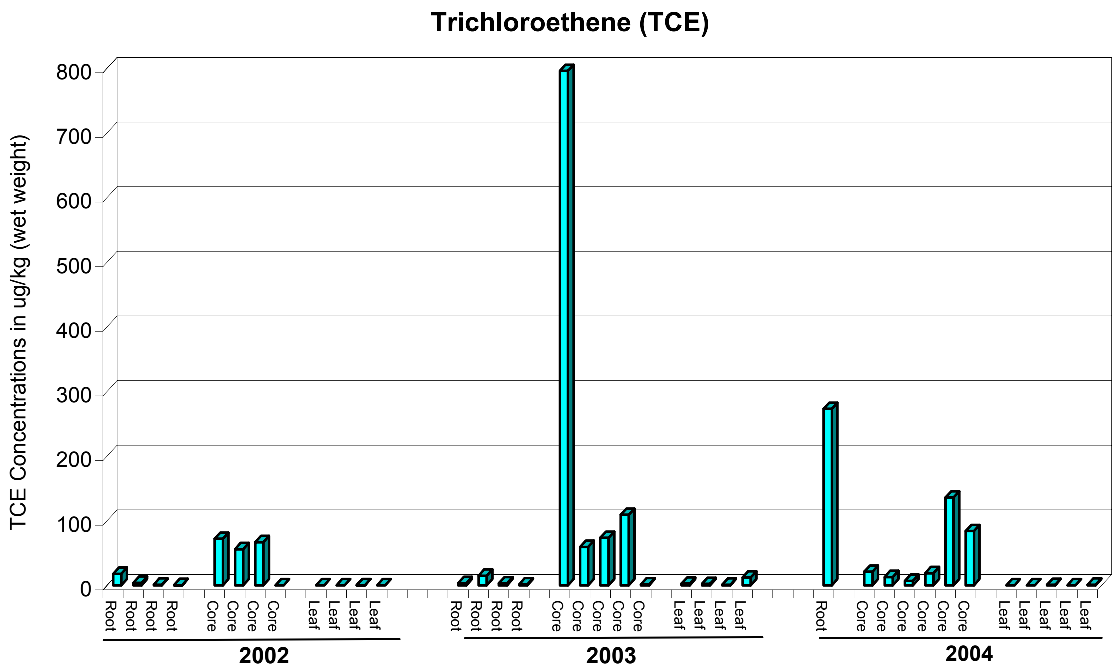
FIGURE 4.17

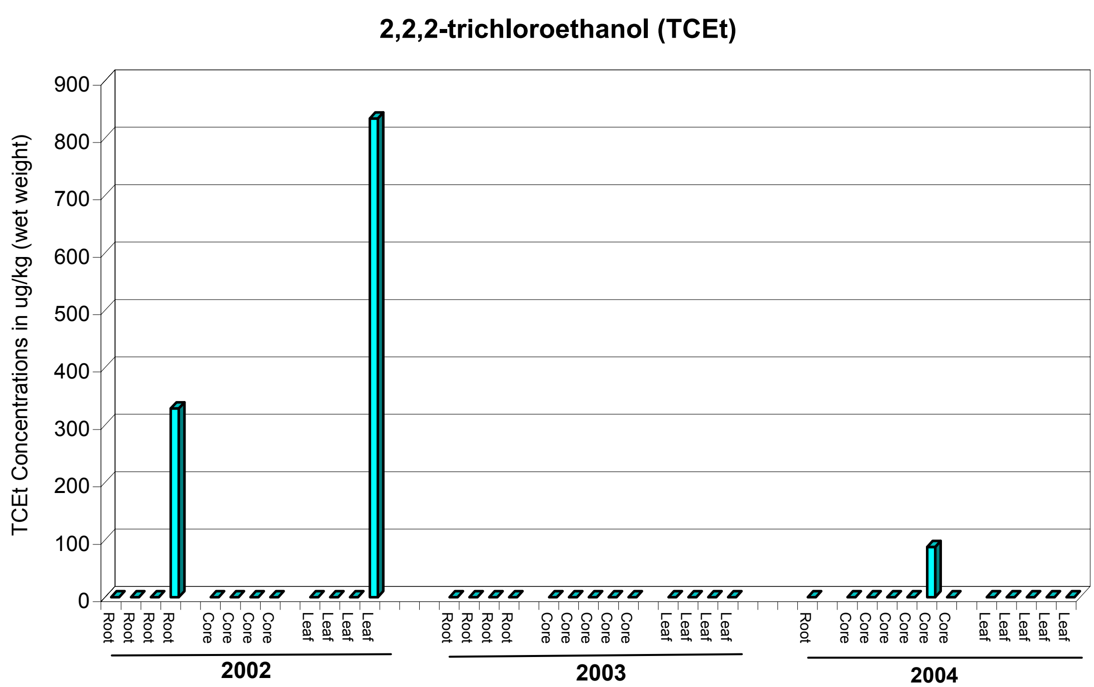
TCE AND TCE METABOLITE CONCENTRATIONS IN PLANT TISSUES

PHYTOSTABILIZATION DEMONSTRATION

BUILDING 755

TRAVIS AIR FORCE BASE, CALIFORNIA





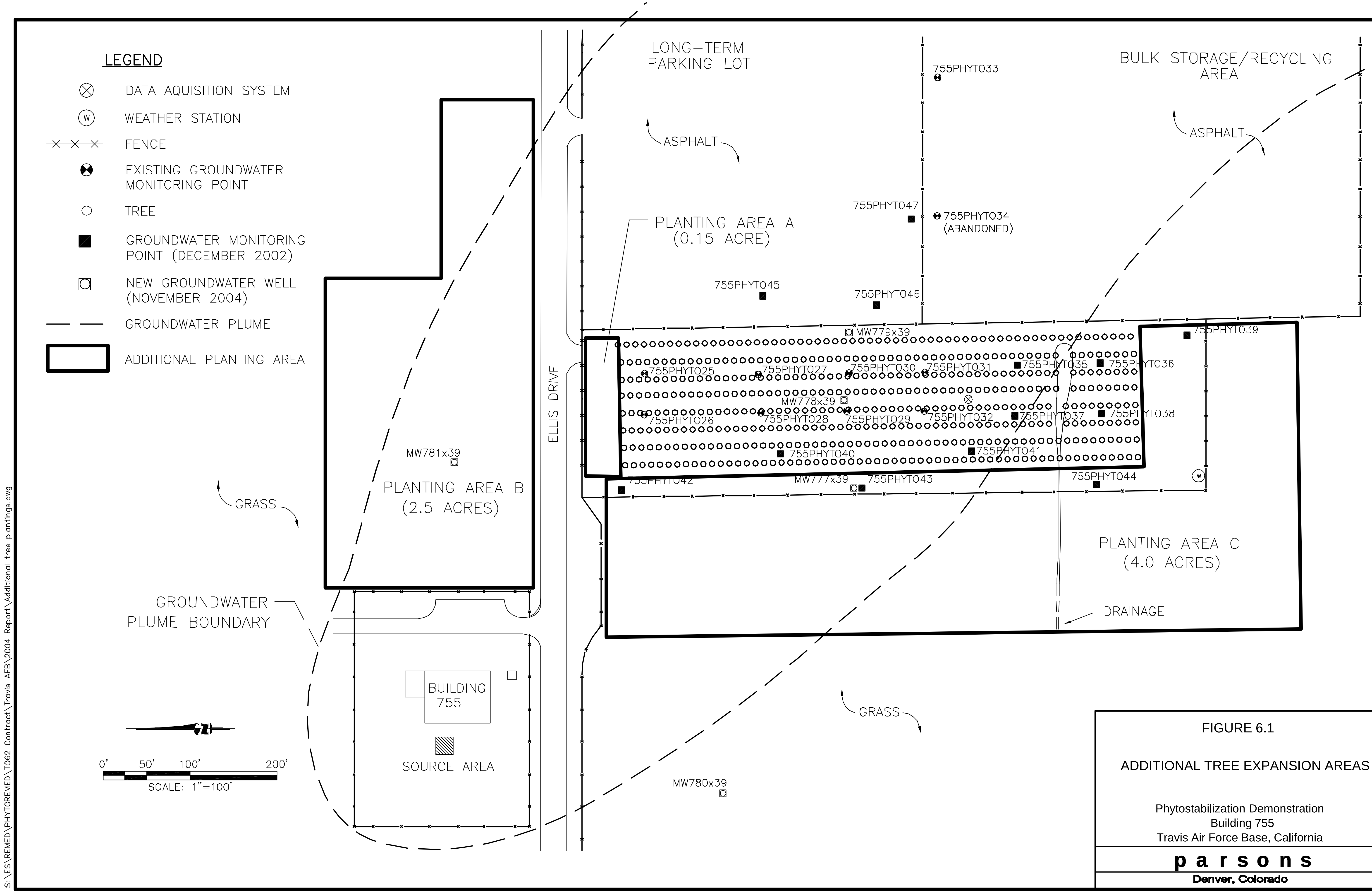


FIGURE 6.1

ADDITIONAL TREE EXPANSION AREAS

Phytostabilization Demonstration
Building 755
Travis Air Force Base, California

parsons
Denver, Colorado

TABLES

TABLE 2.1
TREE MEASUREMENTS FOR INITIAL PLANTING

PHYTOSTABILIZATION DEMONSTRATION

BUILDING 755

TRAVIS AIR FORCE BASE, CALIFORNIA

Location[b/]	1998 Height (meters)	2000 Height (meters)	2001 Height (meters)	2002 Height (meters)	2003 Height (meters)	2004 Height (meters)	1998 Circumference[c/] (centimeters)	2000 Circumference[c/] (centimeters)	2001 Circumference[c/] (centimeters)	2002 Circumference[c/] (centimeters)	2003 Circumference[c/] (centimeters)	2004 Circumference[c/] (centimeters)
R1/T12	3.0	3.0	4.6	5.6	6.4	6.7	5.7	15.9	27.3	27.0	33.6	33.9
R1/T21	2.9	3.7	4.0	4.5	4.9	5.5	5.7	15.9	26.7	28.0	32.0	27.6
R1/T33	3.4	4.6	6.7	6.7	7.3	7.6	5.7	21.0	37.5	44.6	53.1	57.5
R1/T40	3.7	2.7	4.4	6.1	6.7	7.3	5.7	12.7	25.4	28.0	35.2	40.8
R2/T10	3.4	4.6	6.7	5.5	6.1	7.6	5.7	19.7	34.3	39.3	47.1	50.3
R2/T19	3.0	4.9	6.1	6.1	6.4	6.7	5.7	21.6	34.3	41.5	49.0	51.2
R2/T26	2.7	4.9	5.8	5.8	6.1	6.1	5.7	18.4	30.5	36.4	36.4	39.3
R3/T3	3.2	4.9	6.4	6.7	7.0	7.3	5.7	19.1	30.5	32.4	36.8	38.3
R3/T12	3.2	5.2	6.1	6.1	6.9	7.3	5.7	20.3	33.0	33.9	40.2	40.2
R3/T20	3.0	4.0	6.7	7.0	7.6	7.6	5.7	22.9	40.6	47.4	53.1	57.2
Average	**3.2**	**4.2**	**5.7**	**6.0**	**6.5**	**7.0**	**5.7**	**18.7**	**32.0**	**35.8**	**41.7**	**43.6**
Standard Deviation	**0.2**	**0.8**	**1.0**	**0.7**	**0.7**	**0.7**	**0.0**	**2.9**	**4.6**	**6.9**	**7.7**	**9.5**

[a/] Intitial trees planted in November 1998 and consisted of 100, 15-gallon Eucalyptus trees, species *Eucalyptus sideroxylon* (red ironbark).

[b/] Location indicates row number (R1) and tree number (T12).

[c/] Measurement taken 1 meter above the ground surface.

TABLE 2.2
TREE MEASUREMENTS FOR SUPPLEMENTAL PLANTING

PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

Location[b/]	2000 Height (meters)	2001 Height (meters)	2002 Height (meters)	2003 Height (meters)	2004 Height (meters)	2001 Circumference [c/] (centimeters)	2002 Circumference [c/] (centimeters)	2003 Circumference [c/] (centimeters)	2004 Circumference [c/] (centimeters)
R1T41	1.1	1.8	1.7	2.3	1.8	2.51	3.14	3.14	4.71
R1T60	0.9	2.1	2.1	2.7	3.0	3.77	9.42	16.34	13.19
R2T51	1.2	3.0	4.6	5.8	7.6	15.39	11.62	35.19	40.84
R2T60	0.8	2.0	1.8	2.9	3.0	2.51	7.54	7.85	7.85
R3T31	0.8	1.5	1.1	1.4	1.5	2.51	3.14	3.14	4.71
R3T41	1.2	1.4	0.8	0.8	0.6	2.51	1.57	1.57	3.14
R3T51	1.1	2.4	1.8	4.0	4.0	2.51	1.57	11.94	12.57
R3T60	1.1	2.7	3.0	3.9	4.0	6.28	8.80	13.82	11.94
R4T1	0.8	2.1	2.7	3.5	3.7	5.03	9.74	9.74	11.00
R4T11	0.8	2.4	2.9	4.5	4.6	5.03	11.62	15.08	25.13
R4T21	0.8	1.5	2.2	2.5	2.4	2.51	5.34	6.60	10.05
R4T31	0.9	1.7	2.1	3.5	3.7	2.51	8.80	11.62	11.00
R4T41	0.8	2.1	2.1	3.9	4.0	7.54	12.57	18.22	23.25
R4T51	0.8	1.8	1.8	3.3	3.4	2.51	5.34	9.42	12.88
R5T1	1.2	2.0	2.7	2.8	2.7	2.51	7.85	7.85	8.80
R5T11	1.0	1.8	2.6	3.0	3.0	2.51	7.85	9.42	10.37
R5T21	1.2	2.1	3.4	4.0	4.3	6.28	10.68	14.45	13.19
R5T31	0.8	1.5	1.5	2.5	2.7	2.51	5.65	6.28	6.28
R5T41	1.1	1.4	0.8	1.3	0.9	10.05	1.57	1.57	3.14
R5T51	0.9	1.8	2.1	2.6	2.7	2.51	9.42	9.42	11.00
R5T60	1.2	2.4	2.4	3.7	3.7	7.54	7.54	14.14	15.71
R6T1	0.9	2.1	3.0	3.9	4.6	6.28	14.14	19.48	29.85
R6T11	0.6	2.1	3.3	3.1	5.8	3.77	10.05	10.37	26.70
R6T21	0.6	1.7	3.0	4.7	4.6	2.51	9.11	16.34	20.73
R6T31	0.8	2.6	3.7	4.3	4.3	6.28	12.57	19.48	21.36
R6T41	0.8	2.7	6.1	5.1	5.2	8.80	14.45	21.36	24.50
R6T60	0.6	2.6	3.0	3.3	3.4	6.28	6.60	9.42	15.71
R7T1	0.8	1.8	2.4	3.3	4.1	3.77	8.80	12.57	21.99
R7T11	0.8	2.1	2.9	3.3	4.9	2.51	8.80	11.00	21.36
R7T21	0.8	1.8	2.0	4.8	4.9	2.51	5.34	19.16	22.93
R7T31	0.6	2.1	3.3	3.7	3.7	2.51	11.00	10.68	12.57
R7T41	0.9	2.9	3.7	4.2	5.5	11.31	14.14	18.22	27.65

TABLE 2.2 (Continued)
TREE MEASUREMENTS FOR SUPPLEMENTAL PLANTING

PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

Location[b/]	2000 Height (meters)	2001 Height (meters)	2002 Height (meters)	2003 Height (meters)	2004 Height (meters)	2001 Circumference [c/] (centimeters)	2002 Circumference [c/] (centimeters)	2003 Circumference [c/] (centimeters)	2004 Circumference [c/] (centimeters)
R7T51	0.8	1.8	1.7	0.9	5.5	2.51	4.71	4.71	23.88
R7T60	0.8	1.5	1.2	1.5	2.7	2.51	5.03	5.03	5.97
R8T1	0.8	1.4	1.6	2.4	2.7	2.51	4.71	6.91	10.05
R8T11	0.8	2.0	1.8	3.6	4.3	2.51	5.65	14.14	23.56
R8T21	0.8	2.1	2.3	3.5	4.1	6.28	9.11	11.00	17.91
R8T31	0.8	1.2	1.8	2.8	3.4	2.51	3.14	6.28	11.31
R8T41	0.8	1.5	1.5	1.9	2.9	2.51	4.08	4.71	7.85
R8T52	0.6	0.9	2.0	3.3	3.8	2.51	6.91	12.88	18.22
R8T60	0.6	2.1	2.4	3.6	4.3	2.51	7.85	12.88	16.65
Average	**0.9**	**2.0**	**2.4**	**3.2**	**3.7**	**4.4**	**7.7**	**11.5**	**15.6**
Standard Deviation	**0.2**	**0.5**	**1.0**	**1.1**	**1.3**	**3.0**	**3.5**	**6.4**	**8.3**

[a/] Secondary tree planting took place in March or April and July of 2000, and consisted of 380, 1-gallon Eucalyptus trees, species *Eucalyptus sideroxylon* (Red Ironbark).

[b/] Location indicates row number (R1) and tree number (T12).

[c/] Measurement taken 1 meter above the ground surface.

[d/] --- = data not collected; tree was dead.

TABLE 4.1
FIELD-MEASURED GROUNDWATER ELEVATIONS

PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

Date	Time	Groundwater Elevation (meters amsl)[a/] MP Location[b/]																					
		25	26	27	28	29	30	31	32	33	35	36	37	38	39	40	41	42	43	44	45	46	47
01-10-99	---[c/]	13.12	13.22	12.84	13.08	12.98	12.95	12.80	12.87	12.01	---	---	---	---	---	---	---	---	---	---	---	---	---
01-07-00	---	13.26	13.34	13.01	13.23	13.12	13.09	12.92	12.97	12.21	---	---	---	---	---	---	---	---	---	---	---	---	---
13-07-00	9:45	13.25	13.32	12.98	13.22	13.11	13.01	12.90	12.91	12.20	---	---	---	---	---	---	---	---	---	---	---	---	---
"	10:45	13.25	13.01	12.98	13.22	13.10	13.06	12.90	12.96	12.20	---	---	---	---	---	---	---	---	---	---	---	---	---
"	11:45	13.25	13.33	12.96	13.22	13.10	13.06	12.90	12.96	12.20	---	---	---	---	---	---	---	---	---	---	---	---	---
"	12:45	13.25	13.33	12.99	13.22	13.10	13.07	12.90	12.97	12.20	---	---	---	---	---	---	---	---	---	---	---	---	---
"	13:45	13.26	13.33	12.99	13.22	13.11	13.07	12.91	12.96	12.21	---	---	---	---	---	---	---	---	---	---	---	---	---
"	14:45	13.26	13.33	13.00	13.23	13.11	13.08	12.91	12.97	12.21	---	---	---	---	---	---	---	---	---	---	---	---	---
"	16:00	13.26	13.33	13.00	13.23	13.12	13.08	12.92	12.97	L [d/]	---	---	---	---	---	---	---	---	---	---	---	---	---
"	16:45	13.26	13.33	13.01	13.23	13.12	13.08	12.92	12.97	L	---	---	---	---	---	---	---	---	---	---	---	---	---
"	17:45	13.26	13.34	13.01	13.23	13.12	13.09	12.92	12.97	L	---	---	---	---	---	---	---	---	---	---	---	---	---
14-07-00	8:20	13.25	13.32	12.98	13.21	13.10	13.06	12.90	12.96	12.20	---	---	---	---	---	---	---	---	---	---	---	---	---
"	9:20	13.25	13.33	12.98	13.21	13.10	13.06	12.90	12.96	---	---	---	---	---	---	---	---	---	---	---	---	---	---
"	10:20	13.25	13.33	12.98	13.21	13.10	13.06	12.90	12.96	12.20	---	---	---	---	---	---	---	---	---	---	---	---	---
"	11:20	13.26	13.33	12.99	13.21	13.11	13.07	12.91	12.96	---	---	---	---	---	---	---	---	---	---	---	---	---	---
"	12:20	13.26	13.33	13.00	13.22	13.11	13.08	12.91	12.97	12.21	---	---	---	---	---	---	---	---	---	---	---	---	---
"	13:20	13.26	13.33	13.00	13.23	13.12	13.08	12.92	12.97	---	---	---	---	---	---	---	---	---	---	---	---	---	---
"	14:20	13.27	13.34	13.01	13.23	13.13	13.09	12.92	12.97	12.22	---	---	---	---	---	---	---	---	---	---	---	---	---
"	15:40	13.27	13.35	13.02	13.25	13.14	13.10	12.94	12.98	12.23	---	---	---	---	---	---	---	---	---	---	---	---	---
"	16:40	---	13.35	13.02	13.25	13.14	13.10	12.94	12.98	L	---	---	---	---	---	---	---	---	---	---	---	---	---
20-09-00	930-1200	13.00	13.07	12.69	12.95	12.85	12.81	12.68	12.71	11.95	---	---	---	---	---	---	---	---	---	---	---	---	---
10-09-01	1129-1150	12.46	12.56	12.08	12.44	12.35	12.29	12.17	12.20	11.60	---	---	---	---	---	---	---	---	---	---	---	---	---
18-11-02	1159-1258	12.25	12.33	11.79	12.19	12.11	12.05	--	12.01	--	---	---	---	---	---	---	---	---	---	---	---	---	---
12/6-12/2002	--	12.17	--	--	--	11.98	--	--	--	--	---	---	---	10.78	---	---	---	---	13.18	---	---	11.91	---
12-12-03	0930-1545	12.06	12.11	roots [e/]	roots	11.87	11.81	roots	roots	--	11.96	11.74	11.80	11.74	11.54	12.06	11.92	12.27	12.10	11.80	11.90	11.77	11.70
08-06-04	0830-1735	12.34	12.44	11.88	12.14	12.15	12.12	12.92	12.23	11.82	12.04	11.98	12.11	12.02	11.95	12.37	12.22	12.60	12.37	12.09	12.16	12.04	11.92
07-09-04	1700-1800	12.09	12.21	roots	12.39	11.86	11.83	11.84	11.84	11.62	11.98	11.48	11.86	11.74	11.66	12.49	12.00	12.41	12.18	12.03	11.99	11.85	11.79
08-02-05	1200-1800	12.28	13.54	12.79	10.89	12.19	12.08	roots	12.10	11.54	12.14	11.75	12.13	11.87	13.08	12.19	12.10	12.48	12.30	12.13	12.46	12.09	12.13

[a/] amsl = above mean sea level.

[b/] Monitoring point (MP) locations 25 through 47 represent MPs 755PHYTO25 through 755PHYTO47.

[c/] --- = data not collected.

[d/] L = access gate to the MW had been locked.

[e/] Tree roots in the wells prevented the water level indicator from reaching the water table.

TABLE 4.2
GROUNDWATER TARGET ANALYTES

PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

MATRIX Analyte	METHOD [a]	FIELD (F) OR ANALYTICAL LABORATORY (L)	NUMBER OF SAMPLES [b]
GROUNDWATER			
VOCs	USEPA SW8260B	L	22 [b]
Chloride	E300.0	L	19
Sulfate	E300.0	L	19
Dissolved Organic Carbon	USEPA SW9060	L	19
Methane, Ethane, Ethene	RSK 175	L	21
Nitrate	E353.3	L	19
Nitrite	E353.3	L	19
Alkalinity	E300.0	L	19
Redox Potential	Direct-reading meter	F	13
Dissolved Oxygen	Direct-reading meter	F	12
pH	Direct-reading meter	F	13
Conductivity	Direct-reading meter	F	13
Temperature	Direct-reading meter	F	13
Ferrous Iron (Fe^{+2})	Colorimetric, Hach Method 8146	L	17
Manganese	Colorimetric, Hach Method 8034	L	16
Hydrogen Sulfide	Colorimetric, Hach Method 8131	L	18
Carbon Dioxide	Titrimetric, Hach Method 1436-01	L	16

[a] USEPA = United States Environmental Protection Agency.

[b] Includes one duplicate sample.

TABLE 4.3
TRICHLOROETHENE AND DICHLOROETHENE CONCENTRATIONS IN GROUNDWATER
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

Location	Date	Screened Interval (meters bgs) [b]	Analytical Groundwater Data (µg/L)[a]	
			TCE	1,1-DCE
755PHYTO25	7/98 [c]	5.18-9.14	15,000	370
	09-18-00		9,000	180
	09-01-01		8,300	270
	12-02-02		12,000	350 J [d]
	06-08-04		14,300	423
755PHYTO26	7/98 [c]	5.18-9.14	17,000	520
	09-18-00		16,000	350
	09-01-01		17,000	200
	12-03-02		17,000	270 J
	06-10-04		20,900	360 J
	6/10/2004 (Dup) [e]		21,600	339
755PHYTO27	7/98 [c]	5.18-9.14	4,300	360
	09-18-00		2,200	230
	09-01-01		1,800	300
	12-03-02		3,100	450
	06-17-04		2,950	526
755PHYTO28	7/98 [c]	5.18-9.14	10,000	740
	09-18-00		660	180
	09-01-01		980	140
	12-04-02		1,500	240
	06-10-04		2,300	351
755PHYTO29	7/98 [c]	4.57-8.53	3,200	550
	09-18-00		1,400	310
	09-01-01		1,500	460
	12-03-02		2,400	580
	06-08-04		3,500	700
755PHYTO30	7/98 [c]	4.57-8.53	2,800	540
	09-18-00		890	240
	09-01-01		400	100
	12-03-02		--- [f]	---
	06-11-04		1,170	228
755PHYTO31	7/98 [c]	3.96-7.92	2,700	400
	09-18-00		1,600	290
	09-01-01		1,400	330
	12-03-02		1,100	230
	06-11-04		2,620	491
755PHYTO32	7/98 [c]	3.96-7.92	5,700	720
	09-18-00		810	160
	09-01-01		700	140
	12-03-02		---	---
	06-10-04		1,570	251
755PHYTO33	7/98 [c]	4.27-8.23	260	32
	09-18-00		490	77
	09-01-01		430	83
	12-03-02		---	---
	06-14-04		273	250 U [g]

TABLE 4.3 (Continued)
TRICHLOROETHENE AND DICHLOROETHENE CONCENTRATIONS IN GROUNDWATER
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

Location	Date	Screened Interval (meters bgs) [b/]	Analytical Groundwater Data (µg/L)[a/]	
			TCE	1,1-DCE
755PHYTO35	12-02-02	2.44-5.49	--	--
	06-08-04		--	--
755PHYTO36	12-02-02	3.05-6.10	--	--
	06-16-04		32	1.3
755PHYTO37	12-09-02	3.05-7.62	94	15
	06-17-04		336	54
755PHYTO38	12-09-02	3.05-6.10	63	11
	06-17-04		26	3.1
755PHYTO39	12-06-02	3.05-6.10	30	4.1
	06-17-04		1.4	0.12 J
755PHYTO40	12-06-02	3.05-7.62	390	100
	06-16-04		927	401
755PHYTO41	12-06-02	4.57-7.62	130	25
	06-16-04		731	129
755PHYTO42	12-05-02	4.57-10.67	8,000	590
	06-14-04		12,700	756
755PHYTO43	12-06-02	4.57-9.14	440	71
	06-09-04		843	141
755PHYTO44	12-06-02	3.05-6.10	59	9
	06-16-04		111	9
755PHYTO45	12-06-02	3.96-8.53	97	4.1
	06-11-04		471	12
755PHYTO46	12-06-02	3.96-8.53	280	56
	06-09-04		583	79
755PHYTO47	12-05-02	3.35-7.92	600	140
	06-10-04		301	18
MW777x39 [h/]	11-22-04	4.88-7.92	2,850	607
MW778x39	11-22-04	4.88-7.92	2,370	592
MW779x39	11-22-04	4.88-7.92	1,770	236
MW780x39	11-22-04	7.01-10.06	1.67	0.14 J
MW781x39	11-22-04	8.23-11.28	39.7	0.3 J

[a/] ug/L = micrograms per liter, TCE = trichloroethene, DCE = 1,1-dichloroethene.
[b/] bgs = below ground surface.
[c/] Sampled between 16 and 23 July 1998 by the US Army Corps of Engineers, Kansas City District.
[d/] J = estimated value.
[e/] Dup = duplicate sample.
[f/] --- = data not collected, well was dry.
[g/] U = compound not detected, the value shown is the reporting limit.
[h/] New wells installed and sampled in November 2004 by CH2M Hill, Inc.

TABLE 4.4
GEOCHEMISTRY LABORATORY AND FIELD DATA (2000-2004)
PHOTOSTABILIZATION DEMONSTRATION PROJECT
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

Well ID	Sample Date	Temp °C [a]	pH SU [b]	Conductivity mS/cm [c]	Redox Potential mV [d]	Dissolved Hydrogen nM [e]	Dissolved Organic Carbon mg/L [f]	Dissolved Oxygen mg/L	Manganese mg/L	Ferrous Iron mg/L	Sulfate mg/L	Hydrogen Sulfide mg/L	Alkalinity as $CaCO_3$ mg/L	Carbon Dioxide mg/L	Chloride mg/L	Ammonia mg/L	Nitrate/ Nitrite-N mg/L	Nitrate mg/L	Nitrite mg/L	Methane mg/L	Ethene mg/L	Ethane mg/L
755PHYTO25	Sep-00	20.5	7.2	1.46	229	--- [g]	0.8	4.6	0.7	ND [h]	4.8	<0.1	202	35	318	ND	5.8	---	---	ND	ND	ND
	Sep-01	19.2	7.4	1.62	160	---	0.9	5.2	ND	ND	4.2	<0.1	206	15	344	ND	5.9	---	---	0.0005 U [i]	0.001U	0.0005 U
	Dec-02	18.6	5.7	1.16	202	---	1.1	3.9	ND	ND	5.1	ND	210	37.5	230	---	---	6.1	1 U	0.00026 J [j]	ND	ND
	Jun-04	**---**	**---**	**---**	**---**	**---**	**1.7**	**---**	**---**	**ND**	**4.0 B** [k]	**0.1**	**230**	**---**	**149**	**---**	**4.8**	**---**	**---**	**0.00013 J**	**0.00058 U**	**0.00056 U**
755PHYTO26	Sep-00	19.7	7.0	1.21	166	---	0.9	5.4	ND	ND	8.6	<0.1	208	30	233	ND	6.2	---	---	ND	ND	ND
	Sep-01	18.8	7.4	1.49	156	---	0.8	4.9	ND	ND	4.0	<0.1	212	15	294	ND	5.6	---	---	0.0005 U	0.001U	0.0005 U
	Dec-02	18.2	6.0	2.21	207	---	1	3.1	ND	ND	3.9	ND	170	40	560	---	---	5.5	5 U	0.00016 J	ND	0.00011 J
	Jun-04	**19.8**	**7.4**	**1.47**	**208**	**---**	**3.7**	**5.0**	**ND**	**ND**	**3.8 B**	**ND**	**216**	**---**	**325**	**---**	**5.1**	**---**	**---**	**0.00022 J**	**0.000068 J**	**0.00013 J**
755PHYTO27	Sep-00	20.5	7.1	1.31	216	---	0.9	5.6	ND	ND	4.3	<0.1	166	35	360	ND	4.2	---	---	ND	ND	ND
(DUP) [l]	Sep-00	---	---	---	---	---	0.7	---	---	---	4.3	---	162	---	343	---	5.4	---	---	ND	ND	ND
	Sep-01	18.5	7.4	1.61	83	---	0.7	5.9	ND	ND	4.0	<0.1	166	15	340	ND	5.6	---	---	0.0005 U	0.001U	0.0005 U
(DUP)	Sep-01	---	---	---	---	---	0.7	---	---	---	5.0	---	166	---	342	---	5.5	---	---	0.0005 U	0.001U	0.0005 U
	Dec-02	17.8	5.9	1.37	177	---	0.94 J	6.3	ND	ND	4.6	ND	190	34	270	---	---	7.4	1 U	0.00022 J	ND	0.00008 J
(DUP)	Dec-02	---	---	---	---	---	1.1	---	---	---	4.6	ND	180	28.0	270	---	---	7.4	1 U	0.00017 J	ND	ND
	Jun-04	**---**	**---**	**---**	**---**	**---**	**12.0**	**---**	**ND**	**ND**	**3.5 B**	**10.0**	**213**	**55**	**152**	**---**	**5.3**	**---**	**---**	**0.00047**	**0.00022 J**	**0.0001 J**
755PHYTO28	Sep-00	18.5	7.0	0.56	166	1.03	0.7	5.4	0.1	ND	13.0	<0.1	142	30	83	ND	5.3	---	---	ND	ND	ND
	Sep-01	19.6	7.3	0.94	156	4.1	0.6	7.0	ND	ND	6.6	<0.1	136	15	179	ND	7.6	---	---	0.0005 U	0.001U	0.0005 U
	Dec-02	17.2	5.9	1.04	214	---	1.1	2.8	ND	ND	6.2	ND	300	34	170	---	---	6.0	1 U	0.00018 J	ND	0.00041 J
	Jun-04	**20.4**	**7.3**	**1.4**	**84**	**---**	**4.4**	**---**	**1.5**	**0.9**	**5.7**	**ND**	**310**	**75**	**230**	**---**	**1.4**	**---**	**---**	**0.00245**	**0.00011 J**	**0.000063 J**
755PHYTO29	Sep-00	19.6	7.1	0.79	254	---	1	5.4	---	ND	7.8	<0.1	216	30	117	ND	5.7	---	---	ND	ND	ND
(DUP)	Sep-00	-	-	-	-	---	1	---	---	---	7.9	---	210	---	114	---	7.6	---	---	ND	ND	ND
	Sep-01	18.8	7.4	1.01	140	---	0.9	6.0	ND	ND	6.5	<0.1	214	20	155	ND	4.8	---	---	0.0012	0.001U	0.0005 U
	Dec-02	18.3	6.0	1.06	226	---	0.86 J	4.3	ND	ND	4.2	ND	190	28	180	---	---	10.0	1 U	0.00019 J	ND	ND
	Jun-04	**19.0**	**7.5**	**1.2**	**278**	**---**	**1.9**	**5.2**	**ND**	**ND**	**3.6 B**	**0.3**	**200**	**60**	**163**	**---**	**8.4**	**---**	**---**	**0.00017 J**	**0.00056 U**	**0.00053 U**
755PHYTO30	Sep-00	20.1	7.3	0.67	178	---	1	4.9	ND	ND	8.5	<0.1	210	30	87	ND	4.3	---	---	ND	ND	ND
	Sep-01	19.6	7.5	0.74	-57	---	1.3	2.5	0.8	0.46	7.3	<0.1	218	15	76	0.6	7.1	---	---	0.0005 U	0.001U	0.0005 U
	Jun-04	**26.1**	**7.7**	**0.8**	**-36**	**---**	**4.5**	**8.9**	**1.0**	**1.0**	**4.9**	**ND**	**200**	**65**	**133**	**---**	**4.8**	**---**	**---**	**0.00024 J**	**0.000023 J**	**0.00046 U**
755PHYTO31	Sep-00	19.0	7.1	1.10	222	1.04	0.7	5.6	---	ND	4.1	<0.1	182	30	245	ND	7.1	---	---	ND	ND	ND
	Sep-01	20.4	7.4	1.28	134	2.4	0.8	6.4	ND	0.11	5.3	<0.1	190	15	227	ND	7.0	---	---	.00038 J	0.001U	0.0005 U
	Dec-02	19.1	6.0	0.81	112	---	1.2	4.0	ND	ND	7.1	0.1	210	36	190	---	---	6.2	1 U	0.0017	ND	ND
	Jun-04	**19.5**	**7.4**	**1.2**	**134**	**---**	**4.6**	**1.5**	**---**	**---**	**3.8 B**	**0.1**	**196**	**60**	**205**	**---**	**7.8**	**---**	**---**	**0.00168**	**0.000091 J**	**0.000024 J**
755PHYTO32	Sep-00	19.8	7.1	0.98	229	---	1.7	4.9	---	ND	14.1	<0.1	214	30	191	ND	3.3	---	---	ND	ND	ND
	Sep-01	20.2	7.1	1.48	43	---	1.9	2.0	1	ND	11.0	<0.1	188	25	300	0.4	3.3	---	---	.00038 J	0.001U	0.0005 U
(DUP)	Sep-01	---	---	---	---	---	1.9	---	---	---	10.8	---	182	---	306	---	0.1	---	---	0.0011	0.001U	0.0005 U
	Jun-04	**17.5**	**7.3**	**1.4**	**-126**	**---**	**5.2**	**8.3**	**ND**	**17.0**	**3.6 B**	**0.1**	**250**	**110**	**193**	**---**	**2.9**	**---**	**---**	**0.00238**	**0.00184**	**0.00465**
755PHYTO33	Sep-00	22.6	6.9	1.38	293	0.13	0.6	3.5	---	ND	11.7	<0.1	198	30	340	ND	7.2	---	---	ND	ND	ND
	Sep-01	21.8	7.2	1.60	123	---	1.2	3.6	ND	ND	9.1	<0.1	188	15	316	ND	6.6	---	---	0.0005 U	0.001U	0.0005 U
	Jun-04	**22.4**	**7.1**	**1.7**	**-52**	**---**	**4.2**	**0.1**	**ND**	**ND**	**12.6**	**ND**	**466**	**110**	**221**	**---**	**2.2**	**---**	**---**	**0.27**	**0.000027 J**	**0.00055 U**
755PHYTO36 [m]	Dec-02	18.9	7.0	2.76	-195	---	---	0.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	Jun-04	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**0.00017 J**	**0.000029 J**	**0.000057 J**
755PHYTO37 [m]	Dec-02	18.2	6.9	2.22	-222	---	4.7	0.0	0.6	ND	46	<0.1	160	22	240	---	---	0.92 J	5 U	0.0059	0.0038 J	0.0034 J
	Jun-04	**---**	**---**	**---**	**---**	**---**	**4.7**	**---**	**ND**	**ND**	**8.6**	**ND**	**186**	**40**	**232**	**---**	**6.4**	**---**	**---**	**0.00016 J**	**0.000041 J**	**0.000067 J**

TABLE 4.4 (Continued)
GEOCHEMISTRY LABORATORY AND FIELD DATA (2000-2004)
PHOTOSTABILIZATION DEMONSTRATION PROJECT
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

Well ID	Sample Date	Temp °C [a/]	pH SU [b/]	Conductivity mS/cm [c/]	Redox Potential mV [d/]	Dissolved Hydrogen nM [e/]	Dissolved Organic Carbon mg/L [f/]	Dissolved Oxygen mg/L	Manganese mg/L	Ferrous Iron mg/L	Sulfate mg/L	Hydrogen Sulfide mg/L	Alkalinity as $CaCO_4$ mg/L	Carbon Dioxide mg/L	Chloride mg/L	Ammonia mg/L	Nitrate/ Nitrite-N mg/L	Nitrate mg/L	Nitrite mg/L	Methane mg/L	Ethene mg/L	Ethane mg/L
755PHYTO38 [m/]	Dec-02	19.1	7.0	1.41	-122	---	4.7	4.3	---	---	---	---	---	---	---	---	---	---	---	0.0019 J	0.00093 J	0.00080 J
	Jun-04	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	0.00023 J	0.000027 J	0.00054 U
755PHYTO39 [m/]	Dec-02	18.0	7.3	1.73	-122	---	1.5	4.1	ND	ND	59	<0.1	66	14	270	---	---	1.5	1 U	0.0038 J	0.0015 J	0.0019 J
	Jun-04	19.7	7.6	0.46	64	---	5.3	0.9	ND	ND	16.5	ND	170	50	38.4	---	0.54	---	---	0.00015 J	0.000074 J	0.00053 U
755PHYTO40 [m/]	Dec-02	19.3	7.4	2.29	-159	---	5.7	4.4	0.9	0.1	39.0	<0.1	230	28	250	---	---	1.3	5 U	0.01	0.013	0.0097
	Jun-04	---	---	---	---	---	5.1	---	ND	ND	4.8 B	ND	234	65	104	---	4.4	---	---	0.0094	0.00034 J	0.00088
755PHYTO41 [m/]	Dec-02	19.6	7.3	2.03	-214	---	3.1	1.0	0.2	ND	26.0	<0.1	170	20	300	---	---	3.6	1.8	0.0067	0.0039 J	0.0038 J
	Jun-04	20.6	7.6	1.4	229	---	4.4	2.8	ND	ND	3.5 B	ND	184	60	271	---	7.8	---	---	0.00049	0.000028 J	0.000036 J
755PHYTO42	Dec-02	18.7	7.1	1.19	-86	---	1.9	0.0	ND	ND	25.0	<0.1	230	44	160	---	---	6.2	1 U	0.0024 J	ND	0.0013 J
	Jun-04	22.8	7.4	1.0	214	---	4.4	2.6	ND	ND	4.8 B	ND	254	65	109	---	7.8	---	---	0.00029 J	0.000025 J	0.000055 J
755PHYTO43 [m/]	Dec-02	20.0	7.3	3.19	-198	---	3.2	1.1	---	---	39.0	---	120	---	420	---	---	1.4	5 U	0.012	0.016	0.019
	Jun-04	23.2	8.1	1.4	232	---	3.8	9.9	---	---	6.8	---	170	---	192	---	7.8	---	---	0.00012 J	0.000027 J	0.0005 U
755PHYTO44 [m/]	Dec-02	19.3	7.7	1.52	-148	---	3.1	3.2	0.15	ND	20.0	<0.1	150	24	340	---	---	4.8	5 U	0.005	0.002 J	0.0022 J
	Jun-04	---	---	---	---	---	3.4	---	ND	ND	3.6 B	ND	168	80	297	---	7.4	---	---	0.00012 J	0.00053 U	0.0005 U
755PHYTO45 [m/]	Dec-02	20.9	7.9	1.59	-164	---	3.3	2.4	ND	ND	20.0	<0.1	240	28	250	---	---	2.0	1.8	0.0064	0.0035 J	0.0022 J
	Jun-04	---	---	---	---	---	4.4	---	ND	0.3	5.0 B	ND	305	83	225	---	4.3	---	---	0.00017 J	0.000038 J	0.000036 J
755PHYTO46 [m/]	Dec-02	21.0	7.7	0.73	-249	---	2.8	0.2	0.1	ND	21.0	<0.1	180	16	140	---	---	0.36 J	1 U	0.0063	0.006	0.0081
	Jun-04	23.5	7.2	0.9	256	---	1.4	8.9	ND	ND	4.5 B	0.1	194	50	130	---	5.5	---	---	0.0336	0.000059 J	0.000024 J
755PHYTO47	Dec-02	21.2	7.3	1.11	-124	---	0.95 J	3.4	ND	ND	9.3	<0.1	190	42	170	---	---	5.2	1 U	0.0021 J	ND	0.0015 J
	Jun-04	21.8	7.1	1.2	212	---	4.0	3.9	ND	ND	5.1	ND	220	35	244	---	4.2	---	---	0.00012 J	0.00056 U	0.00054 U
MW777x39	Nov-04	18.3	7.3	1.1	260	---	1.3	6.7	---	---	4.7 J	---	197	---	206	---	9.9	---	---	0.00033 J	0.00071 J	0.000041 J
MW778x39	Nov-04	18.6	7.2	1.3	229	---	1.7	3.1	---	---	13	---	237	---	263	---	8.3	---	---	0.00051 J	0.001	0.00014 J
MW779x39	Nov-04	20.3	7.3	1.1	219	---	1.2	5.6	---	---	7.4	---	190	---	212	---	5.9	---	---	0.00029 J	0.00094	0.000034 J
MW780x39	Nov-04	18.3	7.1	1.7	205	---	---	7.1	---	---	---	---	---	---	---	---	---	---	---	---	---	---
MW781x39	Nov-04	18.8	7.5	1.1	210	---	---	7.6	---	---	---	---	---	---	---	---	---	---	---	---	---	---

[a/] °C = degress Celsius.
[b/] SU = standard units.
[c/] mS/cm = milli Siemens per centimeter
[d/] mV = millivolts
[e/] nM = nanomoles per liter
[f/] mg/L = milligrams per liter
[g/] --- = data not collected.
[h/] ND = compound not detected.
[i/] U = compound not detected above the stated reporting limi
[j/] J = estimated value.
[k/] B = the analyte was found in an associated blank, as well as in the sampl
[l/] DUP = sample is a field duplicate for the previous sample
[m/] Well puged dry prior to sampling. Direct-reading meter measurements and field and fixed-base laboratorty results may not be representative of ambient groundwa

TABLE 4.5
TCE AND TCE METABOLITES IN PLANT TISSUE IN 2004
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

			Analytes[a/]			
Sample Location	Sample Date	Tissue Type	TCE µg/kg	TCEt µg/kg	TCAA µg/kg	DCAA µg/kg
Initial Planting Area						
R3T4[b/]	09-08-04	Root	**273**	<MDL [c/]	<MDL	<MDL
		Core (3') [d/]	**21**	<MDL	<MDL	<MDL
		Leaf (6')	<MDL	<MDL	<MDL	<MDL
		Stem (9')	**13**	<MDL	<MDL	<MDL
		Leaf (9')	**0.95**	<MDL	<MDL	<MDL
		Stem (14')	**7**	<MDL	<MDL	<MDL
		Leaf (14')	<MDL	<MDL	<MDL	<MDL
R1T4	09-08-04	Core	**19**	<MDL	<MDL	<MDL
		Leaf	<MDL	<MDL	<MDL	<MDL
Secondary Planting Area						
R7T3	09-08-04	Core	**136**	**87.14**	<MDL	<MDL
		Core (dup) [e/]	**84**	<MDL	<MDL	<MDL
		Leaf	**1.2**	<MDL	<MDL	<MDL
Background Area						
Background Tree	09-08-04	Core	<MDL	<MDL	<MDL	<MDL
		Leaf	<MDL	<MDL	<MDL	<MDL
		Leaf	<MDL	---[f/]	---	---

Note: All TCE and TCE metabolite samples were analyzed by Utah State University, Utah Water Research Laboratory.

[a/] TCE = trichloroethene; TCEt = 2,2,2-trichloroethanol; TCAA = 2,2,2-trichloroacetic acid; DCAA = dichloroacetic acid; µg/kg = micrograms per kilogram wet weight.
[b/] R3T4 = row 3, tree 4.
[c/] MDL = Analyte not detected above the method detection limit.
[d/] Sample height above ground surface is indicated in parentheses.
[e/] dup = duplicate result.
[f/] --- = not analyzed.

TABLE 4.6
HYDROGEN AND OXYGEN ISOTOPE ANALYSIS
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

		Analytes[a/]	
Location	Sample Date	δ [18] Oxygen (‰)	δ Hydrogen (‰)
Tree Sap (R1T4)[b/]	08-09-04	-5.8	-59
Tree Sap (R1T4)	08-09-04	-5.7	-58
Tree Sap (R1T4)	08-09-04	-4.2	-59
Tree Sap (R1T4)	08-09-04	-5.9	-58
Groundwater	08-09-04	-6.5	-45
Groundwater	08-09-04	-6.1	-54
Groundwater	08-09-04	-7.0	-47
Groundwater	08-09-04	-6.5	-47
Groundwater	08-09-04	-6.4	-50
Groundwater	08-09-04	-6.1	-51
Precipitation	10-12-03	-5.5	-32
Precipitation (Replicate)	10-12-03	-5.5	-32
Precipitation	09-12-02	-6.2	-74
Precipitation (Replicate)	09-12-02	-6.4	-75

Note: All isotope samples were analyzed by Utah State University, Utah Water Research Laboratory.

[a/] δ = delta; parts per thousand (per mil or ‰) relative to Vienna Standard Mean Ocean Water (SMOW).

[b/] R1T4 = row 1 tree 4.

TABLE 4.7

PHYTOVOLATILIZATION RESULTS [a]

PHYTOSTABILIZATION DEMONSTRATION

BUILDING 755

TRAVIS AIR FORCE BASE, CALIFORNIA

Sample Location	2004 Sample Date	Sample Time	2004 Transpiration Stream - Concentration of TCE in Aqueous Phase[b] (µg/L) [d]	Mass Water Collected (g)	Groundwater Conc. (µg/L)
R1T4 [e] Initial Planting	07-09-04 9/7/2004 (Dup)	1422 1514	4,350 10,970	0.06 0.08	21,600 21,600
R3T16 Initial Planting	07-09-04	1615	45,600	0.10	2,950
R7T3 Secondary Planting	07-09-04	1711	2,999	0.13	12,700
R2T6 Initial Planting	08-09-04	931	187,070	0.09	18,000
R1T27 Initial Planting	08-09-04 9/8/2004 (Dup)	1006 1116	213,600 252,200	0.14 0.08	3,500
R3T4 Initial Planting	08-09-04 9/8/2004 (Dup)	1215 1251	112,800 239,600	0.07 0.04	14,300

[a] Samples collected and analyzed by Utah State University, Utah Water Research Laboratory.

[b] Concentration are artifically high due to high temperatures (>100˚F) and low humidity (15-25%).

[c] Estimated evapotranspiration rate.

[d] TCE = trichloroethene; µg/L - micrograms per liter.

[e] R1T4 = row 1 tree 4.

TABLE 5.1
ESTIMATED WATER USE PER MONTH FOR INITIAL PLANTING AREA
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

Date	PET (mm) [a/]	K_L [b/]	LAI [c/]	Area (m^2) [d/]	Q_t for Planting Area (liters) [e/]	Q_t for Planting Area (mm)[e/]	Average Q_t for Planting Area (liters/day) [f/]	Average Q_t for Planting Area (mm/day) [f/]	Total Q_t per Tree (liters) [g/]	Total Q_t per Tree (mm)[g/]	Average Q_t per Tree (liters/day)	Average Q_t per Tree (mm/day)
April 2000	52.63	0.14	0.75	232	1,282	5.5	99	0.43	13	0.06	1.0	0.004
May 2000	152.20	0.14	0.75	232	3,707	16.0	120	0.52	37	0.16	1.2	0.01
June 2000	193.95	0.14	0.75	232	4,725	20.4	157	0.68	47	0.20	1.6	0.01
July 2000	178.34	0.14	0.75	232	4,344	18.7	145	0.62	43	0.19	1.4	0.01
August 2000	102.33	0.14	0.75	232	2,493	10.7	125	0.54	25	0.11	1.2	0.01
September 2000	130.63	0.14	0.75	232	3,182	13.7	114	0.49	32	0.14	1.1	0.005
October 2000	72.31	0.14	0.75	232	1,762	7.6	61	0.26	18	0.08	0.6	0.003
November 2000	27.43	0.14	0.75	232	668	2.9	37	0.16	7	0.03	0.4	0.002
December 2000	13.39	0.14	0.75	232	326	1.4	22	0.09	3	0.01	0.2	0.001
Total/Average 2000	**923**				**22,489**	**97**	**98**	**0.4**	**225**	**1.0**	**1.0**	**0.004**
January 2001	37.31	0.17	1.5	446	4,243	9.5	137	0.31	42	0.10	1.4	0.003
February 2001	45.97	0.17	1.5	446	5,228	11.7	187	0.42	52	0.12	1.9	0.004
March 2001	83.72	0.17	1.5	446	9,521	21.3	307	0.69	95	0.21	3.1	0.01
April 2001	103.81	0.17	1.5	446	11,806	26.5	394	0.88	118	0.26	3.9	0.01
May 2001	139.24	0.17	1.5	446	15,836	35.5	587	1.32	158	0.36	5.9	0.01
June 2001	129.62	0.17	1.5	446	14,741	33.1	590	1.32	147	0.33	5.9	0.01
July 2001	152.58	0.17	1.5	446	17,352	38.9	560	1.26	174	0.39	5.6	0.01
August 2001	139.67	0.17	1.5	446	15,885	35.6	512	1.15	159	0.36	5.1	0.01
September 2001	102.08	0.17	1.5	446	11,610	26.0	387	0.87	116	0.26	3.9	0.01
October 2001	75.29	0.17	1.5	446	8,562	19.2	276	0.62	86	0.19	2.8	0.01
November 2001	37.39	0.17	1.5	446	4,252	9.5	142	0.32	43	0.10	1.4	0.003
December 2001	18.80	0.17	1.5	446	2,138	4.8	79	0.18	21	0.05	0.8	0.002
Total/Average 2001	**1,065**				**121,173**	**272**	**346**	**0.8**	**1,212**	**2.7**	**3.5**	**0.008**
January 2002	28.52	0.2	1.5	929	7,949	8.6	256	0.28	79	0.09	2.6	0.003
February 2002	47.85	0.2	1.5	929	13,336	14.4	1111	1.20	311	0.14	11.1	0.01
March 2002	75.59	0.2	1.5	929	21,066	22.7	680	0.73	211	0.23	6.8	0.01
April 2002	94.64	0.2	1.5	929	26,376	28.4	879	0.95	9	0.28	8.8	0.01
May 2002	146.96	0.2	1.5	929	40,958	44.1	1321	1.42	410	0.44	13.2	0.01
June 2002	190.68	0.2	1.5	929	53,140	57.2	1771	1.91	531	0.57	17.7	0.02
July 2002	198.04	0.2	1.5	929	55,193	59.4	1780	1.92	552	0.59	17.8	0.02
August 2002	169.90	0.2	1.5	929	47,350	51.0	1527	1.64	473	0.51	15.3	0.02
September 2002	148.16	0.2	1.5	929	41,291	44.4	1376	1.48	413	0.44	13.8	0.01
October 2002	93.80	0.2	1.5	929	26,142	28.1	901	0.97	261	0.28	9.0	0.01
November 2002	46.38	0.2	1.5	929	12,926	13.9	431	0.46	129	0.14	4.3	0.005
December 2002	28.82	0.2	1.5	929	8,032	8.6	259	0.28	80	0.09	2.6	0.003
Total/Average 2002	**1,269**				**353,759**	**381**	**1,025**	**1.1**	**3,461**	**3.8**	**10.2**	**0.01**

travis-tbls-2004.xls

TABLE 5.1 (Continued)
ESTIMATED WATER USE PER MONTH FOR INITIAL PLANTING AREA
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

Date	PET (mm) [a/]	K_L [b/]	LAI [c/]	Area (m^2) [d/]	Q_t for Planting Area (liters) [e/]	Q_t for Planting Area (mm) [e/]	Average Q_t for Planting Area (liters/day) [f/]	Average Q_t for Planting Area (mm/day) [f/]	Total Q_t per Tree (liters) [g/]	Total Q_t per Tree (mm) [g/]	Average Q_t per Tree (liters/day)	Average Q_t per Tree (mm/day)
January 2003	25.76	0.22	1.7	1000	9,632	9.6	497	0.50	154	0.10	5.0	0.005
February 2003	51.71	0.22	1.7	1000	19,341	19.3	1105	1.11	309	0.19	11.1	0.01
March 2003	84.25	0.22	1.7	1000	31,509	31.5	1016	1.02	315	0.32	10.2	0.01
April 2003	78.99	0.22	1.7	1000	29,543	29.5	985	0.98	295	0.30	9.8	0.01
May 2003	138.91	0.22	1.7	1000	51,952	52.0	1676	1.68	520	0.52	16.8	0.02
June 2003	173.33	0.22	1.7	1000	64,823	64.8	2161	2.16	648	0.65	21.6	0.02
July 2003	203.20	0.22	1.7	1000	75,995	76.0	2451	2.45	760	0.76	24.5	0.02
August 2003	174.45	0.22	1.7	1000	65,241	65.2	2105	2.10	652	0.65	21.0	0.02
September 2003	144.75	0.22	1.7	1000	54,137	54.1	1805	1.80	541	0.54	18.0	0.02
October 2003	109.50	0.22	1.7	1000	40,952	41.0	1321	1.32	410	0.41	13.2	0.01
November 2003	42.34	0.22	1.7	1000	15,835	15.8	528	0.53	158	0.16	5.3	0.01
December 2003	22.20	0.22	1.7	1000	8,302	8.3	268	0.27	83	0.08	2.7	0.003
Total/Average 2003	**1,249**				**467,263**	**467**	**1,326**	**1.3**	**4,846**	**4.7**	**13**	**0.01**
January 2004	24.08	0.25	2	1135	13,665	12.0	441	0.39	137	0.12	4.4	0.00
February 2004	39.75	0.25	2	1135	22,558	19.9	2179	1.92	632	0.20	21.8	0.02
March 2004	100.23	0.25	2	1135	56,878	50.1	1835	1.62	569	0.50	18.3	0.02
April 2004	128.50	0.25	2	1135	72,921	64.2	2431	2.14	729	0.64	24.3	0.02
May 2004	160.73	0.25	2	1135	91,212	80.4	2942	2.59	912	0.80	29.4	0.03
June 2004	180.44	0.25	2	1135	102,398	90.2	3503	3.09	1051	0.90	63.3	0.06
July 2004	184.40	0.25	2	1135	104,646	92.2	3376	2.97	1046	0.92	33.8	0.03
August 2004	171.88	0.25	2	1135	97,540	85.9	3146	2.77	975	0.86	31.5	0.03
September 2004	152.88	0.25	2	1135	86,758	76.4	2892	2.55	868	0.76	28.9	0.03
October 2004	86.97	0.25	2	1135	49,354	43.5	1592	1.40	494	0.43	15.9	0.01
November 2004	42.55	0.25	2	1135	24,144	21.3	805	0.71	241	0.21	8.0	0.01
December 2004	24.28	0.25	2	1135	13,780	12.1	445	0.39	138	0.12	4.4	0.00
Total/Average 2004	**1,297**				**735,854**	**648**	**2,132**	**1.9**	**7,792**	**6.5**	**24**	**0.02**

[a/] PET = potential evapotranspiration measured by the weather station; mm = millimeter

[b/] K_L = landscape coefficient (dimensionless) from California Department of Water Resources (2000) for eucalyptus trees.

[c/] LAI = leaf area index square meter leaf per square meter ground area covered by canopy) from Ferro *et al*. (2001).

[d/] Estimated canopy area for initial 100 trees; m^2 = square meters.

[e/] mm = millimeter. Water use by a tree stand per time (Q), calculated by the following formula (modified Ferro *et al*., 2001):

$$Q_t = PET * K_L * LAI$$

[f/] mm/day = millimeters per day

[g/] To calculate volume per tree, the volume for the plant stand was divided by the number of trees in the planting area (100 trees).

TABLE 5.2
ESTIMATED WATER USE PER MONTH FOR SECONDARY PLANTING AREA
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

Date	PET (mm) [a/]	K_L [b/]	LAI [c/]	Area (m^2) [d/]	Q_t for Planting Area (liters) [e/]	Q_t for Planting Area (mm) [e/]	Average Q_t for Planting Area (liters/day) [f/]	Average Q_t for Planting Area (mm/day) [f/]	Total Q_t per Tree (liters) [g/]	Total Q_t per Tree (mm) [g/]	Average Q_t per Tree (liters/day)	Average Q_t per Tree (mm/day)
January 2001	37.31	0.14	0.5	317	828	2.6	27	0.1	2	0.01	0.1	0.0002
February 2001	45.97	0.14	0.5	317	1,020	3.2	36	0.1	3	0.01	0.1	0.0003
March 2001	83.72	0.14	0.5	317	1,858	5.9	60	0.2	5	0.02	0.2	0.0005
April 2001	103.81	0.14	0.5	317	2,303	7.3	77	0.2	6	0.02	0.2	0.0006
May 2001	139.24	0.14	0.5	317	3,090	9.7	114	0.4	8	0.03	0.3	0.0009
June 2001	129.62	0.14	0.5	317	2,876	9.1	115	0.4	8	0.02	0.3	0.0010
July 2001	152.58	0.14	0.5	317	3,386	10.7	109	0.3	9	0.03	0.3	0.0009
August 2001	139.67	0.14	0.5	317	3,099	9.8	100	0.3	8	0.03	0.3	0.0008
September 2001	102.08	0.14	0.5	317	2,265	7.1	76	0.2	6	0.02	0.2	0.0006
October 2001	75.29	0.14	0.5	317	1,671	5.3	54	0.2	4	0.01	0.1	0.0004
November 2001	37.39	0.14	0.5	317	830	2.6	28	0.1	2	0.01	0.1	0.0002
December 2001	18.80	0.14	0.5	317	417	1.3	15	0.05	1	0.003	0.04	0.0001
Total/Average 2001	**1,065**				**23,642**	**75**	**68**	**0.2**	**62**	**0.2**	**0.2**	**0.001**
January 2002	28.52	0.16	0.6	551	1,509	2.7	49	0.1	4	0.01	0.1	0.0002
February 2002	47.85	0.16	0.6	551	2,531	4.6	90	0.2	7	0.01	0.2	0.0004
March 2002	75.59	0.16	0.6	551	3,998	7.3	129	0.2	11	0.02	0.3	0.001
April 2002	94.64	0.16	0.6	551	5,006	9.1	167	0.3	0.4	0.02	0.4	0.0008
May 2002	146.96	0.16	0.6	551	7,774	14.1	251	0.5	21	0.04	0.7	0.001
June 2002	190.68	0.16	0.6	551	10,086	18.3	336	0.6	27	0.05	0.9	0.002
July 2002	198.04	0.16	0.6	551	10,475	19.0	338	0.6	28	0.05	0.9	0.002
August 2002	169.90	0.16	0.6	551	8,987	16.3	290	0.5	24	0.04	0.8	0.001
September 2002	148.16	0.16	0.6	551	7,837	14.2	261	0.5	21	0.04	0.7	0.001
October 2002	93.80	0.16	0.6	551	4,962	9.0	171	0.3	13	0.02	0.5	0.0008
November 2002	46.38	0.16	0.6	551	2,453	4.5	82	0.1	7	0.01	0.2	0.0004
December 2002	28.82	0.16	0.6	551	1,524	2.8	49	0.1	4	0.01	0.1	0.0002
Total/Average 2002	**1,269**				**67,142**	**122**	**184**	**0.3**	**168**	**0.3**	**0.5**	**0.001**

TABLE 5.2 (Continued)
ESTIMATED WATER USE PER MONTH FOR SECONDARY PLANTING AREA

PHYTOSTABILIZATION DEMONSTRATION

BUILDING 755

TRAVIS AIR FORCE BASE, CALIFORNIA

Date	PET (mm) [a]	K_L [b]	LAI [c]	Area (m^2) [d]	Q_t for Planting Area (liters) [e]	Q_t for Planting Area (mm) [e]	Average Q_t for Planting Area (liters/day) [f]	Average Q_t for Planting Area (mm/day) [f]	Total Q_t per Tree (liters) [g]	Total Q_t per Tree (mm) [g]	Average Q_t per Tree (liters/day)	Average Q_t per Tree (mm/day)
January 2003	25.76	0.18	0.75	804	2,795	3.5	90	0.1	8	0.01	0.3	0.0003
February 2003	51.71	0.18	0.75	804	5,613	7.0	200	0.2	16	0.02	0.6	0.001
March 2003	84.25	0.18	0.75	804	9,144	11.4	295	0.4	26	0.03	0.9	0.001
April 2003	78.99	0.18	0.75	804	8,574	10.7	286	0.4	25	0.03	0.8	0.001
May 2003	138.91	0.18	0.75	804	15,077	18.8	486	0.6	44	0.05	1.4	0.002
June 2003	173.33	0.18	0.75	804	18,813	23.4	627	0.8	54	0.07	1.8	0.002
July 2003	203.20	0.18	0.75	804	22,055	27.4	711	0.9	64	0.08	2.1	0.003
August 2003	174.45	0.18	0.75	804	18,934	23.5	611	0.8	55	0.07	1.8	0.002
September 2003	144.75	0.18	0.75	804	15,711	19.5	524	0.7	45	0.06	1.5	0.002
October 2003	109.50	0.18	0.75	804	11,885	14.8	383	0.5	34	0.04	1.1	0.001
November 2003	42.34	0.18	0.75	804	4,596	5.7	153	0.2	13	0.02	0.4	0.001
December 2003	22.20	0.18	0.75	804	2,409	3.0	78	0.1	7	0.01	0.2	0.0003
Total/Average 2003	**1,249**				**135,606**	**169**	**370**	**0.5**	**392**	**0.5**	**1.1**	**0.001**
January 2004	24.08	0.2	1.0	1144	5,509	4.8	178	0.2	16	0.01	0.5	0.0005
February 2004	39.75	0.2	1.0	1144	9,095	7.9	314	0.3	27	0.02	0.9	0.001
March 2004	100.23	0.2	1.0	1144	22,932	20.0	740	0.6	67	0.06	2.2	0.002
April 2004	128.50	0.2	1.0	1144	29,400	25.7	980	0.9	86	0.08	2.9	0.003
May 2004	160.73	0.2	1.0	1144	36,774	32.1	1186	1.0	108	0.09	3.5	0.003
June 2004	180.44	0.2	1.0	1144	41,284	36.1	1412	1.2	124	0.11	7.5	0.01
July 2004	184.40	0.2	1.0	1144	42,190	36.9	1361	1.2	123	0.11	4.0	0.003
August 2004	171.88	0.2	1.0	1144	39,325	34.4	1269	1.1	115	0.10	3.7	0.003
September 2004	152.88	0.2	1.0	1144	34,979	30.6	1166	1.0	102	0.09	3.4	0.003
October 2004	86.97	0.2	1.0	1144	19,898	17.4	642	0.6	58	0.05	1.9	0.002
November 2004	42.55	0.2	1.0	1144	9,734	8.5	324	0.3	28	0.02	0.9	0.001
December 2004	24.28	0.2	1.0	1144	5,556	4.9	179	0.2	16	0.01	0.5	0.0005
Total/Average 2004	**1,297**				**296,676**	**259**	**813**	**0.7**	**871**	**0.8**	**2.7**	**0.002**

[a] PET = potential evapotranspiration measured by the weather station; mm = millimeter

[b] K_L = landscape coefficient (dimensionless) from California Department of Water Resources (2000) for eucalyptus trees.

[c] LAI = leaf area index square meter leaf per square meter ground area covered by canopy) from Ferro *et al*. (2001).

[d] Estimated canopy area for secondary trees; m^2 = square meters.

[e] mm = millimeter. Water use by a tree stand per time (Q), calculated by the following formula (modified Ferro *et al*., 2001):

$$Q_t = PET * K_L * LAI$$

[f] mm/day = millimeters per day

[g] To calculate volume per tree, the volume for the plant stand was divided by the number of trees in the planting area (380 trees in 2001, 371 trees in 2002, 346 trees in 2003, and 342 trees in 2004).

travis-tbls-2004.xls

TABLE 5.3

WATER BALANCE FROM THE SECOND TO SIXTH GROWING SEASONS FOR THE INITIAL PLANTING AREA

PHYTOSTABILIZATION DEMONSTRATION

BUILDING 755

TRAVIS AIR FORCE BASE, CALIFORNIA

Date	Qt for Plant Stand (mm) [a/]	Total Precipitation (mm) [b/]	Plant Stand Area (m^2) [c/]	Irrigation Water Applied (mm) [d/]	Water Balance (mm) [e/]	Water Balance (liters)
April 2000	5	0.3	232	449	444	103,116
May 2000	16	21	232	133	138	32,045
June 2000	20	5	232	133	118	27,345
July 2000	19	1	232	1,028	1009	234,191
August 2000	11	0	232	352	341	79,048
September 2000	14	2	232	539	527	122,260
October 2000	8	47	232	270	309	71,759
November 2000	3	18	232	192	207	47,995
December 2000	1	11	232	80	90	20,929
Total	**97**	**105**		**3,176**	**3,184**	**738,689**
January 2001	9	56	446	0	47	20,795
February 2001	12	118	446	0	106	47,437
March 2001	21	38	446	0	17	7,740
April 2001	27	23	446	0	-4	-1,960
May 2001	35	0	446	61	26	11,726
June 2001	33	3	446	205	175	78,115
July 2001	39	0	446	161	122	54,395
August 2001	36	0	446	167	131	58,308
September 2001	26	3	446	191	168	74,815
October 2001	19	7	446	143	131	58,366
November 2001	10	104	446	78	173	77,019
December 2001	5	116	446	58	169	75,392
Total	**272**	**352**		**1,006**	**1260**	**562,148**
January 2002	9	55	929	0	46	42,370
February 2002	14	19	929	0	5	4,691
March 2002	23	41	929	0	18	16,623
April 2002	28	1	929	0	-27	-25,067
May 2002	44	37	929	0	-7	-6,189
June 2002	57	0	929	0	-57	-52,951
July 2002	60	0	929	0	-60	-55,738
August 2002	51	0	929	0	-51	-47,378
September 2002	44	0	929	0	-44	-40,875
October 2002	28	0	929	0	-28	-26,011
November 2002	14	0	929	0	-14	-13,006
December 2002	9	15	929	0	6	5,537
Total	**381**	**168**		**0**	**-213**	**-197,994**

TABLE 5.3 (Continued)
WATER BALANCE FROM THE SECOND TO SIXTH GROWING SEASONS FOR THE INITIAL PLANTING AREA
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

Date	Qt for Plant Stand (mm) [a]	Total Precipitation (mm) [b]	Plant Stand Area (m^2) [c]	Irrigation Water Applied (mm) [d]	Water Balance (mm) [e]	Water Balance (liters)
January 2003	10	0.3	1,000	0	-10	-9,750
February 2003	19	46	1,000	0	27	26,719
March 2003	31	30	1,000	0	-1	-770
April 2003	30	47	1,000	0	17	16,989
May 2003	52	14	1,000	0	-38	-37,519
June 2003	65	0	1,000	0	-65	-64,998
July 2003	76	1	1,000	0	-75	-75,488
August 2003	65	7	1,000	0	-58	-57,888
September 2003	54	0	1,000	0	-54	-53,998
October 2003	41	0	1,000	0	-41	-40,999
November 2003	16	28	1,000	0	12	12,450
December 2003	8	120	1,000	0	112	111,627
Total	**467**	**293**		**0**	**-174**	**-173,625**
January 2004	12	51	1,135	0	39	44,613
February 2004	20	145	1,135	0	125	141,621
March 2004	50	18	1,135	0	-32	-35,992
April 2004	64	1	1,135	0	-63	-72,061
May 2004	80	2	1,135	0	-78	-88,779
June 2004	90	0	1,135	0	-90	-102,147
July 2004	92	0	1,135	0	-92	-104,417
August 2004	86	0	1,135	0	-86	-97,607
September 2004	76	8	1,135	0	-68	-76,744
October 2004	43	56	1,135	0	13	14,907
November 2004	21	68	1,135	0	47	53,713
December 2004	12	123	1,135	0	111	126,197
Total	**646**	**473**		**0**	**-173**	**-196,696**

[a] Qt = amount of water per time for the initial 100 trees (see Table 5.1).

[b] Precipitation measured by weather station; mm = millimeters.

[c] Estimated canopy area for initial 100 trees; m^2 = square meters.

[d] Amount of irrigation water estimated by taking the total amount of water applied to the initial planting area (0.2 hectare) and dividing by the entire planting area (0.91 hectares) to get a percentage (22 percent) of water use for the 100 trees.

[e] Water balance was calculated by adding the total precipitation and irrigation water together and subtracting the sum from the Qt for the plant stand to determine the potential water deficit (negative number) versus excess water (positive number) added to the plant stand.

TABLE 5.4
WATER BALANCE FROM THE SECOND TO FOURTH GROWING SEASONS FOR THE SECONDARY PLANTING AREA
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

Date	Qt for Plant Stand (mm) [a/]	Total Precipitation (mm) [b/]	Plant Stand Area (m^2) [c/]	Irrigation Water Applied (mm) [d/]	Water Balance (mm) [e/]	Water Balance (liters)
January 2001	3	56	317	0	53	16,682
February 2001	3	118	317	0	115	36,569
March 2001	6	38	317	0	32	10,256
April 2001	7	23	317	0	16	4,947
May 2001	10	0	317	306	296	93,747
June 2001	9	3	317	1,024	1018	322,749
July 2001	11	0	317	803	792	251,038
August 2001	10	0	317	832	822	260,483
September 2001	7	3	317	953	948	300,613
October 2001	5	7	317	711	713	226,081
November 2001	3	104	317	391	492	155,949
December 2001	1	116	317	81	197	62,298
Total	**75**	**469**		**5,100**	**5494**	**1,741,412**
January 2002	3	55	551	0	52	28,436
February 2002	5	19	551	0	14	7,741
March 2002	7	41	551	0	34	18,675
April 2002	9	1	551	0	-8	-4,399
May 2002	14	37	551	0	23	12,859
June 2002	18	0	551	0	-18	-9,918
July 2002	19	0	551	0	-19	-10,469
August 2002	16	0	551	0	-16	-8,816
September 2002	14	0	551	0	-14	-7,714
October 2002	9	0	551	370	361	199,138
November 2002	4	0	551	741	737	405,991
December 2002	3	15	551	370	382	210,687
Total	**121**	**168**		**1,482**	**1,529**	**842,213**

TABLE 5.4 (Continued)
WATER BALANCE FROM THE SECOND TO FOURTH GROWING SEASONS FOR THE SECONDARY PLANTING AREA
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

Date	Qt for Plant Stand (mm) [a/]	Total Precipitation (mm) [b/]	Plant Stand Area (m^2) [c/]	Irrigation Water Applied (mm) [d/]	Water Balance (mm) [e/]	Water Balance (liters)
January 2003	3	0.3	804	0	-3	-2,211
February 2003	7	46	804	0	39	31,130
March 2003	11	30	804	0	19	15,460
April 2003	11	47	804	0	36	28,935
May 2003	19	14	804	0	-5	-3,634
June 2003	23	0	804	0	-23	-18,491
July 2003	27	0.5	804	0	-26	-21,297
August 2003	24	7	804	0	-17	-13,579
September 2003	20	0	804	0	-20	-16,080
October 2003	15	0	804	0	-15	-12,060
November 2003	6	28	804	0	22	18,049
December 2003	3	120	804	0	117	93,768
Total	**169**	**293**		**0**	**124**	**99,990**
January 2004	5	51	1092	0	46	50,567
February 2004	8	145	1092	0	137	149,359
March 2004	20	18	1092	0	-2	-1,869
April 2004	26	0.5	1092	0	-25	-27,836
May 2004	32	2	1092	0	-30	-33,001
June 2004	36	0	1092	0	-36	-39,311
July 2004	37	0	1092	0	-37	-40,403
August 2004	34	0	1092	0	-34	-37,127
September 2004	31	8	1092	0	-23	-24,698
October 2004	17	56	1092	0	39	42,733
November 2004	8	68	1092	0	60	65,874
December 2004	5	123	1092	0	118	129,060
Total	**259**	**473**		**0**	**214**	**233,347**

[a/] Qt = amount of water per time for the secondary trees (see Table 5.2).

[b/] Precipitation measured by weather station; mm = millimeters.

[c/] Estimated canopy area for secondary trees; m^2 = square meters.

[d/] Amount of irrigation water estimated by taking the total amount of water applied to the initial planting area (0.71 hectare) and dividing by the entire planting area (0.91 hectares) to get a percentage (78 percent) of water use for the secondary trees.

[e/] Water balance was calculated by adding the total precipitation and irrigation water together and subtracting the sum from the Qt for the plant stand to determine the potential water deficit (negative number) versus excess water (positive number) added to the plant stand.

APPENDIX A

DATA ACQUISITION SYSTEM CALIBRATION REPORT

MEASURETEK, Inc.
P.O. Box 1717
Corvallis, Oregon 97339
(541) 757-8564 · Fax: 753-5754
www.measuretek.com

Travis AFB
Weather Station
Calibration Summary

Date: 2/5/2004

Time: 9:00 A.M.

Report By: Michael Louie

Station Operation By: Parsons Engineering Science
Amber Brenzikofer

Location: Travis Air Force Base, CA

Overall Summary: The MeasureTek MonitorX weather station was in good shape.

Historical data looked good.

Relative humidity sensor was reading 15% high. RH chip was replaced and the readings were corrected to within specifications.

Solar radiation initially reading 3% low. Sensor was cleaned, and now reads within 1%.

Air temperature sensor is OK.

Raingage was reading 14% low. Raingage was recalibrated to within 1%. The raingage screen was missing. A new screen was sent via FedEx for replacement by on-site personnel.

Wind speed anemometer is OK.

Desiccant pack was replaced. Station, solar panel, and sensors were thoroughly cleaned. The solar panel was found on the ground leaning against the field stand. A solar panel mount was attached to the field stand to raise the panel off the ground and ensure proper orientation. To address a lingering problem, foam installation was installed around cables running from the enclosure into the ground, hopefully providing some protection against future string trimmer damage.

Site Conditions: Sunny, clear, light breeze.

Station Description: MeasureTek MonitorX Weather Station, S/N 1516. Monitoring Air Temperature, Relative Humidity, Solar Radiation, Wind Speed, and Rainfall. Communication via "satellite" cable to main MonitorX station.

Microprocessor/Controller: CR510 Micrologger, Campbell Scientific, S/N 3311.

Power Supply: 12V lead acid automobile battery, being trickle charged with a 20-watt solar panel and Sunsaver-6 voltage regulator. Voltage measured at 14.5 V with solar charging, 13.9 V with no charging, therefore battery is in good condition. About ½ gallon of distilled water was added to the battery cells.

Time/Date: At 9:34 AM PST, station was at 9:30 AM PST. Year 2004, February 5. Station time adjusted. Year, day and time OK. Weather station should remain on PST year-around (no daylight savings adjustment).

****

Air Temperature: Vaisala 50Y Temp and RH Probe, S/N V1420014.
Reference: 107 Calibration Probe, No S/N

Time	Station	Reference
9:55 AM	51.8F	51.7F

Comments: Radiation shield was removed and thoroughly cleaned, including removal of the spider nest inside. Field check OK.

****

Rainfall: Texas Electronics TE-525 Tipping Bucket Raingage, S/N 25182-1199.
Reference: Measurement of volume, graduated cylinder.

Time	Station	Reference	Notes
10:05 AM	0.86	0.98	Original Calibration
11:25 AM	0.94	0.98	Recalibration #1
11:55 AM	0.98	0.98	Recalibration #2

Comments: Screen was missing upon arrival. Funnel was completely clogged with dirt and debris. Tipping bucket was dusty, but not clogged with debris. Gage was thoroughly cleaned. Initial calibration was 14% low. Recalibrated to within 1%. A replacement screen was sent via FedEx for installation by on-site personnel.

****

Relative Humidity: Vaisala 50Y Temp and RH Probe, S/N V1420014
Reference: Sperry DP-I22 Digital Psychrometer S/N 9020959

Time	Station	Reference	Notes
11:10 AM	63%	48%	Original humidity chip
11:30 AM	56%	52%	New humidity chip

Comments: Radiation shield was removed and thoroughly cleaned, including removal of the spider nest inside. The dust filter inside the sensor was cleaned. Humidity was initially reading 14% high. New chip was installed, and humidity reading within 4%. Calibration now within specifications.

****

Wind Speed: RM Young 03001 Wind Sentry Anemometer.
Reference: RM Young Model 18810 Calibrating Unit, no S/N.

Comments: Top bearing rusty. Both top and bottom bearings turned rough. Top and bottom bearings replaced.

****

Solar Radiation: LI200X Pyranometer, S/N PY35120.
Reference: LI200X PY41804

Time	Station	Reference	Notes
10:00 AM	0.420	0.432	Before Cleaning
10:05 AM	0.442	0.443	After Cleaning
10:07 AM	0.002	0	covered

Comments: Sensor initially reading 3% low. After cleaning, sensor reading within 1%. Calibration OK.

****

Historical Data Review: Reviewed historical data from 1/1/2004 to present (2/2/2004).

Raingage – OK.
Air Temperature – OK, consistent.
Wind Speed – OK
Solar Radiation – OK, tracks well with events.
Humidity – OK, Tracks rain, solar events.

MEASURETEK, Inc.

P.O. Box 1717
Corvallis, Oregon 97339

(541) 757-8564 · Fax: 753-5754
www.measuretek.com

Travis AFB
Main Station
Calibration Summary

Date: 2/5/2002

Time: 2:00 P.M.

Report By: Michael Louie

Station Operation By: Parsons Engineering Science
Amber Brenzikofer

Location: Travis Air Force Base, CA

Overall Summary: The MeasureTek MonitorX station was in fair shape.

Historical data looked OK. The second water content reflectometer has been reading 100% for some time. The first pressure transducer was reading unusually low.

Both pressure transducers were cleaned and repositioned to about 12 inches off the well bottom. The calibration offset on the first transducer was found to be off. It was corrected and the sensor now reads accurately. Dessicant packs within the pressure transducer junction boxes were replaced.

Soil water content and soil moisture sensors were working well, and appeared responsive. The second water content reflectometer may have a damaged buried cable, as it has been reading 100% for some time.

The sap flow sensors were not in use. The connector for sap flow sensor #1 had suffered minor damage, and was repaired in the field. The connector and cable for sap flow sensor #2 had been irreparably damaged by landscape equipment. A new sap flow connector #2 was installed, and a new cable mailed to Parson's Denver office. The new sap flow connector #2 and cable is identical to the cables used at Fairchild AFB, Ellsworth AFB, Hill AFB, and Vandenberg AFB. The existing sap flow connector #1 is specific to Travis AFB, and requires the sap flow cable originally supplied with the station. If this sap flow cable ever requires replacement, it will be upgraded to the "universal" connector used at the other stations.

Station enclosures, solar panel, and sensors were thoroughly cleaned. Desiccant packs within the enclosures were replaced. To address a lingering problem, foam installation was installed around cables running from the enclosure into the ground, hopefully providing some protection against future string trimmer damage.

Site Conditions: Sunny, clear, light breeze.

Station Description: MeasureTek MonitorX Station, S/N 1515. Monitoring (2) Pressure Transducers (water level), (4) Water Content Reflectometers, (12) Watermark Soil Moisture Sensors, (2) Dynagage Sap Flow Gages, and (1) Soil Temperature. Communication via COM200 modem and Motorola cellular phone.

Microprocessor/Controller: CR10X Micrologger, Campbell Scientific, S/N 20635.

Power Supply: 12V lead acid automobile battery, being trickle charged with a 30-watt solar panel and Sunsaver-6 voltage regulator. Voltage measured at 13.5 V with solar charging, 13.9 V with no charging, therefore battery is in good condition. About ¼ gallon of distilled water was added to the battery cells.

Time/Date: At 2:26 PM PST, station was at 2:26 PM PST. Year 2004, February 5. Year, day and time OK. Station should remain on PST year-around (no daylight savings adjustment).

****

Water Level: Druck Model PDCR 1830 pressure transducers.

Installation Depth #1	**Installation Depth #2**
26.0 ft	24.0 ft

Comments: Sensors were removed, cleaned thoroughly with water, and repositioned up off the bottom of the well at the depths indicated above. The calibration offset for sensor #1 was adjusted to 7.5019. The calibration offset for sensor #2 was adjusted to 0.18872. Both sensors now read accurately. Desiccant packs were replaced in the junction boxes.

****

Soil Temperature: MeasureTek Soil Temperature Probe.

Comments: Historical data showed soil temperature probe producing consistent results. No evidence of the erratic readings that were correct in 2002 were observed.

****

Soil Water Content: Campbell Scientific 615 Water Content Reflectometers.

Comments: Historical data review shows probes 1, 3, and 4 responding well. Probe #2 has been reading 100% for some time. The buried cable to probe #2 may have been damaged.

****

Soil Water Potential: Irrometer Watermark Soil Moisture Sensors

Comments: Historical data review showed all 12 probes responding well, most recently to heavy rains on February 2^{nd}-3^{rd}.

****

Sap Flow: Dynagage Sap Flow Gages (various models).

Comments: The sap flow sensors were not in use. The connector for sap flow sensor #1 had suffered minor damage, and was repaired in the field. The connector and cable for sap flow sensor #2 had been irreparably damaged by landscape equipment. A new sap flow connector #2 was installed, and a new cable mailed to Parson's Denver office. The new sap flow connector #2 and cable is identical to the cables used at Fairchild AFB, Ellsworth AFB, Hill AFB, and Vandenberg AFB. The existing sap flow connector #1 is specific to Travis AFB, and requires the sap flow cable originally supplied with the station. If this sap flow cable ever requires replacement, it will be upgraded to the "universal" connector used at the other stations.

The remote voltage regulator was tested at various voltages, and continues to operate properly.

APPENDIX B

AUTOMATED MONITORING SYSTEM RESULTS

FIGURE B.1
MAXIMUM AND MINIMUM DAILY AIR TEMPERATURES IN 2004
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

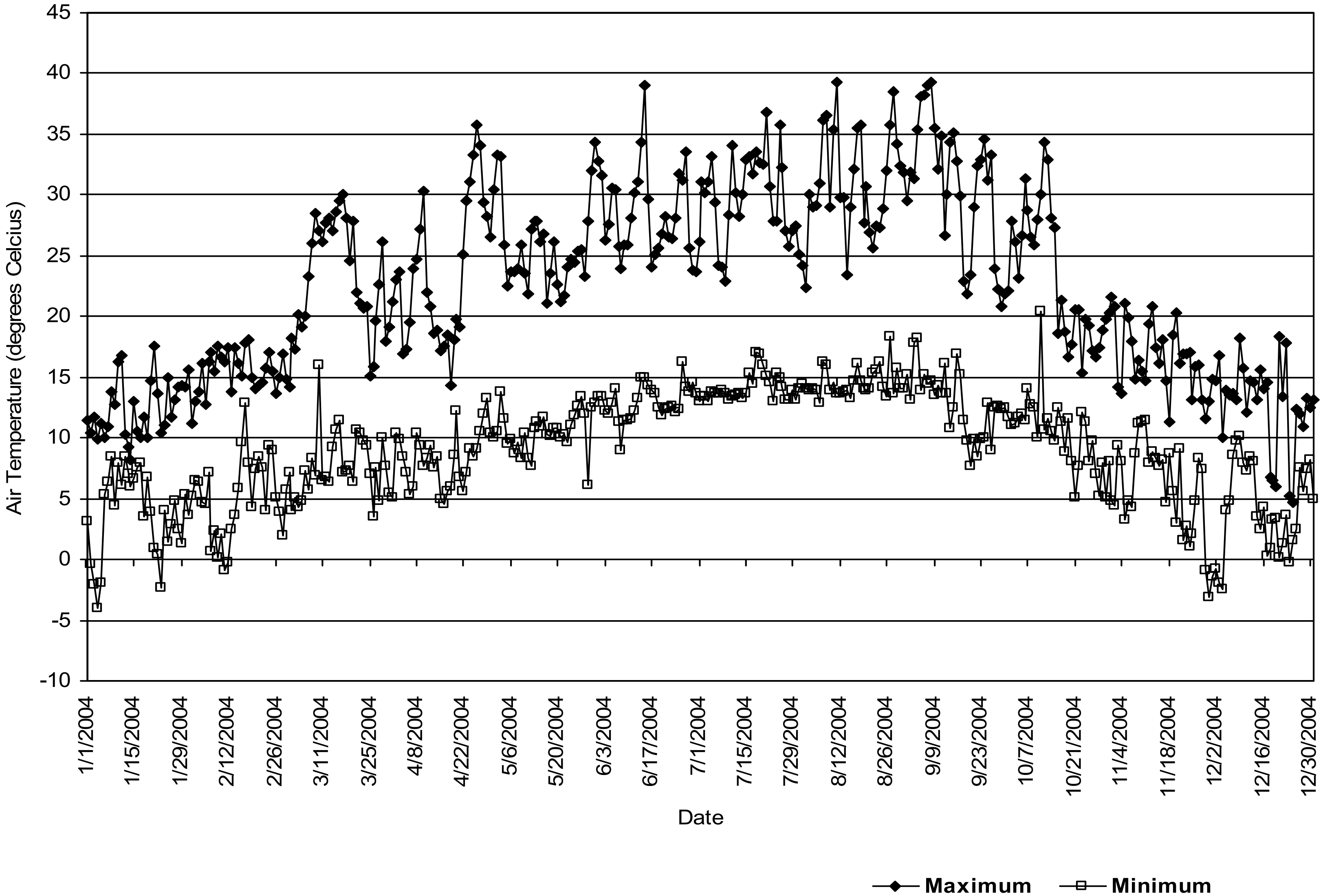


FIGURE B.2
AVERAGE DAILY WIND SPEED IN 2004
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

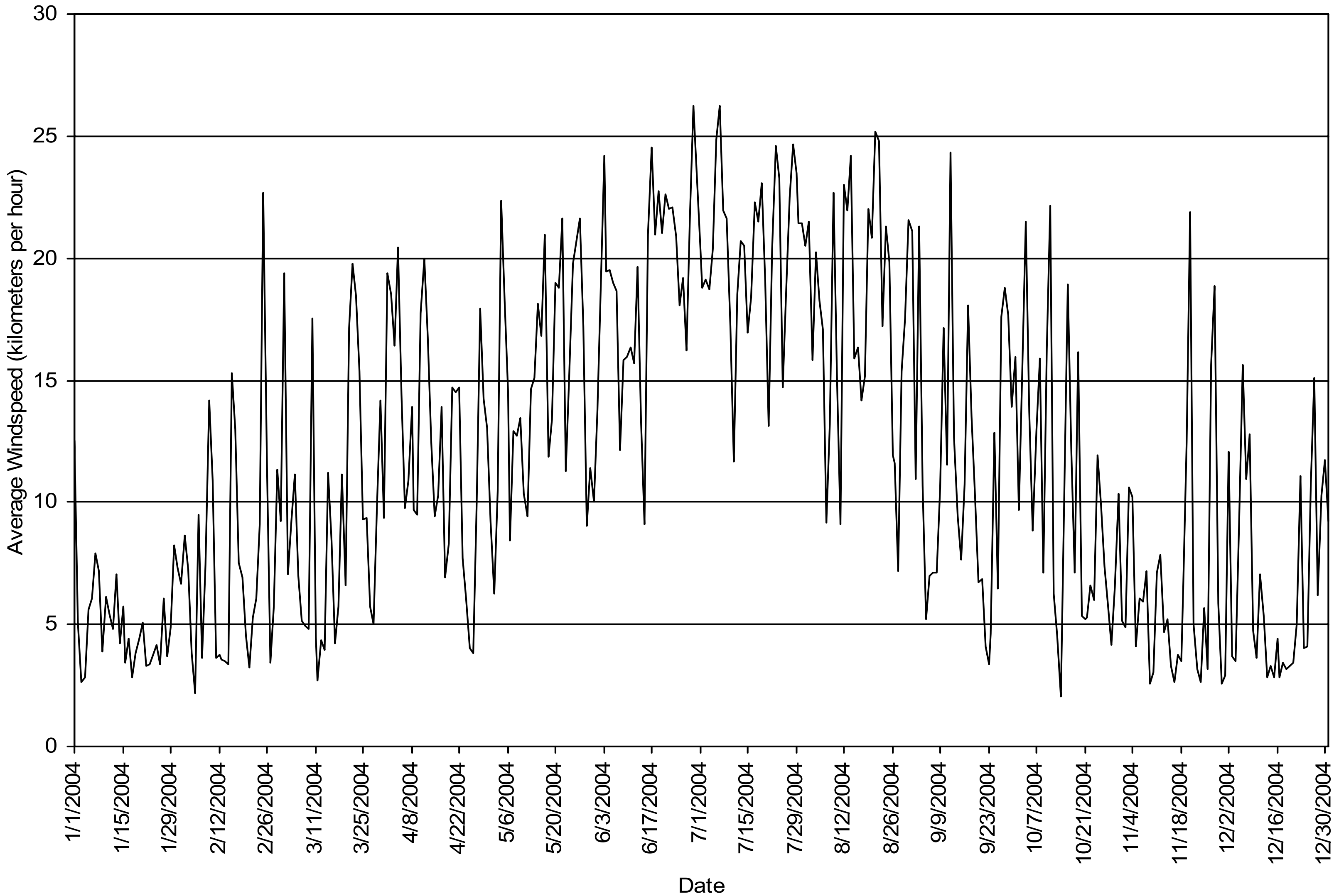


FIGURE B.3
MAXIMUM AND MINIMUM DAILY RELATIVE HUMIDITY IN 2004
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

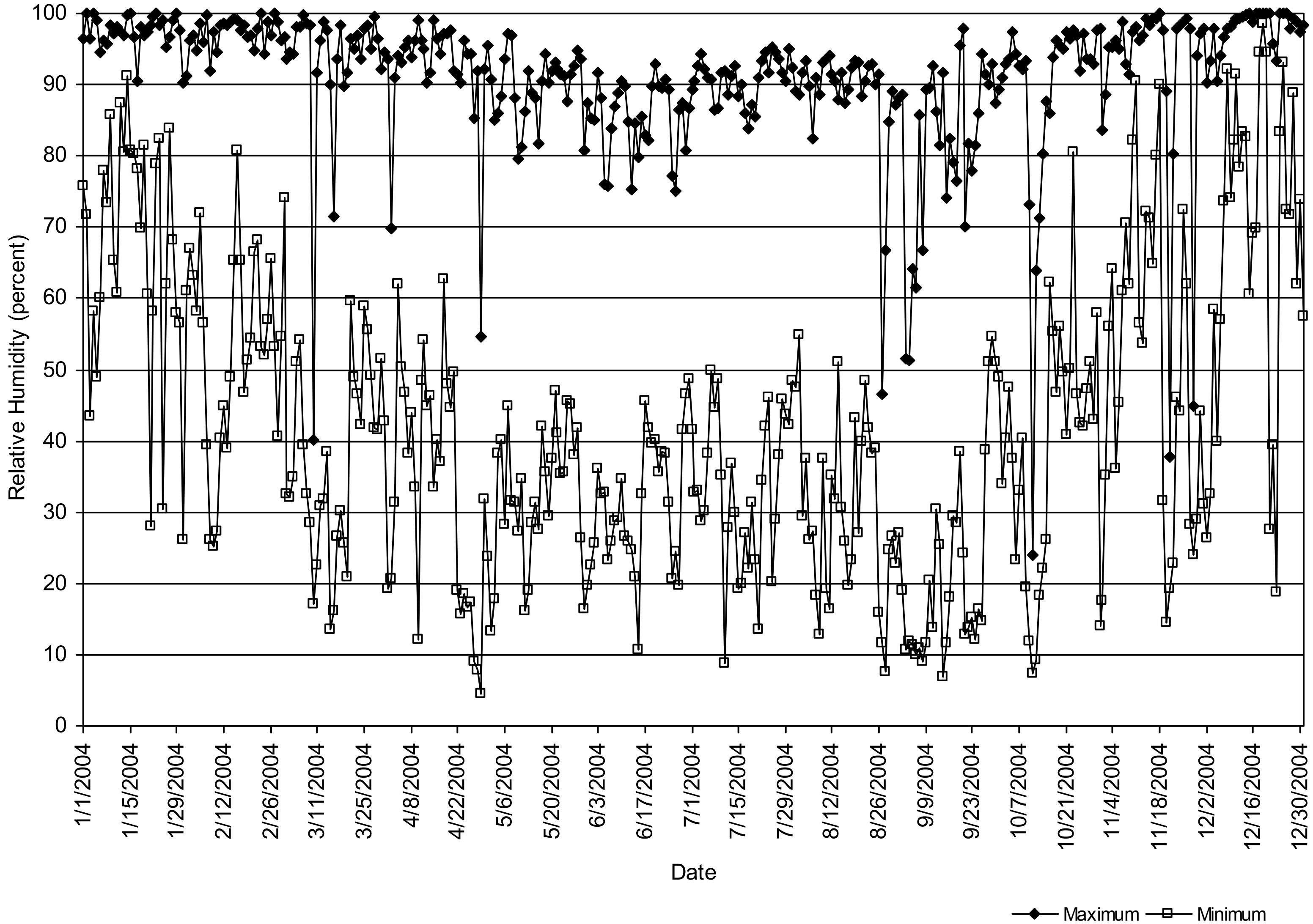


FIGURE B.4
AVERAGE SOLAR RADIATION IN 2004
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

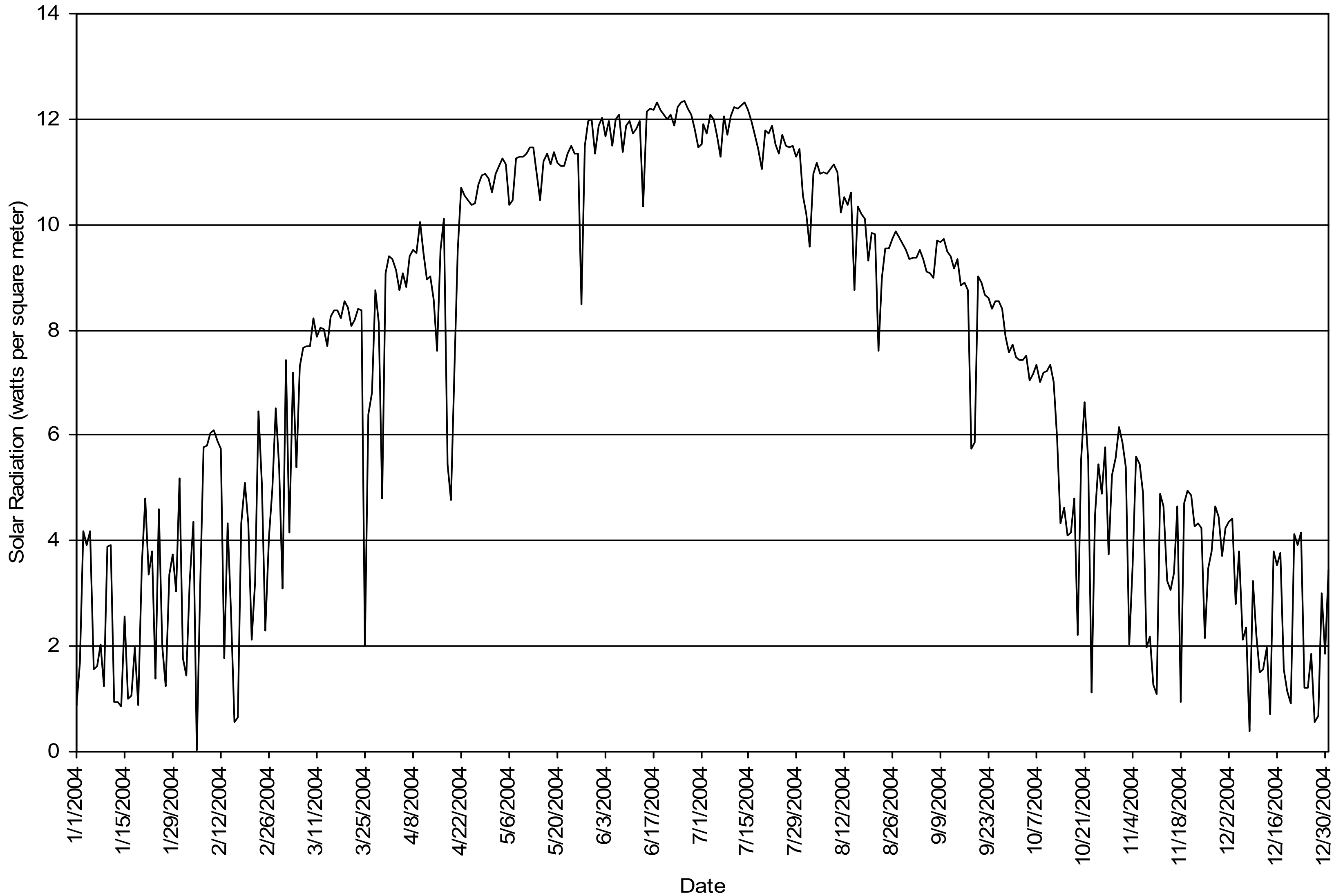


FIGURE B.5
DAILY WATERMARK SOIL SENSOR READINGS (SS1 AND SS2)
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

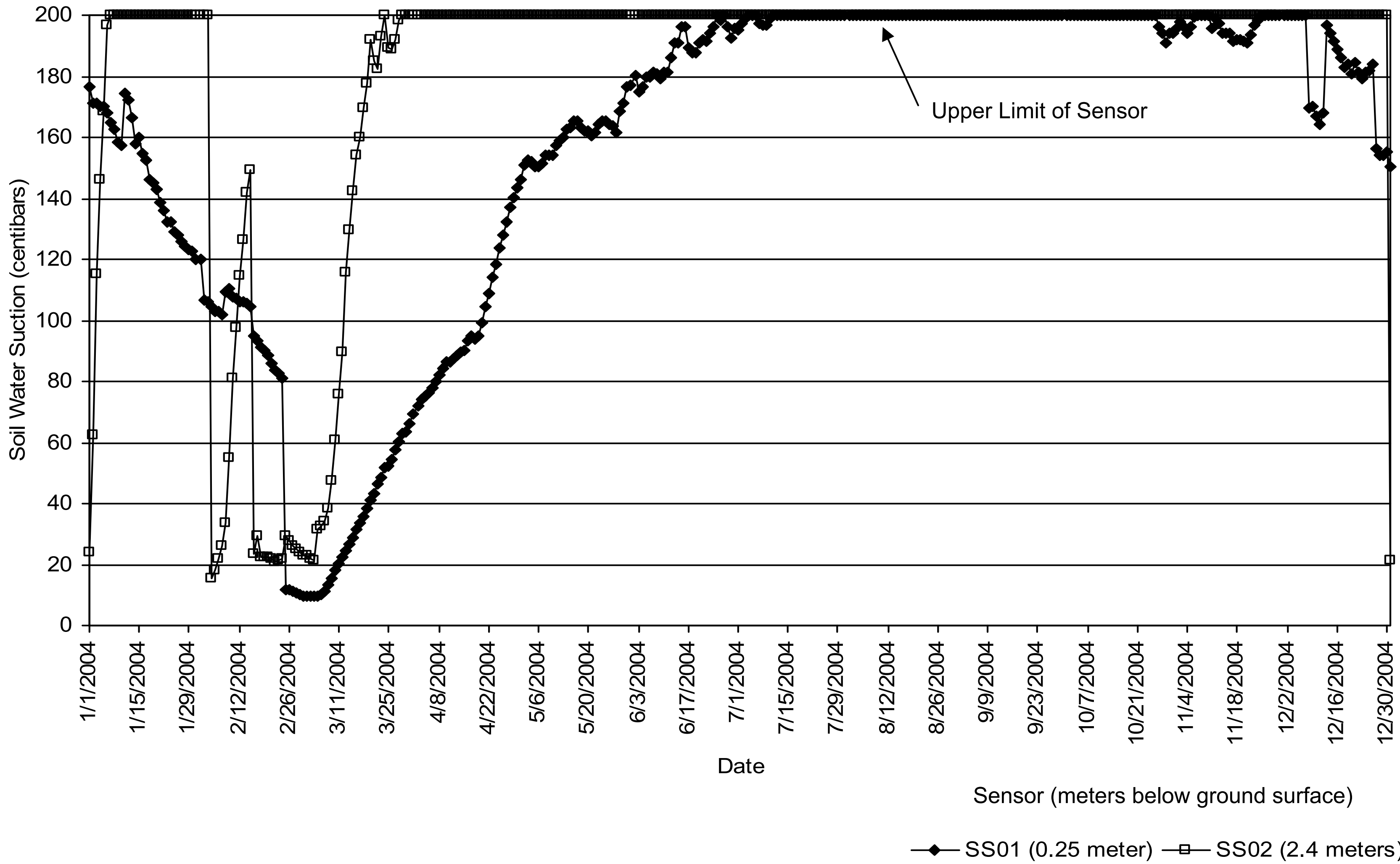


FIGURE B.6
DAILY WATERMARK SOIL SENSOR READINGS (SS3 AND SS4)
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

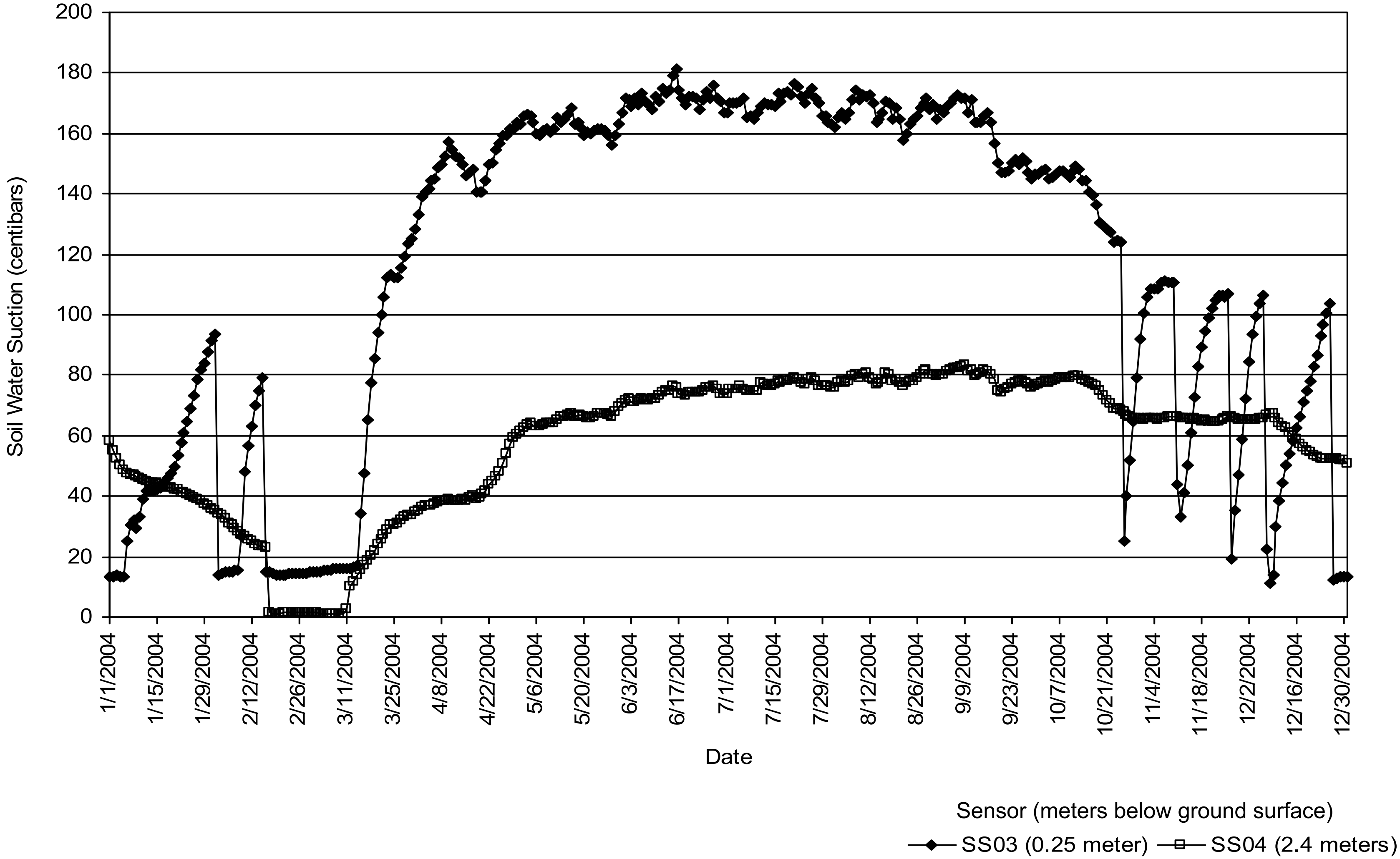
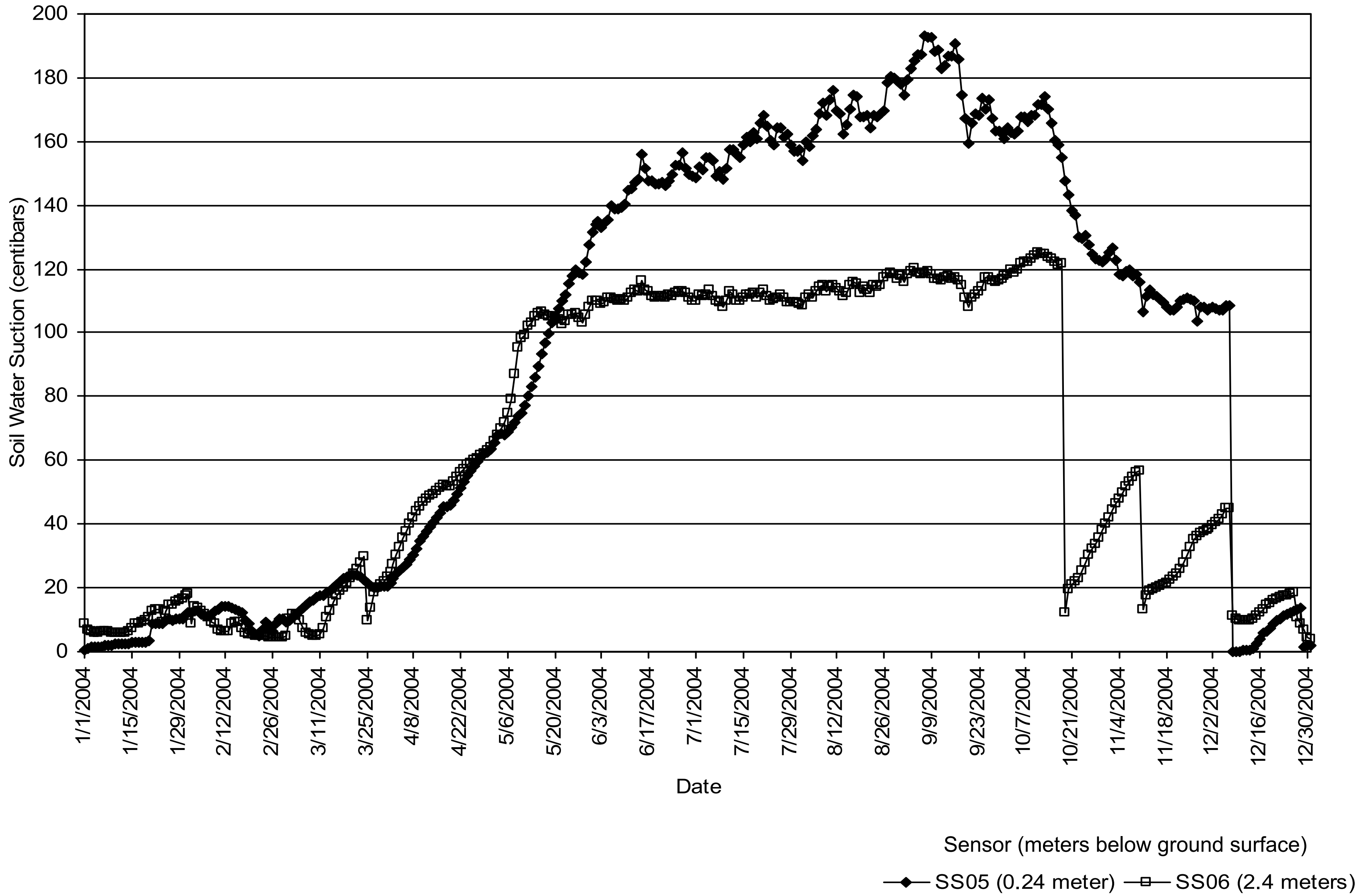
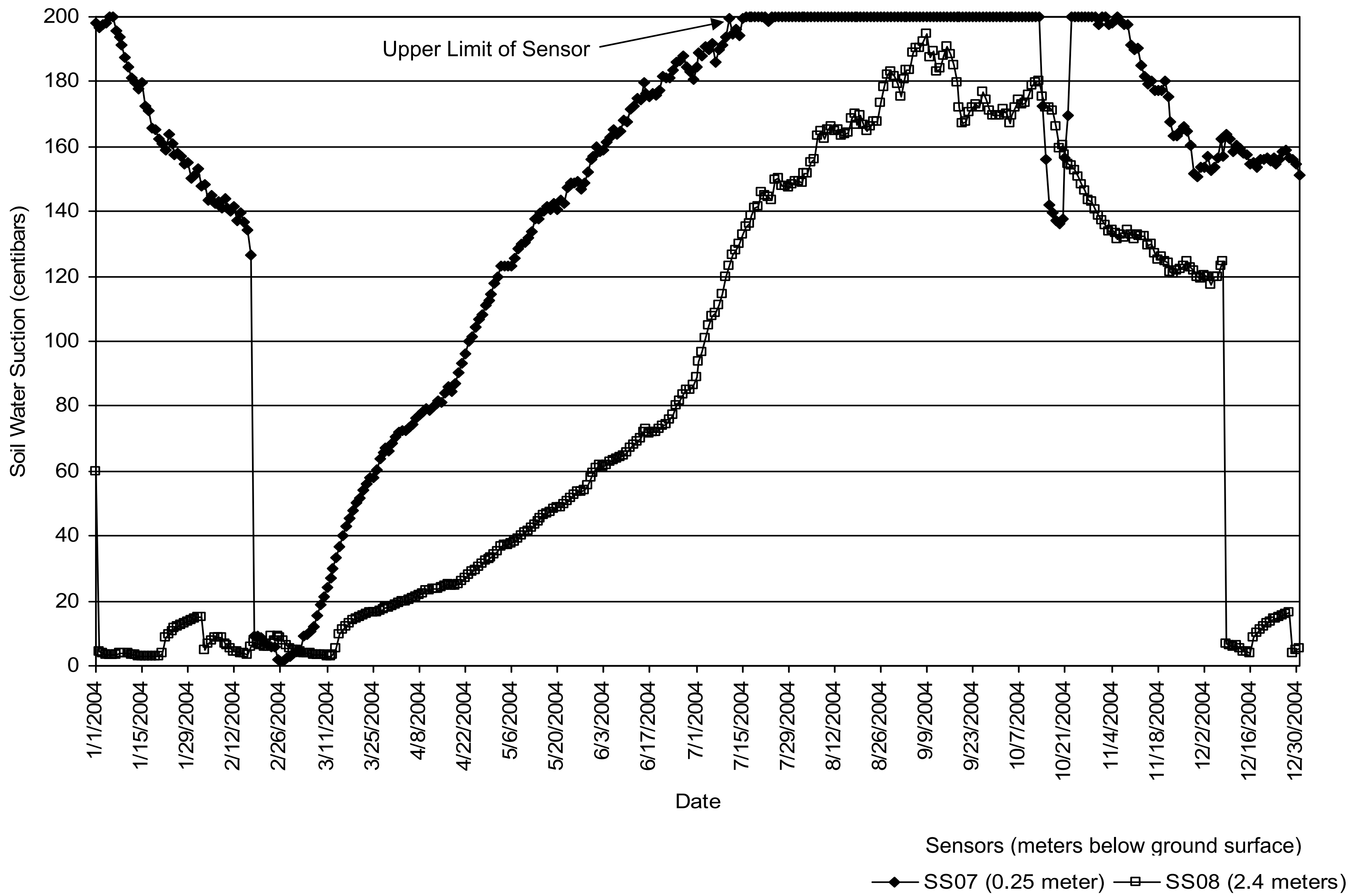


FIGURE B.7
DAILY WATERMARK SOIL SENSOR READINGS (SS5 AND SS6)
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA



Travis-B-Figs.xls

FIGURE B.8
DAILY WATERMARK SOIL SENSOR READINGS (SS7 AND SS8)
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA



Travis-B-Figs.xls

FIGURE B.9
DAILY WATERMARK SOIL SENSOR READINGS (SS9 AND SS10)
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA

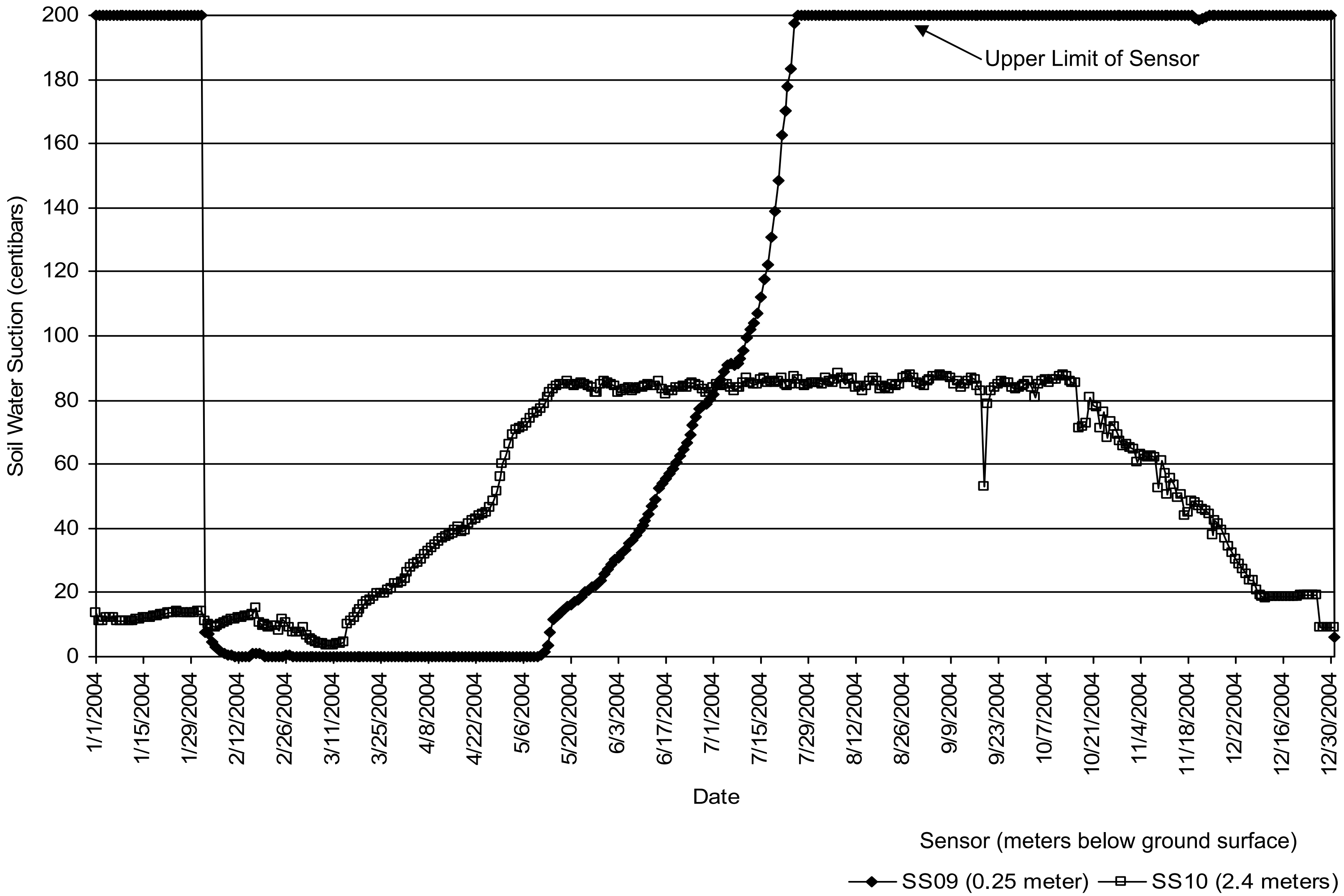
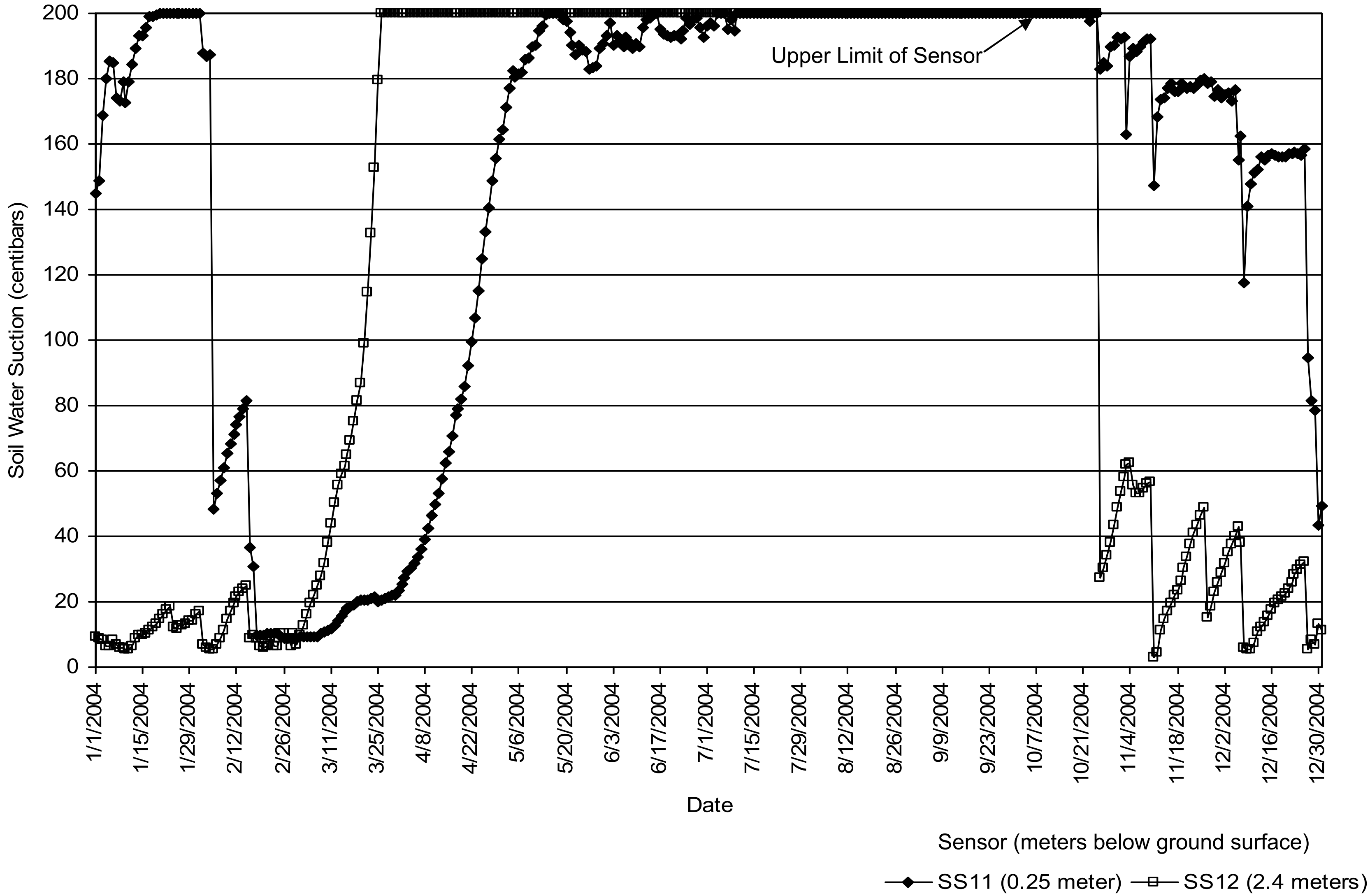


FIGURE B.10
DAILY WATERMARK SOIL SENSOR READINGS (SS11 AND SS12)
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AIR FORCE BASE, CALIFORNIA



APPENDIX C

GROUNDWATER SAMPLING SUMMARY

Sampling Wells at Travis AFB Site DP039 Phytoremediation Site

TO:	Glenn Anderson/Travis AFB Chuck Elliott/CH2M HILL
COPIES:	Amber Brenzikofer/Parsons
FROM:	Rob Pexton/CH2M HILL Jeanette Harris/CH2M HILL
DATE:	June 24, 2004

CH2M HILL sampled 21 wells at Travis AFB Site DP039 from June 8 to June 21, 2004. These are small diameter 3/4-inch PVC wells installed with a cone penetrometer rig as opposed the four-inch diameter conventional monitoring wells installed at other sites at Travis AFB. The majority of these wells went dry during low flow micro-purging with a peristaltic pump and had to be sampled the following day after water levels recovered.

The wells were sampled for the following analyses: Volatile Organic Compounds by SW8260, Methane, Ethane and Ethene by RSK-175, Dissolved Organic Carbon (field filtered) by SW9060modified, Nitrite plus Nitrate by E353.2, and Chloride, Sulfate and Alkalinity by E300 and E310 methods. In addition, field test kits (by Hach and CHEMetrics) were run for Ferrous Iron by Hach Method 8146, Manganese by CHEMetrics Colorimetric Kit, Hydrogen Sulfide by CHEMetrics Colorimetric Kit, and Carbon Dioxide by Hach Method 1436-01.

Six wells, 755PHYT025, 755PHYT026, 755PHYT029, 755PHYT033, 755PHYT042, and 755PHYT047 were successfully micro-purged with the water coming into the well keeping up with the peristaltic pump so that samples could be taken immediately after purging.

Two wells, 755PHYT030 and 755PHYT031, were sampled the same day as they were purged with the water levels recovering fairly quickly after the wells went dry during purging.

Well 755PHYT035 was dry and was not sampled.

Two wells, 755PHYT036 and 755PHYT038, went dry repeatedly and the water levels did not recover enough to obtain a complete sample set. Only 40 ml vials were filled for these wells over several days.

The remaining 11 wells were pumped dry with a peristaltic pump and complete sample sets were taken the following day.

The sampling activities are summarized on the Table 1 below. Wells which were sampled immediately following purging are in bold face type.

Table 1. Summary of Well Sampling June 8 to 21, 2004 at Travis AFB DP039 Phytoremediation Site

Well	Date	Activity
755PHYTO25	**6/8**	**Sampled at 12:10 no problems**
755PHYTO26	**6/10**	**Sampled at 15:52 no problems, took duplicate sample**
755PHYTO27	6/16	Pumped dry and let recharge overnight
	6/17	Sampled at 11:04
755PHYTO28	6/9	Pumped dry and let recharge overnight
	6/10	Sampled at 10:25
755PHYTO29	**6/8**	**Sampled at 15:10 no problems**
755PHYTO30	6/11	Sampled at 15:10 (Problems, waited for well to recharge)
755PHYTO31	6/11	Sampled at 14:25 (problems with air in tubing as if well was going dry, let it recharge)
755PHYTO32	6/9	Pumped dry let recharge overnight
	6/10	Sampled at 9:55
755PHYTO33	**6/14**	**Sampled at 11:44 no problems**
755PHYTO34		Well Destroyed and replaced by 755PHYTO47
755PHYTO35	6/15	Well dry so did not sample
755PHYTO36	6/15	Pumped dry and let recharge overnight
	6/16	Partial sample not enough water
	6/17	Problems - not enough water to sample
	6/21	Partial sample-not enough water, did not get dissolved organic carbon nitrite plus nitrate, alkalinity, chloride or sulfate. Did not get water for Hack kits.
755PHYTO37	6/16	Pumped dry and let recharge overnight.
	6/17	Sampled at 12:56
755PHYTO38	6/16	Pumped dry and let recharge overnight
	6/17	Partial sample-not enough water
	6/21	Partial sample-not enough water, did not get nitrite plus nitrate, alkalinity, chloride or sulfate. Did not get water for Hach kits.
755PHYTO39	6/16	Pumped dry and let recharge overnight.

	6/17	Sampled at 10:19
	6/18	Pumped water for Hack kits.
755PHYTO40	6/15	Pumped dry and let recharge overnight
	6/16	Partial sample at 9:42
	6/17	Remaining sample taken
	6/18	Pumped water for Hach kits
755PHYTO41	6/15	Pumped dry and let recharge overnight
	6/16	Sampled at 9:13
755PHYTO42	**6/14**	**Sampled at 14:30 no problems**
755PHYTO43	6/8	Pumped dry and let recharge overnight
	6/9	Sampled at 10:02
755PHYTO44	6/15	Pumped dry and let recharge overnight
	6/16	Partial sample at 08:30
	6/17	Partial sample taken
	6/18	Took remaining sample and water for Hach kits
755PHYTO45	6/10	Pumped dry and let recharge overnight
	6/11	Sampled at 09:28
755PHYTO46	6/8	Pumped dry and let recharge overnight
	6/9	Sampled at 11:05
755PHYTO47	**6/10**	**Sampled at 14:21 no problems**

NOTE: Sometimes a well would stop producing water with the peristaltic pump but the water level meter indicated there was water in the well. Changing the flexible tubing for the peristaltic pump solved the problem.

Travis AFB Site DP039 Monitoring Well Sampling Conditions

Well Number	Did the well go dry during micropurging?	Did it Recover Overnight enough to fill all sample bottles?	Comments
755PHYTO 25	NO	n/a	
755PHYTO 26	NO	n/a	
755PHYTO 27	YES	YES	
755PHYTO 28	YES	YES	
755PHYTO 29	NO	n/a	
755PHYTO 30	YES	n/a	
755PHYTO 31	NO	n/a	problems with air in tubing, let recharge and sampled same day
755PHYTO 32	YES	YES	
755PHYTO 33	NO	n/a	
755PHYTO 34	well destroyed and replaced by 755PHYTO47		
755PHYTO 35	well dry did not sample		well dry
755PHYTO 36	YES	NO	Had to come back twice to get partial sample, did not get nitrite plus nitrate, alkalinity, chloride or sulphate
755PHYTO 37	YES	YES	
755PHYTO 38	YES	NO	Had to come back twice to get partial sample, did not get dissolved organic carbon, nitrite plus nitrate, alkalinity, chloride or sulphate
755PHYTO 39	YES	YES	
755PHYTO 40	YES	NO	Had to come back twice to get all samples. Didn't get Hach kit water.
755PHYTO 41	YES	YES	
755PHYTO 42	NO	n/a	
755PHYTO 43	YES	YES	
755PHYTO 44	YES	NO	Had to come back twice to get all samples.
755PHYTO 45	YES	YES	
755PHYTO 46	YES	YES	
755PHYTO 47	NO	n/a	

Field Test Kit Results.
Travis AFB Site DP039 phyto well sampling

Well Number	Date	Ferrous Iron, Fe+2 (mg/L)	Manganese (mg/L)	Hydrogen Sulfide (mg/L)	Carbon Dioxide (mg/L)	Comments
Phyto 25	08-Jun-04	0		0.1		
Phyto 26	10-Jun-04	0	0	0	no data	
Phyto 27	17-Jun-04	0	0	10	55	
Phyto 28	09-Jun-04	0.9	1.5	0	75	
Phyto 29	08-Jun-04	0	0	0.3	60	
Phyto 30	11-Jun-04	1	1	0	65	
Phyto 31	11-Jun-04	water to muddy to see color	water to muddy to see color	0.1	60	
Phyto 32	09-Jun-04	17	<10 (5 to 1 dilution)	0.05	110	used first water out of well for hach kits
Phyto 33	14-Jun-04	0	0	0	110	
Phyto 34						Well destroyed
Phyto 35	15-Jun-05					well was dry
Phyto 36	16-Jun-04					well pumped dry repeatedly
Phyto 37	16-Jun-04	0	0	0	40	
Phyto 38	16-Jun-04					well pumped dry repeatedly
Phyto 39	16-Jun-04	0	0	0	50	Difficult to read turbidity high
Phyto 40	15-Jun-04	0	0	0	65	
Phyto 41	16-Jun-04	0	0	0	60	sampled over a couple days
Phyto 42	14-Jun-04	0	0	0	65	
Phyto 43	08-Jun-04					Did Amber have these measurements? She showed how to used the kits the first day.
Phyto 44	16-Jun-04	0	0	0	80	
Phyto 45	06/10/2004 June 11	0.3	0	0	82.5	sampled over a couple days
Phyto 46	08-Jun-04	0	0	0.05	50	
Phyto 47	10-Jun-04	0	0	0	35	

APPENDIX D

PHYTOVOLATILIZATION REPORT

PHYTOVOLATILIZATION MEASUREMENTS AT TRAVIS AIR FORCE BASE, CALIFORNIA

January 2005

Prepared for
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Prepared by

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EXECUTIVE SUMMARY

This report summarizes the results of a sampling and analysis survey conducted at Travis Air Force Base (AFB), California on September 7-8, 2004, to determine if eucalyptus planted at the phytostabilzation demonstration site are phytovolatilizing (transpiring TCE [trichloroethylene] along with water) measurable amounts of TCE. The 2.4-acre site is located in the West/Annexes/Base Wide Operable Unit where 480 trees were planted in 1998 and 2000 to hydraulically control a TCE groundwater plume.

Phytovolatilization samples were obtained by sealing a glass chamber over a representative section of branch, purging the chamber with compressed breathing air, and collecting the transpired water and TCE on sorbent traps. The mass of water collected in the silica gel traps was determined gravimetrically and the amount of TCE collected on the Tenax© sorbent tubes was determined using thermal desorption gas chromatography mass spectrometry (GC/MS). The amount of phytovolatilized TCE was expressed in terms of a transpiration stream concentration (TSC), mg TCE per liter of water transpired. Assuming the TSC values measured in the field are representative of all the eucalyptus trees in the operable unit, they can be used along with transpiration measurements to estimate the amount of TCE phytovolatilized at the site.

TCE was detected in the transpiration stream of the six trees sampled during September 2004 with TSC values ranging from 3 to 250 mg TCE per L of transpired water collected. This is contrary to results obtained during previous sampling in December 2003 where no significant phytovolatilization of TCE was observed. The difference in phytovolatilization observed between the two sampling events was likely due to seasonal differences and the specific environmental conditions at the site during the two different sampling events. The December 2003 sampling was characterized by low light (cloudy), intermittent rain, high humidity (near 100%), and low temperature (50˚ F) conditions that minimized transpiration and

phytovolatilization of the TCE while the September 2004 sampling event was conducted during a period of very high daytime temperatures (100˚ F) and relatively low humidity (15-25%).

The results of the September 2004 sampling show that the eucalyptus trees are removing TCE from the subsurface through phytovolatilization. However, using the TSC values obtained in September 2004 to predict yearly TCE phytovolatilization is not recommended because the ratios of TCE to water obtained are thought to be artificially high. The extreme heat and dry mid-day conditions likely restricted normal water transpiration but not the short-term TCE volatilization as it continued to diffuse through the leaf cuticle because of its higher lipophilicity. Over the long term, the TCE flux from the leaves would also be reduced because it would no longer be moved to the leaves via transpiration.

To more accurately estimate the potential impact of phytovolatilization at the site, similar sampling should be conducted at additional times throughout the year to determine a more representative TSC value. However, until that information is obtained, a range of TSC values estimated from literature transpiration stream concentration factors (TSCF) (0.1 and 0.75) and site groundwater concentrations (0.1 to 15 mg/L) was used along with an estimate of yearly transpiration by the trees (6.3×10^6 L) to yield values of TCE phytovolatilized ranging from 63 to 69300 g/yr.

This range of values is likely to be lower because of restricted uptake, sorption and metabolism within the trees themselves, and any leakage from the trunk that might occur as the TCE is being transferred to the leaves. However, this approach should provide a reasonable best-case estimate the total amount of TCE removed from the groundwater by the trees though phytovolatilization. Volatilization directly from the soil surface can also be significant at some sites especially if the tree roots change the soil structure as to increase pathways for direct volatilization from the soil.

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SECTION 1

INTRODUCTION

This report summarizes the results of a field sampling effort designed to determine if TCE is being volatilized along with the water transpired (i.e. phytovolatilized) by Eucalyptus trees planted at the phytostabilization demonstration located in the West/Annexes/Base Wide Operable Unit (WABOU) at Travis Air Force Base (AFB), California. This report consists of five sections, including this introduction. Section 2 describes the sampling and analysis methods used in this study. Section 3 describes the results and Section 4 provides conclusions and recommendations for future studies. Section 5 contains references cited. Supporting data, including Tables and Figures, are presented in the Appendix.

1.1 Background

Plants have profound effects on physical, chemical, and biological processes in soils and can significantly impact the fate of organic chemicals in soil. Microbial and chemical activities in the rhizosphere are increased relative to the bulk soil, primarily due to the impact of root exudates. Plants can also take-up, metabolize and transpire organic chemicals directly. For TCE, enhanced rhizosphere degradation, uptake and transpiration (phytovolatilization), and uptake and metabolism have been identified as potential plant mediated processes (*e.g.* Walton and Anderson 1990, Schroll *et al*. 1994, Anderson and Walton 1995, Narayanan *et al*. 1995, Schnabel *et al*. 1997, Gordon *et al*. 1997, Newman *et al*. 1997, Burken and Schnoor 1998, Orchard *et al*. 2000a and 2000b). These processes are impacted by the flow of water to the root surface *via* the transpiration of water from plant leaves. If the water flow to the root is large enough, hydraulic control of contaminant plumes can also occur.

For non-ionic, xenobiotic organic compounds like TCE, uptake by plants is believed to be a passive process (McFarlane 1995) and related to the amount of water transpired, the concentration of the contaminant in the water used by the plant, and the lipophilicity of the contaminant.

Predicting the uptake of organic contaminants by individual plants is difficult, particularly in field situations, because of the impact of variables such as depth to groundwater, contaminant concentration in the groundwater, age and species of plant, climate, and the amount of groundwater used by the plant (Doucette *et al.* 2003). However, the following general expression illustrates a simple approach for estimating the uptake of TCE from a shallow aquifer per unit area of plants per year based on several key variables:

$$\text{Mass of TCE taken up by plant} = (TSCF)(\mathrm{C}_{TCE})(T)(f) \qquad (1)$$

where *TSCF* is the transpiration stream concentration factor (assumed to be constant), C_{TCE} is the average groundwater concentration of TCE (mg/L), *T* is the cumulative volume of water transpired per unit area per year (L/m^2-yr), and *f* is the fraction of the plant water needs met by contaminated groundwater. This expression assumes that C_{TCE} is constant. A more realistic calculation would incorporate the reduction in C_{TCE} that would occur over time as a function of the physical, chemical, or biological processes that may be occurring.

Transpiration stream concentration factors (TSCFs) are dimensionless ratios of the chemical's concentration in the xylem sap to its concentration in the root-zone solution (Russell and Shorrocks 1959). For TCE, values ranging from (0.02 to 0.75) that have been reported in the literature (*e.g.,* Orchard *et al*. 2000b, Burken and Schnoor 1998). When measured TSCF values are not available, they have been estimated from the lipophilicity of the chemical as described by the octanol-water partition coefficient (K_{ow}) (e.g. Briggs *et al.* 1982).

For nutrient cations like NH_4^+, PO_4^+ and K^+, active uptake (TSCF > 1.0) occurs. However, with the possible exception of some hormone-like chemicals (2,4-D), there is no evidence of active uptake of anthropogenic chemicals (McFarlane 1995). Passive uptake (TSCF = 1.0) occurs when a chemical is taken up directly with water because of the gradient of water potential resulting from evapotranspiration (McFarlane 1995). A chemical is said to be excluded (TSCF < 1.0) when uptake is not directly proportional (1:1) to water uptake, although the mechanism of uptake is still thought to be a passive process. Factors such as membrane permeability and xylem sap solubility of the contaminant may limit the extent or kinetics of passive uptake (Hsu *et al*. 1990). Sorption and rapid metabolism of contaminants within the plant would also act to reduce xylem concentrations and keep the apparent TSCF values from reaching one.

Transpiration rates in the field vary widely depending on the soil water availability and evaporative demand. Potential transpiration rates, calculated from pan evaporation rates, are widely used to schedule irrigation of crop plants. The potential annual transpiration rate can be as high as 1800 L/m^2-yr in hot desert climates such as Arizona, and as low as 200 L/m^2-yr in cool, moist environments like Alaska (Camp *et al*. 1996). However, even well watered crops can fail to attain the potential transpiration rate in the summer because of partial stomatal closure during periods of high evaporative demand. During winter months, deciduous trees drop leaves and evergreen trees have low transpiration rates as the result of shorter days, lower light levels, and colder temperatures. When forced to use groundwater, phreatophytic plants typically do not achieve the high transpiration rates that occur with vegetation that uses surface water (Camp *et* *al*. 1996). Thus, the actual annual transpiration rate is usually below the potential rate. In a recent review of 52 water use studies since 1970, Wullschleger *et al*. (1998) found that 90% of the observations for maximum rates of daily water use were between 10 and 200 L/day for individual trees that averaged 21 m (70 feet) in height.

1.2 Objectives of Project

The objective of this project was to determine if Eucalyptus trees planted at the Travis AFB phytostabilzation demonstration site are phytovolatilizing (transpiring TCE along with water) measurable amounts of trichloroethylene (TCE).

SECTION 2

METHODS AND MATERIALS

2.1 Sampling: Type, Number, and Location

Gas samples used to determine the potential flux of TCE from leaves to the atmosphere as a function of transpired water (i.e. phytovolatilization) were collected from six Eucalyptus trees located at the phytostabilization demonstration site on September 7-8, 2004 using a flow-through sampling apparatus (Figure A1), (Doucette *et al.* 2003). Control samples were also collected to determine the background levels of TCE in the compressed breathing air used to purge the sampling chambers and in the ambient air at the site. A complete listing of samples collected is provided in Table A1.

The sample names listed in Table A1 consist of a Tree Identifier and a Trap Identifier separated by a hyphen. The Tree Identifier indicates the location of the tree by Row (1-8) and Tree Number within the row from north to south (1-60). Figure A2 provides a schematic of the relative tree locations sampled. The Trap Identifier specifies the position (front or back, left or right) of the Tenax trap in the sampling train. For example, a phytovolatilization sample collected from a tree in the first row, four in from the north, on the front, left Tenax trap would be designated R1T4-FL.

2.2 Plant Transpiration Samples

A glass chamber was placed over a representative section of each tree and sealed on the open end with closed-cell foam and electrical tape to produce a flexible, yet tight seal around the stem and chamber (Figure A1). Compressed air (Ultra Zero Ambient Monitoring grade, Praxair Part number AI 0.0UM) was used to purge the chambers of TCE and water vapor. The two cylinders of air were tested for TCE and CO_2 at the Utah Water Research Laboratory prior to being shipped to the site. This grade compressed air, typically containing 315-385 ppm CO_2, was used to maintain natural stomatal response. The resulting slightly positive chamber pressure also minimized the potential introduction of any TCE that might be in the ambient air surrounding the chamber (i.e., TCE volatilizing directly from the soil surface).

All tubing and connections attached to the chamber were constructed of stainless steel to minimize sorption of TCE. Portable sampling pumps were used to sub-sample the air leaving the chamber. Sub-sampling was necessary because of the relatively high flow rates (6 to 10 L/min) used to minimize humidity increases within the chamber and prevent the condensation of transpired water on the interior walls of the chamber. Sample collection time intervals were between 20 to 40 minutes using flow rates of 150 to 200 mL/minute. Specific time intervals and flow rates were recorded for each sample collected.

Tenax® was used as the sorbent for the TCE traps because of high sorption capacity for volatile chlorinated organics and low affinity for water. Silica gel traps were used to determine the amount of water transpired. The volume of gas sample (3 to 7 L) collected was calculated from the flow rate through the Tenax® trap and the sampling time. After sampling, Tenax® traps were sealed with stainless steel caps, placed in bubble-pack envelopes, and shipped to the Utah Water Research Laboratory at Utah State University for analysis. Chamber blanks and ambient air samples were also collected.

Transpiration rates were determined with a portable balance by measuring the mass of condensed water that collected in the silica traps. Traps were weighed prior to and after being connected to the sample effluent stream. The weight of the water collected and the volume of effluent passing through the trap were used to calculate the transpiration rate. Transpiration measurements were used to determine the ratio of TCE to water transpired. Coupled with seasonal evapotranspiration rates, this ratio can be used to estimate the impact of vegetation on the flux of TCE to the atmosphere.

Prior to going to the field, and between each sampling event, the interior chamber surfaces were rinsed with distilled water.

2.3 Tenax Tube Analysis

Tenax traps were analyzed using a thermal desorption gas chromatography/mass spectrometry (GC/MS) procedure. Trap samples were introduced into a Hewlett-Packard® 6890/5793 GC/MS equipped with a DB-624 capillary column (30 m x 0.25 mm ID x 1.4 µm film thickness) using a Tekmar 6000 AeroTrap Desorber equipped with cryo-focusing and moisture control-system. Desorber operating conditions were as follows: 1 minute trap sweep at 35°C; cryo-trap temperature = -165°C; Tenax trap desorb = 200°C for 10 minutes; cyro-trap desorb = 225°C for 1 minute. The moisture control system and the various traps were thermally cleaned between each sample.

Chromatographic conditions were as follows: DB-624, 30 m x 0.25 mm, 1.4 µm film thickness column (J&W Scientific, Folsom, CA, USA); helium carrier gas at 0.7 mL/min (3.52 psi); temperature program 35ºC for 3 min to 170 ºC at 30ºC/min, then 170 to 200ºC at 50 ºC/min. with a 1 min. hold at the final temperature; split ratio was 15:1 and the GC inlet temperature was set at 250°C. The MS was operated in selected ion monitoring (SIM) mode (m/z 60, 95, and 130). An external standard approach was used to quantify the mass of TCE collected in each trap. Standards were prepared by loading known amounts of TCE dissolved in methanol onto clean Tenax traps with a microsyringe.

SECTION 3

RESULTS AND DISCUSSION

3.1 TCE in Phytovolatilization Samples

The results of the September 2004 transpiration sampling at Travis AFB are summarized in Table A1. All the trees sampled showed measurable phytovolatilization of TCE. Phytovolatilization, expressed as a transpiration stream concentration (TSC), ranged from about 3 to 250 mg TCE/L of transpired water collected. For several of the trees sampled, the TSC values are higher than the groundwater concentrations at the site. Theoretically, this is impossible unless the amount of water transpired is restricted relative to the amount of TCE leaving the leaves. Because of the unusually high mid-day temperatures at the site (Table A2) during the time of sampling, it is likely that the trees were stressed and closed their stomata to conserve water (Nilsen and Orcutt, 1996). This would restrict the amount of water transpired but would not substantially reduce the amount of the more volatile and lipophilic TCE leaving the leaves, at least in the short term. Evidence of restricted transpiration is provided in Table A1 were it can be observed that the highest amounts of water transpired were collected in the earlier morning sampling periods. The trend of higher transpiration in the morning is typical of trees stressed by high mid-day temperatures and low precipitation (Nilsen and Orcutt, 1996)..

For comparison, the results of a similar sampling event performed at Hill Air Force Base in the summer of 2002 (Doucette *et al.* 2003) are briefly summarized. The phytovolatilization of TCE from mature trees (willow, poplar and Russian olive growing over TCE plumes of 1 to 10 mg/L at an groundwater depth of 7.5 feet below surface were sampled using the same apparatus and similar flow rates and sampling times that were used at Travis AFB. Silica gel traps collected between 0.02 to 0.1 grams of water while the mass of TCE trapped on Tenax ranged from 24 to 105 ng of TCE. These resulted in TSC values ranging from 0.35 to 2.2mg/L. Because the depth to groundwater and TCE concentration are similar at the Travis and Hill AFB sites, it was anticipated that the TSC values would be similar. However, it should be noted that differences in tree age and species at the two sites could influence the extent of TCE phytovolatilization.

3.2 Scaling Transpiration and Trichloroethylene Efflux from Chambers to Entire Trees

Phytovolatilization measurements made in small flow-through chambers can be scaled to whole trees or planting by multiplying the measured TSC values by an appropriate transpiration rate. This assumes that the TSCs determined for the individual branches are representative of the entire tree or tree planting and are independent of the transpiration rate and the concentration of TCE in the groundwater.

However, instead of using the artificially high TSC values obtained in September 2004 to estimate yearly photovolatilization, a range of TSC values was developed by multiplying the high and low literature TSCF values for TCE (0.1 to 0.75) by the range of TCE groundwater concentrations (0.1 to 15 mg/L) at the site. This produced a series of TSC values ranging from to 0.01 to 11 mg/L. Multiplying the low and high estimated TSC values by an estimate of the yearly water transpired by the trees (6.3×10^6 L) yields values of TCE phytovolatilized from 63 to 69300 g/yr. This also assumes that the trees use contaminated groundwater for all their water needs. However, based the measurements of hydrogen and oxygen isotopic ratios in the xylem and groundwater, this may not be the case since they were significantly different (Table A4). Groundwater is typically more enriched in the heavier isotopes (more negative values) than precipitation and isotopic ratios are equal to (for trees using only groundwater) or more negative than the xylem (for trees using groundwater and precipitation). Unfortunately, no precipitation samples were available for comparison. The more negative xylem values for the hydrogen isotope ratio are puzzling but plant stem water may not reflect its source water relative to hydrogen isotope ratio for some salt tolerant plant species (Chimner and Cooper, 2004).

The total yearly volume of water transpired by the trees (Vt) was estimated using the following simplified approach (Ferro et al., 2002):

$$Vt = ETo * Kc * LAI * A$$

where ETo is potential evapotranspiration obtained from the on-site weather station, Kc is the "crop coefficient" or rate of water use per leaf as a percentage of ETo (estimated to be 1 in this case), LAI is the leaf area index or leaf area per unit ground area (estimated to be 3 from observations at the site), and A area of the tree planting (2.4 acres).

3.3 TCE and TCE metabolites in Plant Tissue Samples

In addition to finding TCE in the transpiration stream samples collected from the six eucalyptus trees, evidence of TCE uptake was also documented by the presence of TCE in stem samples collected from the same trees (Table A3). Separate plant tissue samples were also collected and analyzed for three TCE metabolites: trichloroacetic acid, dichloroacetic acid and trichloroethanol. However, no metabolites were identified above the method detection limits.

SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 Summary of Findings

The primary objective of this project was to determine if TCE was taken up and volatilized along with transpired water (phytovolatilized) by eucalyptus trees growing over TCE contaminated groundwater at the Travis AFB phytostabilization demonstration site. The main findings of the study are summarized below.

1. All the trees sampled showed measurable phytovolatilization of TCE. Phytovolatilization, expressed as a transpiration stream concentration (TSC), ranged from about 3 to 250 mg TCE/L of collected transpired water.
2. TSC values for several of the trees were unrealistically high (greater than groundwater concentrations) due to the reduced transpiration as the result of stomata closure associated with the unusually high temperature at the site during the time of sampling. Because of this, estimated TSC values were used to calculate the potential TCE removal from the site due to phytovolatilization.
3. TSC values were estimated from laboratory derived TSCF values and groundwater concentrations at the site. TCE removed from the site by phytovolatilization was estimated to range from 63 to 69300 g/yr. Representative TSC values, measured at several times during the year, would improve the reliability of the phytovolatilization estimates.
4. TCE was identified in stem or core samples collected from the same trees sampled for phytovolatilization providing additional evidence of TCE uptake by the eucalyptus trees.

5. Stable isotope measurements of xylem and groundwater, designed to determine the source of water (i.e. groundwater vs. precipitation vs. irrigation) used by the trees at the site, were inconclusive relative to last year when the trees were shown to use groundwater almost exclusively. This may have been associated with an artifact associated with the high temperatures at the site during the time of sample collection.

4.2 Recommendations for Future Activity

Additional phytovolatilization and stable isotope samples should be collected at representative times throughout the year to improve estimates of yearly TCE removals via phytovolatilization and better understand the source of water used by the trees.

SECTION 5

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Appendix A

Table A1. Summary of Phytovolatilization Sampling Data Collected on September 7-8, 2004 at Travis AFB.

Field ID	Air Tank #	Sample Date	Sample Duration (hr:min:sec)	Ave Flow mL/min	Total Sample volume (L)	Mass Water collected (g)	Analysis Date	Mass TCE on trap (pg)	Conc TCE in Air, pg/L	Conc TCE in air (pg/L) corr for chamb blk	Ave Mass TCE per L Water Transpired (mg/L) corr	Ave Mass of TCE per leaf area (mg/cm2 min)
Chamber Blank R1T4-FL	1	9/7/04	0:30:44	119	3.647	0.00	09/08/04	0	3			
Chamber Blank R1T4-BL	1	9/7/04	0:30:44	119	3.647	0.00	09/09/04	11				
R1T4-FL	1	9/7/04	0:31:58	87	2.793	0.04	09/09/04	78	30	27	4.35	0.018736
R1T4-BL	1	9/7/04	0:31:58	87	2.793	0.04	09/09/04	7				
R1T4-FR	1	9/7/04	0:31:58	147	4.699	0.06	09/08/04	348	90	87		
R1T4-BR	1	9/7/04	0:31:58	147	4.699	0.06	09/09/04	73				
R1T4-FL (duplicate)	1	9/7/04	0:47:02	91	4.285	0.08	09/10/04	636	207	204	10.97	0.045075
R1T4-BL (duplicate)	1	9/7/04	0:47:02	91	4.285	0.08	09/10/04	253				
R1T4-FB (duplicate)	1	9/7/04	0:47:02	138	6.506	0.08	09/09/04	855	138	135		
R1T4-BR (duplicate)	1	9/7/04	0:47:02	138	6.506	0.08	09/09/04	44				
R3T16-FL (near well 27)	2	9/7/04	0:48:00	95	4.571	0.09	9/21/04	1310	346	343	45.60	0.261136
R3T16-BL	2	9/7/04	0:48:00	95	4.571	0.09	9/21/04	270				
R3T16-FR	2	9/7/04	0:48:00	136	6.512	0.10	9/21/04	1330	1136	1133		
R3T16-BR	2	9/7/04	0:48:00	136	6.512	0.10	9/21/04	6070				
R7T3-FL	1	9/7/04	0:45:00	109	4.920	0.09	9/20/04	NA	NA	NA	2.99	0.016304
R7T3-BL	1	9/7/04	0:45:00	109	4.920	0.09	9/20/04	4.08				
R7T3-FR	1	9/7/04	0:45:00	160	7.178	0.13	9/20/04	354.22	57	54		
R7T3-BR	1	9/7/04	0:45:00	160	7.178	0.13	9/20/04	56				
Chamber Blank R1T27	2	9/8/04	0:52:00	120	6.240	-0.01	09/14/04	1020	173			
Chamber Blank R1T27	2	9/8/04	0:52:00	120	6.240	-0.01	09/14/04	59				
Chamber Blank R1T27	2	9/8/04	0:52:00	124	6.448	-0.02	09/14/04	483	75			
Chamber Blank R1T27	2	9/8/04	0:52:00	124	6.448	-0.02	09/14/04	0				
R2T6-FL	1	9/8/04	0:50:00	147	7.367	0.09	09/14/04	27430	3907	3784	187.07	0.544617
R2T6-BL	1	9/8/04	0:50:00	147	7.367	0.09	09/14/04	1350				
R2T6-FR	1	9/8/04	0:50:00	159	7.967	0.07	09/14/04	4220	689	566		
R2T6-BR	1	9/8/04	0:50:00	159	7.967	0.07	09/14/04	1270				
R1T27-FL	2	9/8/04	0:55:00	126	6.930	0.10	09/14/04	15260	3101	2978	213.6	1.290
R1T27-BL	2	9/8/04	0:55:00	126	6.930	0.10	09/15/04	6230				
R1T27-FR	2	9/8/04	0:55:00	190	10.432	0.14	09/14/04	23270	3086	2963		
R1T27-BR	2	9/8/04	0:55:00	190	10.432	0.14	09/14/04	8920				
R1T27-FL (duplicate)	2	9/8/04	0:45:00	119	5.340	0.08	09/15/04	14260	2961	2838	252.2	1.133
R1T27-BL (duplicate)	2	9/8/04	0:45:00	119	5.340	0.08	09/15/04	1550				
R1T27-FR (duplicate)	2	9/8/04	0:45:00	130	5.850	0.07	09/15/04	16320	3892	3769		
R1T27-BR (duplicate)	2	9/8/04	0:45:00	130	5.850	0.07	09/15/04	6450				
R3T4-FL	1	9/8/04	0:41:00	75	3.089	0.06	09/15/04	1900	3286	3283	112.8	0.487
R3T4-BL	1	9/8/04	0:41:00	75	3.089	0.06	09/15/04	8250				
R3T4-FR	1	9/8/04	0:41:00	207	8.501	0.07	09/15/04	1510	469	466		
R3T4-BR	1	9/8/04	0:41:00	207	8.501	0.07	09/15/04	2480				
R3T4-FL (duplicate)	1	9/8/04	1:11:00	94	6.639	0.03	09/15/04	7590	1149	1146	239.6	0.332
R3T4 (duplicate)	1	9/8/04	1:11:00	94	6.639	0.03	09/15/04	36				
R3T4-FL (duplicate)	1	9/8/04	1:11:00	162	11.502	0.04	09/15/04	2210	788	785		
R3T4-BR (duplicate)	1	9/8/04	1:11:00	162	11.502	0.04	09/15/04	6850				
Atm air blank-FL (R3T4)	NA	9/8/04	0:46:00	104	4.769	-0.03	09/14/04	2650	1231			
Atm air blank-BL (R3T4)	NA	9/8/04	0:46:00	104	4.769	-0.03	09/14/04	3220				
Atm air blank-FR (R3T4)	NA	9/8/04	0:46:00	138	6.348	-0.12	09/14/04	1430	225			
Atm air blank-BR (R3T4)	NA	9/8/04	0:46:00	138	6.348	-0.12	09/14/04	62970*				

*Value not used

Tree ID#	Leaf mass (g)	Stem mass (g)	Leaf area (cm2)
R1 T4	17.71	2.97	421.99
R3 T16 (well 27)	12.66	1.81	358.21
R7 T3 (WP 3)	19.09	4.46	559.13
R2 T6 (WP 4)	20.53	5.19	629.25
R1 T27 (well 29)	16.83	4.61	378.31

Table A2. Weather Data for Travis AFB During the September 7-8, 2004 Sampling

Weather Station Data for Travis AFB, CA

Hourly Data from September 7-9, 2004

Date/Time	Maximum Air Temperature (¡F)	Minimum Air Temperature (¡F)	Average Air Temperature (¡F)	Total Precipitation (inches)	Average Wind Speed (mph)	Max. Relative Humidity Avg. (%)	Min. Relative Humidity Avg. (%)	Average Solar Radiation (kW/m^2)	Total ETo (inches water)
9/7/04 12:00 AM	72.1	70.6	71.2	0	6.284	33.16	31.2	0	0.002
9/7/04 1:00 AM	71.5	66.85	69.52	0	6.114	51.76	32.55	0	0.001
9/7/04 2:00 AM	67.46	66.36	67.1	0	5.32	59.02	51.29	0	0.001
9/7/04 3:00 AM	66.97	62.46	65.13	0	3.052	72.1	57.26	0	0
9/7/04 4:00 AM	66.28	62.73	64.46	0	1.901	72.4	66.03	0	0
9/7/04 5:00 AM	64.32	59.58	61.9	0	0.701	79.5	68.88	0	0
9/7/04 6:00 AM	59.98	58.0	58.64	0	0.447	85.7	78.6	0.006	0
9/7/04 7:00 AM	73.3	59.98	66.23	0	0.776	76.7	37.26	0.124	0.002
9/7/04 8:00 AM	81.9	74.3	77.5	0	2.141	35.29	28.95	0.3	0.008
9/7/04 9:00 AM	85.4	80.3	82.9	0	1.603	29.97	23.51	0.482	0.012
9/7/04 10:00 AM	88.0	86.3	87.1	0	4.357	23.17	20.86	0.639	0.019
9/7/04 11:00 AM	91.8	87.9	89.8	0	4.546	21.81	19.84	0.755	0.024
9/7/04 12:00 PM	95.8	92.1	93.1	0	4.085	19.77	16.45	0.814	0.027
9/7/04 1:00 PM	98.5	94.7	96.5	0	3.4	17.26	15.1	0.814	0.026
9/7/04 2:00 PM	101.6	97.8	99.8	0	2.969	15.09	12.38	0.752	0.026
9/7/04 3:00 PM	102.3	100.2	100.8	0	4.767	13.53	11.64	0.642	0.025
9/7/04 4:00 PM	102.1	100.4	101.2	0	5.916	14.14	12.45	0.484	0.023
9/7/04 5:00 PM	100.8	97.4	99.9	0	8.41	13.94	10.83	0.184	0.018
9/7/04 6:00 PM	96.8	91.1	94.2	0	8.55	16.66	14.42	0.124	0.015
9/7/04 7:00 PM	90.2	84.1	87	0	6.107	23.65	17.67	0.007	0.005
9/7/04 8:00 PM	83.3	78.6	81	0	5.117	28.81	25.41	0	0.002
9/7/04 9:00 PM	78.2	75.3	76.5	0	5.942	32.74	28.54	0	0.002
9/7/04 10:00 PM	77.3	74.1	76.1	0	6.252	36.14	30.04	0	0.001
9/7/04 11:00 PM	76.2	72.8	74.8	0	6.827	44.49	33.77	0	0.002
9/8/04 12:00 AM	72.7	69.75	71.1	0	7.3	56.43	45.64	0	0.001
9/8/04 1:00 AM	69.64	67.58	68.58	0	6.112	58.21	54.6	0	0.001
9/8/04 2:00 AM	69.17	66.97	68.33	0	4.961	56.04	49.59	0	0.001
9/8/04 3:00 AM	64.31	61.86	63.29	0	2.363	61.47	50.83	0	0
9/8/04 4:00 AM	65.08	59.83	62.95	0	0.799	55.32	46.69	0	0
9/8/04 5:00 AM	61.79	58.49	60.13	0	0.811	59.94	52.88	0	0
9/8/04 6:00 AM	61.3	58.74	59.57	0	0.839	58.99	56.62	0.005	0
9/8/04 7:00 AM	73.9	61.18	67.21	0	0.566	60.56	45.48	0.122	0.002
9/8/04 8:00 AM	78.8	73.7	76.4	0	1.056	46.96	38.51	0.304	0.007
9/8/04 9:00 AM	85.3	78.9	81.8	0	1.344	39.59	28.26	0.518	0.013
9/8/04 10:00 AM	87.6	85.3	86.6	0	6.079	26.35	23.58	0.691	0.022
9/8/04 11:00 AM	93.6	87.6	90.1	0	5.164	23.23	17.13	0.814	0.026
9/8/04 12:00 PM	95.5	93	94	0	5.765	19.09	16.38	0.879	0.031
9/8/04 1:00 PM	98.7	95.5	97.1	0	4.59	16.45	12.73	0.883	0.029
9/8/04 2:00 PM	101.6	99.1	100.2	0	2.677	12.32	9.95	0.824	0.029
9/8/04 3:00 PM	102.8	100.3	101.4	0	3.642	10.89	9.27	0.697	0.026
9/8/04 4:00 PM	101.3	100.1	100.7	0	5.709	12.72	9.75	0.521	0.022
9/8/04 5:00 PM	100.6	95	97.8	0	9.12	16.45	9.07	0.216	0.02
9/8/04 6:00 PM	94.3	89.1	91.8	0	8.46	22.28	16.38	0.115	0.013
9/8/04 7:00 PM	88.5	81.2	84.9	0	4.572	29.27	22.89	0.005	0.004
9/8/04 8:00 PM	81.7	77.4	78.9	0	5.033	35.58	28.05	0	0.001
9/8/04 9:00 PM	78.4	74.8	76.3	0	5.14	40.55	32.2	0	0.001
9/8/04 10:00 PM	74.8	72.1	73.3	0	7.11	49.64	40.95	0	0.001
9/8/04 11:00 PM	72.2	69.62	71	0	7.09	57.92	50.12	0	0.001
9/9/04 12:00 AM	69.38	67.71	68.67	0	7.05	66.76	58.94	0	0.001
9/9/04 1:00 AM	67.95	66.73	67.41	0	5.779	68.72	62.69	0	0
9/9/04 2:00 AM	68.19	65.39	66.75	0	6.382	71.4	62.89	0	0
9/9/04 3:00 AM	65.15	62.49	63.55	0	1.829	79.8	73.1	0	0
9/9/04 4:00 AM	61.88	59.1	60.59	0	0.485	84.3	77.7	0	0
9/9/04 5:00 AM	61.06	57.76	59.8	0	1.727	86.4	82.5	0	0
9/9/04 6:00 AM	58.13	56.43	57.44	0	0.583	89.2	86	0.005	0
9/9/04 7:00 AM	70.5	58.28	64.98	0	0.75	87.2	59.27	0.128	0.002

Table A3. Summary of Plant Tissue Analysis: TCE

Field ID	Sample Type	Sample Date	Analysis Date	Wet Wt. of Tissue (g)	Dry Wt. of Tissue (g)	Conc. TCE (ug/kg) Wet Wt.	Conc. TCE (ug/kg) Dry Wt.	Percent Recovery TCE
TAFB-1-R R3T4	roots	09/09/08	09/15/08	1.74		273.14		n/a
TAFB-1-L R3T4	tree leaves	09/09/08	09/15/08	4.10	2.24	<MDL	<MDL	n/a
TAFB-1-S R3T4	tree stems	09/09/08	09/15/08	7.23	4.06	21.12	37.59	n/a
TAFB-2-L bkgrd tree	tree leaves	09/09/08	09/15/08	2.04	0.92	<MDL	<MDL	n/a
TAFB-2-L bkgrd tree	tree leaves	09/09/08	09/15/08	1.58	0.71	<MDL	<MDL	n/a
TAFB-2-S bkgrd tree	tree stems	09/09/08	09/15/08	2.59	1.40	<MDL	<MDL	n/a
TAFB-3-L R1T4	tree leaves	09/09/08	09/15/08	3.02	1.55	<MDL	<MDL	n/a
TAFB-3-S R1T4	tree stems	09/09/08	09/15/08	4.55	2.54	18.70	33.53	n/a
TAFB-4-L R3T4	tree leaves	09/09/08	09/15/08	2.11	1.07	0.95	1.86	n/a
TAFB-4-L2 R3T4	tree leaves	09/09/08	09/15/08	2.98	1.54	<MDL	<MDL	n/a
TAFB-4-S R3T4	tree stems	09/09/08	09/15/08	7.63	3.96	12.60	24.28	n/a
TAFB-4-S2 R3T4	tree stems	09/09/08	09/15/08	5.39	2.97	6.64	12.04	n/a
TAFB-5-L R7T3	tree leaves	09/09/08	09/15/08	3.13	1.42	1.15	2.53	n/a
TAFB-5-S R7T3	tree stems	09/09/08	09/15/08	5.24	2.83	136.39	252.67	n/a
TAFB-5-S R7T3	tree stems	09/09/08	09/15/08	4.39	2.37	84.45	156.44	n/a
QA/QC 0.1 ppb	other	09/15/08	09/15/08	n/a	n/a	n/a	n/a	90
QA/QC 0.1 ppb	other	09/15/08	09/15/08	n/a	n/a	n/a	n/a	110
QA/QC 0.1 ppb	other	09/15/08	09/15/08	n/a	n/a	n/a	n/a	100
QA/QC blank	other	09/15/08	09/15/08	n/a	n/a	n/a	n/a	n/a
QA/QC blank	other	09/15/08	09/15/08	n/a	n/a	n/a	n/a	n/a
QA/QC blank	other	09/15/08	09/15/08	n/a	n/a	n/a	n/a	n/a

Root dry weight data not available for PH-200
No trip QA/QC this sampling event

Table A4. Summary of Stable Isotope Analysis

Parsons ID/Sample	Sample Name	Sample Description	D/H Isotope Ratio	18O/16O isotope ratio
IS-01	TAFB-SF #1	Tree R1T4 (branch)	-59	-5.8
IS-02	TAFB-SF #2	Tree R1T4 (branch)	-58	-5.7
IS-03	TAFB-SF #3	Tree R1T4 (branch)	-59	-4.2
IS-04	TAFB-SF #4	Tree R1T4 (branch)	-58	-5.9
	Average		-59	-5.4
PV-50	Groundwater	well 755phyto26	-45	-6.5
PV-52	Groundwater	well 755phyto26	-54	-6.1
PV-54	Groundwater	well 755phyto26	-47	-7.0
PV-56	Groundwater	well 755phyto26	-47	-6.5
PV-63	Groundwater	well 755phyto26	-50	-6.4
PV-64	Groundwater	well 755phyto26	-51	-6.1
	Average		-49	-6.4
		standard: smow		

Figure A1. Photo of Phytovolatilization Sampling at Travis AFB.

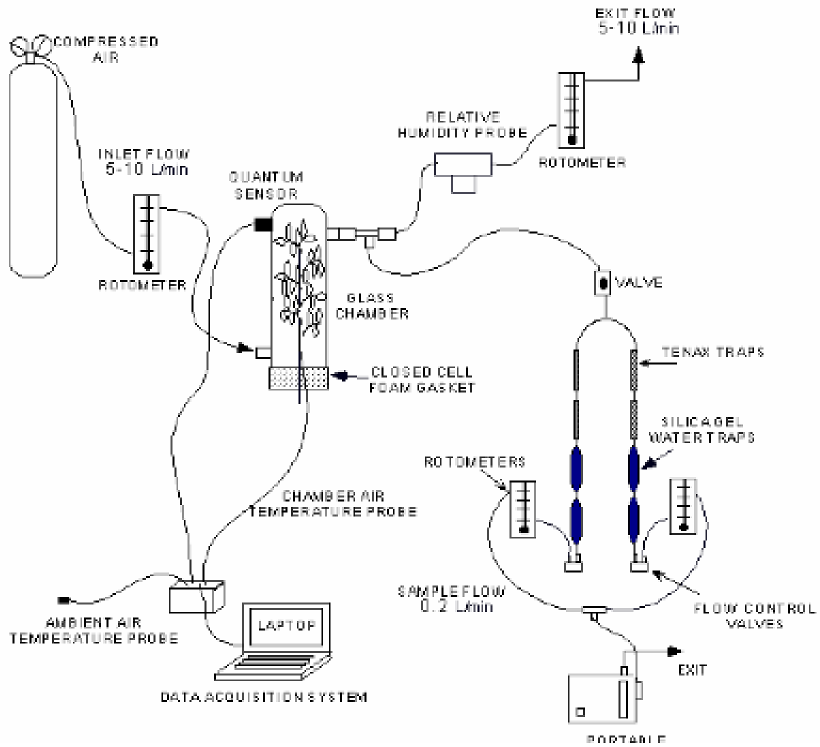

Figure A2. Schematic of Phytovolatilization Sampling System.

APPENDIX E

COST AND PERFORMANCE REPORT

FINAL
ADDENDUM REPORT NO. 3

TO THE

INTERIM COST AND PERFORMANCE REPORT FOR THE DEMONSTRATION OF PHYTOSTABILIZATION OF SHALLOW CONTAMINATED GROUNDWATER USING TREE PLANTINGS AT TRAVIS AIR FORCE BASE, CALIFORNIA

September 2005

Prepared for

Air Force Center for Environmental Excellence
Environmental Science Division
Brooks City-Base, Texas

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FINAL
ADDENDUM REPORT NO. 3
TO THE
INTERIM COST AND PERFORMANCE REPORT FOR THE DEMONSTRATION OF PHYTOSTABILIZATION OF SHALLOW CONTAMINATED GROUNDWATER USING TREE PLANTINGS AT TRAVIS AIR FORCE BASE, CALIFORNIA

PROGRAM DESCRIPTION

This project is part of an initiative being conducted by the Air Force Center for Environmental Excellence Environmental Science Division (AFCEE/TDE) in conjunction with Parsons Infrastructure and Technology Group, Inc. (Parsons). AFCEE/TDE has implemented a multi-site program to independently evaluate phytostabilization of chlorinated solvents. The primary goal of this multi-site initiative is to develop a systematic process for scientifically investigating and documenting the potential for hydraulic control of groundwater contaminant plumes by the use of tree plantings.

BACKGROUND INFORMATION

Travis Air Force Base (AFB) is an Air Mobility Command (AMC) installation located in Solano County, California, approximately 5 kilometers (km) east of the city of Fairfield, California, midway between the cities of San Francisco and Sacramento. The primary mission of Travis AFB is to provide rapid, responsive, reliable airlift of forces to any point on earth in support of our national objectives and to fulfill the global logistics needs of the Department of Defense (DoD) in sustaining its world-wide activities. Known as the "Gateway to the Pacific," Travis AFB handles more cargo and passenger traffic through its aerial port than any other military air terminal in the United States.

The 1.2-hectare (3-acre) phytostabilization demonstration site at Travis AFB is located in an area designated as the West/Annexes/Basewide Operable Unit (WABOU). Within this OU, Building 755 is a Battery and Electric Shop with a former battery acid neutralization sump. Groundwater below and immediately downgradient of this former sump is contaminated with chlorinated aliphatic hydrocarbons (CAHs). The contaminant plume is located approximately 5 meters below ground surface (bgs) and extends approximately 500 meters downgradient of the source area. Building 755 was selected as the candidate site for this demonstration due to several compatible site conditions.

The land surrounding the Base is used primarily for agriculture. The northeastern portion of the Base is bordered by irrigated croplands. Travis AFB is situated on a generally flat alluvial plain bounded on the north and west by low hills. Surface water hydrology from the site consists of sheet flow to the south and southeast. The West Branch of Union Creek is located approximately 457 meters (1,500 feet) to the east of the site. At the planting area, groundwater is located at approximately 4.6 to 6 meters bgs. General climate and soil characteristics are shown in Table 1.

INITIAL ACTIVITIES

Prior to planting activities, monitoring points (MPs) were installed in 1998 at 10 locations to monitor groundwater conditions. Initial planting activities included site preparation, irrigation system installation, tree planting, automated site monitoring equipment installation, baseline groundwater sampling, and other construction activities. Red ironbark (*Eucalyptus sideroxylon* 'Rosea') was specified for use at Travis AFB because of its presence on Base, water use, and its availability at local nurseries. In addition, the species is a broadleaf evergreen that will not lose its leaves in the winter.

The planting of the site started in November 1998 with 100, 15-gallon-size trees covering approximately 0.2 hectare (0.5 acre). Trees were planted in planting pits above holes that were augered to the groundwater table, backfilled with permeable material, and a vent pipe was inserted. In April and July 2000, the site was expanded by 380 1-gallon-size trees for a total areal coverage of approximately 0.91 hectare (2.24 acres). Planting was completed in a more conventional fashion during this expansion (i.e., no augered holes). In conjunction with the additional trees, additional monitoring and irrigation equipment were installed.

For a detailed technology description of this phytostabilization demonstration please refer to the *Final Interim Technical Report for the Demonstration of Phytostabilization of*

TABLE 1
SITE CHARACTERISTICS
PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AFB, CALIFORNIA

Parameter	Value
Climate conditions	Temperature range: 4°C[a/] to 41°C Growing season: Predominantly year-round Annual average precipitation: 570 mm[b/]
Annual average ET[c/] rate	1,245 mm
Soil texture	Silt and clay loam mixtures
Soil pH	7.2 standard units
Soil fertility	0.03 to 7.6 ppm[d/] nitrate-nitrogen No Data ppm potassium No Data ppm phosphorous
Primary CAH[e/] contaminants	490 µg/L to 17,000 µg/L[f/] TCE[g/] 5 µg/L to 120 µg/L cis-1,2-DCE[h/]

[a/] °C = degrees Celsius
[b/] mm = millimeters
[c/] ET = evapotranspiration
[d/] ppm = parts per million
[e/] CAH = chlorinated aliphatic hydrocarbon
[f/] µg/L = micrograms per liter
[g/] TCE = trichloroethene; Data from 2000 sampling event wells 01HSPSD through 10HSPSD.
[h/] DCE = dichloroethene

Shallow Contaminated Groundwater Using Tree Plantings at Multiple Air Force Demonstration Sites (Parsons, 2003).

TECHNOLOGY PERFORMANCE AND ONGOING OPERATION MAINTENANCE AND MONITORING ACTIVITIES

At Building 755, the phytostabilization demonstration was implemented to evaluate the ability to treat and control the migration of a shallow groundwater plume containing dissolved chlorinated solvents that is moving downgradient from its source. It is estimated that approximately two to four more years of data need to be collected to establish the trees' impact on groundwater.

During the first five growing seasons, mortality rates of the trees were fairly low. Of the 100 trees that were planted in 1998, six trees (6 percent) were replaced after the first growing season because of freeze damage. From the second to fifth growing season, there was no additional mortality of the initial plantings. In 2000 and 2001, 20 (5 percent) of the 380 supplemental trees died and were either replaced or removed. During the third year (2002) of growth, another 9 supplemental trees (2 percent) died. In 2003, 25 additional trees died or were nearly dead (7 percent mortality of the remaining trees). In 2004, an additional 7 supplemental trees (2 percent) died or fell over. Trees that were lost from 2002 to 2004 were not replaced. A total of 100 trees from the initial planting and 342 trees (90 percent) from the supplemental planting remain at the end of the demonstration project.

After six years, the initial 100 trees ranged in height from 5.5 meters to 7.6 meters, or an average of 7.0 meters. The trees planted in 2000 range from 0.3 meters to 5.8 meters in height, or an average of 3.7 meters (after four growing seasons). Wind stress on the trees has been the largest maintenance issue to date. Irrigation, pruning, and weed control activities have been successful.

Data collected from the weather station indicate below average precipitation in most years of the demonstration project. The planting area used 6.8 million liters (1.8 million gallons) of water for irrigation, mainly in the first few years. From October 1998 to November 1999 (first growing season), 1,135,600 liters (300,000 gallons) of irrigation water were applied to the 0.91-hectare site. From January to December 2000 (second growing season for the initial trees and first growing season for the smaller trees), 3,492,110 liters (922,545 gallons) of water were applied to the 0.91-hectare site. From January to December 2001 (third growing season for the initial trees and second growing season for the smaller trees), 2,120,487 liters (560,190 gallons) were applied to the site. For the fourth growing season, irrigation was cut off to the initial trees and 408,207 liters (107,840 gallons) were applied to the supplemental trees; significantly lower water amounts than previous years. No irrigation water was applied to any of the trees in 2003 or 2004.

Estimated and measured water use of the trees planted in 1998 from their second to fifth growing season averaged 0.01 to 0.1 millimeter (12 to 164 liters) per day per tree. In the sixth growing season (2004), the estimated water use for these trees ranged from 0.02 to 0.34 millimeters (49 to 710 liters) per day per tree. A simple water balance completed for the 1998 plantings indicated that the there was a water surplus in the second and third growing season, but a deficit occurred in the fourth, fifth, and sixth season. Therefore, the trees required soil moisture and groundwater to account for the water deficit.

Plant tissue, isotope, groundwater, and phytovolatilization sampling was conducted in 2004. Groundwater was tested for various organic, inorganic, and geochemical indicators. Additionally, plant tissue sampling was conducted to evaluate the potential for trees to uptake and translocate contaminants (namely trichloroethene [TCE]) from the groundwater system. To determine the source or sources (e.g., irrigation water, groundwater, precipitation) of water that was taken up by plants; stable isotope (i.e., oxygen and hydrogen) analyses were conducted on tree cores and compared to the isotopes in the different sources of water collected. Lastly, phytovolatilization sampling was conducted by Utah State University to determine if TCE was being transpired through the leaves.

Overall, the phytostabilization demonstration project at Travis AFB has shown positive results in the potential uptake of contaminants from the Building 755 groundwater plume. As the plant stand grows in size to close the canopy and increase its root mass, increased water uptake will result.

DEMONSTRATION COSTS

The costs for this site can be divided into two categories; initial capital and actual OM&M costs. Initial capital costs included background screening, work plan development, site development and initial planting, final reporting, and project management. The initial costs do not include irrigation water supply and fence installation, which were supplied by the Base. Actual OM&M costs included tree replacement, weeding, pruning, and monitoring of site conditions such as climate data, soil moisture, and groundwater levels. As of December 2004, $331,076 has been spent on site development and six years of maintenance of the trees. Yearly maintenance and monitoring costs averaged $36,400 per year. This annual OM&M cost is higher than what could be expected at a normal site because of the increased sampling associated with the nature of the project (i.e., a demonstration). Table 2 shows a breakdown of project costs. Utah State University Water Research Laboratory costs for tissue and isotope analyses and phytovolatilization sampling and analyses have been broken out from each year's total OM&M costs for reference.

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REFERENCES

Parsons. 2003. *Final Interim Technical Report for the Demonstration of Phytostabilization of Shallow Contaminated Groundwater Using Tree Plantings at Multiple Air Force Demonstration Sites.* January.

TABLE 2

DEMONSTRATION COSTS

PHYTOSTABILIZATION DEMONSTRATION
BUILDING 755
TRAVIS AFB, CALIFORNIA

Initial Capital Costs	
Background Screening	**$6,033**
Work Plan Development	**$10,937**
Planting	**$76,636**
Data Acquisition System	**$22,000**
Interim Report	**$12,820**
Piezometer Installation/CPT	**$17,042**
Total Initial Cost	**$145,468**
OM&M Costs	
OM&M 1999	**$3,571**
OM&M 2000	**$28,877**
OM&M 2001	**$20,697**
OM&M 2002	**$30,894**
OM&M 2003	**$55,380**
Tree-Specific Monitoring [a/]	*($14,405)*
OM&M 2004 [b/]	**$46,189**
Tree-Specific Monitoring [a/]	*($22,000)*
Total OM&M Cost	**$185,608**

[a/] Costs associated with plant tissue and isotope analyses, as well as phytovolatilization sampling and analyses.

[b/] Includes preparation costs of final Addendum Report No. 3.