Phytoremediation to Prevent the NPS Discharge of Gasoline Contaminated Ground Water to the Pasquotank River.

Division of Water Quality, North Carolina Department of Environment and Natural Resources Section 319 US EPA Federal NPS Program

2009

Contract# EW06028

October 1st, 2005 to April 30th, 2009

$145,054

Elizabeth Guthrie Nichols, Ph.D.
Associate Professor
Environmental Technology Program
Department of Forestry and Environmental Resources
North Carolina State University

April 30th, 2009

Acknowledgements

We would like to thank Pete Lazaro, David Black, Thorne Gregory, Dr. Morton Barlaz for their assistance with petroleum hydrocarbon analyses at North Carolina State University (NCSU). We also thank George Shaw of Gore Environmental for soil gas analyses. We also thank Dr. Ted Shear (NCSU) and Dr. Heather Cheshire (NCSU) for their assistance with of global positioning and geographical information systems. We also thank Easter Carolina Landscaping Company and training cadets at the US Coast Guard Training Center for assistance with tree planting.

This work was supported with funds from the EPA/NC DENR Division of Water Quality 319 NPS Pollution Control Grant #EW06028, the U.S Coast Guard and Department of Homeland Security Am, British Petroleum America, the U.S. Geological Survey Cooperative Water and Toxic Substances Hydrology Programs, and North Carolina State Universty..

Project Collaborators and Contributors

James E. Landmeyer, Ph.D., U. S. Geological Survey, S.C. Water Science Center, Columbia, SC, USA

Brad Atkinson, North Carolina Department of Environment and Natural Resources-Division of Waste Management, Raleigh, NC, USA

Jean-Pierre Messier, U.S. Department of Homeland Security, U. S. Coast Guard, Elizabeth City, North Carolina, USA

Elizabeth Guthrie Nichols, Ph.D., North Carolina State University, Department of Forest and Environmental Resources, Raleigh, NC, USA

Rachel L. Cook, (M.Sc. Graduate Student), North Carolina State University, Department of Forest and Environmental Resources, Raleigh, NC, USA

Jeff Welty, NC Division of Waste Management, Washington, NC 27889

Davis Tsao, Ph.D., BP America, Inc. Naperville, IL 60563

CAPT. Joseph L. Salyer, RS, MPH, Environmental Health Specialist, Chief, Environmental Compliance Division, US Coast Guard Support Center, Elizabeth City, NC 27909

Joseph Rose, High School student, Elizabeth City, NC

Table of Contents

	page
Acknowledgements	**1**
Table of Contents	**2**
List of Tables, figures, abbreviations	**3**
Executive Summary	**4**
Introduction /Background	**7**
Purpose and Goals	**10**
Deliverables	**11**
Methodology/Execution	**13**
Outputs and Results	**19**
Outcomes and Conclusions	**23**
Budget	**25**
References	**26**
Appendices	**29**

List of Figures

page

Figure A. After planting the site with trees in April 2007, there was a substantial soil gas mass loss (µg) of benzene, toluene, ethylbenzene, and xylenes (BTEX) after one and half growing seasons for the trees (July 2008). 5

Figure B. After planting the site with trees in April 2007, there was a substantial soil gas mass loss (µg) of total petroleum hydrocarbons (TPH) in soil gas as measured in July 2008. TPH would represent BTEX plus larger, volatile petroleum hydrocarbons. Most of the trees that did not survive the 2007 planting, with 13% mortality recorded in 2008, were in the hot zones or red areas. 5

Figure 1. Satellite image of the former fuel farm (FFF) and the aboveground tanks of the current fueling station [C] at the US Coast Guard Support Center, Elizabeth City, NC. 8

Figure 2 (A) Location of fuel storage areas in 1942 at the Former Fuel Farm Site, US Coast Guard Support Center, Elizabeth City, NC. (B) Soil gas analyses show greater total petroleum hydrocarbon (TPH) mass (µg) in areas of former fuel bunkers (GORE™, 2007). Note: Photo and soil gas map are oriented to same direction. 8

Figure 3. Ground water monitoring wells installed in 2006 for 319 project. 9

Figure 4. Overall planting design of phytoremediation plan. 10

Figure 5. USCG efforts to educate base personnel and recreational users of collaborative efforts of 319 project. 12

Figure 6. 2008 Inventory of tree growth (size of green dots) and areas with high subsurface fuel contamination (red). 17

Figure 7. Example of different tree growths at the FFF site (June 2008). Trees were planted in 2007.1 18

Figure 8. After planting the site with trees in April 2007, there was a substantial soil gas mass loss (µg) of benzene, toluene, ethylbenzene, and xylenes (BTEX) after one and half growing seasons for the trees (July 2008). 19

Figure 9. After planting the site with trees in April 2007, there was a substantial soil gas mass loss (µg) of total petroleum hydrocarbons (TPH) in soil gas as measured in July 2008. TPH would represent BTEX plus larger, volatile petroleum hydrocarbons. Most of the trees that did not survive the 2007 planting, with 13% mortality recorded in 2008, were in the hot zones or red areas. 19

Figure 10. Average soil gas masses decrease from 2007 to 2008. Total Petroleum Hydrocarbon mass is pulled out for scale. All constituents labeled with percent decrease are statistically significant ($P<0.001$). Significance based on Wilcoxon Signed Ranks test 20

Figure 11. Petroleum (BTEX) and fuel oxygenate (MTBE) concentrations in ground water at monitoring wells installed for 319 (EW06028) project. Wells were installed in April 2006. The NC 2L ground water standard for benzene is 1g/L. 20

Figure 12. Wells monitored for ground water contamination by USCG since 1993. The yellow circle highlights well 14 that is down gradient from the trees and an important well to monitor the effect of the trees on fuel migration towards the river. 21

Figure 13. Petroleum hydrocarbons (BTEX) concentrations in ground water at monitoring wells since June 2001. Wells have been monitored since 1993. The NC 2L ground water standard for benzene is 1g/L. The dotted green line marks the when trees were first planted. 21

Figure 14. 2007 Soil gas TPH (µg) overlaid by tree mortality and total stem length (cm). 22

Executive Summary

Coastal plain surface waters are particularly vulnerable to underground storage tank (USTs) contamination due to shallow water tables, porous soils, and proximity of USTs to surface water bodies. Phytoremediation uses plants to remediate or contain contaminants at a relatively low cost. This project established a viable tree community (2,984 trees) at the Former Fuel Farm, United States Coast Guard Support Center (USCG) in Elizabeth City, NC., with the goal to prevent further ground water discharge of gasoline, fuel oxygenates, and fuel oils to the Pasquotank River. Specific project objectives were to establish a viable tree community and assess the impact of the tree community on contaminant concentrations in ground water. The field site is 150 meters from the river with approximately 150,000 to 200,000 gallons of free fuel product in the subsurface. Fuel oils and gasoline exist in a smear zone 3-4 feet below ground surface. The ground water table fluctuates from 4 to 9 feet below surface except after major precipitation events. During these events, the water table may rise to ground surface and bring dissolved fuel constituents up with it.

Tree planting began in 2006, but previously unquantified fuel sources on part of the site resulted in high tree mortality (28%). Fuel contamination on the site was very well characterized and documented, but ground water data did not indicate contamination in the southeastern portion of the site. We determined the presence of this contamination by measuring volatile fuels in the soil column for the entire site using soil gas analyses. This screening helped delineate "hot spots" and was not part of the original 319 grant. Funds from the USCG and in kind support from W.L. Gore and Associates, Inc. of Elkton, Maryland enabled this assessment. The hot spots detected by soil gas analyses matched historical locations of former fuel bunkers used in World War II.

After delineating these hot spots of contamination, we changed our planting methods to provide trees a better chance to establish root systems before interacting with contaminated ground water and soil. In 2007, trees were planted in four foot deep, 9 inch augered holes that were back filled with clean top soil and then mulched. Most of the trees now on site (2,196) were planted in 2007 after which tree mortality declined to 13% which is an acceptable range of tree mortality and a much lower loss reported for similar contaminated sites in the U.S. Hybrid poplars survived and grew better than the three willow species planted so most of the site consists of hybrid poplar trees (90%). In 2008, each tree's location was spatially recorded using GPS, and each tree was measured by hand for total stem length as a metric of tree growth. Trees did not grow as well where subsurface contamination was greatest. The 13% mortality measured in 2008 for trees planted in 2007 were primarily in two 30 x 30 meter areas where the former fuel bunkers existed. An alternative planting design is suggested for future planting in these two areas, for example, native grasses. We believe trees planted in these two areas have less opportunity to establish roots prior to lethal exposure to contaminated ground water.

During the tree installation process (April 2006 until April 2008), petroleum hydrocarbons and fuel oxygenates were monitored using ground water samples and soil gas analyses. The USCG continued to monitor ground water wells already on site prior to project activities, and NCSU monitored ground water wells installed specifically for the 319 project. Brad Atkinson (NCDENR) coordinated and conducted soil gas analyses with W.L. Gore and Associates. The costs of these analyses were shared by USCG and Gore Associates and were not part of the original 319 proposal.

Figures A and B show the difference in estimated fuel mass in soil vapors, or residual buildup of subsurface contaminant vapors, between February 2007 (before the major tree planting in April 2007) and one and a half growing seasons later (July 2008). Substantial declines in contaminant masses in soil gases is evident for the lighter fuel fractions, benzene, toluene, ethylbenzene, and

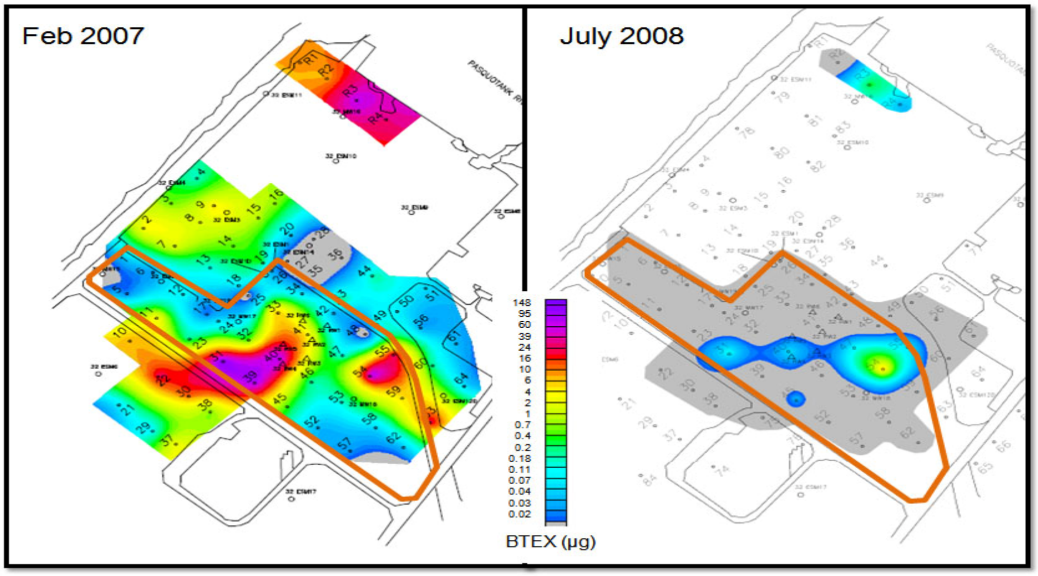

Figure A. After planting the site with trees in April 2007, there was a substantial soil gas mass loss (µg) of benzene, toluene, ethylbenzene, and xylenes (BTEX) after one and half growing seasons for the trees (July 2008).

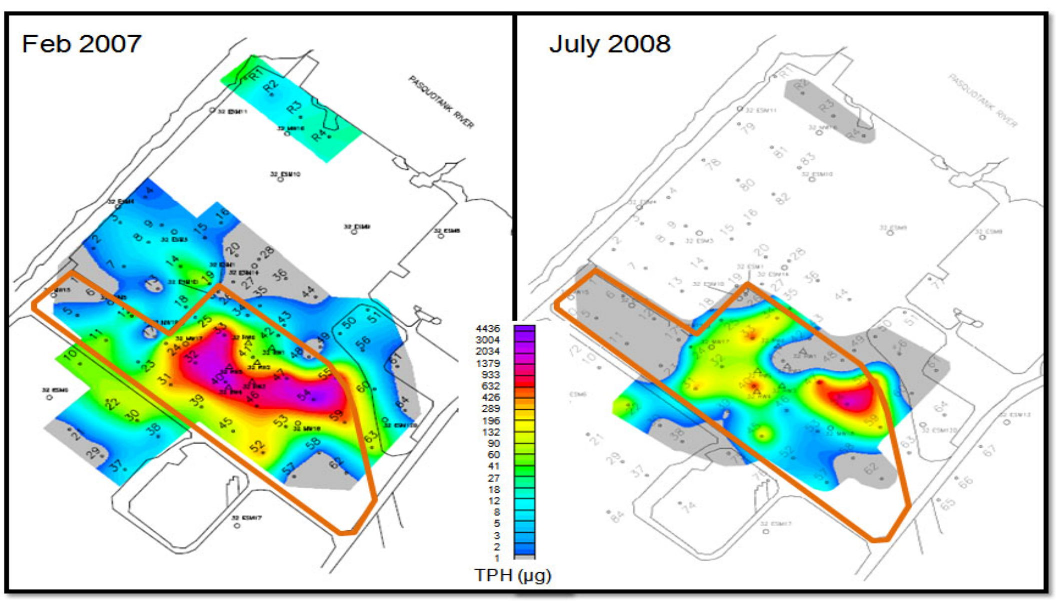

Figure B. After planting the site with trees in April 2007, there was a substantial soil gas mass loss (µg) of total petroleum hydrocarbons (TPH) in soil gas as measured in July 2008. TPH would represent BTEX plus larger, volatile petroleum hydrocarbons. Most of the trees that did not survive the 2007 planting, with 13% mortality recorded in 2008, were in the hot zones or red areas.

xylene (BTEX), and all volatile fractions of fuel between February 2007 and July 2008.

Analysis of fuel contaminants in ground water also showed a discrete reduction in contaminant levels after tree plantings. In April 2006, 319 funds were used to install new ground water monitoring wells and monitor them for changes to BTEX and MTBE concentrations in ground water. Dramatic decreases in BTEX (79%) and MTBE (96%) were observed for ground water at these new monitoring wells. Other monitoring wells were already on site and sampled for compliance monitoring by USCG. As observed for soil gas analyses and 319 ground water analyses, USCG wells also showed dramatic declines for BTEX constituents after installation of the trees.

Project costs were supported with funds from the 319 program, an in kind cash match from British Petroleum America and W.L. Gore and Associates, salary, tuition, and travel costs match from North Carolina State University, and federal matches from the United States Geological Survey and U.S. Coast Guard. Tree mortality due to site conditions and unexpected "hot spots" of contamination extended the time projected to complete phase I and II, site characterization (Phase I) and installation of the phytoremediation system (Phase II). Support from industry was critical to over-coming unexpected site challenges.

We have presented compelling data that partially meets our prior 319 funding Phase III and IV objectives to effectively monitor, assess, and verify the performance of the phytoremediation system in meeting project goals. Our preliminary results suggest that this system is decreasing subsurface contamination in the site footprint as well as decreasing pollution entering the Pasquotank River by retarding ground water discharge of fuel contaminants from the site footprint via hydraulic control. If true, contaminant results and data on tree mortality/growth will make this particular site of great interest not only to relevant government, academic, and private industry stakeholders in North Carolina but across the country. However, these data represent only one monitored time point (2008) of changes to fuel contamination in the subsurface after the installation of the trees. The important and critical benchmark is ***Verification***. Future efforts will verify and optimize the performance of this tree system.

Phytoremediation is not yet approved for reimbursement by the State of North Carolina Underground Storage Tank (UST) Trust fund. Therefore, this remedial option is not pursued by companies engaged in cleaning up contaminated soil and groundwater at UST sites. Successful phytoremediation projects at UST sites in North Carolina are needed before reimbursement will be authorized from the UST Trust Fund on anything other than a demonstration project basis. If reimbursement is approved, more firms can be expected to use this technology near surface water bodies to protect surface waters. Verification of this site's performance will be critically important to remedial options and expectations in the near future for more affordable technologies that achieve ground water control of contaminated sites and remediate contaminants in soil and ground water. An important aspect of this project is to disseminate verification results to UST stakeholders tasked with soil and groundwater remediation at UST sites.

This project has resulted in one Master's of Science thesis, one peer-reviewed publication, five presentations at scientific conferences, three invited talks, one high school senior project (Elizabeth City), and 13 quarterly reports.. The USCG as part of the base's effort to promote environmental awareness and sustainability.

Introduction /Background

Describe the background to the project.

Leaking underground storage tanks (USTs) at commercial and residential sites continue to release kerosene, gasoline, fuel oil, and oxygenated fuel additives such as MTBE to surface waters by direct surface discharge or via groundwater discharge to surface waters and surface water sediments. A recent U.S. Government Accounting Office assessment (2001) reported that 29% of regulated USTs (201,001 USTs nationwide) were not properly operated or maintained to prevent leaks (USGAO, 2001). Even properly maintained USTs can still leak 6,632 liters (1,752 gallons) per year because federal UST regulations require UST leak detection systems to detect only 0.8 liters or more per hour (Moyer, 2003). Although leaking USTs at commercial sites attract more regulatory attention, leaking USTs at private residences also occur and can contribute to non point source pollution to surface waters.

North Carolina has sustained over 19,300 known releases from different Underground Storage Tank (UST) sites across the state. 5,790 sites have confirmed impact to groundwater above the North Carolina 2L Groundwater Standards (personal communication, Brad Atkinson, DWM). Generally, assessment and remediation costs at sites with fuel and gasoline releases are paid by federal and state funded UST Trust Funds after deductibles ranging ($20,000 -$75,000). For 2002-2003, the State UST Trust Fund expended approximately 29 million dollars to address petroleum releases from USTs. However, revenues to the Trust Fund were approximately 28 million dollars for that same time period resulting in a 1 million dollar shortfall for the year. Less expensive yet effective remedial alternatives are needed: (1) to relieve financial pressures on the UST Trust Fund; (2) to ensure as many sites as possible are cleaned up to acceptable levels; and (3) to protect public health and valuable groundwater and surface water resources.

Coastal plain surface waters may be particularly vulnerable to UST contamination due to shallow water tables, porous soils, and proximity of USTs to surface water bodies. Phytoremediation, a relatively low cost/low maintenance technology, uses plants to remediate or contain contaminants. At sites with groundwater contamination, trees are used to reduce the contaminant levels in the groundwater and to reduce the overall volume of water migrating from the site. Candidate sites must have a relatively shallow water table where trees can be planted. Frequently, sites that meet these conditions are located near surface water bodies. The vegetated systems can be designed: to remove contaminants from contaminated water prior to discharge to surface water; to control and contain contaminated groundwater migration toward the surface water discharge point; and to restore contaminated soil and groundwater. Monitored Phytoattenuation (MPA) systems are potential cost-effective strategies to protect surface waters from UST discharges (Landmeyer, 2001).

Phytoremediation is not yet approved for reimbursement by the UST Trust fund. Therefore, this remedial option is not pursued by companies engaged in cleaning up contaminated soil and groundwater at UST sites. Successful phytoremediation projects at UST sites in North Carolina are needed before reimbursement will be authorized from the UST Trust Fund on anything other than a demonstration project basis. If reimbursement is approved, more firms can be expected to use this technology near surface water bodies.
Guard Support Center, Elizabeth City, NC.

We selected a site on the Pasquotank River to implement an innovative phytoremediation system. The Former Fuel Farm Site (FFFS) at the US Coast Guard Support Center (Elizabeth City, NC, Pasquotank Co.) is a site with direct discharge of a mixed gasoline and fuel oil to the Pasquotank River (see Figure 1). From 1942 to 1991, the USCG operated the FFFS for aircraft refueling and contained seven concrete and steel underground storage tanks (USTs) and two aboveground storage tanks (ASTs). The Pasquotank river lies approximately 600 feet northeast of the site; remaining free product is approximately 500 feet from the river.

Figure 1. Satellite image of the former fuel farm (FFF) and the aboveground tanks of the current fueling station [C] at the US Coast Guard Support Center, Elizabeth City, NC.

Groundwater samples in 2004 indicated areas where petroleum contamination such as benzene were significantly greater than the NC 2L Groundwater Standard of 1µg/L (Arcadis 33RD Groundwater Monitoring Report, 2004). Figure 2 shows concentrations of total petroleum hydrocarbons (TPH) determined by soil gas analyses by W.L. Gore and Associates (GORE™ Surveys Final Report, 2007). In February 2007, this area contained an estimated 150-200,000 gallons of free-product fuels in the near surface soils (4 feet) and floating on top of the ground water (3-9 feet)(Figure 2B) that reflect areas where prior above ground and below ground storage tanks existed (Figure 2A). Contamination was also detected at the river (Figure 2B). Prior efforts by USCG to remove remaining petroleum free product had not been very successful. The free product plume is approximately 2.65 acres in size; further efforts to remove free product are not likely. ***Therefore, this site provided the opportunity to demonstrate the ability of a vegetative system to contain residual free product and to retard the migration of dissolved phased petroleum to the river***.

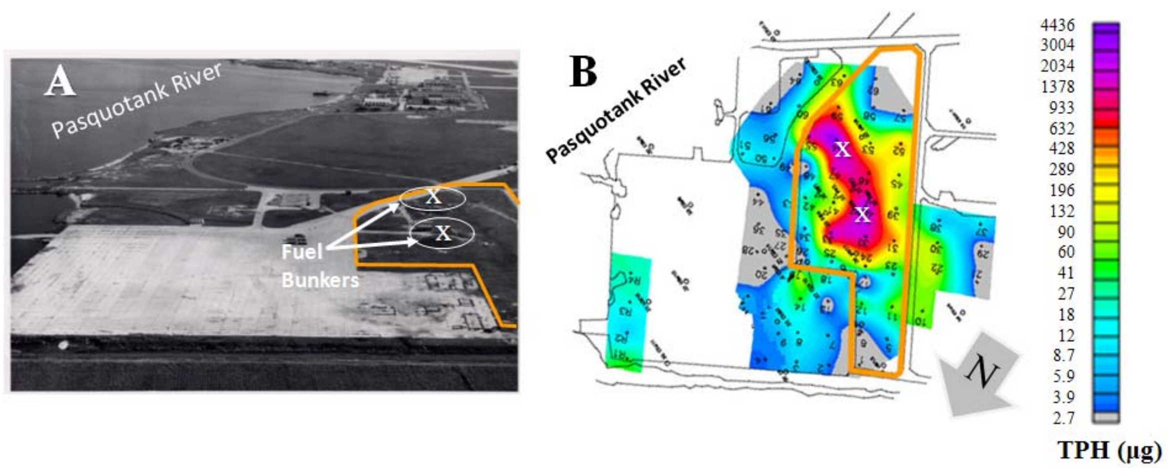

Figure 2 **(A)** Location of fuel storage areas in 1942 at the Former Fuel Farm Site, US Coast Guard Support Center, Elizabeth City, NC. **(B)** Soil gas analyses show greater total petroleum hydrocarbon (TPH) mass (µg) in areas of former fuel bunkers (**GORE™, 2007).** Note: Photo and soil gas map are oriented to same direction.

Explain the problem and how the project sought to address it.
The approach to solving the problem of surface water degradation and release of fuels to the Pasquotank River from contaminated ground water is based on the fact that plants such as trees take up groundwater to meet evapotranspirational demands. Such plants are called "phreatophytes", literally meaning "*well plant*." Although such phreatophytes are found naturally along floodplains in the humid Southeastern United States (such as river birch and sycamore), these trees also rely on surface water and recent rainfall to meet evapotranspirational demands, in addition to using groundwater. Moreover, the natural distribution of such native trees is not typically dense enough to achieve significant reductions in groundwater flux necessary to reach remedial goals within realistic timeframes.

The *designed* installation of phreatophytes, however, enables the trees to be planted in groves dense enough to affect groundwater flow and contaminant concentrations. Used in a regulatory context in conjunction with ambient natural attenuation processes, the technology can be referred to as Monitored Phytoattenuation (MPA). MPA can be used to achieve the goals of hydraulic control and/or containment, as well as contaminant remediation to prevent and reduce release of subsurface contaminants to surface waters.

The approach to achieve this goal consisted of four phases. In brief:

- Phase I involved additional site characterization to establish baseline, or pre-phytoremediation, conditions of groundwater and surface water flow and contamination was used to determine the exact requirements for successful tree installation and survival.
- Phase II included the installation of the phytoremediation system.
- Phase III was focused on efforts to collect appropriate field data to effectively monitor, assess, and verify the performance of the phytoremediation system in meeting project goals.
- Phase IV consisted of data synthesis and interpretation, and preparation of a draft final report.

Using ground water data from USCG required monitoring for 2004 and 2005, additional ground water monitoring wells were installed as shown in Figure 3. A mixed hybrid poplar (Populus spp.)

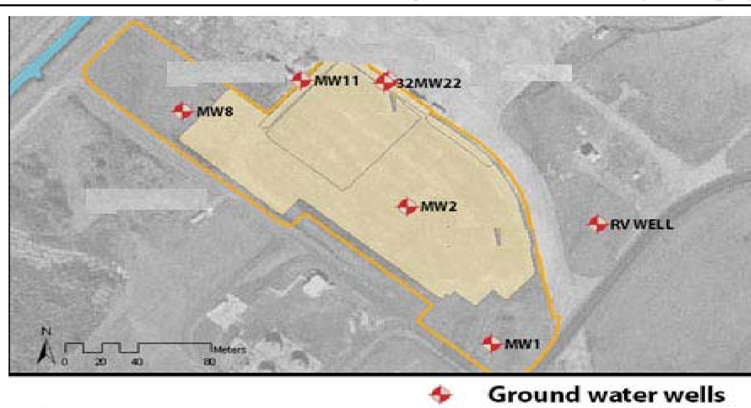

Figure 3. Ground water monitoring wells installed in 2006 for 319 project.

and willow (Salix sp.) phytoremediation was installed from April 2006 until April 2008 as shown below in Figure 4. *Pinus taeda* (loblolly pine) was also planted across the site and particularly in a random-selected control plot installed in April 2008. The general planting design for the site is shown below in Figure 4.

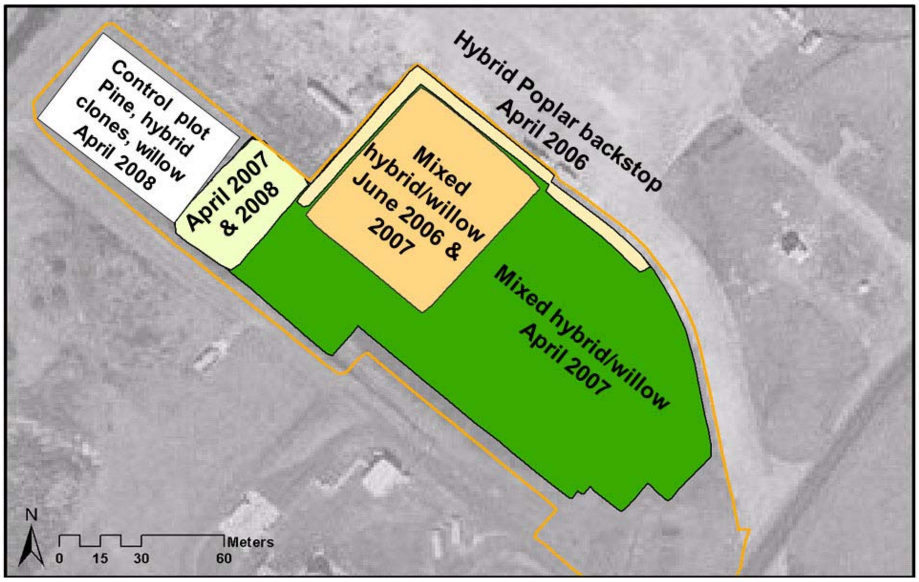

Figure 4. Overall planting design of phytoremediation plan.

Purpose and Goals

The overall goal of this project was to use trees to decrease the discharge of ground water contaminated with fuel oxygenates, gasoline, and fuel oils to a sensitive surface water receptor, the Pasquotank River. Our objectives were to successfully establish a viable tree community on site to retard ground water discharge of contaminants to the Pasquotank river and to enhance natural attenuation of the remaining contaminated footprint of residual fuel contamination in the actual site. Our goals did not change during the project but the project was extended without cost from October 30th, 2008 until April 30th, 2009.

Tree mortality due to site conditions and unquantified “hot spots” of contamination extended the time projected to complete phase I and II, site characterization (Phase I) and installation of the phytoremediation system (Phase II). The impact of unquantified contamination on the project timeline, work plan, and budget are detailed in the Methodology/Execution section and Budget sections.

Despite initial tree mortalities and the need to change our planting methods and replant portions of the site, we do provide compelling data in the Output and Results section that a viable tree community was established and Phase III (monitoring of site) and Phase IV (analysis of site data) efforts show measurable reductions of fuel contamination in the site foot print as well as reductions in contaminant discharge to the Pasquotank River.

Deliverables

List the deliverables as stated in the accepted and contracted workplan.

1. Quarterly progress reports will be submitted after the start date and will include:

   - **Participants and time**- people on the project
   - **Activities and findings**: Summarize the major activities of project and results for year
   - **Publications and Products**: list published, in press, and submitted papers, titles of talks and papers presented at meetings.

2. Final Project Report due at termination of project funding – 8/30/08.

Describe the tangible deliverables the project produced.

Quarterly Reports.

13 Quarterly Reports starting Oct/Dec 2005 until Oct/Dec 2008.

Peer-Reviewed Publications:

Cook. R. L., J. Landmeyer, B. Atkinson, J.P. Messier, Elizabeth Guthrie Nichols. *Field Note: Successful Establishment of a Phytoremediation System at a Petroleum Hydrocarbon Contaminated Shallow Aquifer: Trends, Trials, and Tribulations*. In Review: *International Journal of Phytoremediation.*

Theses:

Cook, R.L. 2008. Phytoremediation of a Petroleum-Hydrocarbon Contaminated Shallow Aquifer, Elizabeth City, NC: Planting Methods and Preliminary Results. M.Sc. Thesis, North Carolina State University.

Presentations:

Nichols, E. Guthrie, Cook. R. L., J. Landmeyer, B. Atkinson, J.P. Messier. 2009. *How to Torture Trees and Still Remediate*. Spring 2009 Annual Meeting of the Carolinas Chapter of the Society of Environmental Toxicology and Chemistry (Carolinas SETAC), The Citadel, Charleston, SC, March 26-28, 2009.

Cook. R. L., J. Landmeyer, B. Atkinson, J.P. Messier, Elizabeth Guthrie Nichols. *Using geographical information systems (GIS) and spatial relationships to monitor petroleum-hydrocarbon contaminants and tree growth at a field scale phytoremediation system, U.S. Coast Guard Support Center, Elizabeth City, North Carolina, USA.* 5th International Phytotechnology Conference in Nanjing, China from October 22-25, 2008.

Cook. R. L., J. Landmeyer, B. Atkinson, J.P. Messier, Elizabeth Guthrie Nichols. *Comparison of planting methods effects on tree height and mortality at a U.S. Coast Guard site contaminated with petroleum-hydrocarbons*. 5th International Phytotechnology Conference in Nanjing, China from October 22-25, 2008.

Cook, R.L., J. Landmeyer, B. Atkinson, J.P. Messier, and E. Guthrie Nichols. 2008. *Phytoremediation of a Petroleum-Hydrocarbon Contaminated Aquifer.* 3rd Annual NCSU Graduate Student Research Symposium, March 19th, Raleigh, NC.

Nichols, E. Guthrie. 2008. "*Phytotechnologies and Dendro-Forensics*." Forestry Seminar Speaker. North Carolina State University, Raleigh, NC. February 4th, 2008.

Nichols, E. Guthrie 2008. "*Phytotechnologies*" ET 202, Soil and Plant Monitoring. North Carolina State University, Raleigh, NC. January 21st, 2008.

Nichols, E. Guthrie. 2007. "*Phytoremediation*." FOR 295I. CNR Undesignated class, North Carolina State University, Raleigh, NC. November 12th, 2007.

Cook, R.L., J. Landmeyer, B. Atkinson, J.P. Messier, and E. Guthrie Nichols. 2007. *Phytoremediation of a Petroleum-Hydrocarbon Contaminated Aquifer*. 4th International Phytotechnologies Conference, September 24-26, 2007. Denver, Colorado.

Figure 5. USCG efforts to educate base personnel and recreational users of collaborative efforts of 319 project.

The extension of the project from October 2008 until April 2009 provided for more quarterly reports submissions. Other enhancements included public communications by the US Coast Guard Training Facility to highlight environmental awareness actions on base as shown above (Figure 5).

Methodology/Execution

Summarize the overall approach the PI chose to take, over other options considered.~~onsidered~~
Studies have shown that trees, especially poplars (Populus spp.) and willows (Salix spp.), can effectively dissipate (or attenuate) fuel contaminants such as BTEX, MTBE, and some PAHs in contaminated ground water and soils (Burken and Schnoor, 1998; Hong et al., 2001; Ma et al., 2004; O'Neill and Nzengung, 2004; Rubin and Ramaswami, 2001; Widdowson et al., 2005). Hybrid poplars (Populus deltoides Bartram ex Marsh. x nigra L.) were selected for their deep root systems, rapid growth, high water uptake rates, tolerance to contaminants, and well-documented success in phytoremediation systems (Ferro et al., 2001; Widdowson et al., 2005; Vose et al., 2000; Hong et al., 2001, Zalesny et al., 2005b). Black, coyote, and sandbar willows (Salix nigra Marsh., Salix interior Rowlee, and Salix exigua Nutt., respectively) were selected for general tolerance for saturated conditions, ability to rapidly produce adventitious roots (Schaff, et al., 2002), and success in removing gasoline and PAHs from ground and surface waters **(**Corseuil and Moreno, 2001**;** O'Niell and Nzengung, 2004; Vervaeke et al., 2003). Unrooted cuttings are the standard of propagating poplars and willows, because they are less expensive to produce and easy to handle (Hansen, 1986; Zalesny et al., 2005a; Vose et al., 2000; Hoag, 1995; Schaff et al., 2002). *Pinus taeda* was also planted across the site to evaluate how well evergreen species would grow.

Ground water quality was monitored before and after installation of the tree system. Ground water monitoring wells were added specifically for this project, but monitoring wells already on site were also used to monitor changes to dissolved fuel constituents. Soil gas analyses were also used to assess changes to subsurface contamination across the site. To manage environmental monitoring data and tree data (position, mortality, and growth), all trees, monitoring wells, and soil gas wells were located using global positioning rovers. After one season of growth, tree survivability, mortality, and growth were measured for each tree on site. Geographical information system software was used to manage all environmental data and to evaluate tree mortality and growth to contaminant plumes.

Explain the methodology in detail

Soil Characterization and Analysis. The soil on site is classified as Udorthent, loamy with 0-2% slope (USDA/NRCS, 2007). Parent material is classified as loamy mine spoil or earthy fill and is well drained. Fill dirt has raised the elevation of the site to an average of three meters above mean sea level (NC State Climate Office, 2008). Native, fine gray clays and sand can be found approximately one meter below land surface.

To test for soil characteristics, samples were collected according to the procedures of the North Carolina Department of Agriculture and Consumer Services (NCDA&CS, 2008) and analyzed by the Agronomic Division. Triplicate soil samples were collected at 60 cm depths at three different locations across the site. Samples were sieved through a two millimeter screen, homogenized with a mortar and pestle, combined for each location, and submitted for analysis according to NCDA&CS protocol. The soils were classified as mineral soils with the cation exchange capacities ranging from 4.7 to 11.7 meq/100cm^3 (milliequivalents per cubic centimeter), 0.18 to 0.32 percent humic matter, and pH from 6.2 to 7.3. Hand augered soil profiles to a depth of 1 to 1.5 m and analytical results have shown great soil heterogeneity across the site, most likely due to backfilling and soil movement during construction and deconstruction of underground storage tanks, treatment systems, pipelines, and utilities. Oftentimes, similar subsurface uncertainties at potential phytoremediation sites can hamper the ability to perform a rigorous statistical comparison of the planting approaches.

Plant Selection. Phreatophytic trees, such as willows and poplars, can reach and extract water from the capillary fringe or saturated zone and are beneficial for ground water contaminated with biodegradable organics (Dietz and Schnoor, 2001; Landmeyer, 2001; Collins, 2007). Hybrid poplars (*Populus deltoides* Bartram ex Marsh. *x nigra* L.) were selected for their deep root systems, rapid growth, high water uptake rates, tolerance to contaminants, and well-documented success in phytoremediation systems (Ferro *et al.,* 2001; Widdowson *et al.*, 2005; Vose *et al.,* 2000; Hong *et al.,* 2001, Zalesny *et al.,* 2005b). Black, coyote, and sandbar willows (*Salix nigra* Marsh.*, Salix interior* Rowlee*,* and *Salix exigua* Nutt., respectively*)* were selected for general tolerance for saturated conditions, ability to rapidly produce adventitious roots (Schaff, *et al.,* 2002), and success in removing gasoline and PAHs from ground and surface waters (Corseuil and Moreno, 2001; O'Niell and Nzengung, 2004; Vervaeke *et al*., 2003). Unrooted cuttings are the standard of propagating poplars and willows, because they are less expensive to produce and easy to handle (Hansen, 1986; Zalesny *et al*., 2005a; Vose *et al*., 2000; Hoag, 1995; Schaff *et al.,* 2002). Furthermore, Zalesny *et al.* (2005a) found that commercial clones had a greater rate of survival than experimental clones.

Planting Approaches. Planting approaches over the three-year installation period were modified and adapted based on mortality or slow growth of trees and additional site characterization (i.e. soil-gas analyses) of previously unquantified subsurface contamination. Commercial hybrid poplar stock, approximately one meter in length, included clonal cuttings of DN-34, OP-367, 49-177, and 15-29, and coyote or sandbar willows were obtained from Segal Ranch Hybrid Poplars© Grandview, WA. In 2007, in addition to more of the same four poplar hybrids, black willows were purchased from the Coastal Plain Conservation Nursery, Edenton, NC. Clones were planted in blocks of two to three consecutive rows each in 2006 and in large, solid blocks in 2007 (Figure 4).

All cuttings were soaked in less than 30 cm of clean water for approximately one week prior to planting for each approach used to increase adventitious rooting, survival, and growth rates (Hansen, 1986; Hansen *et al*., 1993; Schaff *et al*., 2001). Typically soaked cuttings should be planted within a day or two of the initial root emergence (Hansen, 1986). Once root primordia start to swell, respiration increases dramatically and if cuttings are not planted promptly, their stored energy reserves will be drained (Phipps *et al*., 1983).

Approach 1. In the first year of planting, 2006, a direct-push rig augered 8 cm diameter, 1.2 m deep holes that were backfilled with excavated, *in situ* soil once trees were placed in the borehole. No additional, off-site soil was added, though all trees were mulched. The same approach was used for two separate phases of plantings in 2006: April 25th consisted of 114, 1.2 m long bare root poplars; June 5th & 6th consisted of 403, 1.2 m unrooted poplar and willow cuttings. All trees in approach 1 were planted on three meter centers.

Approach 2. In the second year of plant establishment, 2007, two new approaches were used to plant the remainder of the site. From April 9–13th, 2,176 new trees (2,123 poplars, 43 willows, and 10 trial loblolly pines) were planted using a labor-intensive approach consisting of augering larger, 23 cm diameter holes to a depth of 1.2 m, and backfilling with clean topsoil. Fourteen poplars in the approach 1, April area and 221 trees in the approach 1, June area were replaced using approach 2 as well. All trees were mulched after planting to help control weeds. Four different hybrid poplar clones were planted as three-foot cuttings in each of the four main sections and one of these clones (OP-367) was planted in a fifth smaller area (Figure 4).

Approach 3. On April 19th & 24th, 2007, an alternative, low cost, common poplar plantation (Hansen *et al.,* 1993) was used to plant 65 poplars and 208 willows. A dibble was used to create a hole, 15 to 30 cm deep, with just enough diameter to insert a cutting, often called a "planting slit." Air gaps were filled by pushing soil against the cutting; no backfill was needed. Poplar clones and willows were planted at random in this approach. Regardless of the approach, all 2007 trees were planted on a two meter center grid to maximize area coverage.

Stand Maintenance. While several studies have used composted manure or other organically rich soil amendments when plantings trees (Table 1), tree cuttings were not irrigated nor fertilized due to budget constraints of project funds and the interest of the site owner to limit site maintenance labor and costs. The site was mowed regularly to control grass and weeds. Providing adequate weed control is of utmost importance for establishment of hardwoods (Hansen, 1986; Hansen *et al*., 1993) regardless of contamination. In fact, Zalesny *et al*. (2005a) found that poplar clones survived equally well on contaminated soil with proper weed control as they did on heavy clay soils with poor weed management. Additionally, proper row spacing facilitates better weed management and easier replanting by allowing equipment to maneuver without damaging trees.

Tree Mortality and Growth. Field measurements were recorded for each tree in the entire population. Tree mortality was inventoried after the 2006 and 2007 growing seasons. In early 2008, all 2,984 tree locations were mapped using global positioning systems (GPS) and mortality was integrated with GPS information as well as species and/or clone variety. Surviving trees were measured for total stem length. Total stem length was measured, as opposed to height, to better represent tree growth. Simple height measurements do not account for the differences between trees which have only one tall stem versus many shorter stems. To measure total stem length, all major stems were measured by hand from the base of the cutting to the apical bud (to the nearest 1.0 centimeter) and totaled for each living tree. All field measurements and GPS locations were incorporated into a GIS database for monitoring and analysis of percent mortality and mean total stem lengths.

Ground Water Sampling. Ground water was collected by U.S. Geologic Survey and North Carolina State University researchers in February and November 2006 and December 2007. Wells were chosen by USGS personnel to delineate the plume and look for indications of hydraulic control. Additional wells were installed during the first planting and were sampled by NCSU in December 2007. Subsequent sampling was performed by ARCADIS in August 2008. Samples should be obtained in spring to determine the maximum extent of the plume due to seasonality of plant evapotranspiration capabilities.

Wells were only sampled when a visible layer of free product was not present and purged using a low-flow peristaltic pump and ¼-inch PFTE tubing. Duplicate samples from each well were collected in clean 40 ml volatile organic analysis (VOA) vials that were free of headspace and capped with Teflon-coated septa cap. Samples were transported back to NC State University campus on ice for laboratory analysis of BTEX and MTBE using Method SW 846 5030B and

8015B (USEPA, 1986) by the NCSU Civil Engineering Department. Since June 1993, routine ground water samples have been collected by ARCADIS G&M of North Carolina, Inc. and tested for BTEX and MTBE (ARCADIS, 2006).

Soil Gas Analysis. Soil gas sampling and analysis were performed by W.L. Gore and Associates, Inc. of Elkton Maryland. Sixty-eight GORE™ passive sampling modules were placed in permanent soil gas monitoring stations consisting of 2.5 cm diameter, 75 cm long slotted PVC screens installed in borings of the same diameter and depth. These stations were located on 30 m centers for consistent, repeated sampling. Corks were used as caps and the sorbent modules were tied to a string and hung from a screw-in eyelet on the bottom of the cork. Four inch well boxes were placed over the soil-gas wells to complete the monitoring stations. The Gore Modules™ were placed in the soil-gas wells for approximately five days. These devices were then placed in glass vials and shipped back to GORE™ for analysis. Analytical reports provide a quantitative measurement of soil gas mass levels present in the vapor phase underground in the vicinity of the sample location. This vapor phase can be released from either soil or ground water contamination (ARCADIS, 2006; GORE™, 2007).

GPS and Field Measurements. Points were mapped using a hand-held Trimble GPS device. Four to eight satellites were available for positioning and a minimum of thirty positions were recorded. Soil-gas and ground water wells and tree locations were recorded. In early 2008, total stem length, survival, and species/clone were recorded for each tree. Planting areas and site perimeter were delineated. All GPS points were differentially corrected and incorporated into a GIS map. Total stem length was determined manually with tape measures, summing the length of all major stems to the nearest 1.0-centimeter. Total stem length was measured instead of height to compensate for differences between trees with a singular tall stem or many shorter stems.

Laboratory Methods

Ground Water Samples. Water samples analyzed by NCSU department of Civil Engineering for BTEX and MTBE used heated purge and trap gas chromatography with flame ionization detection (FID) (heated P&T – GC/FID). An inert gas was bubbled through a portion of the aqueous sample and the volatile compounds were transferred from the aqueous phase to the vapor phase. The vapor was swept through a sorbent column where the volatile compounds are adsorbed. After purging is completed, the sorbent column is heated and back flushed with inert gas to desorb the components onto a gas chromatographic column where the compounds are separated and quantified. Relative percent difference was calculated for wells sampled by both NCSU and ARCADIS for ground water analysis.

Soil Gas Analysis. Sample preparation includes cutting the tip off the bottom of a sample module and transferring the absorbent to a thermal desorption tube. Instrumentation consists of gas chromatographs with mass selective detectors, coupled with thermal desorption units. The analytical methods are a modified EPA method 8260/8270 (USEPA, 1996). Before each run sequence, two instrument blanks, a sorber containing 5 µg bromofluorobenzene (BFB), and a method blank are analyzed. The BFB mass spectra must meet the criteria set forth in the method before samples can be analyzed. A method blank and a sorber containing BFB are also analyzed after every 30 samples and/or trip blanks. Standards containing the selected target compounds at five calibration levels are analyzed at the beginning of each run. The criterion for each target compound is less than 25% relative standard deviation. If this criterion is not met for any target compound, the analyst has the option of generating second or third order standard curves as appropriate. A second source reference standard, at a level of 10 µg per target compound, is analyzed after every ten samples and/or trip blanks, and at the end of the run sequence. Positive identification of target compounds is determined by 1) the presence of the target ion and at least two secondary ions; 2) retention time versus reference standard; and, 3) the analyst's judgment (GORE™, 2007).

Spatial Relationships. Soil gas total petroleum hydrocarbon (TPH) masses were assigned to sampling locations through GIS using ESRI ArcMap 9.2™. To visually monitor these concentrations and discover patterns associated with plant growth, estimated concentrations between sampling locations were interpolated with inverse distance weighting (IDW). In Spatial Analyst, a variable search radius with 12 point option and a power of 2 was used. Surfaces are divided into ten value ranges by the Natural Breaks (Jenks) method. IDW uses a weighted average of a defined number of sampled points where the assigned weight diminishes as distance from that point increases (Chuanyan et al., 2005). Though this method creates a rougher surface than other methods such as spline, it was chosen for its simplicity and because it does not allow contaminant concentration values to fall below zero (the newly created surface must pass through input points) While kriging, a geostatistical procedure, can provide the most robust interpolation method and the best models for spatial analysis (Chuanyan et al., 2005), developing variogram models was beyond the scope of this project.

Statistical Analyses. All constituents not normally distributed after log transformation were tested with the Wilcoxon paired signed rank test, which tests the null hypothesis that two related medians are the same and does not assume a given distribution (Gauthier, 2002). In the Wilcoxon test, ranks are based on the absolute value of the difference between the related variables, such as 2007 and 2008 soil gas masses. The sign of the difference classifies it as positive rank, negative rank, or a tie (which is ignored). A Z-variable is a standardized measure of the distance between the rank sum of the negative group and its expected value. A two-tailed asymptotic significance estimates the likelihood of obtaining a Z-statistic that is as or more extreme in absolute value if there is truly no difference between the related groups. Statistics were performed using SPSS™ 16.0. The level of significance was considered to be $p<0.05$.

Figure 6. 2008 Inventory of tree growth (size of green dots) and areas with high subsurface fuel contamination (red).

Note any specific issues that had to be addressed by the methodology, including performance standards developed, scalability etc., site constraints, or other special circumstances.

The first area planted was two rows of hybrid poplar clones in April 2006 as a back stop "V" design on the edge of the site closest to the river. Mortality of this first section was normal at 12%. However, further planting of the rest of the site using the same method as April 2006 resulted in high mortality of trees (55-65%). Replanting of the site as described above lowered overall morality. Unquantified fuel sources on part of the site appear to be the main cause for mortality. Ground water data used in Phase I did not indicate contamination in the southeastern portion of the site (right red zone in Figure 6). We determined the presence of this contamination by measuring volatile fuels in the soil column for the entire site using soil gas analyses (GORE™ Surveys Final Report, 2007). This screening helped delineate "hot spots" and was not part of the original 319 grant. Funds from the USCG and in kind support from W.L. Gore and Associates, Inc. of Elkton, Maryland enabled this assessment. The hot spots (red zones) match historical locations of former fuel bunkers used in World War II.

After delineating these hot spots of contamination, we changed our planting methods to provide trees a better chance to establish root systems before interacting with contaminated ground water and soil (Figure 7). In 2007, trees were planted in four foot deep, 9 inch augered holes that were back filled with clean top soil and then mulched. Most of the trees now on site (2,196) were planted in 2007 after which tree mortality declined to 13% which is an acceptable range of tree mortality and a much lower loss reported for similar contaminated sites in the U.S. (Cook, 2008).

Figure 7. Example of different tree growths at the FFF site (June 2008). Trees were planted in 2007.

In 2008, each tree's location was spatially recorded using GPS, and each tree was measured by hand for total stem length as a metric of tree growth. Hybrid poplars survived and grew better than the three willow species planted so most of the site consists of hybrid poplar trees (90%). As evident in Figure 6 & 7, trees did not grow as well where subsurface contamination is greatest. The 13% mortality measured in 2008 for trees planted in 2007 were primarily in two 30 x 30 meter areas where the former fuel bunkers existed. An alternative planting design is suggested for future planting in these two areas, for example, native grasses. We believe trees planted in these two areas have less opportunity to establish roots prior to lethal exposure to contaminated ground water.

Outputs and Results

Changes to Fuel Contaminants in Soil Vapor. During the tree installation process (April 2006 until April 2008), petroleum hydrocarbons and fuel oxygenates were monitored using ground water samples and soil gas analyses. The USCG continued to monitor ground water wells already on site prior to project activities, and NCSU monitored ground water wells installed specifically for the 319 project. Brad Atkinson (NCDENR) coordinated and conducted soil gas analyses with W.L. Gore and Associates. The costs of these analyses were shared by USCG and Gore Associates and were not part of the original 319 proposal.

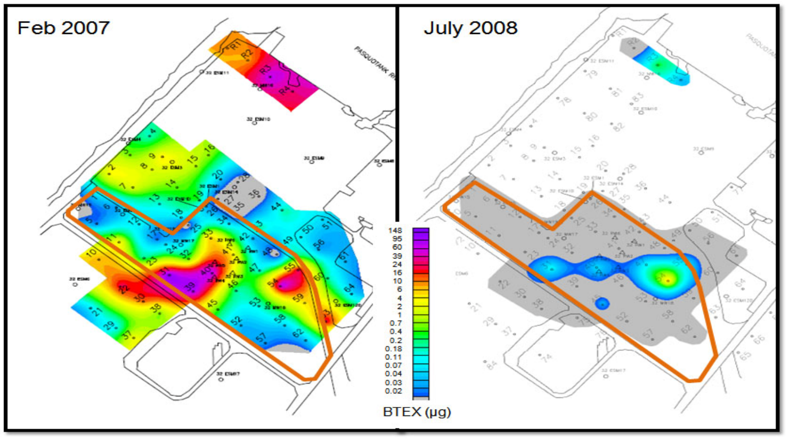

Figure 8. After planting the site with trees in April 2007, there was a substantial soil gas mass loss (µg) of benzene, toluene, ethylbenzene, and xylenes (BTEX) after one and half growing seasons for the trees (July 2008).

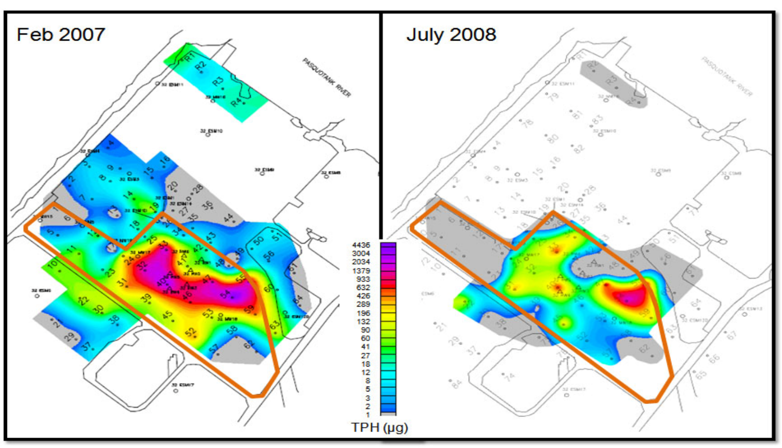

Figure 9. After planting the site with trees in April 2007, there was a substantial soil gas mass loss (µg) of total petroleum hydrocarbons (TPH) in soil gas as measured in July 2008. TPH would represent BTEX plus larger, volatile petroleum hydrocarbons. Most of the trees that did not survive the 2007 planting, with 13% mortality recorded in 2008, were in the hot zones or red areas.

Figures 8 and 9 show the difference in estimated fuel mass in soil vapors, or residual buildup of subsurface contaminant vapors, between February 2007 (before the major tree planting in April 2007) and one and a half growing seasons later (July 2008). Substantial declines in contaminant masses in soil gases is evident for the lighter fuel fractions, benzene, toluene, ethylbenzene, and xylene (BTEX), and all volatile fractions of fuel between February 2007 and July 2008.

Figure 10 shows an average loss of soil gas masses from 2007 to 2008. Total petroleum hydrocarbons decreased significantly ($p < 0.001$) after data were log transformed and analyzed with a paired t-test. BTEX, naphthalene, trimethylbenzenes all significantly decreased ($p < 0.001$) as did tridecane ($p < 0.011$). Soil gas constituents that were sampled and analyzed in February/March 2007 are shown in the Appendix Table 4 and June/July 2008 in Appendix Table 5. Only wells sampled in both 2007 and 2008 are shown, and include those in and around the planting area.

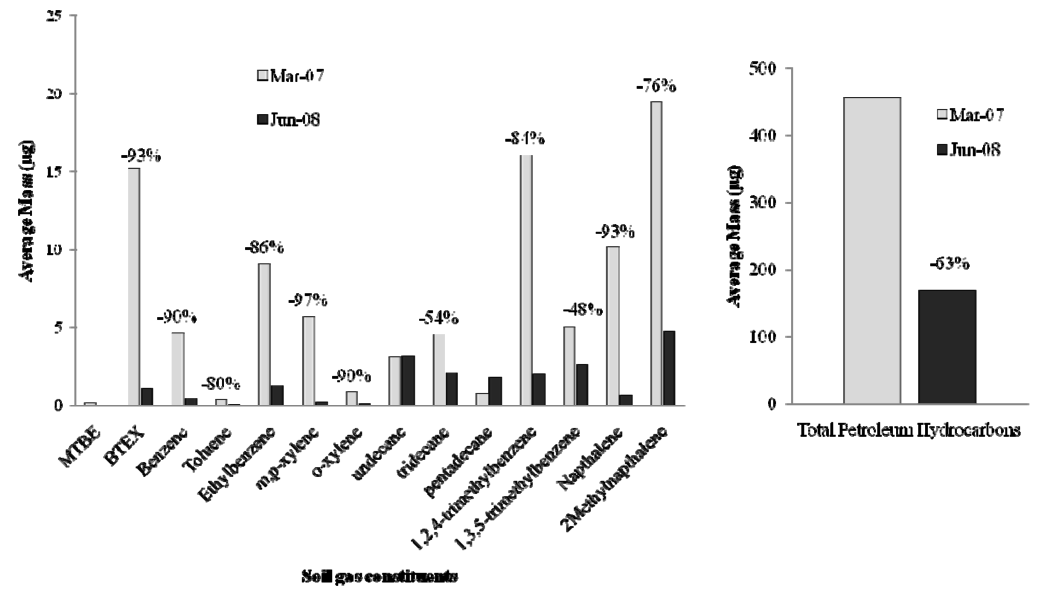

Figure 10. Average soil gas masses decrease from 2007 to 2008. Total Petroleum Hydrocarbon mass is pulled out for scale. All constituents labeled with percent decrease are statistically significant (P<0.001). Significance based on Wilcoxon Signed Ranks test.

Changes to Fuel Contaminants in Ground Water.

Analysis of fuel contaminants in ground water also showed a discrete reduction in contaminant levels after tree plantings. In April 2006, 319 funds were used to install new ground water monitoring wells (Figure 3) and monitor them for changes to BTEX and MTBE concentrations in ground water. Dramatic decreases in BTEX (79%) and MTBE (96%) were observed for ground water at these new monitoring wells (Figure 11). The well MW2 is located in one of the

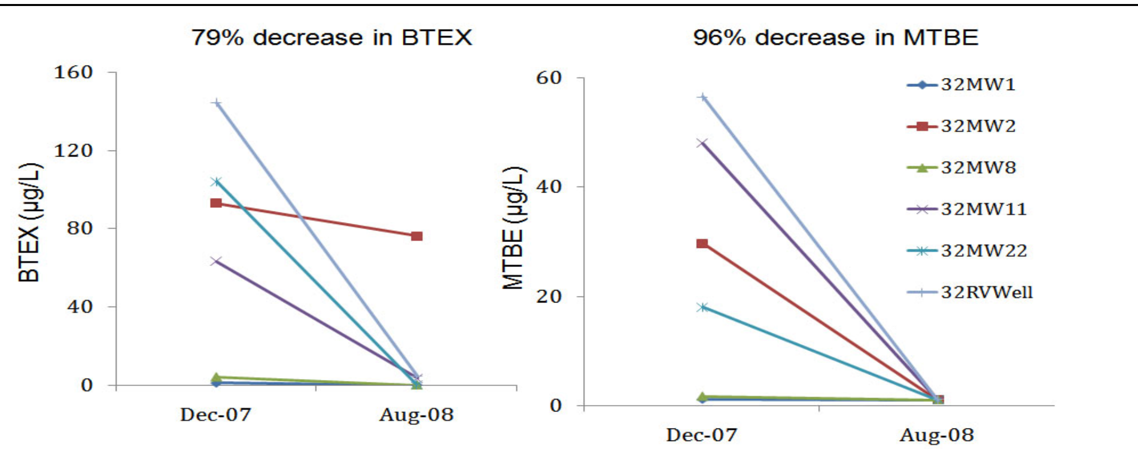

Figure 11. Petroleum (BTEX) and fuel oxygenate (MTBE) concentrations in ground water at monitoring wells installed for 319 (EW06028) project. Wells were installed in April 2006. The NC 2L ground water standard for benzene is 1µg/L.

former bunker areas where free product, or fuel, still exists as a separate phase on top of the ground water as well as in a discrete smear zone in soil due to ground water table fluctuations.

Other monitoring wells were already on site and sampled for compliance monitoring by USCG (Figure 12). As observed for soil gas analyses and 319 ground water analyses, USCG wells also showed dramatic declines for BTEX constituents after installation of the trees (Figure 13). Changes to contaminants in ground water wells are provided in Appendix Tables 1-4

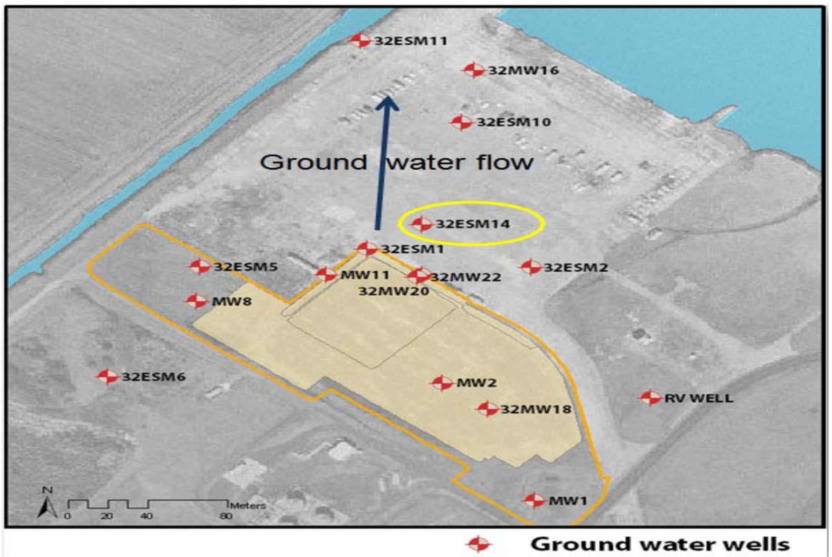

Figure 12. Wells monitored for ground water contamination by USCG since 1993. The yellow circle highlights well 14 that is down gradient from the trees and an important well to monitor the effect of the trees on fuel migration towards the river.

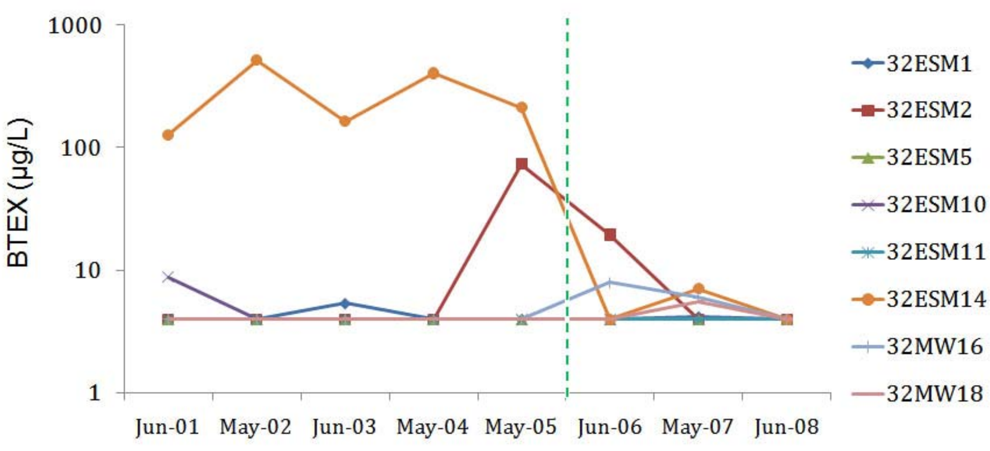

Figure 13. Petroleum hydrocarbons (BTEX) concentrations in ground water at monitoring wells since June 2001. Wells have been monitored since 1993. The NC 2L ground water standard for benzene is 1µg/L. The dotted green line marks the when trees were first planted.

Relationship of Tree Mortality, Tree Growth, and Soil Gas Contamination.
A summary of tree growth, mortality, and soil gas contamination after the first growing season (2007) is presented in Figure 14. The areas with the best growth correspond to areas with the least amount of contamination and the areas of highest mortality correspond to those with the highest contamination.

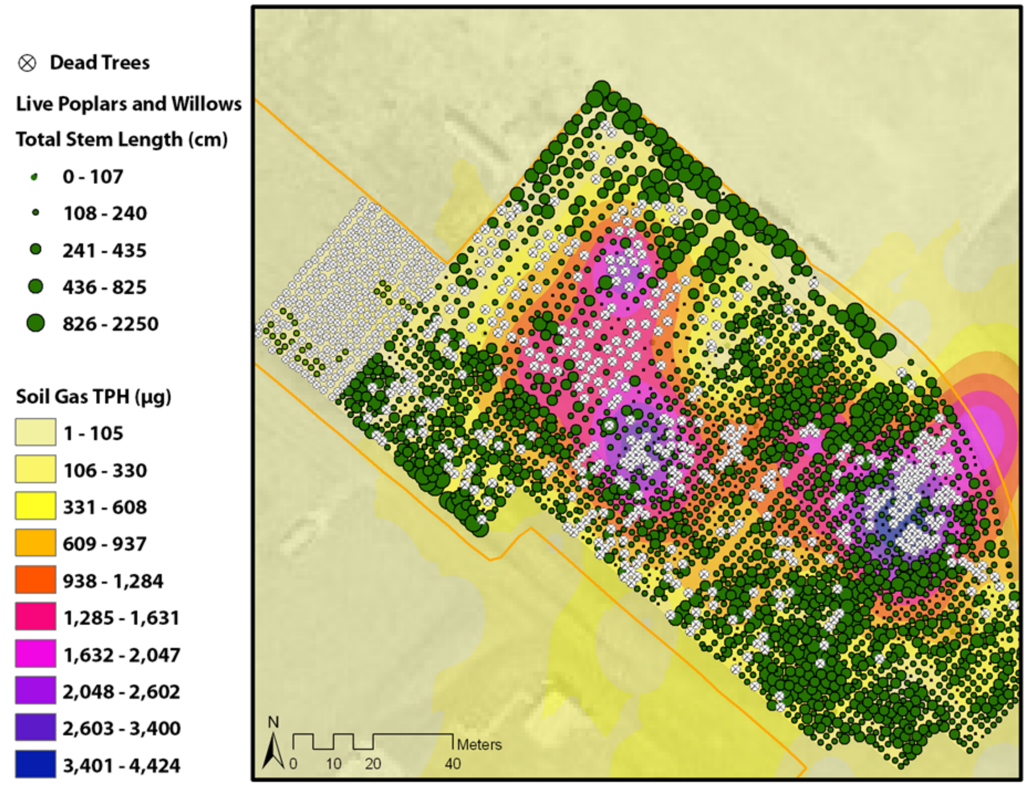

Figure 14. 2007 Soil gas TPH (µg) overlaid by tree mortality and total stem length (cm).

Outcomes and Conclusions

Describe project achievements in regard to the project's purpose and the goals set; did you meet the goals of the project?

The overall goal of the EW06028 319 project was to use trees to decrease the discharge of contaminated groundwater to a sensitive surface water receptor, the Pasquotank River. In 2005, we proposed to meet this goal by completing four phases of the project. Tree mortality due to site conditions and unexpected "hot spots" of contamination extended the time projected to complete phase I and II, site characterization (Phase I) and installation of the phytoremediation system (Phase II). A viable tree community was established after altering planting methods to provide trees a larger circumference of clean soil to establish viable root zones and improve survival in areas of greater contaminant concentrations. Improved characterization of the contaminant area was accomplished for Phase I by adding soil gas analyses to ground water monitoring data. The total cost to establish this viable tree community (2,984 trees) was approximately $12 per tree cutting or $26,892 total.

Comment on project's outcomes and their impact on water quality issues and environmental protection.

Our preliminary soil gas and ground water data suggest that this tree system is significantly decreasing subsurface contamination in the site footprint as well as decreasing pollution entering the Pasquotank River by retarding ground water discharge of fuel contaminants from the site footprint via hydraulic control. These preliminary data are certainly encouraging and almost too good to be true. According to soil gas analyses (Figure 8), the mass amounts of gasoline constituents (BTEX) have been greatly reduced at the outflow of ground water to the river as well as in the site footprint. Total mass amounts of petroleum hydrocarbons (TPH) were not detected at the river and also greatly reduced in the site footprint (Figure 9).

Assess the overall value of the project; who will benefit from the work, how and why.

If mass loss of contamination in soil gas measurements and decreases in contaminant concentrations in ground water continue, contaminant and tree mortality/growth data will make this particular site of great interest to relevant government, academic, and private industry stakeholders in North Carolina as well as across the country.

Phytoremediation is not yet approved for reimbursement by the State of North Carolina Underground Storage Tank (UST) Trust fund. Therefore, this remedial option is not pursued by companies engaged in cleaning up contaminated soil and groundwater at UST sites. Successful phytoremediation projects at UST sites in North Carolina are needed before reimbursement will be authorized from the UST Trust Fund on anything other than a demonstration project basis. If reimbursement is approved, more firms can be expected to use this technology near surface water bodies to protect surface waters. Verification of this site's performance will be critically important to remedial options and expectations in the near future for more affordable technologies that achieve ground water control of contaminated sites and remediate contaminants in soil and ground water. An important aspect of this proposal is to disseminate verification results to UST stakeholders tasked with soil and groundwater remediation at UST sites.

Summarize what was learned and whether the methodology worked and what readers can learn from your experience.

We found that augering large (23 cm diameter x 1.2 m deep) boreholes, backfilling with clean topsoil, and planting early increased tree cutting survival and tree growth at this particular demonstration site. Our planting approaches were chosen in an iterative process as unquantified contamination and subsurface infrastructures were encountered at the site as the project progressed. A traditional statistical examination of the effect of the different planting approaches on plant establishment was not feasible given unforeseen factors at the site that become evident as tree planting progressed. Trenching and irrigation were not used due to subsurface site constraints, such as utilities and an inoperable pump and treat system, and site owner and project concerns for implementation costs. A successful phytoremediation system was established within two years at the site in spite of subsurface and meteorological challenges. A modest increase in installation cost from $9 (approach 1) to $12 per cutting (approach 2) resulted in greater tree cutting survival and growth in areas of the site with highest subsurface TPH contamination.

Professionals, such as foresters, arborists, and other horticultural specialists, can be a valuable resource to engineers, hydrogeologists, or other environmental professionals not familiar with vegetation management. However, traditional forestry or horticultural techniques may require modification to adapt to contaminated, site-specific conditions. Attention to planting techniques and plant care impacts the success of a phytoremediation project. Uncertainties and unforeseen obstacles can still complicate successful plantings. This site was well characterized and met required federal and state regulations for monitoring, yet, initial tree mortality indicated unquantified subsurface site contamination. Additional site characterization using soil gas analyses helped clarify potential factors that resulted in initial tree mortality and poor tree growth. Field-scale studies that report such challenges and adaptations to planting approaches are an important component in expanding our applied knowledge in soil and ground water phytoremediation technologies.

Significant reductions in ground water contaminant concentrations and soil gas masses after establishment of a viable tree community indicate the this phytoremediation system is successfully initiating hydraulic control of the contaminated plume and *in situ* degradation of contaminants in the site footprint. Continued monitoring will indicate if results are temporary, seasonal, or a permanent reduction in contaminants. GIS has been an effective tool in the integration and monitoring of contaminants, tree growth, and spatial data by allowing for easy visualization of site patterns. It is highly recommended that it be used in other phytoremediation systems to compile information. Overall, preliminary results after only two years of tree growth have exceeded any initial expectations for hydraulic control and contaminant reduction. If future monitoring continues to report these initial trends, there will be a strong case to include phytoremediation as a viable, and even preferable, low cost alternative to traditional remediation techniques for the clean-up of petroleum-hydrocarbon contaminated soil and ground water due to leaking underground storage tanks.

Summarize any conclusions/implications that can be drawn from the project, including consideration of the future implications of your work and how others can build on it

We have presented compelling data that meets our 319 funding Phase III objective to effectively monitor, assess, and verify the performance of the phytoremediation system in meeting project goals. Results are preliminary and not mechanistically confirmed in terms of routes of contaminant loss and removal. An important and critical benchmark not yet achieved is ***Verification***. We do need to verify the performance of this tree system over seasonal changes of summer to winter when trees are not transpiring. We need to quantify the impact of this tree community on subsurface contaminant concentrations during active and dormant tree activity. Metrics such as quantitative measurements of tree growth, tree uptake of contaminants, tree transpiration, microbial soil community profiles, and site hydrology would be useful to determine how trees impact contaminant movement and degradation during the growing season and during winter when trees are primarily dormant. Optimization of the tree system could be further enhanced with this information. Potential integration of evergreen trees into the current tree community may provide year around hydraulic impact due to year round transpiration by these trees.

Budget

Section 319(h) funds	Original Contract Amount	Requested Change	Revised Contract Amount	Actual Expenditures
Personnel Costs	50,174		50,174	49,565
Fringe Benefits	6,056		6,056	5,983
Supplies	6,355		6,355	6,271
Analytical Services	0.00		0.00	0.00
Domestic Travel	5,800	(2,552)	3,248	3,048
Foreign Travel		1,202	1,202	1,588
Contractual	50,000		50,000	50,000
Student Aid	12,165	1,350	13,515	13,328
Indirect	14,504		14,504	9,072
Total	145,054		145,054	138,855*

***Remaining $14,504 will be paid after submission of final report and balance will be 0.**

NCSU Matching Funds	Original Contract Amount	Actual Expenditures
Personnel Costs	30,288	30,288
Fringe Benefits	4,093	4,093
Student Aid	8,250	8,250
Indirect	52,899	52,899
Total	95,530	95,530

Additional Match - Not Included in Budget or Counted Toward 40% Match Requirement (Federal Match not applicable to 319 Program).

Additional Matching Funds	Original Contract Amount	Actual Expenditures
Gore Environmental (50% soil gas discount)	25,000	25,000
B.P. America	15,000	11,600
USGS Contractual	50,000	50,000
NCSU travel E Nichols	2,000	2,000
NCSU travel grad student	600	600
Total	92,600	92,600

References

Arcadis. 2004. 33rd Groundwater Monitoring Report. United States Coast Guard. May 2004.

ARCADIS G&M of North Carolina, Inc 2006. 35th Groundwater monitoring report: Former Fuel Farm (SWMUs 32/37/38), USCG Support Center, Elizabeth City, North Carolina.

Burken, J.G. and Schnoor J.L. 1998. Predictive relationships for uptake of organic contaminants by hybrid poplar trees. *Environmental Science and Technology* 32, 3379-3385.

Chuanyan, Z., Zhongren, N., and Guodong, C. 2005. Methods for modeling of temporal and spatial distribution of air temperature at the landscape scale in the southern Ailian mountains, China. *Ecological Modeling* 189, 209-220.

Collins, C.D. 2007. Implementing phytoremediaiton of petroleum hydrocarbons. In: *s in Biotechnology v. 23: Phytoremediation: s and reviews,* part I, pp. 99-108. (Willey, N. Ed.). New Jersey Humana Press.

Cook, R.L. 2008. Phytoremediation of a Petroleum-Hydrocarbon Contaminated Shallow Aquifer, Elizabeth City, NC: Planting Methods and Preliminary Results. M.Sc. Thesis, North Carolina State University.

Corseuil, H.X. and Moreno, F.N. 2001. Phytoremediation potential of willow trees for aquifers contaminated with ethanol-blended gasoline. *Water Research* 35, 3013-3017.

Dietz, A.C. and Schnoor, J.L. 2001. Advances in phytoremediation. *Environmental Health Perspectives* 109, 163-168.

Ferro, A.M., Chard, J., Kjelgren, R., Chard, B., Turner, D., and Montague, T. 2001. Ground water capture using hybrid poplar trees: evaluation of a system in Ogden, Utah. *International Journal of Phytoremediation* 3, 87-104.

Gauthier, T. 2002. Statistical Methods. In: Introduction to Environmental Forensics, pp. 407-408 (Murphy, B.L. and Morrison, R.D., Eds.) Academic Press, San Diego, CA.

GORE™ Surveys Final Report 2007. USCG FFF Phytoremediation Elizabeth City, NC. W.L. Gore and Associates, Inc. Elkton, Maryland.

Hansen, E.A. 1986. Planting date affects survival and height growth of hybrid poplar. *Forestry Chronicle* 62, 164-169.

Hansen, E.A., Netzer, D.A., and Tolsted, D.N. 1993. Guidelines for establishing poplar plantations in the north-central U.S. Research Note NC-363, pp. 5. USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN

Hong, M. S., Farmayan, W. F., Dortch, I.J., Chiang, C.Y., McMillan, S.K., and Schnoor, J.L. 2001. Phytoremediation of MTBE from a ground water plume. *Environmental Science and Technology* 35, 1231-1239.

Landmeyer, J.E. 2001. Monitoring the effect of poplar trees on petroleum-hydrocarbon and chlorinated solvent contaminated ground water. *International Journal of Phytoremediation* 3, 61-85.

Ma, X., Richter, A.R., Albers, S., and Burken, J.G. 2004. Phytoremediation of MTBE with hybrid poplar trees. *International Journal of Phytoremediation* 6, 157-167.

McKnight, J.S. and Biesterfeldt, R.C. 1968. Commercial cottonwood planting in the southern United States. *Journal of Forestry* 66, 670-675.

Morgan, P., Lewis, S.T., and Watkinson, R.J. 1993. Biodegradation of benzene, toluene, ethylbenzene, and xylenes in gas-condensate-contaminated ground water. *Environmental Pollution* 82, 181-190.

Moyer, E, and P. Kostecki. 2003. *MTBE Remediation Handbook*. Amherst Scientific Publishers, Amherst, MA. 669 pp.

National Oceanic and Atmospheric Administration (NOAA): National Climatic Data Center 2008. Elizabeth City Coast Guard Air Station: Daily precipitation. Available at: http://www1.ncdc.noaa.gov/pub/orders/CDO3503601465883.html

O'Niell, W.L., and Nzengung, V.A. 2004. *In-situ* bioremediation and phytoremediation of contaminated soils and water: three case studies. *Environmental Research, Engineering and Management* 4, 49-54.

Phipps, H.M., Hansen, E.A., and Fege, A.S. 1983. Preplant soaking of dormant *Populus* hardwood cuttings. Research Note NC-241, pp. 8. USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN

Rubin, E. and Ramaswami, A. 2001. The potential for phytoremediation of MTBE. *Water Research* 35, 1348-1353.

Schaff, S.D., Pezeshki, S.R., Sheilds, F.D. Jr. 2002. Effects of pre-planting soaking on growth and survival of black willow cuttings. *Restoration Ecology* 10, 267-274.

Tetra Tech NUS, Inc. 2004. Correction Action Plan Addendum No. 6 for the Former Fuel Farm (SWMU No. 32), United States Coast Guard Support Center, Elizabeth City, NC. November 2004.

United States Department of Agriculture, Natural Resources Conservation Service (USDA/NRCS) 2007. Web Soil Survey. Available at: http://websoilsurvey.nrcs.usda.gov/

United States Environmental Protection Agency (USEPA) 1986. SW-846 5030B and 8015B Manual for Waste Testing; EPA Washington, DC. Volumes 1B and 1C.

United States Environmental Protection Agency (USEPA) 1996. Method SW 846 8270. Semivolatile Organic Compounds By Gas Chromatogarphy/Mass Spectrometry (GC/MS). Revision 3.

USGAO (U.S. General Accounting Office). 2001. Environmental Protection – Improved Inspections and Enforcement Would Better Ensure the Safety of Underground Storage Tanks. May 2001. Document Number GAO-01-464, 39pp.

Vervaeke, P., Luyssaert, S., Mertens, J., Meers, E., Tack, F.M.G., and Lust, N. 2003. Phytoremediation prospects of willow stands on contaminated sediment: a field trial *Environmental Pollution* 126, 275-282.

Vose, J.M., Swank,W.T., Harvey, G.J., Clinton, B.D., and Sobek, C. 2000. Leaf water relations and sapflow in eastern cottonwood (*Populus deltoides* Bartr.) trees planted for phytoremediation of a ground water pollutant. *International Journal of Phytoremediation* 2, 53-73.

Widdowson, M.A., Shearer, S., Andersen, R.G., and Novak, J.T. 2005. Remediation of polycylic aromatic hydrocarbon compounds in ground water using poplar trees. *Environmental Science and Technology* 39, 1598-1605.

Zalesny, R.S. Jr., Bauer, E.O., Hall, R.B., Zalesny, J.A., Kunzman, J., Rog, C.J., and Riemenschneider, D.E. 2005a. Clonal variation in survival and growth of hybrid poplar and willow in an *in situ* trial on soils heavily contaminated with petroleum hydrocarbons. *International Journal of Phytoremediation* 7, 177-197.

Zalesny, R.S. Jr., Riemenschneider, D.E., and Hall, R.B. 2005b. Early rooting of dormant hardwood cuttings of *Populus:* analysis of quantitative genetics and genotype x environmental interactions. *Canadian Journal of Forest Research* 35, 918-929.

Appendix.

Table 1 Review of published studies and planting methods for phytoremediation of petroleum hydrocarbons or chlorinated solvents using trees

Site	Contaminant	Plant Species	#/Type Planted	Mortality	Growth	Method	Backfill	Reference
Ogden, UT	Petroleum hydrocarbons	Hybrid Poplars	40 9ft poles	No data	3yr ht= 7.9m	10in diameter x 8ft deep boreholes	Sand, compost, nutrients	Ferro *et al.*, 2001
Fort Worth, TX	TCE	Poplars	440 whips/ 224 seedlings	25-30% Up to 90%	3yr ht= 5.5-6.6m	1m deep x 1.2m wide trenches	Excavated, *in situ*	Braun *et al.*, 2004; Vose *et al.*, 2000
Belgium	PAH/ mineral oil	Willows	2m rods	48% (338,000 shoot/ha decrease)	2yr= 417,000 shoots/ha	Horizontally inlaid cuttings (SALIMAT)	Dredged sediment	Vervaeke *et al.*, 2003
Oneida, TN	PAH/ creosote	Hybrid Poplars	1146 2-3yr trees	No data	3yr ht= 4.89 m	No data	No data	Widdowson *et al.*, 2005
Gary, IN	Petroleum hydrocarbons	Poplars Willows	500 20&60cm cuttings	0-75% Ave=33%	1yr= 14-72cm	7.62cm diameter x 17 or 56 cm deep	Clean sand	Zalesny *et al.*, 2005a
Orlando, FL	TCE/ PCE	Poplars Willows	2000 whips	No data	6mo ht= 5.5m	1.8m deep boreholes	Composted media	Rockwood *et al.*, 2004
Houston, TX	MTBE	Hybrid Poplars	100 whips	No data	1yr ht= 2.7m	1ft diameter x 6-9ft deep boreholes	60% sand 40% mulch & fertilizer	Hong *et al.*, 2001
Athens, GA	Gasoline	Willows	290 2m cuttings	No data	2yr ht= 6m	20cm holes	Composted peanut shells and manure	O'Neill and Nzengung, 2004

Appendices

Table 1 Ground water sampling results from Feb 2006, November 2006, and December 2007 by NCSU, Department of Civil Engineering. All units are in µg/L (ppb).

Date	Well	MTBE	Benzene	Toluene	Ethyl benzene	m+p-xylene	o-xylene	Total xylenes	1,2,4-trimethyl-benzene	1,3,5-trimethyl-benzene	1,2,3-trimethyl-benzene	Trimethyl-benzenes
Feb06	**32MW18**	0.0	0.0	0.0	2.9	2.3	1.9	4.2	2.3	2.7	2.9	7.9
	32RW1	68.0	679.3	7.1	20.5	210.4	0.0	210.4	55.2	164.4	69.4	289.0
	32RW2	99.4	1590.9	20.7	55.5	582.7	19.7	602.4	109.1	355.0	155.9	620.0
	32RW3	129.0	1047.0	33.0	48.3	893.1	9.2	902.3	106.7	322.6	168.2	597.5
	32RW4	506.2	1214.9	16.4	16.0	389.8	12.5	402.3	80.1	328.4	108.9	517.4
	32RW5	600.4	1589.4	22.5	216.7	984.0	14.2	998.2	119.3	372.2	152.5	644.0
	32RW6	48.3	1076.9	10.9	96.3	829.5	21.6	851.1	59.8	176.8	89.1	325.7
	32ESM1	232.9	5.7	0.0	5.3	15.0	1.3	16.3	2.6	6.4	3.0	12.0
	32MW17	42.9	1330.3	10.8	7.5	355.6	6.2	361.8	122.4	84.4	153.7	360.5
	32ESM14	148.4	68.2	0.0	3.8	12.2	2.2	14.4	2.8	5.2	3.3	11.3
Nov06	**32RW1**	420.8	491.8	10.0	0.0	297.7	2.4	300.1	73.8	33.3	115.0	222.1
	32MW18	1.2	12.2	0.0	0.0	1.3	0.0	1.3	0.0	0.0	1.0	1.0
	32ESM1	9.0	11.0	0.0	0.0	1.6	0.0	1.6	0.0	0.0	0.0	0.0
	32MW20	25.8	1195.3	3.7	0.0	6.4	2.1	8.5	0.0	0.0	1.1	1.1
	32MW22	199.1	826.1	0.0	2.4	6.7	0.0	6.7	0.0	0.0	0.0	0.0
Dec07	**MW1**	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	MW2	29.7	82.1	4.7	3.0	0.0	3.2	3.2	0.0	245.5	193.1	438.6
	MW7	44.6	5.5	**	4.7	6.5	0.0	6.5	7.2	0.0	18.0	25.2
	MW8	1.7	2.6	**	0.0	1.5	0.0	1.5	0.0	3.9	3.0	6.9
	MW10	145.5	99.8	9.1	2.7	32.9	6.5	39.4	21.3	35.0	43.9	100.2
	MW11	48.0	11.9	49.7	0.0	1.4	0.0	1.4	0.0	3.8	3.4	7.2
	32MW21	944.4	3243.8	14.4	477.1	518.4	3.0	521.4	133.3	630.2	436.5	1200.0
	32MW22	18.0	45.9	**	14.1	40.4	3.6	44.0	7.1	23.6	13.6	44.3
	MW23	46.8	30.3	10.5	1.2	4	0.0	4.0	1.5	1.5	3.5	6.5
	RV Well	56.6	36.9	103.4	0.0	3.9	0.0	3.9	0.0	3.5	2.3	5.8
	32ESM6	1.7	1.2	0.0	0.0	0.0	0.0	0.0	0.0	3.5	2.2	5.7

** Large interference peak prevented quantification of toluene.

Table 2 December 2008 ground water concentration data analyzed by NCSU Civil Engineering Department. August 2008 ground water data analyzed by ARCADIS. All units are in µg/L (ppb).

Date	Contaminant	32MW1	32MW2	32MW8	32MW11	32MW22	32ESM6	RVWell
Dec07	**Benzene**	< 1.0	82.1	2.6	11.9	45.9	1.2	36.9
	Toluene	< 1.0	3	< 1.0	< 1.0	14.1	< 1.0	< 1.0
	Ethylbenzene	< 1.0	4.7	**	49.7	**	< 1.0	103.4
	Xylenes	< 1.0	3.2	1.5	1.4	44	< 1.0	3.9
	MTBE	1.1	29.7	1.7	48	18	1.7	56.6
Aug08	**Benzene**	<1.0	71	<1.0	<1.0	<1.0	<1.0	<1.0
	Toluene	<1.0	<1.0	<1.0	2.1	<1.0	<1.0	<1.0
	Ethylbenzene	<1.0	5.2	<1.0	1.4	<1.0	<1.0	<1.0
	Xylenes	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	4.6
	MTBE	<10	<10	<10	<10	<10	<10	<10

** Large interference peak prevented quantification of toluene.

Table 3A Historical ARCADIS ground water monitoring data before phytoremediation installation. All units in μg/L.

Date	Contaminant	32ESM1	32ESM2	32ESM5	32ESM10	32ESM11	32ESM14	32MW16	32MW18
Jun01	**Benzene**	<1.0	<1.0	<1.0	5.8	<1.0	120	<1.0	<1.0
	Toluene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
	Ethylbenzene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
	Xylenes	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
	MTBE	18	<1.0	7.3	30	<1.0	530	16	4.1
May02	**Benzene**	<1.0	<1.0	<1.0	<1.0	<1.0	510	<1.0	<1.0
	Toluene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
	Ethylbenzene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
	Xylenes	<1.0	<1.0	<1.0	<1.0	<1.0	3.5	<1.0	<1.0
	MTBE	4.7	<1.0	4.7	16	<1.0	590	44	<1.0
Jun03	**Benzene**	2.4	<1.0	<1.0	<1.0	<1.0	160	<1.0	<1.0
	Toluene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
	Ethylbenzene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
	Total xylenes	NA	NA	NA	NA	NA	5.4	NA	NA
	MTBE	26	<1.0	<1.0	58	5.9	360	45	<1.0
May04	**Benzene**	<1.0	<1.0	<1.0	<1.0	<1.0	400	<1.0	<1.0
	Toluene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
	Ethylbenzene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
	Xylenes	NA	NA	NA	1.0	NA	NA	NA	NA
	MTBE	85	<1.0	2.5	38	2.2	130	61	2.4
May05	**Benzene**	<1.0	31	<1.0	<1.0	<1.0	210	<1.0	<1.0
	Toluene	<1.0	1.5	<1.0	<1.0	<1.0	<10	<1.0	<1.0
	Ethylbenzene	<1.0	4.3	<1.0	<1.0	<1.0	<10	<1.0	<1.0
	Xylenes	<2.0	37	<2.0	<2	<2.0	<20	<2.0	<2.0

Table 3B ARCADIS ground water samples after phytoremediation installation (32MW20 installed April 2006 in tree line). All units in µg/L.

Date	Contaminant	32ESM1	32ESM2	32ESM5	32ESM10	32ESM11	32ESM14	32MW16	32MW18	32MW20
Jun06	**Benzene**	< 1.3	<1.0	<1.0	< 1.3	<1.0	< 1.3	5.0	<1.0	1000
	Toluene	< 1.2	2.5	<1.0	< 1.2	<1.0	< 1.2	< 4.8	<1.0	< 12
	Ethylbenzene	< 2.4	<1.0	<1.0	< 2.4	<1.0	< 2.4	< 9.4	<1.0	< 24
	Total xylenes	< 3.3	15	<2.0	< 3.3	<2.0	< 3.3	< 13	<2.0	< 33
	MTBE	190	<10	<10	66	<10	170	460	14	250
May07	**Benzene**	4.2	< 1.0	< 1.0	< 1.0	< 1.0	3.9	3.0	1.8	2,800
	Toluene	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	1.0	< 1.0	1.8	< 20
	Ethylbenzene	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	1.2	< 1.0	< 1.0	< 20
	Total xylenes	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 40
	MTBE	180	< 10	< 10	37	< 10	160	410	23	200
Jun08	**Benzene**	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	750
	Toluene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
	Ethylbenzene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
	Total xylenes	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
	MTBE	<10	<10	<10	36	<10	51	330	<10	63

Table 5 Soil gas analysis in March 2007 (GORE, 2007). Wells included in table are those sampled again in 2008.

Well	TPH	Benzene	Toluene	Ethyl benzene	m+p-xylene	o-xylene	MTBE	Trimethyl-benzenes	Napthalene	2-methyl napthalene
1	0.77	0.03	0.03		0.02			0		
5	3.28	0.01	0.01					0		
6	0.68	0.01	0.02					0		
11	62.99	0.51	0.03	0.08	3.93	0.05		1.31		
12	59.06	0.02	0.03	0.02	0.05	0.02		0		
17	0.64	0.01	0.01					0		
22	80.34	9.11	0.05	0.96	13.05	0.28		6.13	0.35	0.04
23	14.15	0.13	0.01	0.06	0.12			0.16		
24	187.47	0.02	0.02		0.04			0.06	0.07	0.01
25	10.22							0		0.08
26	0.54		0.02		0.02			0		
30	68.4	8.2	0.03	0.29	4.23	0.04		4.33	0.03	
31	444.84	40.87	0.18	66.03	41.34	0.26		89.09	7.68	2.79
32	1632.28	0.04	0.04	0.35	0.09	0.05		9.78	5.35	17.45
33	2367.33	7.04	0.09	1.49	0.59	0.12		61.04	8.57	77.74
34	4.39	0.01	0.03		0.05			0		
38	4.12	0.12	0.02	0.17	0.68	0.02		0.44		
39	78.49	77.5	0.09	10.59	9.27	0.14	0.19	7.65	0.39	0.13
40	3040.11	3.78	0.1	45.08	33.98	0.37		129.85	51	86.31
41	56.31	0.28	0.46	0.92	2.31	0.52	0.06	10.62	0.84	0.97
42	21.13	0.02			0.02					
45	95.41	0.18	0.1	0.22	0.26	0.03		0.19	0.07	0.03
46	787.09	0.05	0.06	0.03	0.09	0.1		0.07	0.22	0.05
47	1680.82	0.01	0.11		0.05	0.02		0.03	0.16	0.06

Table 5 (continued)

Well	TPH	Benzene	Toluene	Ethyl benzene	m+p-xylene	o-xylene	MTBE	Trimethyl-benzenes*	Napthalene	2-methyl napthalene
54	4431.96	10.38	0.04	62.07	1.11	0.38		44.15	33.18	108.15
55	1997.34	0.02	2.02	4.8	22.02	0.21		111.19	81.93	66.03
56	3.01	0.01	0.01		0.01			0.04	0.06	0.03
57	1.01	0.01	0.01		0.01			0		
58	1.5	0.02	0.03	0.01	0.02			0		
59	539.68	0.02	0.03	4.83	0.08	0.12		8.08	2.01	29.2
60	13.5		0.04	0.06	0.17	0.04		0	0.03	0.05
61	1.22	0.02	0.02		0.01			0		
62	1.59	0.01	0.03		0.01			0		0.01
R2	5.31	0.01	0.98	1.52	4.53	1.12		0.01		
R3	15.18		3.29	12.81	44.49	11.01		0.11		
R3	19.04	0.02	4.18	5.67	16.89	4.05		0.04		

*Trimethyl-benzenes include: 1,2,4-trimethyl-benzene and 1,3,5-trimethylbenzene.

Table 6 Soil gas analysis in July 2008 (GORE report not yet available).

Well	TPH	Benzene	Toluene	Ethyl benzene	m+p-xylene	o-xylene	MTBE	Trimethyl-benzenes	Napthalene	2-methyl napthalene
1	0.12									
5	0.02									
6	0.03									
11	0.49									
12	0.10									
17	0.06									
22	102.76						0.02		0.28	0.02
23	0.02									
24	32.49									
25	25.78									
26	0.01									
30	0.79									
31	322.25			0.01	0.15	0.09	0.03		3.05	0.16
32	60.51									
33	622.24		0.02						0.14	0.24
34	209.73									
38	1.58									
39	1.43									
40	739.05				0.08	0.06	0.04		2.26	1.76
41	0.07									
42	2.20									
45	193.48			0.05			0.05		0.02	0.02
46	3.42									
47	1021.58				0.04	0.16	0.07		7.32	0.62
48	0.00									