Phytoremediation Groundwater Trends at the Doe Portsmouth Gaseous Diffusion Plant

A.C. Lewis, D.R. Baird, P.E.
CDM
P.O. Box 789, Piketon, OH 45661
USA

ABSTRACT

This paper describes the progress of a phytoremediation action being performed at the Department of Energy (DOE) Portsmouth Gaseous Diffusion Plant (PORTS) X-740 Waste Oil Handling Facility to remediate contaminated groundwater under a Resource Conservation and Recovery Act (RCRA) closure action. This action was effected by an Ohio Environmental Protection Agency (OEPA) decision to use phytoremediation as the preferred remedy for the X-740 groundwater contamination. This remedy was recognized as a cost-effective, low-maintenance, and promising method to remediate groundwater contaminated with volatile organic compounds (VOCs), primarily trichloroethylene (TCE).

During 1999, prior to the tree installation at the X-740 Phytoremediation Area, water level measurements in the area were collected from 10 monitoring wells completed in the Gallia Formation. The Gallia is the uppermost water-bearing zone and contains most of the groundwater contamination at PORTS. During the tree installation which took place during the summer of 1999, four new Gallia monitoring wells were installed at the X-740 Area in addition to the 10 Gallia wells which had been installed in the same area during the early 1990s. Manual water level measurements were collected quarterly from these 14 Gallia monitoring wells between 1998 and 2001. These manual water level measurements were collected to monitor the combined impact of the trees on the groundwater prior to root development. Beginning in 2001, water level measurements were collected monthly during the growing season (April-September) and quarterly during the dormant season (October-March). A total of eight water level measurements were collected annually to monitor the phytoremediation system's effect on the groundwater in the X-740 Area.

The primary function of the X-740 Phytoremediation Area is to hydraulically prevent further spreading of the TCE plume. This process utilizes deep-rooted plants, such as poplar trees, to extract large quantities of water from the saturated zone. The focus of any phytoremediation system is to develop a cone of depression under the entire plantation area. This cone of depression can halt migration of the contaminant plume and can create a hydraulic barrier, thereby maintaining plume capture. While a cone of depression is not yet evident at the X-740 Phytoremediation Area, water level measurements in 2004 and 2005 differed from measurements taken in previous years, indicating that the now mature trees are influencing groundwater flow direction and gradient at the site.

Water level measurements taken from 2003 through 2005 indicate a trend whereby groundwater elevations steadily decreased in the X-740 Phytoremediation System. During this time, an average groundwater table drop of 0.30 feet was observed. Although the time for the phytoremediation system to mature had been estimated at two to three years, these monitoring data indicate a period of four to five years for the trees to reach maturity. Although, these trends are not apparent from analysis of the potentiometric surface contours, it does appear that the head gradient across the site is higher during the spring and lower during the fall. It is not clear, however, whether this trend was initiated by the installation of the phytoremediation system. This paper will present the groundwater data collected to date to illustrate the effects of the trees on the groundwater table.

INTRODUCTION

The PORTS facility, enriched uranium from the early 1950s until 2000. Phytoremediation has been implemented to assist in the removal of TCE in the groundwater at the PORTS facility, primarily the X-740 area.

The X-740 Waste Oil Handling Facility was in operation from 1982 to 1992. This facility was primarily used for staging drums of non-radionuclide-contaminated waste oils and solvents generated by various activities at the plant. In 1993 the X-740 facility underwent closure in compliance with the RCRA. Groundwater at the facility is contaminated with detectable levels of TCE.

Phytoremediation technology is based on the ability of certain plant species (in this case hybrid poplar trees) and their associated rhizospheric microorganisms to remove, degrade, or contain chemical contaminants in soil, sediment, surface water, and groundwater. Phytoremediation technology is a promising clean-up solution for a wide variety of pollutants and sites. Some of the inherent benefits of phytoremediation technology include the following:

- Passive technology, producing minimal or no waste during tree installation or during remediation.
- 10% to 20% less costly than mechanical treatments in terms of overall operating costs.
- *In situ* (in place) technology that produces an aesthetically pleasing environment.
- Entirely solar-driven.
- Capable of treating soil which remains in place and is reusable following treatment.
- Applicable to non-source areas and slow moving plumes.

Mature trees, such as the hybrid poplar, can consume up to 3,000 gallons of groundwater per acre per day. Organic compounds are captured in the trees' root systems. These organic compounds are degraded by ultraviolet light as they are transpired along with the water vapor through the leaves of the trees.

The phytoremediation system at the X-740 area includes 766 hybrid poplar trees composed of three varieties (*Populus nigra x nigra*, *Populus nigra x maximowiczii*, and *Populus deltoides x nigra*) that were installed via two innovative planting methods - the trench/boring design and the borehole design as shown in Figure 1. The system was installed with its primary function to manage the VOC contaminant plume by removing contamination from the groundwater and preventing further migration of contaminants via a cone of depression in the groundwater table.

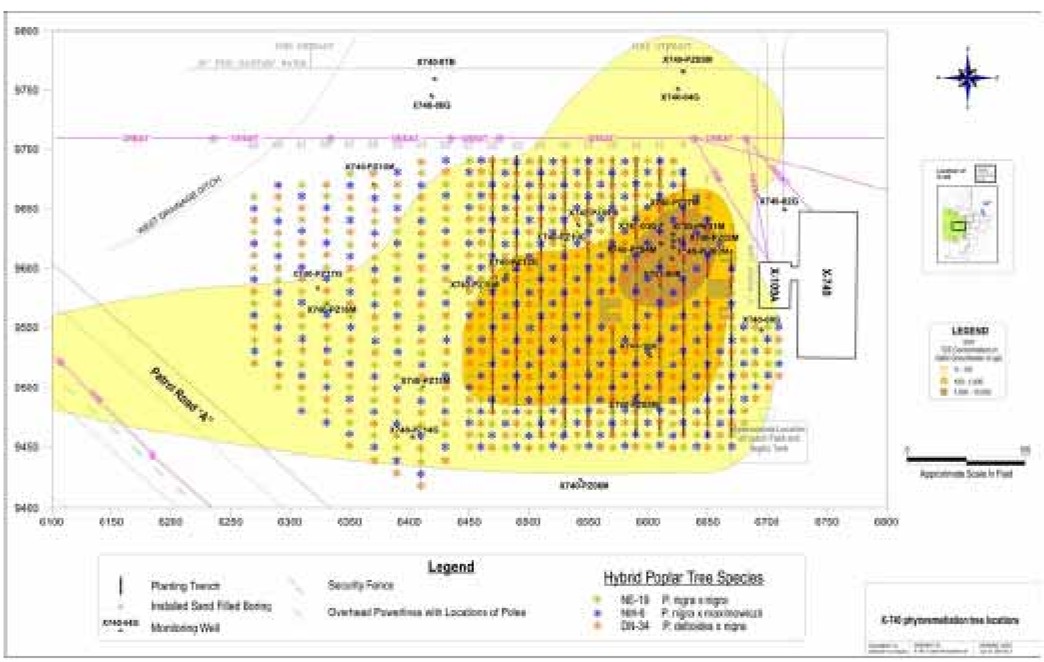

Figure. 1. Overview of the X-740 Phytoremediation Area, TCE plume extent, and tree planting locations.

GROUNDWATER FLOW/DEPTH TO WATER

During 1999, prior to the tree installation at the X-740 Phytoremediation Area, water level measurements in the area were collected from 10 monitoring wells in the Gallia Formation. The Gallia is the uppermost water-bearing zone and contains most of the groundwater contamination at PORTS. During the tree installation which took place during the summer of 1999, four new Gallia monitoring wells were installed at the X-740 Area in addition to the 10 Gallia wells which had been installed in the same area during the early 1990s. Manual water level measurements were collected quarterly from these 14 Gallia monitoring wells between 1998 and 2001. These manual water level measurements were collected to monitor the combined impact of the trees on the groundwater prior to root development. Beginning in 2001, water level measurements were collected monthly during the growing season (April-September) and quarterly during the dormant season (October-March). A total of eight water level measurements were collected annually to monitor the phytoremediation system's effect on the groundwater in the X-740 Area.

The primary function of the X-740 Phytoremediation Area is to hydraulically prevent further spreading of the TCE plume. This process utilizes deep-rooted plants, such as the poplar trees, to pump large quantities of water from the saturated zone. The focal point of any phytoremediation system is to develop a cone of depression in the groundwater table beneath the entire plantation area. This occurrence can halt migration of the contaminant plume and create a hydraulic barrier maintaining plume capture. Although a cone of depression is not yet evident at the X-740 Phytoremediation Area, water level measurements have demonstrated uncharacteristic groundwater trends in 2004 and 2005 compared to previous years, indicating that the now mature trees are likely impacting the groundwater system in the area.

From 1998 through 2005, water level measurements (i.e., depth to water) were examined for wells X740-03G, X740-08G, X740-10G, X740-PZ10G, and X740-PZ12G, each located within the X-740 Phytoremediation System of trees as shown on Figure 2. Additionally, background water level measurements for this same period were examined for wells X740-05G, X740-06G, F-13G, X326-04G, and X330-PZ01G, each located between 100 feet (ft) and 1500 ft upgradient from the X-740 Phytoremediation System as shown in Figure 2. Figure 3 illustrates the increase in depth to groundwater in the five wells installed within the phytoremediation area compared to the five background wells installed outside of the area. The plotted water level measurements were collected twice each year from 1998 to 2005 - once during the dormant season and once during the growing season. The dormant season water levels are the averages of the months of October through March (average of two values); the growing season water levels are the averages of the months of April through September (average of six values).

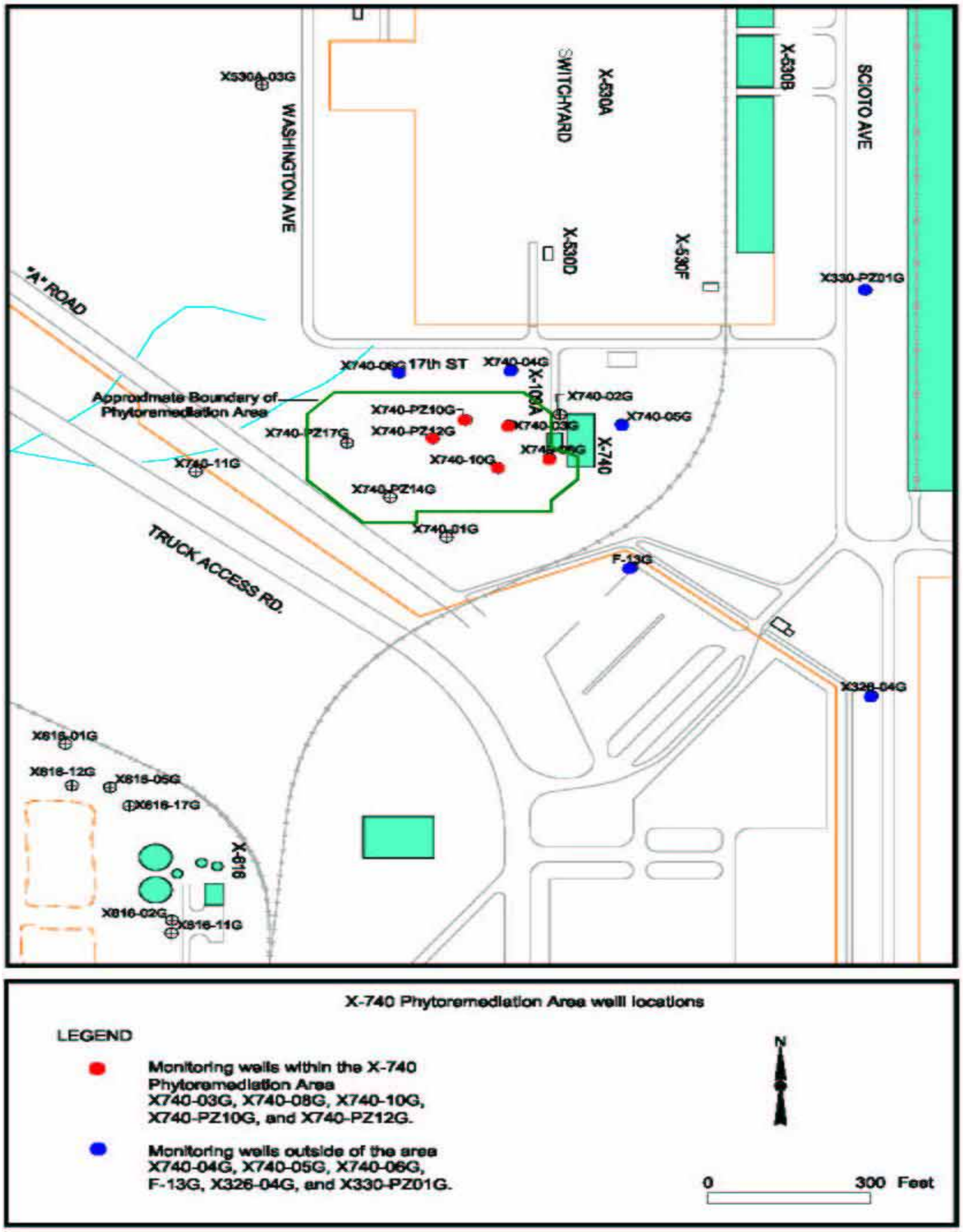

Figure 2. X-740 Area well locations used for the groundwater level and gradient study.

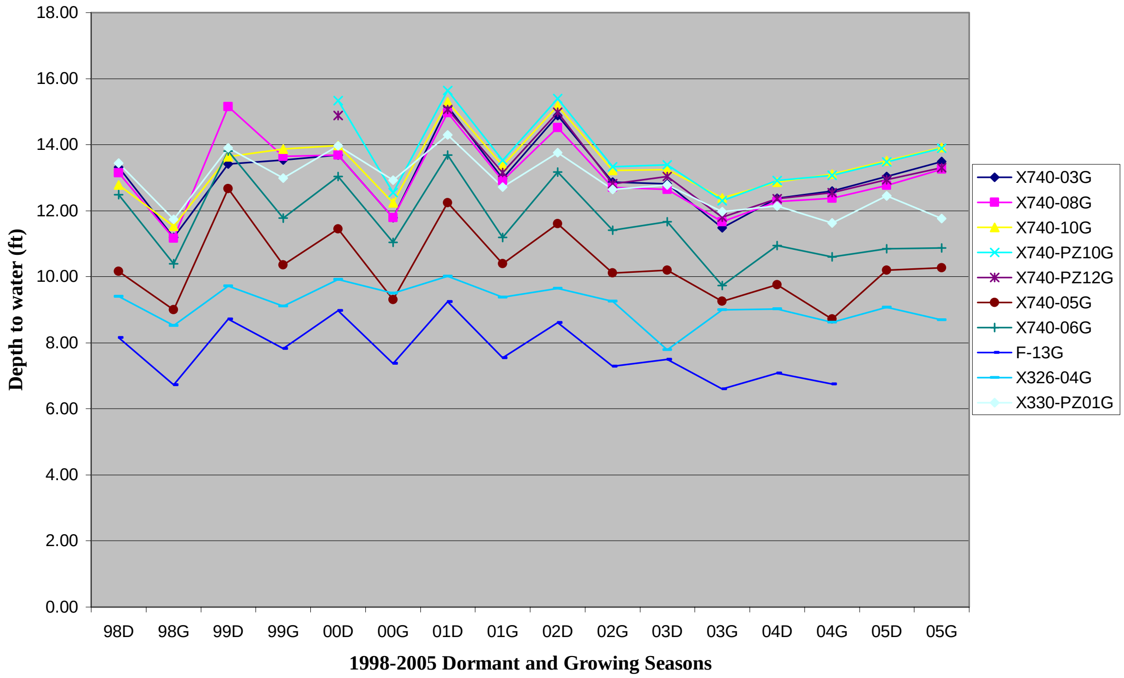

Figure 3. Average groundwater levels from wells in the X-740 Phytoremediation Area (X740-03G, X740-08G, X740-10G, X740-PZ10G, and X740-PZ12G) and outside the Area (X740-05G, X740-06G, F-13G, X326-04G, X330-PZ01G).

Water level measurements collected from 1998 and 1999, prior to root development of the trees in the phytoremediation area (the trees were planted in the summer of 1999), demonstrate greater water level depths during the dormant season than during the growing season. For example, depth to water for well X740-08G located within the phytoremediation system varies between a dormant season average of 14.15 ft and a growing season average of 12.41 ft. Similarly, depth to water for well X330-PZ01G located in the background area approximately 1500 ft upgradient of the phytoremediation system varies between a dormant season average of 13.67 ft and a growing season average of 12.37 ft. These data indicate lower groundwater elevations in the X-740 Phytoremediation Area during the winter season, and higher groundwater elevations in the X-740 Phytoremediation Area during the summer season. This trend is apparent in the water level measurements collected from the five wells installed within the phytoremediation plantation of trees and the five background wells.

However, water level measurements collected from 2003 to 2005 from wells located within the phytoremediation system area show a markedly different trend than that observed prior to this time period; namely, depth to water steadily increased from 2003 to 2005. Over this time period an average groundwater table drop of 0.30 ft was observed. In contrast, water level measurements collected from 1998 to 2005 from the five background wells located outside of and upgradient of the phytoremediation system area show no apparent change in groundwater table elevation since 1998. They do however continue to demonstrate the cycle of decreasing depth to water during the dormant season relative to the growing season. This trend is most apparent in wells X330-PZ01G and X326-04G which are both located approximately 1,500 feet upgradient from the phytoremediation system area.

The X-740 Phytoremediation System was predicted to be mature within two to three years of the initial planting, which would have been by 2001 or 2002. However, according to the water level measurements, the X-740 Phytoremediation System appears to have had no observable impact on groundwater levels until 2004. It appears from these data, that the phytoremediation system required four to five years to mature instead of the originally estimated two to three years.

HYDRAULIC GRADIENT

The hydraulic gradient is the driving force of fluid flow in a porous medium calculated as the change in hydraulic head (pressure) per unit distance. From 1998 (before the phytoremediation system was installed) through 2005, the difference in the hydraulic gradient was calculated upgradient of the phytoremediation system, between wells X740-04G and X740-05G, and within the phytoremediation system, between wells X740-03G and X740-10G located near the center of the plume as shown in Figure 2. The gradients in the well pairs steadily increase over time, although some scatter in the data is apparent as shown in Figure 4. The data were plotted based on a yearly average, combining both growing and dormant seasons. It appears that as the trees mature the increasing groundwater withdrawal can be seen by the increasing gradient across the site. In fact there is a statistically significant difference ($\alpha=0.05$) between average gradients for the two well pairs in 1998 and 1999 to the average gradient for the two well pairs in 2004 and 2005.

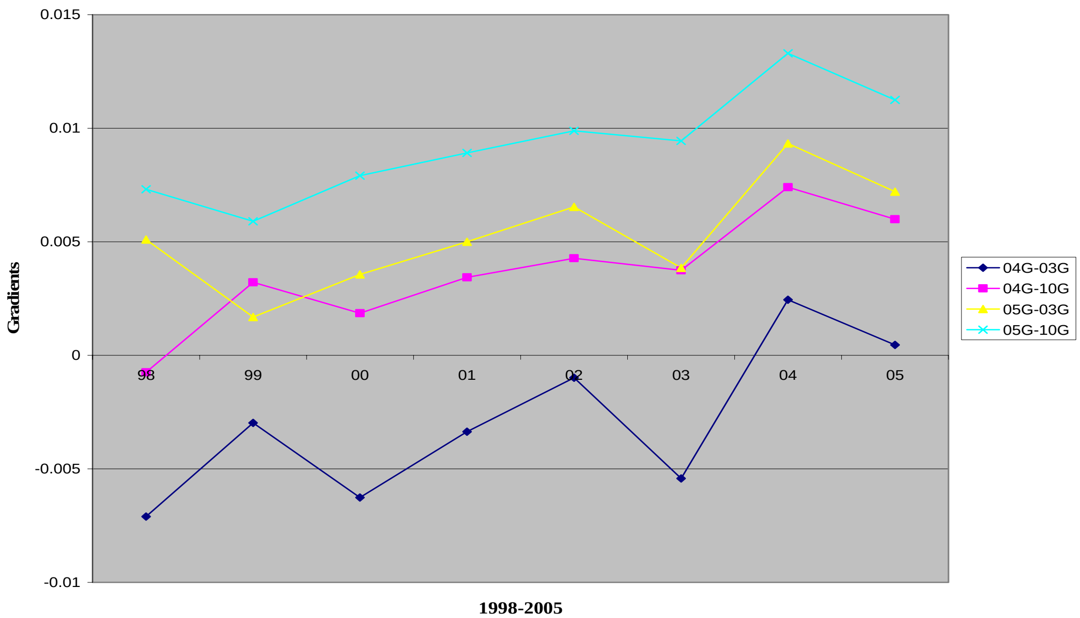

Figure 4. Annual gradient fluctuations between 1998-2005 at the X-740 Area (Wells X740-04G-03G, X740-04G-10G, X740-05G-03G, and X740-05G-10G).

Because trees only transpire four to six months of the year (April-September), it is extremely difficult to determine the amount of groundwater taken up in a phytoremediation system. Additionally, groundwater uptake and transpiration rates depend on many factors such as plant species, plant size and diameter, climatic factors, and precipitation. Further, surface water from precipitation can be absorbed and transpired by a phytoremediation system inhibiting groundwater use and remediation efforts.

Groundwater flow within the the X-740 Phytoremediation Area can be estimated using Darcy's equation:

$$Q = -KA\frac{dh}{dx}$$

Where,

Q is the groundwater flow rate (ft^3/second [s]),
K is the hydraulic conductivity of the aquifer (ft/s),
A is the cross sectional area of the aquifer (ft^2), and
$\frac{dh}{dx}$ is the hydraulic gradient of the aquifer (ft/ft).

The gradients from four well pairs, X740-05G/10G, X740-05G/03G, X740-04G/10G, and X740-04G/03G, were used to calculate the annual groundwater consumption of the phytoremediation system. The hydraulic conductivity of the site (0.0000491 ft/s) was multiplied by the cross sectional area of the phytoremediation system (2400 ft^2), the average thickness of the aquifer (4 ft), and the change in the gradient from the average gradient in 1998 and 1999 to the average gradient in 2004 and 2005. The difference in gradients between the well pairs was 0.98 ft/ft for X740-05G/10G, 0.44 ft/ft for X740-05G/03G, 1.53 ft/ft for X740-04G/10G and 0.99 ft/ft for X740-04G/03G. Based on these results, the X-740 Phytoremediation Area is estimated to transpire an average of 75,000 gallons per day (gpd) of groundwater, or 98 gallons per tree during a normal growing season. Published groundwater uptake rates for four to five-year old poplar trees were estimated at 26 gpd to 53 gpd, while six to seven year old poplar trees were estimated to take up 80 gpd. The poplar trees at the X-740 Phytoremediation Area are seven years old; though somewhat higher, 98 gpd is consistent with these reported values.

CONCLUSION

The X-740 Phytoremediation System was predicted to be mature within two to three years of the initial planting, which would have been by 2001 or 2002. However, according to the water level measurements, the X-740 Phytoremediation System appears to have had no observable impact on groundwater levels until 2003. A trend is apparent in 2003 through 2005 from water level measurements. Groundwater elevations steadily decrease in the X-740 Phytoremediation System from 2003 to 2005. Over that time period an average groundwater table drop of 0.30 ft was observed. Thus, it was expected the system required four to five years to mature instead of the estimated two to three years. It appears that the head gradient between wells within the stand of trees is higher during the spring sampling events while the head gradient outside and upgradient of the site during the fall is lower. However, it is still not clear if this trend was initiated by the installation of the phytoremediation system.

The change in the hydraulic gradient between 1998 (before the phytoremediation system was installed) and 2005 was calculated between two well pairs, one located upgradient of the X-740 Phytoremediation Area and the other located within the trees near the center of the plume. The gradients between the well pairs steadily increase over time, although some scatter in the data is observed. It appears that as the trees mature an increasing rate in groundwater withdrawal can be seen by the increasing gradient across the site. In fact there is a statistically significant difference (α=0.05) between average gradients for the two well pairs in 1998 and 1999 compared to the average gradient for the two well pairs in 2004 and 2005.

The X-740 Phytoremediation Area was estimated to transpire an average 75,000 gpd of groundwater, or, 98 gallons per tree during a normal growing season. Groundwater uptake rates for four to five-year old poplar trees were estimated at 26 gpd to 53 gpd, while six to seven year old poplar trees were estimated to take up 80 gpd. The poplar trees at the X-740 Phytoremediation Area are seven years old; though somewhat higher, 98 gpd is consistent with these reported values.

REFERENCES

1. DOE 2002. *Quadrant I X-749/X-120 Phytoremediation Work plan and Design Final Phase for the U.S. Department of Energy Portsmouth Gaseous Diffusion Plant Piketon, Ohio,* DOE/OR/11-3118&D1, United States Department of Energy Office of Environmental Management, November 2002.

2. DOE 2003. *Five-Year Evaluation Report for the X-740 Phytoremediation Project at the Portsmouth Gaseous Diffusion Plant, Piketon, Ohio,* DOE/OR/11-3135&D1, United States Department of Energy Office of Environmental Management, October 2003.

3. EPA 2001. Office of Solid Waste and Emergency Response. *Groundwater Issue: Phytoremediation of Contaminated Soil and Ground Water at Hazardous Waste Sites.* EPA 540-S-01-500.

4. *Phytoremediation of TCE in Groundwater using Populus.* United States Environmental Protection Agency, 1998.

5. *Phytoremediation.* Envirotools, Hazardous Substances Research Center, Michigan State University, 2002.

6. Schnoor, Jerald L. Center for Global and Regional Environmental Research. *Technology Evaluation Report. Phytoremediation of Soil and Groundwater. Ground-Water Remediation Technologies Analysis Center.* TE-02-01, March 2002.

7. Van Den Bos, Amelie. *Phytoremediation of Volatile Organic Compounds in Groundwater: Case Studies in Plume Control.* National Network of Environmental Management Studies Fellow. August 2002.