THE EFFECTIVENESS OF PHYTOREMEDIATION AT THE DOE PORTSMOUTH GASEOUS DIFFUSION PLANT

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ABSTRACT

The Portsmouth Gaseous Diffusion Plant (PORTS), a Department of Energy (DOE) Facility, enriched uranium from the early 1950s until 2000. The X-740 Waste Oil Handling Facility was in operation from 1982 to 1992. This facility was primarily used for the drum-staging of non-radionuclide contaminated waste oils and solvents generated by various activities at the plant. In 1993 the X-740 facility underwent Resource Conservation of Recovery Act (RCRA) closure. The RCRA closure included the decontamination of the floor and walls and removal of a tank/sump and surrounding contaminated soil. Groundwater contamination remaining at the facility has detectable levels of trichloroethylene (TCE). Phytoremediation has been implemented to assist in the removal of the remaining TCE.

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

- It is a passive technology, it produces minimal or no waste during tree installation or during remediation.
- It is 10% to 20% less costly than mechanical treatments, regarding overall operating costs.
- It is an *in situ* (in place) technology that produces an aesthetically pleasing environment.
- It is entirely solar -driven.
- The soil remains in place and is reusable following treatment.

Mature tress, 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.

In selecting phytoremediation as the remedial option for treatment of the groundwater in the X-740 area, three hybrid poplar tree species (Populus nigra x nigra, Populus nigra x maximowiczii, and Populus deltoides x nigra) were used to provide a greater resistance and resilience to various plant diseases known to be present in the area (A multi-species approach offers an increased success rate for the phytoremediation area). The three hybrid poplar tree species were chosen as a result of their high growth rate and yield, high evapotranspiration rates, root zone depth, long life span, and ease of growth. The phytoremediation system for this site consisted of 766 one-year old hybrid poplar trees that were planted 10 feet apart in rows 10 feet to 20 feet apart, over

an area of 2.6 acres. The system was installed to manage the volatile organic compound (VOC) contaminant plume. The objective of this task was to remove contamination from the groundwater and to prevent migration of contaminants from the area. The goal of the remediation procedure was to achieve a completely mature and functional phytoremediation system within 2 to 3 years of the initial planting of the hybrid poplar trees. The organic compounds were then to be captured and removed from the groundwater.

The estimated cleanup objectives of this corrective action procedure are to be obtained 10 years after the trees mature. Groundwater monitoring, groundwater levels, and surveillance and maintenance inspections will continue on a regular basis in order to evaluate the progress of the phytoremediation system. RCRA 5-year evaluations of the X-740 phytoremediation area are conducted to monitor the effectiveness of the remedial action. These reviews have shown the effects that the trees have had on the groundwater and the contamination. The four wells designated as part of the monitoring plan for the X-740 area (X740-03G, X740-10G, X740-PZ10G, and X740-PZ12G) demonstrate a fluctuation in the TCE level. It should be noted that approximately two years are required for the root system to mature sufficiently to have an observable impact on groundwater. Because the trees were installed in 1999, only three years have passed since a mature root system has been in place. Conclusions regarding system effectiveness are therefore limited.

INTRODUCTION

The Portsmouth Gaseous Diffusion Plant (PORTS), owned by the Department of Energy (DOE), enriched uranium from early 1950s until 2000. The X-740 Waste Oil Handling Facility was used as a switchyard during plant construction and was also in operation between 1982 and 1992. The facility was primarily used for the drum-staging of non-radionuclide contaminated waste oils and solvents generated by various activities on plant site. The facility underwent Resource Conservation of Recovery Act (RCRA) closure in 1993. The RCRA closure decontamination activities included the decontamination of the floor and walls of the facility, the removal of a tank/sump, and the removal of the surrounding contaminated soil. The remaining contamination exists at detectable levels in the groundwater, consisting primarily of trichloroethylene (TCE).

Phytoremediation was chosen as the remedial option for treatment of the groundwater in the X-740 area. The selection was based on the application of the technology to the site geology, contaminants of concern, and the operating life cycle costs. The site geology consists of slow-moving shallow groundwater, which is ideal for a phytoremediation system. TCE, the contaminant of concern, is a dense non-aqueous-phase liquid (DNAPL) and therefore tends to accumulate in the bottom of the aquifer. This characteristic makes DNAPL TCE difficult to remediate by typical pump-and-treat methods. The pump-and-treat methods are only capable of treating TCE in the aqueous phase, which leaves the non-aqueous phase untreated. This incomplete treatment can lead to a continuous process of TCE being pulled from the non-aqueous phase to the aqueous phase, requiring many years and large amounts of energy to complete remediation. A functional phytoremediation system, however, can remove TCE in both the aqueous and non-aqueous phases.

Three species of hybrid poplar trees (Populus nigra x nigra, Populus nigra x maximowiczii, and Populus deltoides x nigra) were chosen due to several positive factors: high growth rate and yield, high transpiration rates, depth of their root zone, long life span, and ease of growth. These species, moreover, have a greater resistance and resilience to various plant diseases known to the surrounding area. Currently the groundwater contains levels of TCE that are above the targeted risk level. The objective of this task was to remove contamination from the groundwater and to prevent migration of contaminants from the area. The goal of the remediation procedure was to achieve a completely mature and functional phytoremediation system within 2 to 3 years of the initial planting of the hybrid poplar trees. The organic compounds are then to be captured and removed from the groundwater.

A RCRA 5-year evaluation of the X-740 phytoremediation area was performed. This 5-year assessment displays the effects of the phytoremediation system on the groundwater flow representing the trees absorbing water from the system. A fluctuation in the TCE level was demonstrated by the four designated wells in the X-740 area (X740-03G, X740-10G, X740-PZ10G, and X740-PZ12G). However, this corrective action was installed in 1999, and approximately two years are required for the root system to mature sufficiently to have an observable impact on groundwater. Because it has been 5 years since the X-740 phytoremediation system was installed, only 3 years of effective growing seasons have elapsed for the trees to reduce the TCE concentrations in the area.

HISTORY

The X-740 Phytoremediation Area is located west of the former X-740 Waste Oil Handling Facility and south of the X-530A Switchyard, as shown in Figure 1. The trees were planted in an area that was previously used as a switchyard during construction of the PORTS facility.

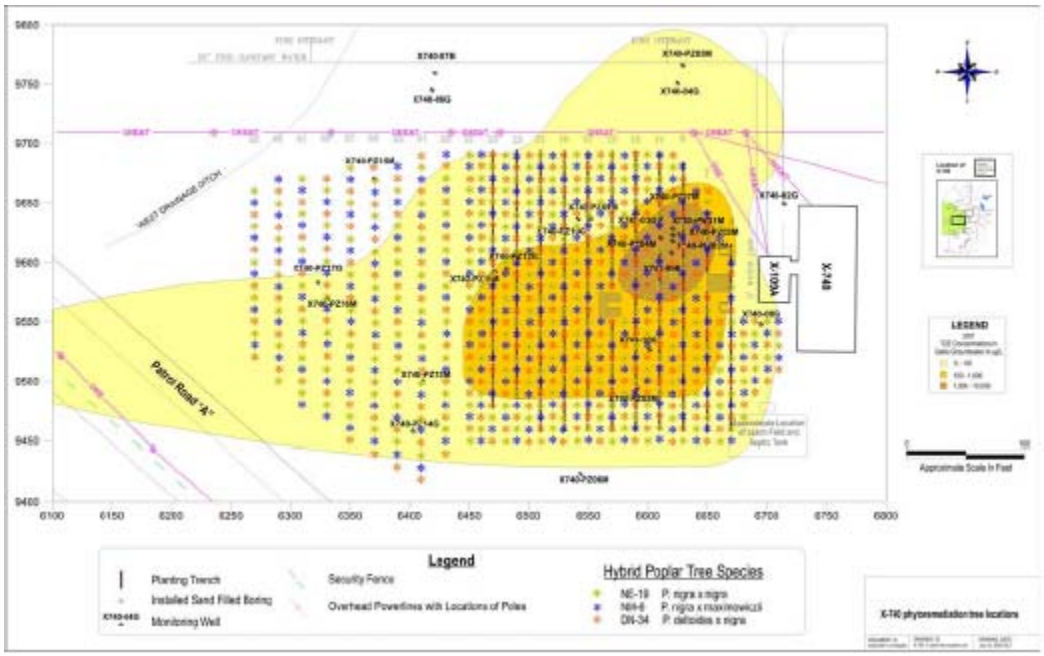

Fig. 1. This is an overview of the X-740 Phytoremediation Area, TCE Plume Extent, and Tree Planting Locations.

In 1999, the Ohio EPA selected the use of *in situ* treatment for the X-740 groundwater plume remediation. Phytoremediation was chosen as the best remedial option for treatment of the groundwater in the X-740 area. The natural growth process of biological systems is utilized by phytoremediation technology to attenuate and reduce contamination in groundwater.

In order to provide a greater resistance and resilience to various plant diseases, three hybrid poplar tree species were selected. A multi-species approach will present an increased success rate for the phytoremediation area. The three hybrid poplar tree species were selected for the application as a result of their high growth rate and yield, high evapotranspiration rates, root zone depth, long life span, and ease of growth. The X-740 phytoremediation system of 766 one-year old hybrid poplar trees were planted 10 feet apart in rows 10 feet to 20 feet apart, over an area of 2.6 acres, in order to manage the volatile organic compound (VOC) contaminant plume. The objective of this task was to remove contamination from the groundwater and to prevent migration of contaminants from the area. The goal of the remediation procedure was to achieve a completely mature and functional phytoremediation system within 2 to 3 years of the initial planting of the hybrid poplar trees. The organic compounds were then to be captured and removed from the groundwater. It is estimated that the cleanup standards can be achieved within 10.5 years after the trees reach maturity.

EVALUATION RESULTS

The X-740 Corrective Action was implemented in 1999. The first five-year review was conducted in 2003. The evaluation of the effectiveness of the X-740 Phytoremediation Project encompassed numerous site activities. The monthly and quarterly X-740 surveillance and maintenance inspections, water level collection, monitoring well inspections, groundwater monitoring, in-well pressure transducer/data logger information, and a tree coring study were evaluated in order to complete the review process.

The surveillance and maintenance inspections began in the spring of 2001 and were performed on monthly and quarterly intervals in order to evaluate the components of concern. The monthly inspections were conducted between October and March while the quarterly inspections were conducted between April and September during the growing season. These inspections included tree inspections, tree growth rates/patterns, and determination mortality rates/patterns. In August of 2000 maintenance included 52 trees being replanted as well as routine activities. In April of 2002 maintenance included 20 trees being replanted as well as continued routine maintenance at the X-740 Phytoremediation area. A total of 240 trees were planted with the trenching approach and a total of 526 were planted with the non-trenched rows approach. The 5-year evaluation noted that the trees planted in the trench are thriving with only 15 recorded as dead and 67.1% having a diameter larger than 8 cm. The non-trench planted trees are also thriving but not as well as the trench planted trees. The 5-year evaluation noted 44 non-trench planted trees recorded as dead and 4.2% having diameters larger than 8 cm. Overall the trees are surviving within predicted expectations.

The tree coring study was conducted in 2003. Samples were collected from 16 trees in the X-740 Phytoremediation area. Measurable levels of TCE, although relatively low, were detected in three of the 16 core samples. These results indicate that the trees are utilizing some groundwater containing TCE. Along with the tree coring study, tree-stem air diffusion trap sampling was conducted. No TCE was detected in the tree-stem air diffusion samples.

The Integrated Groundwater Monitoring Plan (IGWMP) began in 1999. This plan ensures the routine maintenance and monitoring of the PORTS plant. The four designated monitoring wells (X740-03G, X740-10G, X740-PZ10G, and X740-PZ12G) demonstrated lower TCE concentrations during the growing season than during the dormant season concerning data ranging between November 2001 through November 2004. This variation is due to several factors, including rainfall and the influence of the trees which cannot be separated. The TCE concentrations are below the Ohio EPA preliminary performance goal of 495 mg/L in three of the four wells. Well X740-03G is the only well above the target concentration. See Figure 2 for an overview of the four designated monitoring well TCE concentrations versus the EPA preliminary performance goal.

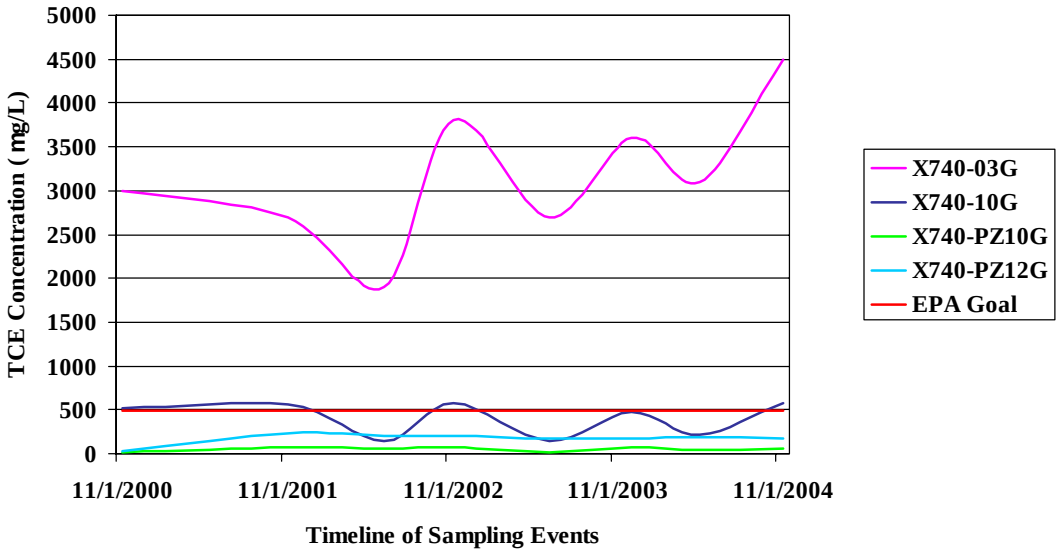

Fig. 2. An overview of TCE concentrations of the four designated X-740 monitoring wells.
Note: Three of the designated monitoring wells are below the EPA preliminary performance goal of 495 mg/L.

Groundwater monitoring, groundwater levels, and surveillance and maintenance inspections continue on a regular basis in order to evaluate the progress of the phytoremediation system. The estimated cleanup objectives of this corrective action procedure were to be obtained 10 years after the trees mature. However, this corrective action was installed in 1999, and approximately two years are required for the root system to mature sufficiently to have an observable impact on groundwater. Because it has been 5 years since the X-740 phytoremediation system was installed, only 3 years of effective growing seasons have elapsed for the trees to reduce the TCE concentrations in the area.

Groundwater level measurements have been collected in the past and are continually collected at the X-740 Phytoremediation area per IGWMP requirements. In the years 2000, 2001, and 2002, there was a detectable change in the groundwater flow in the area through the growing season. Potentiometric surface maps of the area throughout this time illustrate the influence of the phytoremediation system on the groundwater flow. Severe precipitation fluctuations have occurred in the Piketon, Ohio area between 2001 and 2003. The growing season of 2001 was extremely dry, 2002 was normal, and 2003 was extremely wet. The growing season of 2003 demonstrated a downward trend in the groundwater elevations, indicating increased groundwater demand. Groundwater elevations rose during November 2003, the dormant season, demonstrating the effectiveness of the phytoremediation system. The Figure 3 hydrograph demonstrates the X740-03G monitoring well groundwater elevation changes.

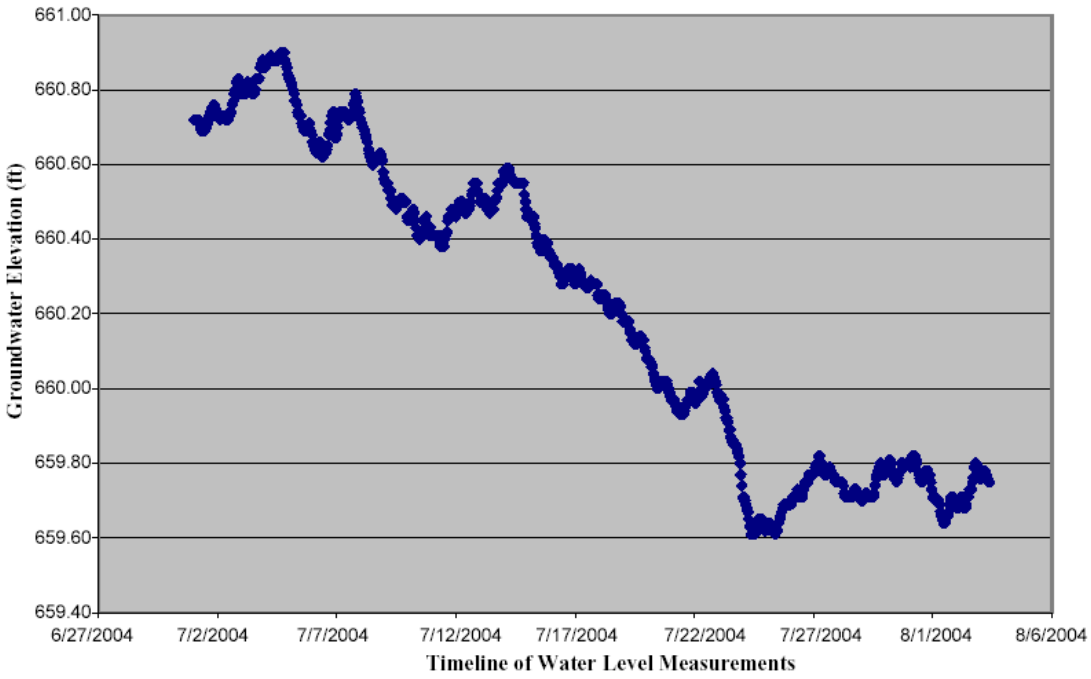

Fig. 3. An overview of a hydrograph for the X740-03G monitoring well demonstrating groundwater elevation changes.
Note: Data in hydrograph represents the year 2004.

DESIGN

Beginning in 1999, the X-740 Phytoremediation Corrective Action was implemented at the X-740 area. The X-740 Phytoremediation area incorporates approximately 2.6 acres of the PORTS reservation. Two inventive planting methods were implemented in order to construct a unique remediation system of hybrid poplar trees. Both methods of the X-740 Phytoremediation system include three multi-species hybrid poplar trees (Populus nigra x nigra, Populus nigra x maximowiczii, and Populus deltoides x nigra) planted in rows perpendicular to groundwater flow. A sand stack and trenching/boring design was implemented throughout the 2.6 acres of the X-740 area.

The first method of planting utilized was the trenching method, which included trees planted in rows typically 2 feet wide and 10 feet deep apart. Excavated soils from the trench installation were combined with fertilizer, lime, coarse sand, and peat moss to create an environment in which the trees will thrive. The trees were planted in the trench backfill material along the length of the trench.

The second method of planting utilized was the boring method which included trees planted in a 2-foot diameter and 10-foot deep boring. Prior to the installation of the trenches, borings 8 inches in diameter were drilled to the bedrock, approximately 30 feet below ground surface (bgs). Each boring was positioned between two adjoining trees in the same row. After reaching

the bedrock, the borings were filled with the excavated soils from the trench installation combined with fertilizer, lime, coarse sand, and peat moss to ground surface. The sand stacks will allow the flow of water upward to the tree planting trenches. The installation of the multi-species hybrid poplar trees was completed in May 1999. A total of 766 trees were planted within a 6-month time frame. This design structure and planting scheme will ensure an effective groundwater remediation system.

CONCLUSION

After five years of monitoring, the movement of groundwater in the area of the X-740 Phytoremediation Project was established by the groundwater level measurements conducted monthly during the growing season (summer months) and quarterly during the remaining months. Although the water level measurements demonstrate water removal from the trenches, the sand pipes do not appear to be removing an adequate amount of groundwater to allow significant TCE removal by the trees.

The four designated monitoring wells (X740-03G, X740-10G, X740-PZ10G, and X740-PZ12G) demonstrated lower TCE concentrations during the growing season than during the dormant season. This discrepancy may be due to the influence of the trees affecting the groundwater during the growing season. The TCE concentrations are below the Ohio EPA preliminary performance goal of 495 mg/L in three of the four wells. Well X740-03G is the only well above the target concentration.

The tree coring study revealed measurable levels of TCE in three of the 16 trees sampled. Because the TCE was detected at relatively low concentrations, however, this discovery proves that the trees are utilizing at least some of the groundwater containing TCE.

This corrective action was installed in 1999, and approximately two years are required for the root system to mature sufficiently to have an observable impact on groundwater. Because it has been 5 years since the X-740 phytoremediation system was installed, only 3 years of effective growing seasons have elapsed for the trees to reduce the TCE concentrations in the area. Although the TCE concentrations do not consistently reach the Ohio EPA preliminary performance goal of 495 mg/L in all four designated monitoring wells, it is evident that the trees at the X-740 Phytoremediation area are impacting the groundwater in the area. Another five-year review of the X-740 Phytoremediation Project will be conducted in 2008.

REFERENCES

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