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White Paper

Using Phytoremediation to Remove 1,4 Dioxane from Groundwater in Ann Arbor, Michigan

By John D'Addona, P.E.

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The groundwater in Ann Arbor is contaminated with 1,4 dioxane that is threatening the drinking water and public health of 110,000 people. This project proposes to utilize trees in shallow groundwater regimes to capture and continually reduce the concentrations of this pollutant.

Background

This project proposes to utilize phytoremediation, an emerging green technology, as an alternative approach to typical remediation techniques for 1,4 dioxane in groundwater. The United States Environmental Protection Agency (EPA) has defined six phytotechnology mechanisms within phytoremediation that eliminate, contain, or degrade contaminants using plants and trees. These six mechanisms include:

1. Phytosequestration – the ability of plants to sequester certain contaminants in the rhizosphere through exudation of phytochemicals and on the root through transport proteins and cellular processes,
2. Rhizodegradation – the exudation of chemicals that can enhance microbial biodegradation of contaminants in the rhizosphere,
3. Phytohydraulics – the ability of plants to capture and evaporate water from the plant, take up and transpire water,
4. Phytoextraction – the ability of plants to take up contaminants into the plant through transpiration,
5. Phytodegradation – the ability of plants to take up and breakdown contaminants during transpiration through internal enzymatic activity and photosynthetic oxidation/reduction reactions,
6. Phytovolatilization – the ability of plants to take up, translocate, and subsequently transpire volatile contaminants.

1,4 dioxane is an emerging contaminant of concern that has been detected in Ann Arbor and many groundwater aquifers throughout the country. It is highly mobile, and spreads quickly once released to the environment, tends to readily reach and travel with the groundwater, both horizontally and vertically, and is a threat to domestic water supplies making it a dynamic problem to solve.

The EPA has classified it as a B2 carcinogen. 1,4 dioxane is a volatile organic compound (VOC) that is a colorless, flammable liquid with a specific gravity that is very close to that of water, is fully immiscible in water, and poorly sorbs to soil. These physical and chemical properties make it difficult and expensive to monitor and remediate once it is released to the environment.

1,4 dioxane was used for decades as a solvent stabilizer, pharmaceutical purifying agent, deicing component in the aircraft industry, solvent in the manufacturing of medical equipment product accessories, such as filters, and byproduct in consumer products, such as cosmetics, lotions and shampoo. It is commonly detected as an artifact of chlorinated solvent plumes that have been identified and undergoing remediation. Its primary uses have decreased significantly over the past decades, but it continues to be used as a byproduct in many grooming and healthcare products.

Recent research conducted under laboratory-controlled conditions has shown that phytotechnologies can successfully transpire, retain, degrade, or volatize 1,4 dioxane in areas with shallow groundwater resources (less than 25 feet below the ground surface). In the study "Phytoremediation of 1,4 Dioxane by Hybrid Poplar Trees" published by the Water Environment Federation (WEF) in June 2000, suggested that 54 percent (with a 19 percent margin of error) of 1,4 dioxane was removed from the growing media over the course of nine days. The planting solution suggested a constant linear decrease over the course of the study,

as well as the existence of a strong linear relationship between 1,4 dioxane removal and total transpiration.

Other similar research suggests that monitoring 1,4 dioxane in tree tissue is an effective method to monitor and delineate the horizontal extent of 1,4 dioxane contaminated groundwater plumes. Using trees for this purpose is called phytoforensics.

Problem Definition

This project proposes to use phytoremediation to treat shallow groundwater contaminated with 1,4 dioxane. Currently, there are two separate and distinct 1,4 dioxane contaminated groundwater plumes underlying the City of Ann Arbor, Michigan.

The first plume emanates from a former municipal landfill with 1,4 dioxane concentrations in the shallow groundwater aquifer (between 9.5 and 21.5 feet below grade surface). This plume will be remediated by planting trees directly within a known area of contamination in deep boreholes just above the water table.

The second plume, known as the Gelman Plume, is the result of a waste discharge from a medical filter manufacturing operation that occurred in the 1970 and 80s. It is approximately three miles long and has contaminated multiple aquifers ranging from near the ground surface to over 150 feet deep. Actively expanding, the leading edge of the plume is migrating east of the source area beneath a large residential area and has nearly reached downtown Ann Arbor. With millions of gallons of groundwater contaminated, the complete capture and treatment of the entire 1,4 dioxane contaminated groundwater is cost prohibitive and unrealistic. However, there are subsets of the contaminated aquifers near the ground surface that pose the highest risk to residents. These risks can be minimized by using trees.

The proposed project will not replace the on-going remediation. it will provide additional risk reduction in areas where 1,4 dioxane in the plume is near the ground surface (less than 25 feet below grade). In these high-risk areas, the contaminant will be intercepted with trees prior to contact by human receptors. For over three decades, Gelman Sciences and its successors have been investigating and treating contaminated groundwater aquifers using advanced remedial oxidation processes that involve pumping large volumes of groundwater with the highest concentrations of 1,4 dioxane into a treatment system prior to its discharge to the receiving water. Although this treatment process has been effective, it is expensive and a large volume of 1,4 dioxane contaminated groundwater remains outside of the groundwater treatment capture zone.

Regulatory Concern

The Michigan Department of Environmental Quality (MDEQ) has recently reduced the 1,4 dioxane drinking water cleanup criteria from 85 ppb to 7.2 ppb, which will require additional delineation and treatment of the contaminant plume in areas where concentrations of 1,4 dioxane were below the previous drinking water criteria. It will also add significantly to the ultimate duration and cost of remediation. While there is currently no 1,4 dioxane federal drinking water standard, the Michigan recently enacted levels make it is extremely difficult and expensive to remediate dilute concentrations of 1,4 dioxane in large volume aquifers.

Public Concern

Given its size and active migration, Ann Arbor residents have concerns regarding public health and the eventual daylighting and discharge of the contaminant plume into the Huron River. Further, the length of the cleanup effort may foster public support to consider the Gelman Plume as a candidate for EPA's National Priority List (NPL), which would make it a "Superfund

Site." This designation has traditionally made federal funding available but has also imposed a negative perception that could adversely impact property values and limit economic growth in the affected community.

Project Objective & Scope

ECT proposes the establishment of phytoremediation tree planting area(s) to demonstrate the engineered removal of 1,4 dioxane from shallow groundwater, as shown in prior laboratory studies, are transferable to field applications. If successful, this technology could reduce the cost and duration of the Ann Arbor cleanup efforts while providing the technical foundation for similar 1,4 dioxane plumes across the nation as a viable, cost effective, green alternative for eliminating 1,4 dioxane from groundwater.

The objective for this project is to conduct a five-year field study building upon the findings resulting from prior laboratory studies. The field study would utilize trees as a low cost green remediation technology to delineate and remove 1,4 dioxane from shallow groundwater resources. To meet the objective, the following tasks are proposed:

Task 1 – Plant Trees Downgradient of the Landfill to Capture and Remove1,4 Dioxane

Phytoremediation trees (native poplars and willows as well as other selected native species) will be planted downgradient of the landfill and within the known contaminant plume footprint to remediate the highest known concentrations of 1,4 dioxane from the shallow groundwater aquifer and to serve as continuing monitoring locations to track further migration of the plume.

Expected subtasks:

1. Initiate a public outreach program to discuss phytoremediation plans at the landfill and potentially in West Park.
2. Identify, select and design the tree planting area(s) based on monitored 1,4 dioxane concentrations in groundwater.
3. Select tree species to implement phytoremediation of shallow groundwater.
4. Plant phytoremediation trees in the contaminant plume footprint downgradient of the landfill.
5. Design a monitoring plan to evaluate changes to 1,4 dioxane concentrations in groundwater and the tree tissue and leaves.
6. Install groundwater monitoring wells both upgradient and downgradient of the phytoremediation area.

Task 2 – Further Delineate Existing 1,4 Dioxane Contaminant Downgradient from the Landfill Using Existing Trees

Existing trees will be sampled downgradient of the landfill to evaluate whether trees can be used to help determine the extent of the 1,4 dioxane contaminant plume and to determine whether phytotechnology mechanisms are currently eliminating 1,4 dioxane from the groundwater. An ongoing monitoring program will be implemented for trees testing positive for 1,4 dioxane. The objectives of this task are to determine whether existing trees can be used to delineate 1,4 dioxane in groundwater (phytoforensics) and if the trees are actively removing 1,4 dioxane from the contaminant plume.

Expected subtasks:

1. Identify existing trees for tissue and leaf sampling.
2. Complete tissue and leaf sampling and analysis on existing trees.
3. Review and analyze data to determine whether existing trees contain 1,4 dioxane.
4. Determine if other existing or additionally planted trees could serve as "sentinel" monitoring locations at the leading edge of the landfill plume.

If other existing trees or additionally planted trees are recommended for further monitoring the extent of 1,4 dioxane or removing this contaminant further downgradient from the landfill, an expanded project scope incorporating the additional trees will be formulated.

Task 3 – Plant Trees in West Park to Capture & Remove 1,4 Dioxane From the Gelman Plume

Similar to Task 1, phytoremediation trees will be planted in or near West Park. These trees will serve as a preventative measure to intercept shallow groundwater potentially containing 1,4 dioxane. There are several areas where shallow groundwater aquifers that have been affected by the Gelman Plume daylights to the ground surface in seeps. These areas are primarily located near the leading edge of the plume in West Park, just west of the downtown area, and potentially further downgradient where groundwater daylights and discharges into the Huron River. At these locations where 1,4 dioxane contaminated groundwater is, or is close to the ground surface, the planting of trees may successfully remove 1,4 dioxane and thereby eliminate the direct contact and volatilization to indoor air exposure pathways where groundwater daylights upstream in the residential neighborhood and where the drinking water and direct contact exposure pathways exist at the river.

In the planting areas, trees can be used to store, degrade, or transpire contaminated groundwater through the root systems, tree tissue and leaves. At present, limited water sampling and analysis of daylighting groundwater in West Park has not tested positive for 1,4 dioxane. However, there is public concern that detection of 1,4 dioxane at the ground surface in West Park and at the edge of the Huron River is imminent. To proactively address these concerns, ECT proposes to presumptively establish phytoremediation tree planting areas at key locations within or close to West Park. Given the 2-3-year timeframe needed for trees to sufficiently mature and eliminate VOC contaminants, including 1,4 dioxane, the establishment of a "sentinel" phytoremediation tree plot that is capable of potentially remediating contaminants from the groundwater will be in place before 1,4 dioxane migrates to the park and before it can impact human health and the environment. Existing trees in the West Park area will be sampled as part of a phytoforensics monitoring program to determine if 1,4 dioxane concentrations are currently being transferred from the groundwater to the trees.

In addition, the control tree planting area established in the contaminant plume downgradient of the landfill as part of Task 1, where concentrations of 1,4 dioxane contaminated groundwater are known to exist, will be evaluated to help prepare an implementation strategy to address potential field conditions at West Park or other identified locations facing similar conditions. For both the West Park and the landfill plume planting areas, regular monitoring of the groundwater, tree tissue and leaves (Task 4) would be completed to determine the efficacy of using phytotechnologies to eliminate 1,4 dioxane from groundwater.

Expected Subtasks:

1. Identify, select and design possible phytoremediation tree planting areas within or close to West Park.
2. Sample nearby existing tree tissue and leaves to stablish whether 1,4 dioxane is already being removed in or near the proposed planting areas. Tree plot areas may be adjusted based on the results of this task.
3. Plant phytoremediation trees in or near West Park to intercept surface seeps potentially containing 1,4 dioxane.
4. Design a monitoring plan for all planting locations that includes additional monitoring wells to

evaluate changes in 1,4 dioxane concentrations in groundwater and in tree tissue and leaves to identify and locate the mechanisms supporting 1,4 dioxane removal.

Task 4 – Monitoring & Reporting

Monitoring and reporting of 1,4 dioxane concentrations in both the landfill plume and the Gelman plume as well as tissue and leaf sampling in the phytoremediation trees will be completed to evaluate the effectiveness of phytoremediation to remove 1,4 dioxane from groundwater.

Both existing and new groundwater monitoring wells will be sampled as part of this project. New monitoring wells in both contaminant plumes will be placed upgradient and downgradient of trees planted in the contaminant plume(s) to observe the net change in 1,4 dioxane and other concentrations across the treatment zones. Groundwater monitoring wells will be sampled and analyzed semi-annually.

Tissue and leaf samples associated with both plumes will be collected and analyzed annually for 1,4 dioxane and VOCs. Based on the tissue and leaf sampling results, the feasibility of additional phytoremediation tree plantings will be evaluated for areas along the Huron River or other appropriate areas where shallow contaminated groundwater is expected to daylight and discharge to the surface water.

All results associated with this project will be reported twice per year with a final report to include an analysis of whether phytoremediation of 1,4 dioxane in Ann Arbor is a success and whether phytoremediation is transferable to additional 1,4 dioxane contaminated sites.

Expected subtasks:

1. Collect groundwater samples semi-annually and tree and leaf tissue samples annually for analysis of 1,4 dioxane and VOCs.
2. Review and analyze monitoring data associated with both contaminant plumes to establish the success of using phytoremediation trees to remove 1,4 dioxane from shallow groundwater.
3. Complete semi-annual status reports (each year) and a final report (last year of study).

Task 5 – Community Outreach

Results of all activities will be communicated to the public in regularly scheduled meetings and on the city's website.

Expected subtasks:

1. Hold semi-annual public meetings to discuss the monitoring results and whether 1,4 dioxane is being removed by the phytoremediation trees.
2. Post monitoring results and status reports on the city's website.

Project Costs

Project costs can be subdivided into the five tasks discussed above. The project is expected to last a minimum of five years with the ability to continue monitoring on a year-to-year basis. The following costs are on a task basis assuming a five-year project.

Task	Cost (in thousands)
1. Plant Trees Downgradient of Landfill	82
2. Further Delineation Downgradient of Landfill	18
3. Plant Trees in West Park	72
4. Monitoring & Reporting (4 years @ $40,000/yr.)	160
5. Community Outreach (4 years @ $10,000/yr.)	40
TOTAL	**$372,000**