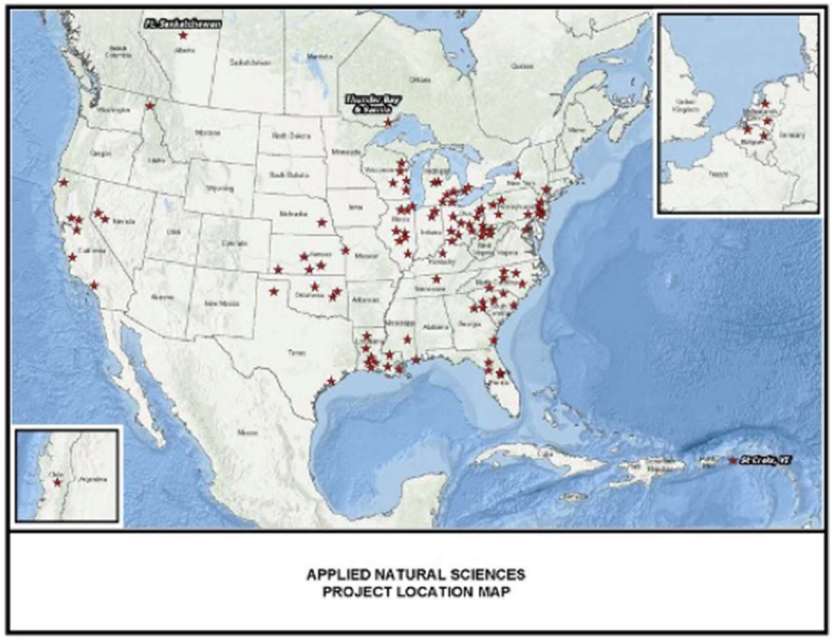
Applied Natural Sciences

Sustainable Nature-Based Solutions
TreeWell® Technologies
Soil and Groundwater remediation

Statement of Qualifications

Mission
To design and provide sustainable, effective, nature-based remedial solutions for contaminated soil and groundwater.

Background
Our pioneering experience with phytoremediation began in 1988. In 1993, Applied Natural Sciences was founded to provide our innovative *TreeWell*® services that go beyond the capabilities of more traditional phytoremediation options. We developed our patented *TreeWell* technology to allow access to deeper contamination not reachable by other phytoremediation methods. Applied Natural Sciences provides a natural and sustainable alternative to energy-intensive mechanical treatment methods.



We have successfully completed dozens of projects in North America, South America, and Europe, including projects with a wide range of climatic and physiographic conditions.

Our engineered phytoremediation systems differ from traditional phytoremediation approaches in their ability to overcome common limitations of depth-to-water, soil conditions, or impermeable stratigraphy. By engineering backfill soil and the growth of roots, we are able to utilize trees to reliably reach groundwater at depths exceeding 100 feet (30 meters) and direct root growth to a target horizon of interest while excluding groundwater from other strata.

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Advantages of the *TreeWell* System vs. Conventional Phytoremediation

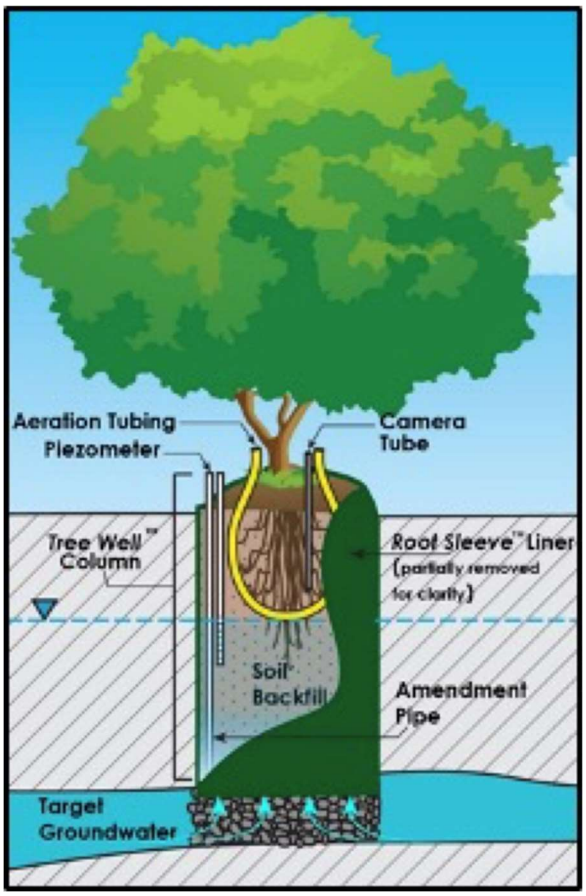
	Conventional Phytoremediation	*TreeWell* System
Effective for shallow soil and groundwater impacts	√	√
Able to treat deep (>15 ft/3 meters) groundwater	X	√ (over 100 ft/30 m deep)
Able to address phytotoxic concentrations of contaminants in soil and groundwater	X	√
Able to remediate specific horizons within the subsurface	X	√

Applied Natural Sciences' technology is effective with most soluble compounds impacting soil and groundwater. Our technology has successfully treated soil and groundwater impacted with the following:

- Volatile Organic Compounds (VOCs)
- Semi-Volatile Organic Compounds (SVOCs including 1,4-dioxane)
- Pesticides
- Agricultural inorganics such as nitrate & ammonium
- Tritium
- Solubilized metals
    - Lead
    - Arsenic
    - Boron
    - Zinc
    - Cadmium

Applied Natural Sciences is currently working on multiple pilot-scale projects for the remediation of PFAS-impacted groundwater.

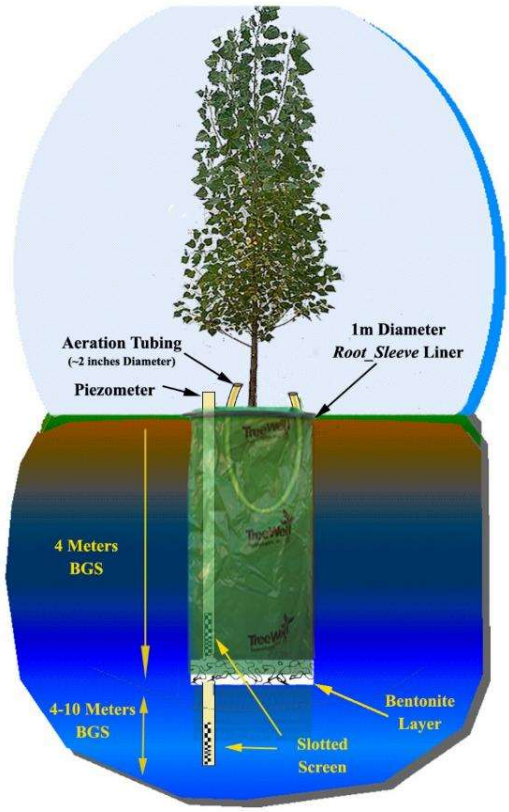
How do *TreeWell* units work?



- Trees operate as a pump; capillary pressure draws groundwater from the target interval up through the *TreeWell* soil column towards the root zone
- Simultaneously encourages downward root growth towards saturated conditions
- *Root_Sleeve*™ liner ("well casing") excludes non-target intervals and surface water infiltration, including percolating precipitation, ensuring trees are consuming water from the target interval
- Aeration tubing installed to provide oxygen to root zone
- *TreeWell* unit acts as a bioreactor where microbially driven contaminant degradation within can substantially reduce groundwater concentrations prior to contact with the roots, thus reducing potential phytotoxic effects commonly associated with high concentrations of some contaminants in traditional phytoremediation
- Residual contaminants may be taken up by the tree and treated within the plant with some molecules transpired into the atmosphere where they can subsequently be photo-oxidized (i.e., 1,4-dioxane, MTBE, Organochlorine Pesticides).

Straw *TreeWell* units

To access deeper groundwater, groundwater underlying confining layers, or fractured rock aquifers, a "straw" unit can be constructed to connect the *TreeWell* unit to the desired water-bearing interval. A *TreeWell* unit is constructed but the bottom of the boring is completed with a bentonite clay layer keyed into the bottom of the *Root_Sleeve* liner to create a "closed" unit. A "straw" well with a lower screen interval installed to the target groundwater interval and an upper screen interval within the *TreeWell* unit is installed through the bentonite bottom. The dual screened "straw" well serves to deliver water from the deep targeted interval to the *TreeWell* unit. The "straw" well can be constructed with an integral removable cartridge containing treatment media (i.e. granular activated carbon) that allows the removal of contaminants that are either untreatable by microbial degradation or too phytotoxic to allow into the *TreeWell* unit.



***PHYTO-INTEGRATED*™ Remediation Services**

Our *PHYTO-INTEGRATED* Remediation Services combine our *TreeWell* technology with other remedial technologies in a holistic effort to achieve remediation objectives. Combining remedial technologies provides aggressive short-term contaminant mass reductions coupled with sustainable long-term treatment and management. Our *TreeWell* systems can easily be incorporated with other more aggressive remedial technologies as part of a combined remedies approach that uses other technologies such as thermal-based remedies or enhanced bioremediation approaches to directly treat high concentration source areas while using our *TreeWell* system to treat dissolved phased portions of the plume. Various other remedial technologies including *in-situ* chemical reduction (ISCR, including ZVI, EZVI, Daramend®), ion exchange resins, and other treatment/absorption media such as granular activated carbon can be integrated directly into the *TreeWell* unit backfill soil to help address source area or elevated/recalcitrant contaminant conditions.

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Project Description: Waste Lagoons

Site Location: Carlyss, LA — 2015 - Present

Contaminants: Benzene, chlorobenzene, toluene, diphenyl ether, phenol; 1,1,2-TCA; 1,2-DCA; PCE; TCE; Chloroform; cis-1,2-DCE; trans-1,2-DCE; 1,1-DCE; vinyl chloride; 1,1-DCA; and lower concentrations of several other VOC constituents in shallow soils and groundwater

Treatment Depth: Approximately 25 – 115 ft bgs

Project Objective: Evaluate the efficacy of a *TreeWell*-based system for providing hydraulic control and remediation of groundwater impacted with high concentrations of VOCs including Dense Non-Aqueous Phase Liquid (DNAPL) impacts. Target treatment depths ranged from 25 to 115 ft below ground surface (bgs).

Implementation: The implementation consisted of 123 *TreeWell* units installed in three different parts of the site in four separate installation phases. The first installation phase was performed in December 2015 and consisted of 18 *TreeWell* units installed in 20 by 20 foot spacing to approximately 25 feet bgs. A set of hackberry, Russian olive, live oak, and black locust trees were planted in each of the 18 *TreeWell* units during the first phase of installation. During the 2015 installation, the 18 *TreeWell* units were divided into three subsets with one subset filled with engineered soil with organic matter amendments, a second subset filled with a mixture of soil and zero-valent iron (ZVI), and a third subset filled with a mixture of soil, ZVI, and Daramend® (a proprietary electron donor). In 2017 phase II of the installation commenced with the installation of 18 close-bottomed straw *TreeWell* units in a second portion of the site. The straw *TreeWell* units were divided into zones with targeted depths ranging from 44-115 ft bgs. One set of shallow Phase II units were filled with a mixture of soil and ZVI, and the second set of shallow Phase II units and set of deep units were filled with engineered soil with organic matter amendments. Phase III of the installation commenced in 2019 with the addition of 51 straw *TreeWell* units in a third part of the site. The 2019 units were planted with 35 willow and 25 black locust trees in March 2020. Phase IV of the project was implemented in 2022 with the installation of 33 *TreeWell* units targeting shallow groundwater migrating away from the Phase I area. Throughout the installations, a monitoring network consisting of piezometers and camera tubes was constructed to monitor the effectiveness of the *TreeWell* system at enhancing biodegradation of the contaminants in shallow soils and groundwater and exert hydraulic influence on groundwater.

Results to Date: For the post installation (2016-2021) growing seasons, tree growth and viability were observed to be very good for the entire *TreeWell* unit plantation with no notable indications of plant stress observed. The height and canopy of most of the trees in the *TreeWell* units continues to increase. To date, no signs of VOC phytotoxicity have been observed.

Results of vertical profiling of total VOC and chloride concentrations in groundwater within *TreeWell* units indicate total VOC concentrations decrease as water flows upwards within all *TreeWell* units installed at the site. Although units with ZVI or ZVI and Daramend in the backfill exhibited slightly more attenuation than units with only loam soil in the backfill, complete degradation of VOCs was still observed in units without ZVI or Daramend. Additionally, the groundwater data indicate the straw *TreeWell* units are functioning as designed by transmitting groundwater from as deep as 115 ft bgs upward into the *TreeWell* units, facilitating remediation of VOCs.

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Project Description: Chemical Plant

Site Location: Terneuzen, Netherlands — 2012 - Present

Contaminants: 1,4-Dioxane

Treatment Depth: Up to approximately 8 meters bgs (~26 ft bgs)

Project Objective: Hydraulic control of a 1,4-dioxane groundwater plume to prevent off-site migration of the plume.

Implementation: The site historically operated as a chemical plant with operations including the production of 1,4-dioxane. Subsequent releases from the chemical plant resulted in concentrations of 1,4-dioxane in groundwater as high as 31,000 mg/l in the source area and up to 5,900 mg/l in the groundwater plume. To provide hydraulic containment of the plume 240 poplar trees were planted in a combination of shallow and deep *TreeWell* units downgradient of a source area at the former chemical plant, which produced 1,4-dioxane. The "deep" zone (4.5 to 8 mbgs) *TreeWell* units were constructed as straw *TreeWell* units to focus groundwater extraction within a more permeable sand unit underlying a laterally continuous low permeability layer.

Results to date: Overall, the health and growth of the trees have been satisfactory with most trees showing fair or better health. Although some trees have shown relatively poor health, these trees are distributed throughout the installation area and there does not appear to be a correlation of tree health with COC concentrations in groundwater. As with tree health, overall tree growth has also been satisfactory with a clear positive correlation with tree health. Overall, the trees have continued to grow and increase in uptake capacity, thereby increasing treatment effectiveness.

Concentrations of 1,4-dioxane in groundwater demonstrate the shallow groundwater plume shifts towards the *TreeWell* system during the growing season, indicating that the system is providing hydraulic control of the shallow aquifer and is drawing the shallow zone groundwater towards the trees. Groundwater elevation data since installation of the *TreeWell* system indicate an upward vertical gradient between the shallow and deep groundwater zones. Therefore, the system is effectively controlling further migration of 1,4-dioxane impacts from the shallow zone to the underlying deep zone. Monitoring of 1,4-dioxane evapotranspiration indicate that the mass of 1,4-dioxane transpired by the trees is substantially lower than anticipated given the water uptake rates of the trees and the concentrations of 1,4-dioxane in the groundwater. Results of a microbiological characterization study show evidence of 1,4-dioxane biodegradation in the root zone of the trees, which may account for the mass difference in the expected vs. measured 1,4-dioxane transpiration.

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Project Description: Manufacturing and Distribution Plant

Site Location: Danville, Illinois – 2014 - Present

Contaminants: Carbon Tetrachloride

Treatment Depth: Approximately 25 ft bgs

Project Objective: To evaluate the efficacy of a *TreeWell* system for treating dissolved-phased contamination and providing hydraulic control of the plume as an alternative to a groundwater pump and treat system.

Implementation: The site is a former refrigerant manufacturing and packaging facility with carbon tetrachloride impacts in the subsurface. Historically a groundwater pump and treat system was operated as an interim remedy to control the groundwater plume and mitigate potential off-site migration. The initial system implementation consisted of 51 *TreeWell* units (alternating willow and poplar trees) installed on a 20 by 20 foot spacing to approximately 25 feet below ground surface. Based on the success of the first installation, a second installation of 28 additional *TreeWell* units (aspen and Norway spruce) was installed two years later to provide hydraulic capture of the contaminant plume. The secondary planting was performed based on the results of predictive computer modeling of groundwater flow that indicated *TreeWell* units would be capable of providing complete hydraulic control of the contaminant plume. To monitor system performance and effectiveness, groundwater monitoring wells were installed upgradient, mid-gradient, and downgradient relative to the *TreeWell* units. Selected wells were equipped with data logging pressure transducers to facilitate continuous monitoring of groundwater elevations. Data loggers were added to select monitoring well locations in the 2016 planting areas during spring 2017. The monitoring wells have also been sampled on a quarterly basis for analysis of VOCs.

Results to date: Since installation, overall tree health has been very good with robust growth since planting. Of the trees planted at the site only one tree exhibiting signs of disease and needed replacement. One additional tree was also damaged by deer rub but was pruned and successfully regrew.

Concentrations of 1,4-dioxane in groundwater demonstrate that the shallow groundwater plume shifts towards the *TreeWell* system during the growing season, indicating that the system is providing hydraulic control of the shallow aquifer and is drawing the shallow zone groundwater towards the trees. Groundwater elevation data since installation of the system indicate an upward vertical gradient between the shallow and deep groundwater zones. Therefore, the *TreeWell* system is effectively controlling further migration of 1,4-dioxane impacts from the shallow zone to the underlying deep zone.

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Project Description: CVOC Groundwater Contaminant Plume

Site Location: Shelby, North Carolina – 2015 - Present

Contaminants: Chlorinated VOCs and 1,4-dioxane

Treatment Depth: Approximately 25 ft bgs

Project Objective: To evaluate the efficacy of phytoremediation to control the subsurface migration of CVOCs in groundwater.

Implementation: The *TreeWell* implementation consisted of 150 *TreeWell* units which were installed in 20 by 20 foot spacing at approximately 25 feet below ground surface in May 2015. Alternations of willow, London plane, and tulip poplar trees were planted in each unit. Nine piezometers were installed for the utilization of transducers to capture water levels, and eight camera tubes were installed to capture root development data. In spring of 2016, 42 willow and poplar trees were planted to replace the 30% of poplar and London planes which had suffered mortality in the fall of 2015. In the spring of 2017, an additional 10 willow and 6 river birch trees were planted to replace the remainder of the tulip poplars.

Results to date: Aside from the 2015 mortality of the poplars (caused by improper storage and a delay in planting due to excessive rainfall), tree growth and viability were observed to be "very good" for the remainder of the *TreeWell* study. In 2017, an infestation of imported willow leaf beetles consumed most of the leaves of the willow trees, which has not affected the overall growth or vitality. However, any reduction of leaf area or early leaf drop has the potential to reduce the hydraulic function of the system. Due to early spring 2019 detection of the Willow Leaf Beetle, followed by a timely insecticide treatment, there was no additional beetle damage to the Willow trees. The height and canopy of most of the trees in the *TreeWell* units have continued to increase. Trees are displaying vigorous growth and, based on hydrogeologic monitoring data, are providing hydraulic capture. Preliminary hydrogeologic data suggest they are on track to perform as designed.