In Situ Treatment of Dissolved-Phase Chlorinated Solvents

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ABSTRACT: Chlorinated solvents and other volatile organics are prevalent groundwater contaminants throughout the United States. These volatile compounds present major risks to human health and the environment, are the most mobile, and commonly remain untreated for decades until fully investigated and/or sufficient funding is available to apply current remediation technologies.

The EcoBox® is a patented (Gee, 2001) in-well treatment technology that can operate simply as an extension to an existing monitoring well or larger treatment well located in a dissolved phase plume. A small high-head low flow pump is installed in the well to pump impacted groundwater up to the EcoBox® where it is treated and discharge back into the well. The EcoBox® can be operated using solar panels in remote areas. The system provides effective removal of dissolved phase chlorinated solvents through abiotic aeration and aerobic biodegradation at a cost that is significantly less than current in-situ or pump and treat techniques. EcoBox® application in several configurations will be presented. The time sequenced effectiveness of EcoBox® installation in removing trichloroethylene (TCE) in groundwater from a continuous 1,000 microgram per liter (ug/l) TCE source will also be presented.

INTRODUCTION

Chlorinated solvents including tetrachloroethene (PCE), trichloroethene (TCE), and their anaerobic degradation products *cis*-1,2-dichloroethene (*cis*-DCE) and vinyl chloride (VC) are prevalent long-term groundwater contaminants across the United States. PCE is resistant to degradation under aerobic conditions and difficult to fully dechlorinate to ethene under anaerobic conditions. As of 1996, soil and groundwater at approximately 400,000 sites in the United States were reported contaminated with chlorinated solvents (Sutfin, 1998). The U.S. Geological Survey (USGS) reports detection of VOCs in up to nine (9) percent of the ambient groundwater resources of the United States (Squillace, et. al., 1999). The United States Air Force (USAF) uses more than 900 sites that are contaminated with chlorinated solvents in excess of drinking water standards (Battelle, 2001). At many sites, sufficient funding is not available for expensive remediation using existing technologies and only long-term monitoring (LTM) is conducted.

Of even greater concern are the number of releases of petroleum related VOCs. EPA reports that as of September 30, 2006, there were 641,881 active underground storage tanks (USTs) in the U.S. (U.S. EPA, 2006). As of September 30, 2006, 464,728 releases from USTs have been confirmed and 435,631 cleanups have been initiated in the United States. Petroleum products such as diesel and gasoline fuels are the most common materials stored in USTs. Benzene from gasoline is most often the contaminant of concern because of its relatively high solubility and its known carcinogenicity. Since 1979, Methyl tertiary-butyl ether (MTBE) has been used in the United States as an octane enhancing replacement for lead in gasoline (at concentrations as high as eight [8] percent by volume). MTBE is approximately 30 times more soluble, ten (10) times less volatile (dissolved water to air phase), less likely to absorb to soil and more resistant to biodegradation than benzene in groundwater (U.S. EPA, 1998). Installation of the EcoBox® as a prototype have been reported effective in removing groundwater impacts from a leaking underground storage tank containing diesel fuel (Gee, 2001).

These and other VOCs in groundwater present major risks to human health and the environment, are the most mobile, and commonly remain untreated for decades until fully investigated and/or sufficient funding is available to apply current remediation technologies. A simple, low-cost treatment technique is needed to begin removal of these and other VOCs without long delays commonly associated with site investigation, regulatory approvals, and obtaining the funding needed to actually implement existing remedial techniques. The EcoBox® is specifically designed to allow deployment and remediation upon discovery of VOC impacted groundwater at a significantly lower cost than other remediation technologies currently employed.

MATERIALS AND METHODS

The EcoBox® configuration presented includes a very low flow vertical cylindrical counter current air stripper installed on a groundwater or monitoring well with a low flow diaphragm pump installed at the base of the well to move water to the top of the air-stripper. Air stripping treatment used by the EcoBox® for removal of VOCs from groundwater (to ambient air) is well understood, effective, and in widespread use. The U.S. EPA estimates that approximately 55% of the treatment facilities installed for groundwater treatment include air strippers (U.S. EPA, 2004). When installed in a VOC groundwater plume, the EcoBox® is designed to remove VOCs from the incoming groundwater flow and produce a downgradient groundwater plume free of VOCs. Both aboveground "stick-up" and below ground "flush-mount" configurations of the EcoBox® are shown in Figure 1.

As shown in Figure 1, a small high-head low flow pump is installed in the well. The discharge tubing from the pump extends up the well casing into the air-stripper. The vertical air stripper well extension consists of a clear Plexiglas vertical air stripper placed on the well either above or below the ground surface through installation in a ventilated vault (sealed outer well casing). The air stripper includes inlet ports for ambient air, an air backflow preventor (if needed) and horizontal drip trays. Conventional air stripper packing materials can also be installed in the drip trays and an air blower can also be connected to the EcoBox® air inlets to increase VOC removal efficiency if needed. Water is pumped from the well and sprayed out at the top of the Plexiglas air stripper in the same manner as a conventional air stripper commonly used in groundwater treatment facilities. Removal of VOCs in groundwater is increased by increasing either air flow and/or the extension length of the EcoBox® above the well.

The well screens of the EcoBox® configuration shown in Figure 1 are somewhat similar to the configuration of groundwater circulating wells (GCWs). Impacted groundwater is withdrawn from deep in the groundwater plume, treated in the air stripper and discharged to the groundwater table. The operation of the EcoBox® does not depend upon circulation in the aquifer for treatment, and no significant groundwater mounding should occur during operation. The EcoBox® has a significantly higher air-to-water ratio than GCWs greatly increasing removal efficiency. The EcoBox® effectiveness is also not impacted by the thickness of the unsaturated zone or depth of the plume since the pump can be set for any pressure head.

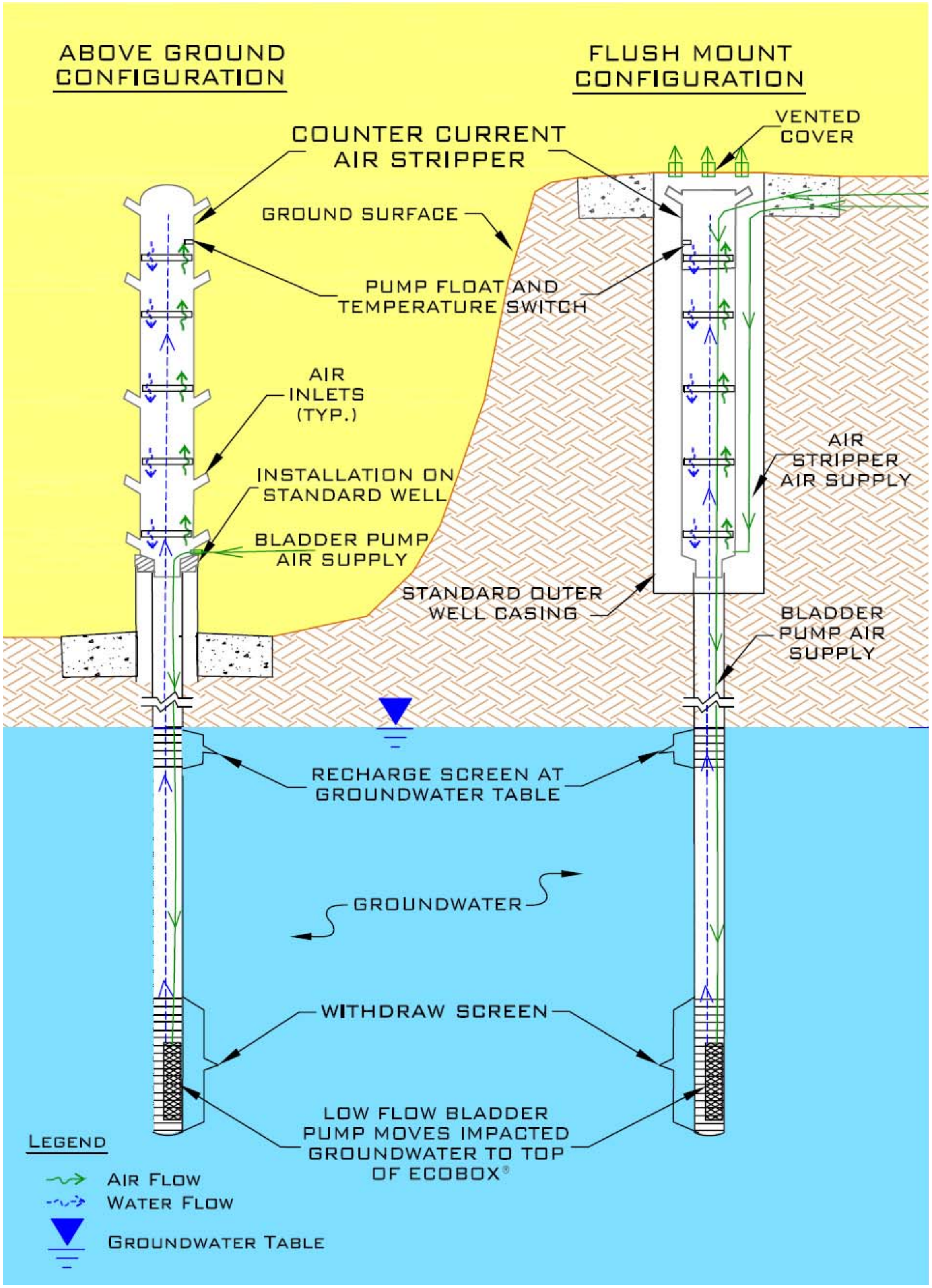

Figure 1
EcoBox® Above and Below Ground Configurations

Advantages of the EcoBox® include:

- Easy to install upon identification of VOC impacted groundwater.
- Effectively removes common solvent (TCE, PCE, etc.) and petroleum related compounds (benzene, toluene, ethylbenzene, xylene [BTEX], etc.)
- Very low pumped groundwater flow required (2 GPM or less).
- Very low operating costs.
- Low cost.
- Groundwater never leaves the well.
- Enhances in-situ aerobic bioremediation.

The number of drip trays, ultimate length of the air stripper required, and pumping rate from the EcoBox® is a direct function of the type and concentration of volatile compounds in the groundwater being treated and the rate of groundwater flow. The more trays and longer the air stripper, the more volatile compound removal will occur. The "air stripper" in the EcoBox® can be designed to be less efficient than a one-pass conventional air stripper used for groundwater treatment since several passes of the well contents through the "air-stripper" can occur to achieve effective contaminant removal. Repeated passes of the groundwater in the well though the "air stripper" is achieved since the rate of groundwater entering each well each day is small relative to the pumping rate used in the EcoBox®.

EFFECTIVENESS EXAMPLE

Groundwater modeling has been conducted to demonstrate the effectiveness of the EcoBox® on a groundwater TCE plume created by a continuous 1,000 microgram per liter (ug/l) TCE source. In this example, a silty sand aquifer is used with a horizontal hydraulic conductivity of 3.5 x 10^{-3} centimeters per second (cm/s or 10 feet per day [ft/d]). Modeling was conducted using MODFLOW-2000 and MT3DMS (public domain flow and transport programs) with the results processed using Groundwater Vistas (Version 4.20 Build 2). The groundwater model aquifer and flow simulation input parameters used in our example were:

- Model domain
  - 700 feet in x direction (width), 400 ft in y direction (length) and 20 ft in z direction (depth below groundwater table).
  - Uniform grid spacing, 5 ft horizontal, 2 ft vertical (140 columns x 80 rows x 10 layers). Bottom of model (layer 10): elevation = 20 feet.
- Hydraulic Gradient
  - Specified head of 50 ft in column 1 (all rows & layers) and specified head of 48 ft in column 140 (all rows & layers) to create uniform hydraulic gradient of 0.0028 feet per foot and "left-to-right" flow direction.
  - Bottom of layer 1 adjusted from 48 ft to 47.9 ft to avoid dry cells in column 140.

- Specified continuous concentration source of 1,000 ug/l TCE in layer 6, column 30, rows 31-50.
- Layer Property Flow (LPF) package input:
  - Uniform Hydraulic Conductivity of 10 ft/d horizontal conductivity and 1 ft/d vertical conductivity.
  - Layer 1 is unconfined
  - Steady state flow assumed.
- Preconditioned Conjugate Gradient (PCG) package used for flow solution as follows:
  - Maximum 100 outer iterations
  - Maximum 25 inner iterations,
  - Head change criterion 0.0001 ft,
  - Residual criterion 0.1 ft^3/d,
  - Relaxation – 1.0, no damping,
  - Cholesky preconditioning
- Finite difference scheme with upstream weighting used for transport solution.
  - Maximum Courant No. 1.0.
  - Implicit formulation with Generalized Conjugate Gradient (GCG) package;
  - Maximum 50 iterations,
  - Modified Choleski preconditioning criterion = 1e-6 ug/L, relaxation = 1.0

The "no action" condition was simulated for 12 years (4,383 days) with an initial TCE concentration of 0 ug/l except at the constant source. The initial time step size was 0.1 days with a maximum time step of 100 days and a time step multiplier of 1.2. Concentration results were recorded every six months (182.625 days).

As shown in Figure 1, the EcoBox® well screens are set in a manner similar to groundwater circulating wells (GCWs). For this example, the screen at the bottom of the well is six (6) feet long where water is withdrawn and the screen at the groundwater table is two (2) feet long where water is discharged back to groundwater after treatment in the EcoBox® air stripper. In the example, groundwater horizontal velocity is 0.028 feet per day. At this velocity, approximately 0.11 gallons of groundwater enters the well each day. For this example, an EcoBox® pumping rate of 2 GPM was used.

A conservative removal efficiency of eight (80) percent for the EcoBox® is used also in our example. Removal efficiencies of greater than 99 percent are common for TCE in well maintained and properly designed air strippers.

In our example, the EcoBox® was installed on a total of six (6) wells located at the 10 ug/l TCE concentration isopleth after 2 years of constant release. The wells with the EcoBox® were installed were spaced 35 feet apart, and directly downgradient of the constant TCE source. To simulate the EcoBox® installation, the six (6) wells with the EcoBox® installed were located at the beginning of year two (2) at:

- Row 37, Column 79
- Row 44, Column 79
- Row 32, Column 76
- Row 49, Column 76
- Row 29, Column 71
- Row 52, Column 71

At each well location the model specifications used were:

- Vertical hydraulic conductivity used was 1,000 ft/d in layers 5-7 (high conductivity to simulate six [6] feet well screen).
- Well withdrawals and injections were set at 385 ft^3/d (2 GPM) per well.
- Withdrawal of groundwater at layer 7.
- Injection of treated water in layer 1 (2 foot upper screen length) at a concentration of 2 ug/l TCE (80% reduction from withdrawal concentration of 10 ug/l).
- Initial step used was 1 day with the maximum time step size of 36.25 days and the multiplier was set at 1.05.

RESULTS AND DISCUSSION

Model results after five (5) years are shown in Figure 2 for the no action alternative and with treatment of the TCE plume using the EcoBox®. At the top in Figure 2 is the size of the plume after five (5) years without EcoBox® installation and at the bottom is the size of the plume after five (5) years with the EcoBox® installed at year two.

As shown in Figure 2, with no action taken after five (5) years, the TCE plume has reached a length of 504 feet from the source to the 5 ug/l TCE concentration isopleth (MCL for TCE), which commonly occurs in the early stages of a TCE plume due to prohibitive costs associated with conventional remedial techniques. However, if the EcoBox® were installed in the six (6) monitoring well locations shown, two (2) years after the constant release began, the TCE plume length would be reduced to 208 feet or a reduction of 296 feet with three (3) years of EcoBox® treatment, eliminating the TCE plume beyond the EcoBox® wells.

CONCLUSIONS

Air stripping treatment used by the EcoBox® (in the configurations shown) for removal of VOCs from groundwater is well understood, effective, and in widespread use. Conservative groundwater modeling shows that the EcoBox® is effective in removing dissolved phase TCE in a groundwater plume and eliminating the TCE downgradient of the location(s) of EcoBox® installation. Additional field installation and testing is needed to confirm results from prototype testing and modeling results.

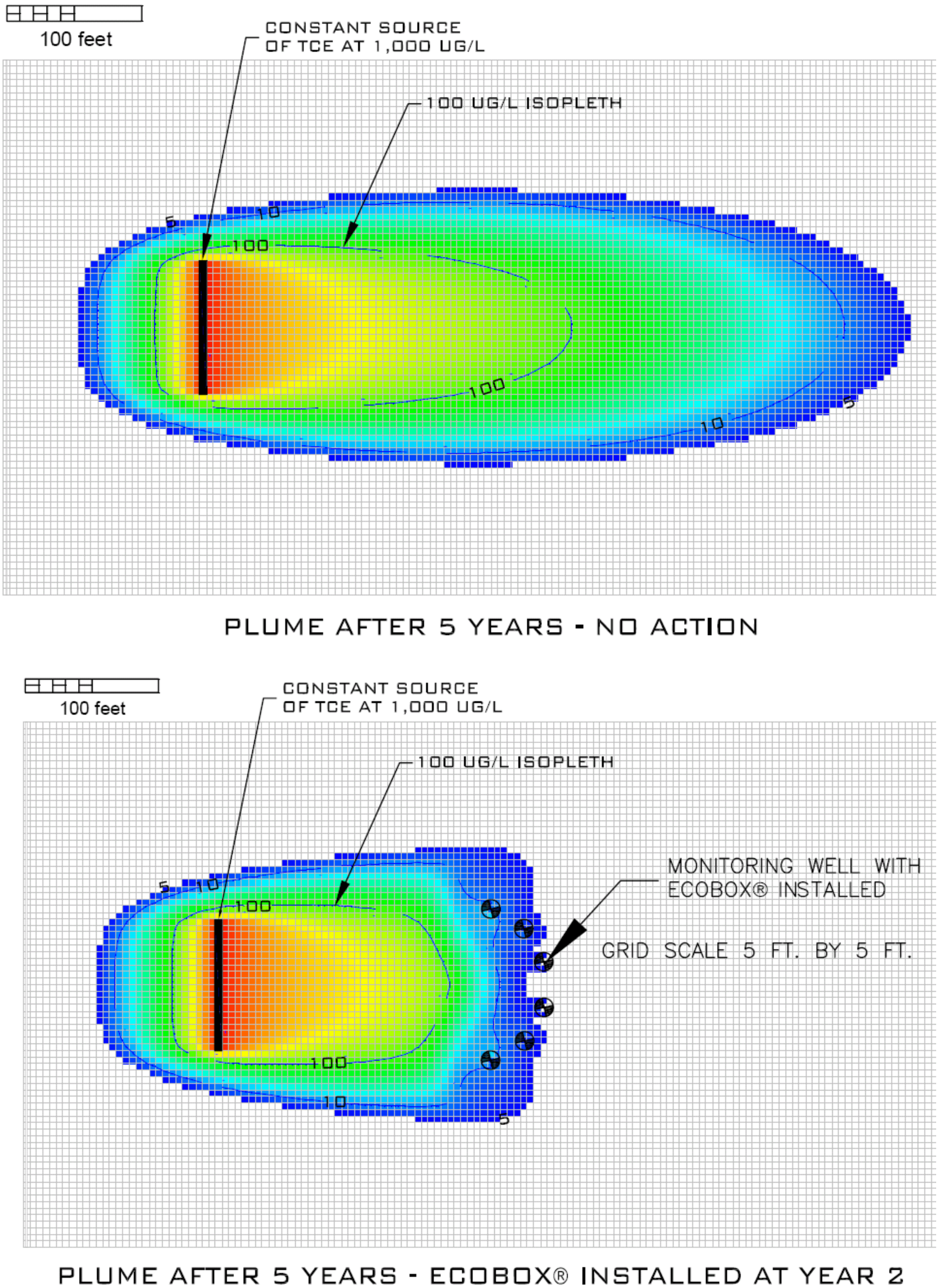

Figure 2
No Action and EcoBox® Results after 5-years

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