# The Art in-Well Technology – An Effective and Cost-Efficient Remedy For Soils and Groundwater in Fractured Bedrock Formations

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## Abstract

Remediation technologies have demonstrated mixed results at reducing subsurface contamination in fractured bedrock formations. It is increasingly apparent that many of these "generally accepted" technologies are not effective or reached contamination reduction asymptote before site cleanup levels were achieved. A remediation technology that can effectively remedy soil, groundwater, and vadose zone in fractured rock geology or move "stalled" sites to acceptable levels of remediation and achieve site closure, while embracing economic reality, is necessary. Accelerated Remediation Technologies, LLC developed a robust, field-flexible technology that shows effective remediation of volatile organic compounds (VOC). This innovative technology was installed at an industrial laundry facility overlying a fractured bedrock system and effectively reduced chlorinated solvent concentrations to regulatory compliance levels within a relatively short period of time and at a comparatively low cost.

The ART technology combines *in situ* air stripping, air sparging, soil vapor extraction, enhanced bioremediation/oxidation and subsurface circulation and flushing in an innovative wellhead system. The system is designed to accommodate a four-inch well and is cost effective when compared with other remediation technologies. The air sparging component results in lifting the water table. This lifting of the water in the well causes a net reduction in head at the well location. Vacuum pressure (the vapor extraction component) is applied atop of the well point to extract vapor from the subsurface. The negative pressure from the vacuum extraction results in water suction that creates additional water lifting (mounding). A submersible pump is placed at the bottom of the well to recirculate water to the top for downward discharge through a spray head. The water cascades down the interior of the well similar to what occurs in an air-stripping tower. Enhanced stripping via air sparging near the bottom of the well occurs simultaneously. In essence, the well acts as a subsurface air-stripping tower. The pumped, stripped, highly oxygenated water flows down the well annulus and over the mounded water back in to the aquifer which creates a circulation zone around the well to further enhance cleanup.

The ART technology has been implemented at several sites nationwide including industrial laundry facilities, manufacturing plants and service stations and has achieved significant reductions in contaminant concentrations. Specifically, a concentration of tetrachloroethene (PCE) at a fractured rock formation site located in Bethlehem, Pennsylvania, decreased from 400 ug/L to below the action limit in approximately 9 months. Other sites utilizing the technology have exhibited similar reduction trends in complex subsurface environments.

## ART INTEGRATED REMEDIATION SYSTEM

ART has developed an innovative remediation technology that is based on well-proven and established concepts. The ART technology combines in-situ air stripping, air sparging, soil vapor extraction, enhanced bioremediation/oxidation and Dynamic Subsurface Circulation™ in an innovative wellhead system. The system is designed to accommodate a four-inch well and is cost effective when compared with other remedial alternatives. The schematics of a typical ART well are diagramed in Exhibit-1.

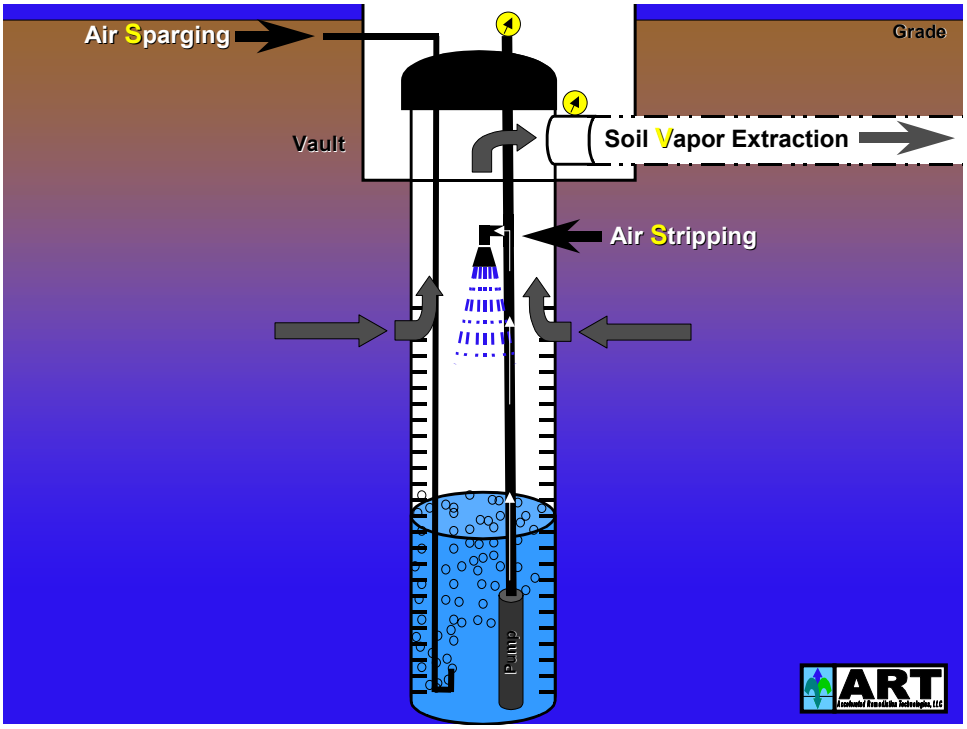


Exhibit-1 Typical ART well schematics

The air sparging component results in lifting the water table. The lifting of the water in the well causes a net reduction in head at the well location, which results in water flowing toward the well. Vacuum pressure (the vapor extraction component) is applied at the well point to extract vapor from the subsurface. The negative pressure from vacuum extraction results in water suction that creates additional water lifting.

A submersible pump is placed at the bottom of the well to recirculate water to the top for downward discharge through a spray head. The water cascades down the interior of the well similar to what occurs in an air-stripping tower. Enhanced stripping via air sparging near the bottom of the well occurs simultaneously. In essence, the well will act as a subsurface air-stripping tower. In addition to the air stripping by the pumping/cascading, the treated, highly oxygenated water flows down the well annulus and over the mounded water back in to the aquifer. This circulation zone surrounding the well further enhances cleanup. Radius of influences of up to ten times the water column in the ART remediation wells was achieved at sites where the ART technology was implemented. Multi-surface packing may be placed in a well to increase the effectiveness of air stripping; however, in most cases, in-well packing will probably not be necessary to achieve desired results. The effects of the synergistic forces in the subsurface in relation to the wellhead technology are shown in Exhibit-2.

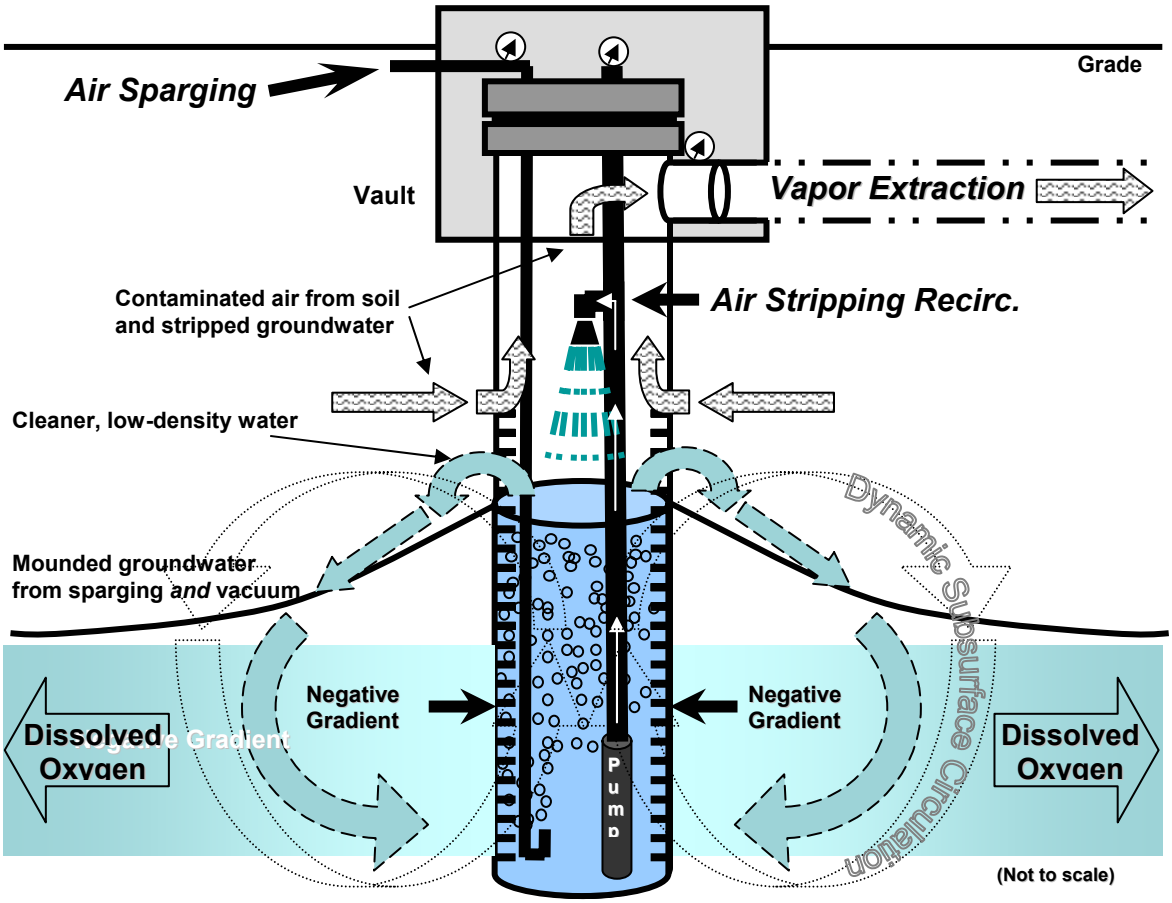


Exhibit-2 Synergistic subsurface effects of a typical ART well

In summary, contaminants are stripped from groundwater as a result of the combined effects of in-well air stripping and air sparging. The radius of treatment is created by a combination of (1) negative gradient as a result of air sparging, (2) additional negative gradient resulting from the application of vacuum extraction, and (3) Dynamic Subsurface Circulation™ induced by a submersible pump and hydraulic mounding. All of these different components can be integrated and installed in a four-inch groundwater well. Exhibit-3 is a photograph of the wellhead manhole components recently installed at a California former service station site.


Exhibit-3 Photograph of an ART wellhead

## Advantages

The ART technology is obviously a significant improvement to existing remedial alternatives. Based on several field implementations, this technology will expedite site closure for facilities where current remedial efforts have had limited success. Advantages of the ART technology include:

- Single well, multiple technologies
- Dynamic Subsurface Circulation
- No injection, discharge or disposal fees
- Groundwater, saturated zone and vadose zone remediation
- Proven remediation effectiveness in various geological formations
- Large screen - well efficiency loss is minimized and fractures are captured
- Jump-start stalled sites, can retrofit to existing systems
- Utilizes common 4" well configuration
- Enhances bioremediation and oxidation of hydrocarbons/MTBE
- No complicated components
- Relatively low installation and O&M costs
- Low Risk

The speed of contaminant concentration reduction will be dependent on the subsurface hydraulic conductivity. Reduction is expected to be at a higher rate in higher permeability soils.

## Site Background

The site, which is located in Bethlehem, Pennsylvania, is an industrial laundry facility and was used for dry cleaning services by the original owner approximately twenty years ago. The facility occupies an area approximately six acres with a 16,000 square foot structure. An industrial laundry operation was established at the site in the mid-1970s and contained a dry cleaning area for several years. Dry cleaning activities ceased in the 1980s and equipment has been removed by Unitog Rental Services, which was purchased by Cintas Corporation in 1999. A site layout is shown in Exhibit-4.

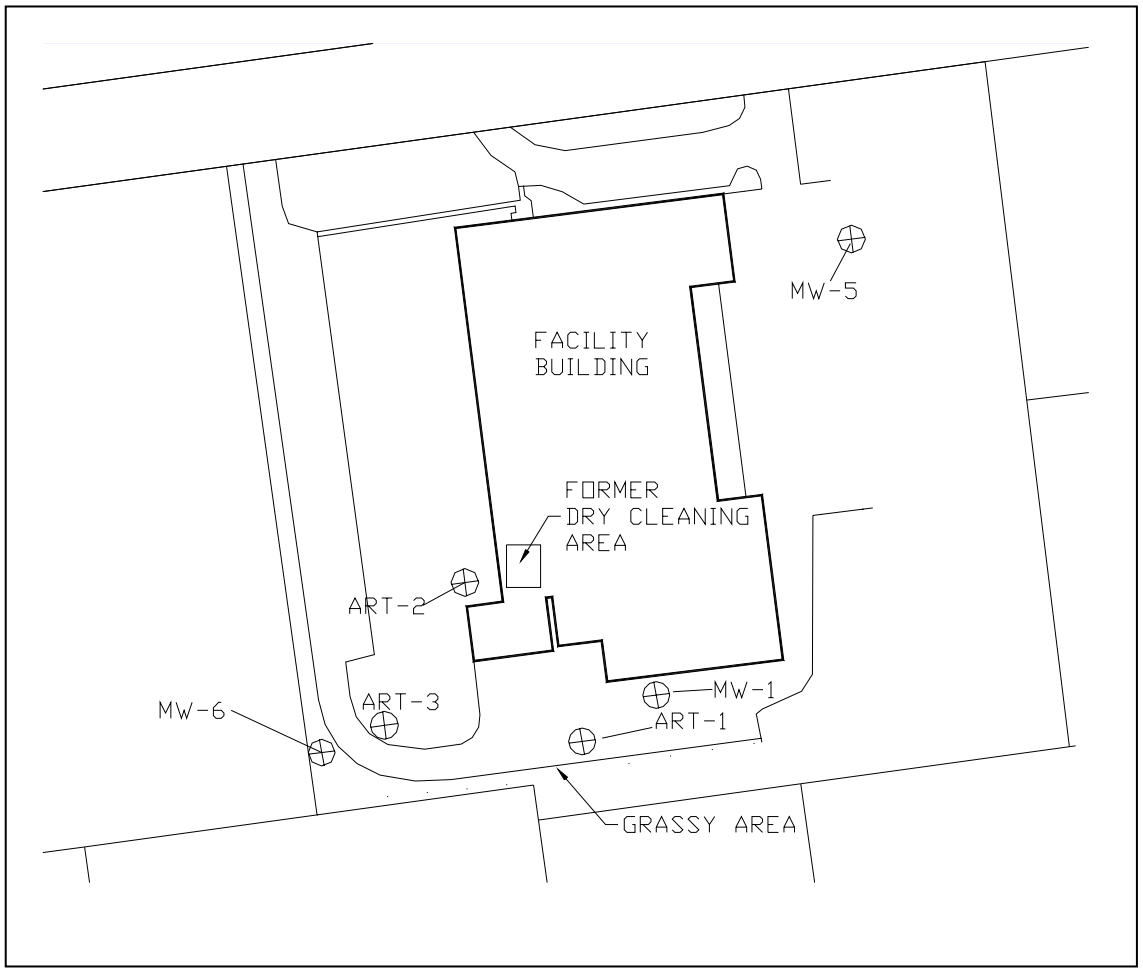


Exhibit-4 Site layout

Subsurface soils consist of silty clay to depths ranging from 10 to 60 feet underlain by limestone and dolomite (Epler Formation, Beekmantown Group). Groundwater flow occurs in secondary porosity along solution channels or bedding and fracture planes in the rock. Depth to groundwater at the site is approximately 90 feet below grade.

Three monitoring wells (MW-1 through MW-3) were installed at the site in 1998 to determine if contamination occurred as a result of a release from an underground commercial heating oil tank formerly located on the property. Subsequent groundwater sampling results indicated the presence of tetrachloroethene (PCE) at concentrations higher than the Pennsylvania state action limits of 5 micrograms per liter (µg/L). In 1999, a soil vapor extraction (SVE) system was installed to remediate the volatile organic compounds (VOCs) inadvertently released to site soils (ERI 2000). After consultations with PADEP, Cintas installed three additional monitoring wells (MW-4 through MW-6) in April 2000. Groundwater sampling and monitoring has been conducted since that time. As of May 2002, the extent of contamination in groundwater was as shown in Exhibit-5.

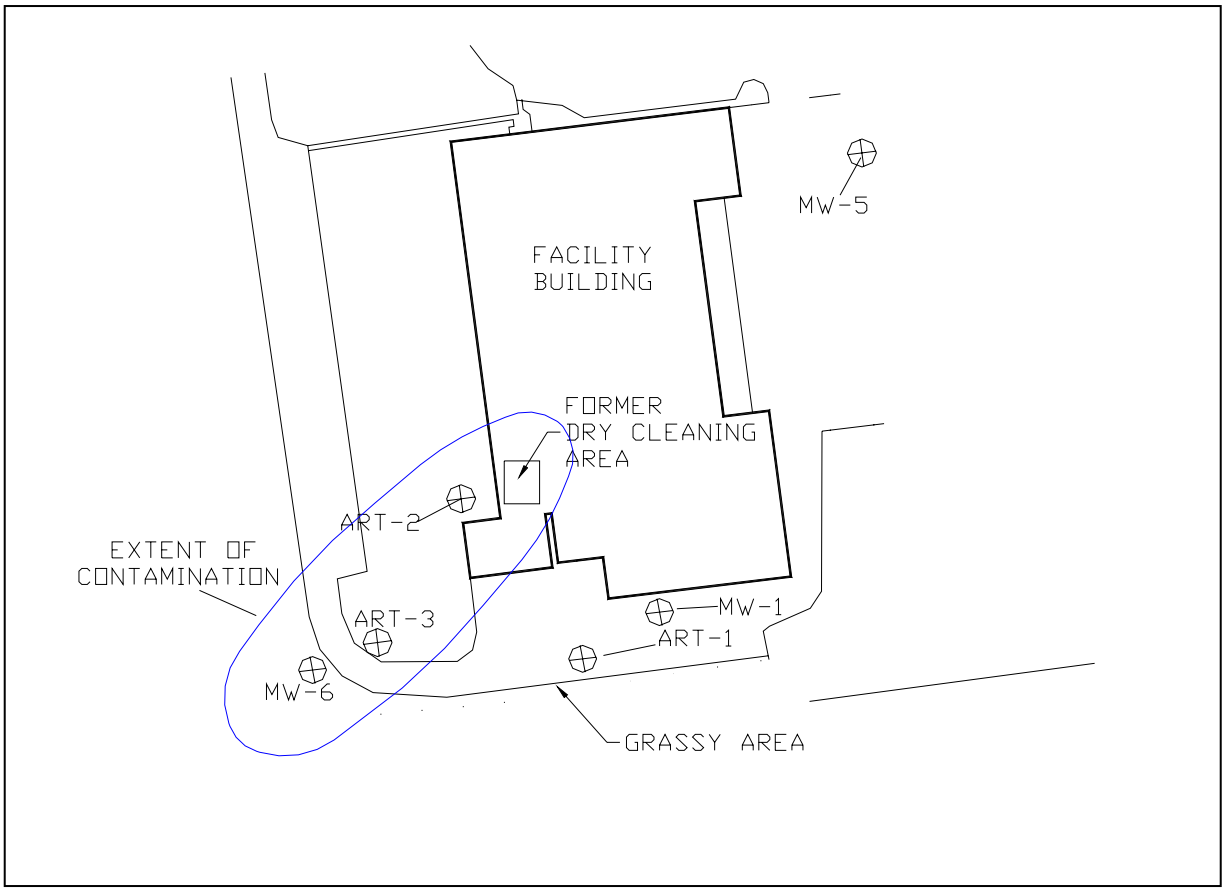


Exhibit-5 Extent of Contamination

As a result of the impending sale of the site, the owner desired a remedial technology that would provide more effective results and reduce contamination at the site to acceptable levels in a shorter period of time. The owner selected the ART Integrated Remediation System, which was approved by their environmental consultant and the state regulatory agency.

In May 2002, two existing four-inch monitoring wells were retrofitted with the ART In Well Technology. A third ART well was installed approximately 50 feet up gradient of the compliance point monitoring well, MW-6, as shown in Exhibit-4. MW-6 was used as the main monitoring point to gauge the effectiveness of the technology. Sampling data collected prior to the implementation of the ART technology indicated that PCE concentrations in groundwater were approximately 400 ug/L. MW-6 was sampled in July 2002, approximately 60 days after the implementation of the ART system. Analytical testing performed in April 2004, nine months after the startup of the

ART system, indicated that PCE concentrations were reduced to below action limits. The system remained in operation and concentrations have been reduced further as detailed in Exhibit 6.

Concentrations of PCE in Monitoring Well MW-6
Pre-ART and Post-ART Installation

| | Action | Pre-ART | Post-ART Installation | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Compound | Limits | Feb-02 | Jul-02 | Sep-02 | Jan-03 | Apr-03 | Jul-03 | Oct-03 | Jan-04 |
| PCE | 50 | 402 | 230 | 252 | 72.3 | 25.2 | 53 | 20.1 | 16.5 |

Exhibit-6 Groundwater sampling results

## Conclusion

The case study presented demonstrates that the ART In Well Technology is an effective alternative technology that is capable of stimulating site remediation and significantly reduces VOC contaminant concentrations over a relatively short period of time in challenging subsurface formations such as fractured bedrock. The combined synergistic effects of the ART technology components have resulted in a very aggressive, effective and cost-efficient remedy.

## References


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## Biographies

**STEVE PUCKE** is Director, Chemical and Environmental Engineering with Cintas Corporation. Steve joined Cintas in 1994 bringing with him ten years in the Chemical industry with Elf Atochem, North America Inc. and Quantum Chemical Inc. Steve also has four years of prior work experience with an environmental consulting firm. Steve holds a Master's in Environmental Engineering from the University of Cincinnati and a Bachelors degree in Chemistry from Wabash College. Mr. Pucke can be contacted at 27 Whitney Drive, Loc 868, Milford, Ohio 45150. Phone (513) 965-4902, Fax (513) 965-0985, Email address puckes@cintasmail.com.

**MARCO M. ODAH, Ph.D., P.E.** is a principal engineer and cofounder of EnviroRemedy International, Inc. and Accelerated Remediation Technologies, LLC. Dr. Odah has more than seventeen years of experience in implementation of soil and groundwater remedial technologies. Dr. Odah developed and holds the patent for the ART In-Well Air Stripping technology. He has served as an expert in projects related to refineries, manufacturing facilities, dry cleaning sites and underground storage tanks. Dr. Odah earned his Ph.D. from the University of Missouri in Kansas City in Engineering and Geosciences and his M.S. and B.S. in Civil Engineering at the University of Kansas. He is a registered professional engineer. Dr. Odah can be contacted at P.O. Box 2697, Olathe, Kansas 66063. Phone (913) 691-8181, Fax (913) 239-8999, Email address MOdah@ARTinwell.com.

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