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Overview Report

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O
SERIES

# In-well Vapor Stripping

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# FOREWORD

## About GWRTAC

The Ground-Water Remediation Technologies Analysis Center (GWRTAC) is a national environmental technology transfer center that provides information on the use of innovative technologies to clean-up contaminated ground-water.

Established in 1995, GWRTAC is operated by the National Environmental Technology Applications Center (NETAC) in association with the University of Pittsburgh's Environmental Engineering Program through a Cooperative Agreement with the U.S. Environmental Protection Agency's (EPA) Technology Innovation Office (TIO). NETAC is an operating unit of the Center for Hazardous Materials Research and focuses on accelerating the development and commercial use of new environmental technologies.

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## About "O" Series Reports

This report is one of the GWRTAC "O" Series of reports developed by GWRTAC to provide a general overview and introduction to a ground-water-related remediation technology. These overview reports are intended to provide a basic orientation to the technology. They contain information gathered from a range of currently available sources, including project documents, reports, periodicals, Internet searches, and personal communication with involved parties. No attempts are made to independently confirm or peer review the resources used.

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# ABSTRACT

This technology summary report is an overview of information collected by the Ground-Water Remediation Technologies Analysis Center (GWRTAC) on in-well vapor stripping (also known as vacuum vapor extraction and in-well air stripping) as an *in situ* ground-water remediation technology. Information provided includes an introduction to the general principles and techniques, a discussion of the general applicability of the technology, available data relating to its utilization, and reported advantages and limitations of the technology. Also provided are a list of references cited, and related references compiled during preparation of this report.

In-well vapor stripping technology involves the creation of a ground-water circulation pattern and simultaneous aeration within the stripping well to volatilize VOCs from the circulating ground-water. Air-lift pumping is used to lift ground-water and strip it of contaminants. Contaminated vapors may be drawn off for aboveground treatment or released to the vadose zone for biodegradation. Partially treated ground-water is forced out of the well into the vadose zone where it reinfiltrates to the water table. Untreated ground-water enters the well at its base, replacing the water lifted through pumping. Eventually, the partially treated water is cycled back through the well through this process until contaminant concentration goals are met.

Modifications of the basic process involve combinations with soil vapor extraction and aboveground treatment of extracted vapors and/or injection of nutrients and other amendments to enhance natural biodegradation of contaminants. Applications of in-well stripping have generally involved chlorinated organic solvents (e.g., TCE) and petroleum product contamination (e.g., BTEX, TPH). Proposed application of this technology, based on system modifications, may address non-halogenated VOC, SVOC, pesticide, and inorganic contamination. In-well stripping has been used in a variety of soil types from silty clay to sandy gravel.

Reported advantages of in-well stripping include lower capital and operating costs due to use of a single well for extraction of vapors and remediation of ground-water and lack of need to pump, handle, and treat ground-water at the surface. Additional advantages cited involve its easy integration with other remediation techniques such as bioremediation and soil vapor extraction and its simple design with limited maintenance requirements. Limitations reported for this technology include limited effectiveness in shallow aquifers, possible clogging of the well due to precipitation, and the potential to spread the contaminant plume if the system is not properly designed or constructed.

This document was prepared for distribution by GWRTAC. GWRTAC is operated by the National Environmental Technology Applications Center (NETAC), under a Cooperative Agreement with the United States Environmental Protection Agency's (EPA) Technology Innovation Office (TIO).

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# 1.0 INTRODUCTION

## 1.1 GENERAL

In-well vapor stripping, also known as *in situ* vapor or *in situ* air stripping, is a pilot scale technology for the *in situ* remediation of ground-water contaminated by volatile organic compounds (VOCs) (and possibly other types of contaminants, see Section 2.1). The in-well stripping process, an extension of air sparging technology, involves the creation of a ground-water circulation cell around a well through which contaminated ground-water is cycled. The air stripping well (See Figure 1) is a double-cased well ("well-within-a-well") with hydraulically separated upper and lower screened intervals within the same saturated zone (aquifer). The lower screen, through which ground-water enters, is placed at or near the bottom of the contaminated aquifer and the upper screen, through which ground-water is discharged, is installed across or above the water table.

Air is injected into the inner casing, decreasing the density of the ground-water and allowing it to rise within the inner casing. This constitutes a type of ***air-lift pumping system***, similar to that found in an aquarium filter system. Through this air-lift pumping, volatile contaminants in the ground-water are transferred from the dissolved phase to the vapor phase by the rising air bubbles through an ***air stripping*** process. Contaminated vapors can be drawn off and treated above ground (similar to a soil vapor extraction system) or discharged into the vadose zone, through the upper screened interval, to be degraded via *in situ* bioremediation.

The ground-water, which has been partially stripped of volatile contaminants, continues to move upward within the inner casing and is eventually discharged into the outer casing, moving through the upper screened interval into the vadose zone or the upper portion of the aquifer. Once returned to the subsurface, ground-water flows vertically downward, eventually reaching the lower portion of the aquifer where it is cycled back through the well into the lower screened interval, replacing the water that rose due to the density gradient.

This cycling of water in the area around the well creates a hydraulic circulation pattern or cell that allows continuous cycling of ground-water *in situ* through the air stripping process. Ground-water is repeatedly circulated through the system until sufficient contaminant removal has taken place.

In the in-well vapor stripping process, contaminants that are dissolved in ground-water are transferred to the vapor phase, which is generally easier and less expensive than ground-water to treat. Ground-water is not removed from the subsurface, but is circulated back into the well to facilitate further vapor removal. The vapors can be removed using the same stripping well, or, if applicable, can be discharged into the vadose zone for *in situ* bioremediation (See Figure 1).

## 1.2 MODIFICATIONS

Modifications to the basic in-well stripping process may involve additives injected into the stripping well to enhance biodegradation (e.g., nutrients, electron acceptors, etc.). In addition, the area around the well affected by the circulation cell (radius of influence) can be modified through the addition of certain chemicals to allow *in situ* stabilization of metals originally dissolved in ground-water. (4, 5, 7, 9, 11 14,15).

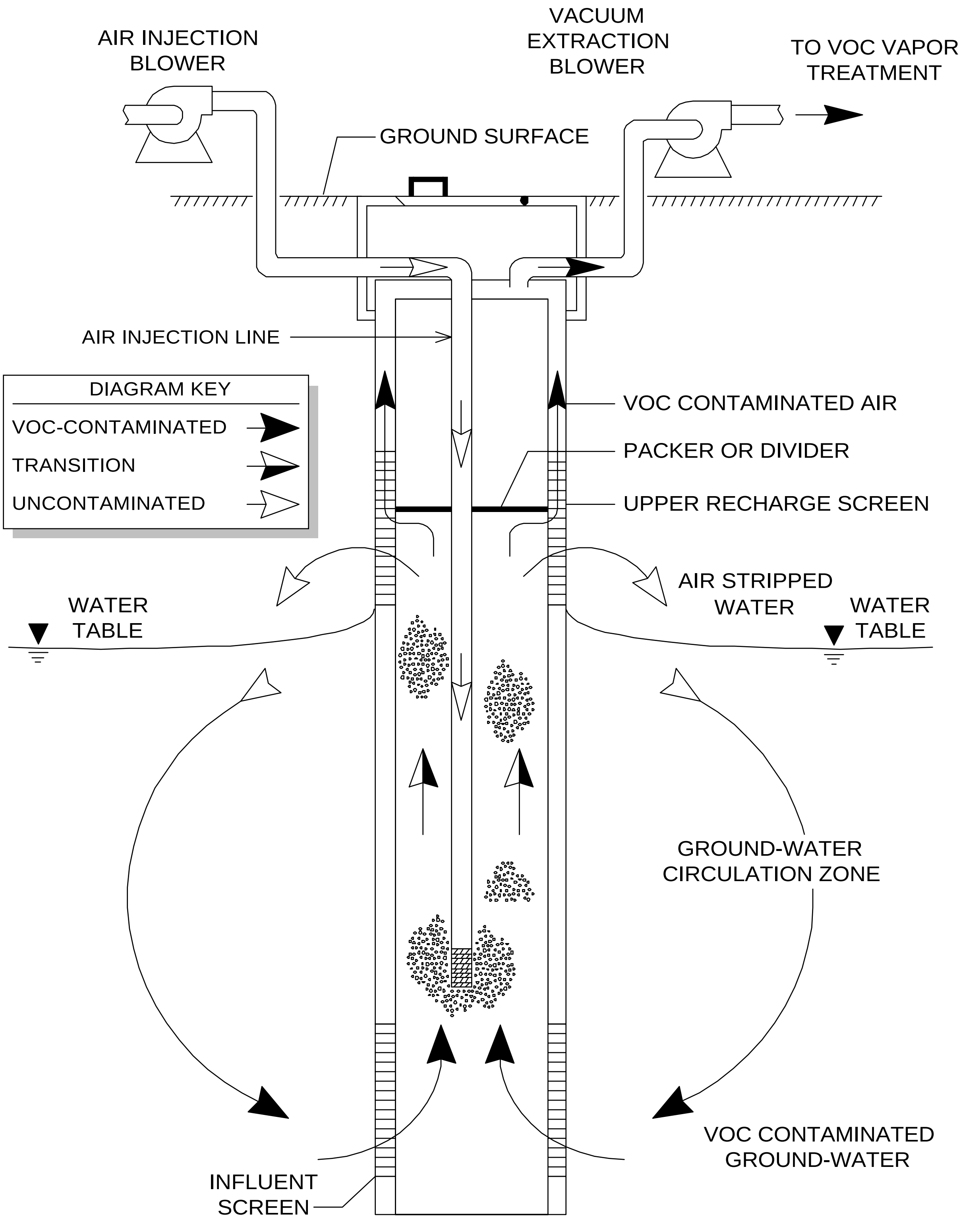

FIGURE 1. IN-WELL VAPOR STRIPPING PROCESS

# 2.0 APPLICABILITY

## 2.1 CONTAMINANTS

Most of the field applications of this technology have involved halogenated volatile organic compounds (VOCs), such as trichloroethylene (TCE), and petroleum products/constituents such as benzene, toluene, ethylbenzene, and xylene (BTEX). Applications of in-well stripping to non-halogenated VOCs, semi-VOCs (SVOCs), pesticides and inorganics have been proposed based on modifications of the basic remedial process. In addition, the technology has been applied to ground-water contaminated with both radionuclides and VOCs. (2, 5, 7, 11,15).

## 2.2 SITE CONDITIONS

Site soil conditions seem to be less of a limitation for in-well stripping than air sparging, since air movement through aquifer material is not required for contaminant removal. In-well vapor stripping has been applied to a wide range of soil types ranging from silty clay to sandy gravel (8, 9, 10).

# 3.0 METHODOLOGY

## 3.1 GENERAL

Several commercial variations of the basic in-well stripping process have been developed. The following is a synthesis of information from all information reviewed about the operations of these current systems. Modifications of standard methods will be explored following the general discussion.

As described in Section 1.0, the in-well stripping well consists of an inner and outer casing hydraulically separated from one another (See Figure 1). This separation, generally accomplished by a packer assembly, metal plate, or grout seal, ensures one-directional flow of water into the well at its base (through the lower screen in the inner well) and out of the well above the water table (through the upper screens in both casings). The outer well may also be screened above the water table if the well is to be used for soil vapor extraction (7, 14, 15).

The following outlines the general steps in the in-well stripping process (See Figure 1):

- ***Air*** (or an inert gas) is ***injected into the inner well*** through a gas injection line using a vacuum blower, compressor, diffuser plate or other means, releasing bubbles into the contaminated ground-water. The ***resulting bubbles aerate the water,*** forming an air-lift pumping system and causing ground-water to flow upward in the well.

- The ***gas bubbles rise through the water in the well and also lift the water*** due to a density gradient (ground-water containing air bubbles is less dense than ground-water without bubbles outside of well).

- As the bubbles rise through the VOC-contaminated ground-water, these **c*ompounds are naturally transferred from the dissolved to the vapor phase*** through an air stripping process (In the UVB process, this occurs in a stripper reactor.).

- The ***air/water mixture rises until it encounters the dividing device*** within the inner well, above the contaminated zone. The dividing device is designed and located to maximize volatilization.

- The water/air mixture is forced out of the upper screen below this divider.

- The outer casing is under a vacuum, and ***vapors are drawn upward*** through the annular space and are collected at the surface for treatment, or may be released to the unsaturated zone for *in situ* bioremediation.

- The ***ground-water***, from which some VOCs have been removed, ***re-enters the contaminated zone***.

- As a result of rising ground-water lifting at the bottom of the well, ***additional water enters the well at its base***. This water is then lifted via aeration.

- The partially treated water re-entering the aquifer is eventually cycled back through the process as ground-water enters the base of the well. This pattern of ground-water movement forms a ***circulation cell*** around the well, ***allowing ground-water to undergo sequential treatment cycles*** until remedial goals have been met. The area affected by this circulation cell, and within which ground-water is being treated, is called the radius of influence of the stripping well. (11, 14)

In-well vapor stripping systems can utilize soil vapor extraction techniques simultaneously with other modifications. In addition, in-well stripping technologies can be modified through the use of bioremediation principles and other physical and chemical treatment technologies as described below (7).

## 3.2 TYPES OF SYSTEMS

**NOTE: Information provided in this report about technologies from a specific company are presented for informational purposes only.**

*GWRTAC (EPA TIO, NETAC, and the University of Pittsburgh) neither endorses nor in any way recommends the companies discussed. No effort has been made, nor will be made, to verify the accuracy of the information provided, or to assess the validity of any claims about the companies or their products. GWRTAC makes no warranties, expressed or otherwise, without limitation or liability, for the completeness, accuracy, or usefulness on the information provided.*

The three main types of in-well vapor stripping systems examined for inclusion in this report include:

- **NoVOCs™** system patented by Stanford University and purchased in 1994 by EG&G Environmental;
- **Unterdruck-Verdampfer-Brunnen** (UVB) or "vacuum vaporizer well" system, developed in Germany by IEG Technologies Corporation and being demonstrated by Roy F. Weston, Inc.;
- **Density Driven Convection** (DDC) system, developed and patented by Wasatch Environmental, Inc.

### 3.2.1 NoVOCs™

The basic ***NoVOCs™*** system (See Figure 2) is largely similar to the generic description provided in Section 3.1. The NoVOCS™ system uses a compressor to deliver the air to the contaminated water column. The bubble-water mixture rises to a point where optimum volatilization has occurred, where it encounters a deflection plate. At this point the air bubbles combine. The water flows out of the well through the upper screen and the coalesced bubbles are drawn off by vacuum for above ground treatment for VOCs. In addition, one modified NoVOCs™ system is purported to allow ***removal of metals from ground-water through* in situ *fixation*** using common water treatment chemicals. Chemicals appropriate for treatment (adsorption and/or precipitation) of the target contaminants are emplaced around the NoVOCs™ well. The ground-water circulation pattern created by the process described above (air-lift pumping of ground-water to the vadose zone where it is released and allowed to reinfiltrate into the aquifer) brings metal-contaminated ground-water into contact with chemicals in the unsaturated zone that are designed to immobilize them. The *in situ* treatment/ infiltration gallery contains the chemicals and other additives necessary to provide

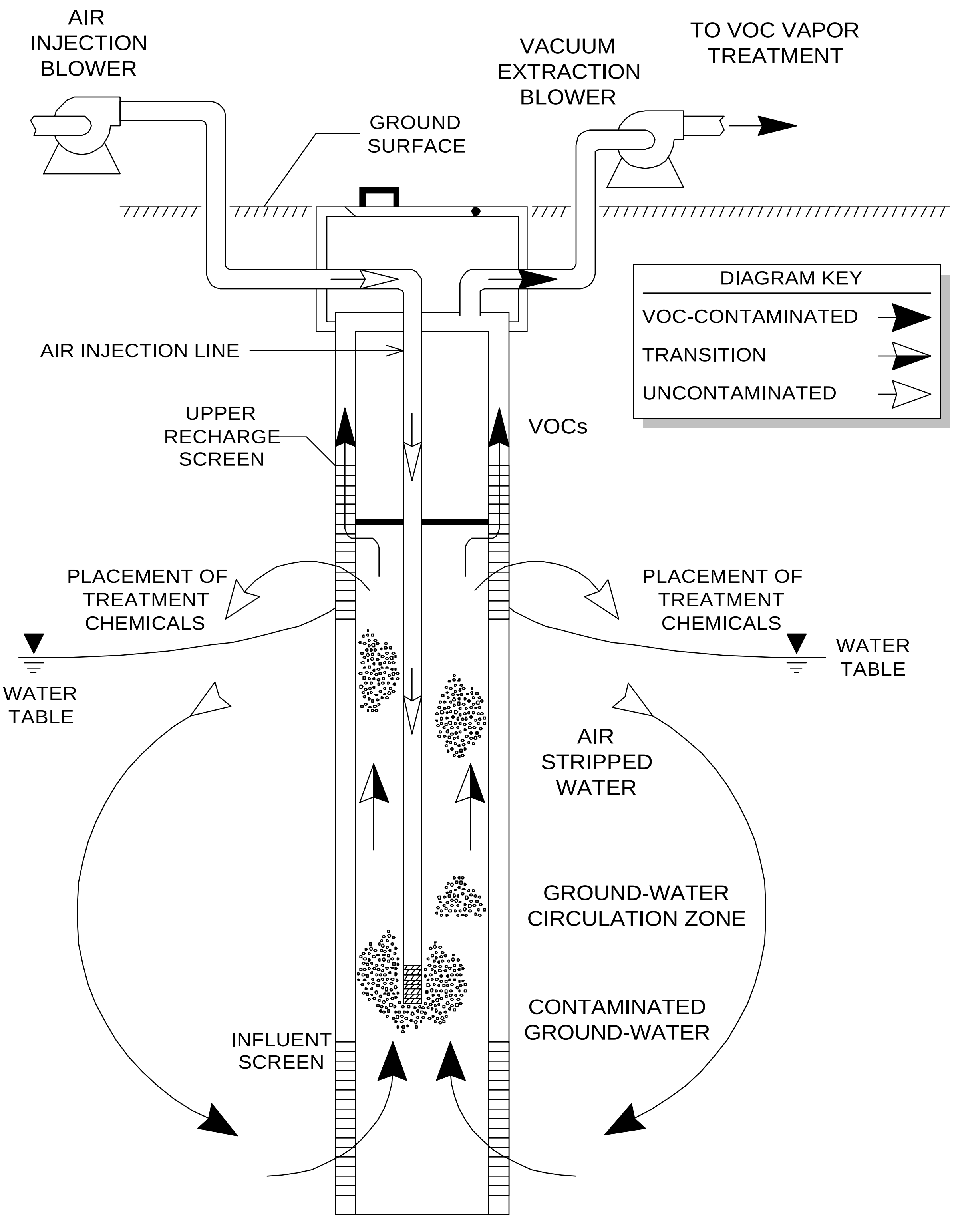

FIGURE 2. NoVOCs ™ IN-WELL VAPOR STRIPPING PROCESS

the proper pH and redox conditions for fixation of metals contained in the ground-water. Following the treatment process, the treatment gallery can be covered in place, excavated and replaced with backfill, or the gallery can be designed as a "retrievable cartridge" that can be "replaced when exhausted" (2).

### 3.2.2 UVB

The ***UVB*** system (See Figure 3) supplements air-lift pumping via a ***submersible pump*** to maintain flow at a standard rate. In addition, the UVB system employs a ***stripper reactor*** to facilitate transfer of volatiles from aqueous to gas phase before the water is returned to the aquifer. This device, located just below the air diffuser, "consists of fluted and channelized column that facilitates transfer of volatile compounds to gas phase by increasing contact time between two phases and by minimizing coalescence of air bubbles" (11).

### 3.2.3 DDC

The ***DDC*** system (See Figure 4) emphasizes the enhancement of bioremediation and involves the discharge of extracted vapors into the vadose zone for degradation by naturally-occurring microorganisms. Nutrient solutions may be added to the DDC well as a concentrated slug. Oxygen is supplied to both the saturated subsurface and the vadose zone promoting natural aerobic processes (8).

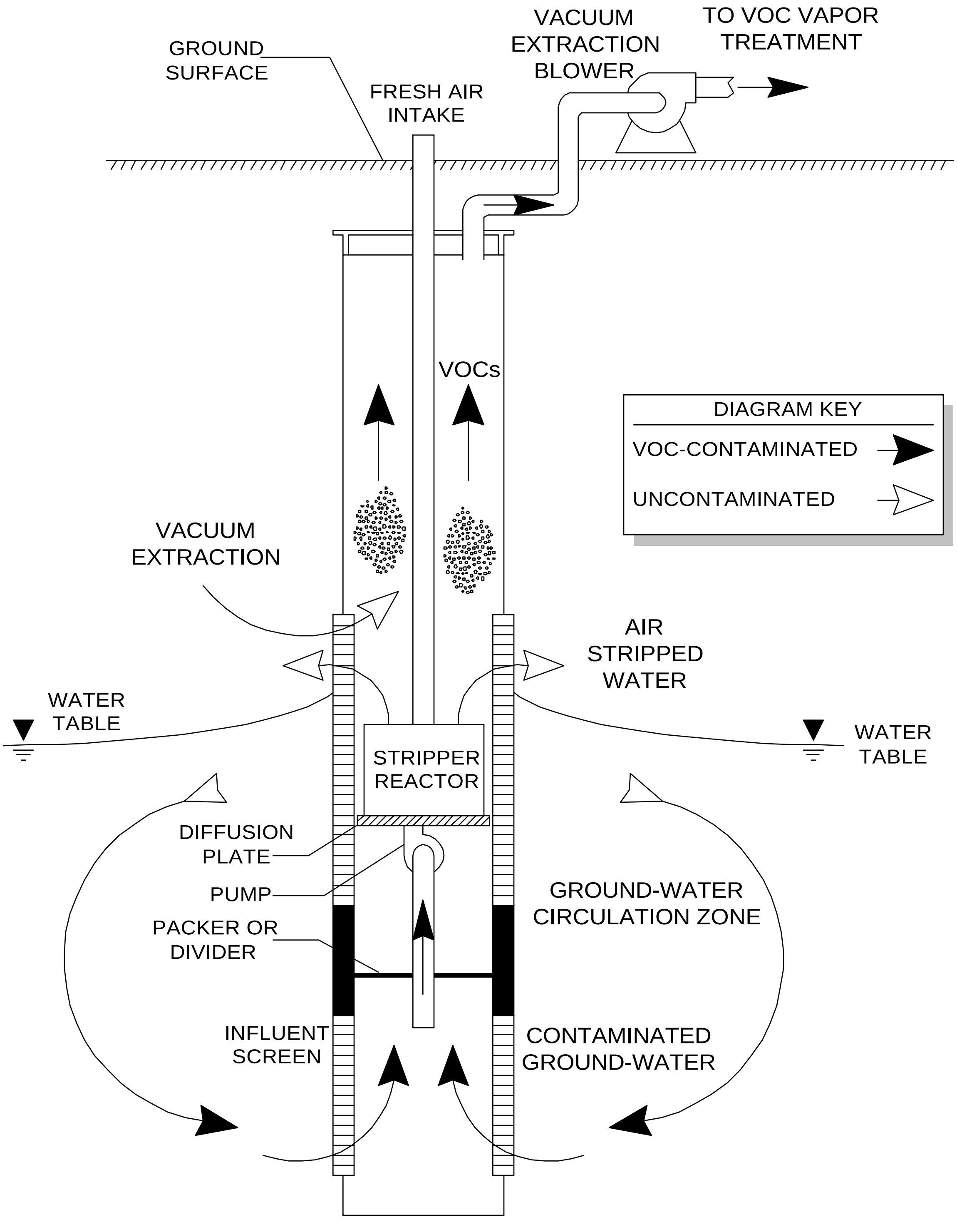

**FIGURE 3. UVB IN-WELL VAPOR STRIPPING PROCESS**

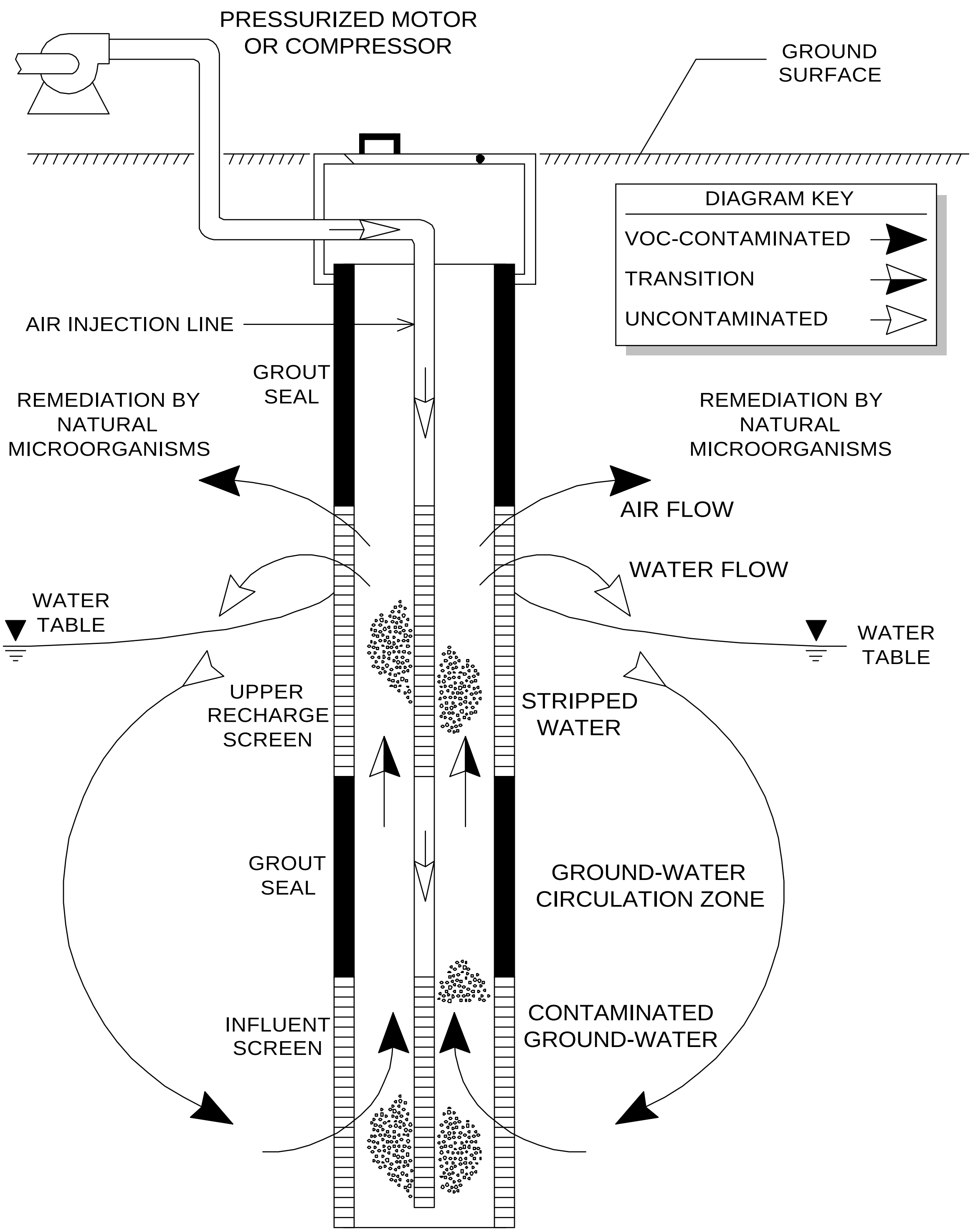

FIGURE 4. DDC IN-WELL VAPOR STRIPPING PROCESS

## TABLE 1. IN-WELL VAPOR STRIPPING--SELECTED PERFORMANCE INFORMATION

| Type of System | Soil Type | Plume Area | Operating Period (in Months) | Initial Contaminant Concentration(s) | Final Contaminant Concentration(s) | Percent Reduction |
|---|---|---|---|---|---|---|
| **NoVOCS™** | Silty sand with clay | -- | 2 | TPH: 10,200 µg/L | TPH: 3,000 µg/L | 71% |
| | Sandy silt/ silty sand | -- | 4 | TCE: 50-310 µg/L | TCE: 4-251µg/L | Average: 63%<br>Maximum: 93% |
| | Fine to medium sand | -- | 18 | TCE: 2,140-3,650 µg/L | TCE: 80-385 µg/L | Average: 91%<br>Maximum: 98% |
| **UVB** | Silt, sand and minor clay | -- | 18 | TCE: 940 µg/L | TCE: 150 µg/L | 84% |
| | Silt, sand and minor clay | -- | 18 | TCE: 1,000 µg/L | TCE: 270 µg/L | 73% |
| | Silt and silty fine sand | -- | 18 | TCE: 400 µg/L | TCE: 45 µg/L | 89% |
| **DDC** | Sand and gravel | 9,000 $ft^2$ | 20 | TPH: 30 mg/L<br>Benzene: 0.049 mg/L | TPH: 15 mg/L<br>Benzene: 0.008 mg/L | TPH: 50%<br>Benzene: 84% |
| | Sand and silt | 2,400 $ft^2$ | 6 | TPH: 0.56 mg/L<br>Benzene: 0.34 mg/L | TPH: <0.02 mg/L<br>Benzene: <0.002 mg/L | TPH: >96%<br>Benzene: >99% |
| | Clay | 1,000 $ft^2$ | 22 | TPH: 110 mg/L<br>Benzene: 0.055 mg/L | TPH: <0.02 mg/L<br>Benzene: <0.002 mg/L | TPH: >99%<br>Benzene: > 96% |

# 4.0 TECHNOLOGY PERFORMANCE

## 4.1 GENERAL DESIGN CONSIDERATIONS

- Packer and well configurations must be designed to maximize volatilization of VOCs and adequately direct ground-water flow into the unsaturated zone;
- Chemical changes in ground-water and soil (chemical precipitation or oxidation) due to use of system must be addressed (7);

Performance data for selected applications of the three in-well vapor stripping processes described are presented in Table 1 on the previous page.

## 4.2 NoVOCs™

Table 2 presents cost comparisons prepared by EG&G Environmental for the NoVOCs™ system and other technologies. This information is provided as normalized costs to account for site-specific variations, including capital and operation and maintenance (O&M) expenses, over an estimated project duration of two years for NoVOCs™, air sparging, and biodegradation and five years for pump and treat. All costs are site specific and actual costs will vary depending on site specific parameters (2).

**TABLE 2. NoVOCs™ COST INFORMATION**

| Technology | Normalized Cost | |
|---|---|---|
| | TCE | BTEX |
| NoVOCs™ with Biocube™ | NA | 1 |
| NoVOCs™ with activated carbon | 1 | 1.5 |
| Air sparging with SVE and activated carbon | 2.5 | 1.9 |
| *In situ* biodegradation | NA | 2.2 |
| Pump and treat with air stripping and activated carbon* | 3 | 2.5 |

* Pump and treat costs vary greatly depending on water disposal costs. For these examples, mid-range disposal costs were assumed when computing site costs.

## 4.3 UVB

Cost information for application of the UVB system for an approximate 65 week period, is presented in Table 3, and provides equivalent U.S. dollars. The costs presented may not be directly applicable to current applications of this system in Germany or other countries due to the "price structure" in West Germany at the time of remediation (1989) and the increased amount of testing/monitoring necessary for what was a relatively unknown technology. This demonstration site contained one UVB well, six ground-water monitoring wells, and four soil air monitoring wells installed at depths generally less than 35 feet. Electricity costs are not included since energy was supplied by the owner, however approximately 35,000 kW-hrs were used during the 11,000 hour run time (3).

## TABLE 3. UVB COST INFORMATION

| Type of Expense | % of Total | Equivalent $ U.S.* |
|---|---|---|
| Planning, organization, project management, remediation equipment | 25.3 | 64,000 |
| Field work | 17.4 | 44,000 |
| Laboratory analytical work | 29.2 | 74,000 |
| Drilling costs | 11.5 | 29,000 |
| Activated carbon and regeneration | 16.6 | 42,000 |
| **Total:** | 100.0 | 253,000 |

* Original cost information was provided in German Marks (DM) and converted at a conversion rate of 1 U.S. dollar = 1.70 DM.

### 4.4 DDC

Representative cost information for installation, operation, and maintenance of a DDC system is presented in Table 4. In addition, an analysis by the developer of the DDC system comparing system costs to areal size of the ground-water plume for numerous applications yielded total costs of $8.82 per square foot of plume, with installation costs comprising $5.80 per square foot and O&M costs of $3.02 per square foot (13).

## TABLE 4. DDC COST INFORMATION

| Type of Expense | Cost | % of Total |
|---|---|---|
| **Capital Costs** | | |
| Drill and install wells (3 extraction, 13 sparging, 6 monitoring) | $16,000 | 10.5 |
| Install ground-water and vapor extraction system | $40,300 | 26.4 |
| Install ground-water sparging system | $25,750 | 16.9 |
| Electrical connections | $4,050 | 2.7 |
| Trenching, soil disposal, backfilling, asphalting | $26,800 | 17.5 |
| Air compressor and control trailer | $26,800 | 17.5 |
| Initial system startup and de-bugging | $3,000 | 2.0 |
| Project management, constructions oversight, regulatory reporting and coordination | $10,000 | 6.5 |
| **Total Capital Costs:** | **$152,700** | **100** |
| **Annual Operating Costs** | | |
| Maintenance labor and parts | $30,000 | 47.8 |
| System monitoring and reporting | $30,000 | 47.8 |
| Electricity (@$0.07/kw-hr) | $2,750 | 4.4 |
| **Total Annual Operating Costs:** | **$62,750** | **100** |

# 5.0 TECHNOLOGY ADVANTAGES

**Cost-effectiveness:**

- Does not require injection wells, discharge lines, discharge fees, etc. to recirculate/discharge ground-water (2, 15);
- Single well can be used for extraction of vapors and ground-water remediation (14);
- Can continuously remove VOCs from ground-water without pumping water to surface, avoiding the need to handle contaminated water above ground and/or to dispose of or store partially-treated water (7, 15);
- Contaminated vapors are more easily and inexpensively removed and treated aboveground than contaminated water (2);
- Contaminants not typically displaced due to lower air injection pressures and flowrates relative to air sparging (8);
- Low operation and maintenance costs (10).

**Integration:**

- Enables recirculation of chemical aids to ground-water remediation (surfactant, catalysts, etc.) (14);
- Enhances bioremediation of hydrocarbons as a result of aeration/ recirculation of treated water (2);
- Wells can be used to distribute nutrients amendments for bioremediation (10);
- Facilitates coupling with soil vapor extraction systems (2).

**Simplicity:**

- Involves no moving parts beneath ground surface;
- Designed to run continuously with only routine maintenance;
- Does not involve complicated components (7, 15).

**Effectiveness:**

- Accelerates restoration due to disruption of free-phase product in capillary fringe (2);
- Creates both vertical and horizontal ground-water flow allowing penetration of low permeability horizontal layers (10).

# 6.0 TECHNOLOGY LIMITATIONS

- Chemical precipitates may form during air stripping and may clog the well screens, limiting ground-water circulation (5, 9);
- Shallow aquifers may limit system effectiveness due to limited space for reinfiltration/circulation (5);
- If air stripping wells are not properly designed or constructed, the plume may be spread beyond the radius of influence of the stripping well (7, 14);
- Ground-water discharges to unsaturated soils may mobilize pockets of contamination, adding to total mass of contaminants in aquifer. (These contaminants can be removed using the in-well stripping system minimizing the impact of this potential problem.) (7, 14).

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