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Horizontal Wells

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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 groundwater.

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 groundwater-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 provides a brief overview of an environmental remediation technology, including an introduction to its general principles, reported applicability and utilization, and cited advantages/disadvantages. This report is provided for informational purposes only and is not intended as a state-of-the-art peer reviewed analysis of this technology. Information used in the preparation of this report was gathered from periodicals, through Internet searches, and in some cases, from personal communications with involved parties. No attempt was made to confirm the veracity of interpretations and/or representations made in any information resource used. In addition, listing of any technology, corporation, company, person, or facility does not constitute endorsement, approval, or recommendation by the National Environmental Technology Applications Center (NETAC).

Horizontal well technology has been incorporated into many current environmental remediation applications (and associated contaminants), such as *in situ* bioremediation, air sparging, vacuum extraction, soil flushing, free product recovery, etc. According to information reviewed, this technology is most applicable to sites with relatively shallow soil and/or groundwater contamination, and can potentially enhance remediation efforts at sites low hydraulic conductivities.

Types of horizontal wells include both trenched and directionally drilled, with trenched wells involving simultaneous borehole advancement and casing/screen and backfill installation (in a larger diameter boring) and directionally drilled wells involves a smaller borehole with well installation subsequent to the completion of drilling activities.

Reported advantages of horizontal wells are related to the fact that their long horizontal screens contact a larger area of contaminated media, and so may more effectively transmit additives associated with remedial activities (amendments, air, surfactants, etc.). In addition, the configuration of these wells is more consistent with natural conditions, since groundwater transmissivity is generally greater in the horizontal, rather than the vertical direction. This may allow more efficient recovery of groundwater and/or vapors via horizontal wells. Directionally drilled horizontal wells can be installed in areas with subsurface obstructions (e.g., vertical wells, utility lines) and can be used beneath surface obstructions such as buildings, lagoons, wetlands, etc. Disadvantages cited include the limited depths to which these wells can be installed and the lack of drilling contractors experienced in horizontal techniques.

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1.0 INTRODUCTION

Horizontal well technology was originally developed for use in petroleum production and underground utility installation, but recently (since the late 1980's) has been adapted for environmental remediation applications. In the environmental remediation industry, horizontal wells provide unique characteristics and advantages that can improve the effectiveness of established soil and groundwater cleanup technologies now using traditional vertical well techniques. To date, over 300 horizontal wells are estimated to have been installed for environmental remediation purposes, with the number of installations doubling every year since 1994 (15).

The "steering" capability associated with some horizontal well drilling techniques allows installation in areas containing underground utilities, vertical wells, and other subsurface obstructions. Horizontal wells can be installed beneath buildings and other surface structures, allowing access for treatment to areas generally inaccessible to vertical wells.

The orientation of horizontal wells compared with vertical wells may require fewer wells to achieve similar remediation goals due to the greater surface area associated with the lengthwise screened area of these wells. Horizontal screens provide greater surface area in contact with contaminated soil or groundwater, allowing more effective transfer of materials used for remedial treatment (e.g., bioremediation amendments, air for air sparging, vacuum for vapor extraction, soil flushing materials, etc.).

Horizontal wells have been adapted for use in many soil and groundwater remediation applications, including (1, 2, 4, 9, 14):

- Groundwater removal
- Air sparging
- Free product recovery
- *In situ* bioremediation/bioenhancement
- Soil vapor extraction
- *In situ* soil flushing
- *In situ* radio frequency heating
- Treatment walls
- Hydraulic and pneumatic fracturing
- Leachate containment/collection.

2.0 APPLICABILITY

2.1 CONTAMINANTS

Contaminants to which horizontal wells technology has been, or could be, applied include (5, 9, 12):

- Petroleum products [Light non-aqueous phase liquids (LNAPLs)];
- Chlorinated solvents [Dense non-aqueous phase liquids (DNAPLs)];
- Semivolatile organic compounds, if, for example, thermal enhancements or other similar methods are used with vapor extraction.

2.2 SITE CONDITIONS

As noted above, many of the remediation methods currently being used/tested for groundwater and soil cleanup have been adapted for use with horizontal well technology (see below). Aside from the general advantages of horizontal wells in improving the efficiency of existing methods, these wells are particularly applicable in the situations where:

- A contaminant plume has linear geometry and contamination covers a large area;
- Remediation needs to be performed in an area of surface obstructions.

By installing higher conductivity materials such as sand as packing in trenched horizontal wells, preferential flow paths may be created, potentially enhancing remediation at sites with low conductivity materials with soil and/or groundwater contamination (4). Sand packing is not known to be effective when used with directionally drilled horizontal wells (17).

Soil and rock types into which horizontal wells can be installed vary with the drilling method used. Trenched wells cannot be installed into rock without pre-trenching, and basic directional drilling methods are usually limited to clay, silt, and sand with blow counts less than 20 to 25 per foot. However, more advanced drilling systems can be used for well installations in other geologic materials, including bedrock in some cases (1, 4, 12). Horizontal wells have been installed to depths as great as 235 feet, but are most are installed at depths below 50 feet below ground surface (BGS)(3).

2.3 REMEDIATION TECHNIQUES ADAPTED TO INCORPORATE HORIZONTAL WELLS

2.3.1 Groundwater Extraction

Extraction of groundwater with horizontal wells is similar to extraction with vertical wells, with a slotted screen intercepting the contaminated zone. Recovery efficiency may be increased relative to vertical wells due to the ability of a single horizontal well to contact a larger horizontal area, and because horizontal aquifer transmissivity in generally greater then vertical transmissivity (2, 4).

2.3.2 Enhanced Bioremediation of Soils, Sediments, and Groundwater

In this technique, an upper horizontal well is used to inject air (sparging), nutrients, and/or methane into a contaminated aquifer. These actions stimulate microbial growth and so increase the rate of contaminant biodegradation. The increased surface area provided by horizontal wells allows more efficient delivery and distribution of amendments to the aquifer, and so increased stimulation of microorganisms, as compared to vertical wells.

Additional benefit can be obtained from the installation of a second horizontal well when remediating volatile chemicals. The second parallel well can be installed in the vadose zone below the injection well and above the plume to extract contaminated soil gas vapors. This increases the efficiency of bioremediation by removing high-concentration and easily stripped vapors, decreasing the quantity of contaminant(s) left to be degraded by microorganisms. Advantages of horizontal wells for vapor stripping, as for amendment delivery, are related to the greater surface area in contact with the zone of contamination provided by the horizontal configuration. This increased surface area being treated also reduces clogging/plugging of the aquifer (1, 2, 9).

2.3.3 Soil Vapor Extraction

Soil vapor extraction using horizontal wells utilizes the same basic principles as vertical wells, pulling volatilized chemicals from soils through the well screens. As noted for groundwater extraction, horizontal wells may be more efficient than vertical wells for soil vapor extraction due to the larger amount of screened area in contact with the contaminated soil zone. Minimal disturbance to soil during horizontal drilling may also minimize “short-circuiting” of extracted air to the atmosphere. An additional advantage is that the same horizontal well can be used to extract vapors and transport them to the surface, eliminating the need for a separate vapor conveyance system (1, 8, 10, 12).

2.3.4 Air Sparging and Air Sparging/Soil Vapor Extraction

Air sparging, a technology that involves the injection of air below the water table to enhance bioremediation and volatilize contaminants in soil and groundwater, can be enhanced using horizontal wells. Air sparging can be used alone or in conjunction with soil vapor extraction to remove dissolved and adsorbed contaminants from the saturated zone and soil vapor contaminants from the vadose zone. These methods can be used to address contamination by light hydrocarbons and chlorinated solvents, including volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs).

Air sparging/soil vapor extraction using horizontal wells involves two parallel wells, one below the water table to inject air and one above the water table to extract vapors. The application of horizontal wells to this technology combination can provide additional improvements to the traditional application of these techniques. Due to their linear configuration and increased surface area, horizontal wells more effectively distribute air through and extract vapors from, the contaminated area. In addition, the effective removal of contaminants by horizontal wells can be combined with hot air sparging or steam injection to remediate even semivolatile contaminants from soil and/or groundwater using this combination of techniques (1, 8, 10, 12).

2.3.5 In Situ Soil Flushing

In situ soil flushing involves the extraction and aboveground treatment of groundwater via a removal well located in the contamination zone and reinjection of the treated water through an injection well located above the contamination zone. This "recycled" water flushes additional contaminants downward for subsequent removal/treatment. The use of a horizontal extraction well for this process takes advantage of the geometry of these wells, which allows contact with a larger area of contaminated soil, resulting in more effective flushing of contaminants (4, 7).

2.3.6 Free Product Recovery

Free product recovery of LNAPLs and DNAPLs using horizontal wells can incorporate all of the general advantages associated with these wells. In addition, the ability to pump at lower rates, with lower resulting decreases in hydraulic head, allows greater recovery of free product while minimizing water and/or air removed concurrently. However, horizontal wells may not be applicable to LNAPL recovery in areas with significant water table fluctuation, seasonal and/or induced, due to the minimal vertical zone of influence of these wells. The ability to install horizontal wells at specific elevations makes them uniquely applicable to the recovery of DNAPLs that have pooled at the top of aquitards. Precise vertical positioning allows these wells to be placed just on top of the confining layer to extract ponded DNAPLs, while reducing the possibility of puncturing the confining layer and potentially contaminating underlying aquifers (2, 4).

2.4 OTHER APPLICABLE TECHNIQUES

Additional remediation scenarios to which the advantages of horizontal wells may be applied include (4):

- Cutoff/Treatment Walls;
- Leachate Containment/Recovery.

3.0 METHODOLOGY

The drilling of a horizontal well begins vertically or directionally at the ground surface and then proceeds horizontally to a depth and length depending on desired installation parameters. Careful monitoring and steering of drilling direction/progress is required with horizontal installations, and this is accomplished using various types of downhole sensing equipment (electronic transmitters/receivers, wirelines). Two general types of horizontal wells have been applied to remediation activities, trenched and directionally-drilled. The drilling of trenched horizontal wells involves the excavation of a relatively large diameter borehole, with simultaneous installation of well materials and backfill. Directional drilling of a horizontal well produces a smaller diameter borehole and is more similar to vertical well installation in that well materials are installed following the completion of drilling activities. Methodologies associated with these two types of horizontal wells are discussed in more detail below.

3.1 TRENCHED HORIZONTAL WELLS

Drilling of a trenched horizontal well involves initial vertical advancement of a 14-inch wide "trench" which changes at the appropriate depth to horizontal advancement. The "one-step" trenched well installation involves concurrent trench advancement with installation of vertical riser, horizontal well screen, and backfilling of the annulus. Backfill can be either excavated cuttings, high permeability sand and gravel media, or possibly other types of media for specific remediation applications. Current maximum depths reached by trenched horizontal wells are approximately 30 feet, but benching has allowed drilling depths of approximately 50 feet. Parallel installation of several trenched horizontal wells packed with sand and gravel can form a high conductivity "wall" that can provide containment/capture and high yields of contaminated groundwater for subsequent treatment (4, 7).

3.2 DIRECTIONALLY DRILLED HORIZONTAL WELLS

Installation of this type of horizontal well begins directionally (at some angle) and then changes to horizontal at an appropriate depth. Boring progress is precisely monitored and modified ("steered") in three dimensions, allowing the well boring to be steered around subsurface obstructions such as utility lines, existing vertical monitoring wells, etc. A relatively small volume of drill cuttings is produced using directionally drilling, resulting in a lower potential for subsidence, since less native material is displaced during drilling.

Directionally drilled wells are generally installed at depths less than 40 to 50 feet below ground surface (BGS), but installation at depths over 200 feet have been reported. Tracking accuracy generally decreases with increasing depth of installation, and is also related to site hydrogeologic conditions. Total linear lengths of horizontal wells are often 3 to 4 times the vertical depths reached (for example, a well installed at 50 feet BGS may require a total of 150 to 200 feet of riser and screen material).

Directionally drilled horizontal wells can be completed as blind holes (single-end completion) or surface-to-surface holes (continuous or double-end completion). Single-end holes involve one drill opening, with drilling and well installation taking place through this single opening. This type of well is usually used to reach a contaminated zone beneath a building or other obstruction. Borehole collapse may be more likely in single-ended drilling since the hole is left unprotected between drilling and reaming and between reaming and casing installation. An additional complication associated with single-ended completion involves the precise steering of reaming tools required to match the original borehole path. Double-end holes, which have entrance and exit "pits," may be easier to install since reaming tools and well casing can be pulled backward from the opposite opening, and the hole does not have to be left open (1, 2, 9).

A recently developed method for installing directionally drilled horizontal wells addresses several common problems and provides significant cost savings (17). The new installation method involves a degradable drilling fluid and a carrier casing through which the well screen is pulled into the borehole. The carrier casing protects the well screen from tensile stress (pulling force), damage from sediments, and clogging from sediments and drilling fluid. In addition, the carrier casing prevents sediments from flowing into the well screen during installation. The casing is also effective carries the fluid used to degrade the drilling fluid, and essentially eliminates the need for post-installation methods for removing drilling fluid from the well (17).

3.3 WELL MATERIALS

Materials used for horizontal wells are essentially the same as those used for vertical environmental wells. Factors to consider in the choice of well screen and casing materials to be used with horizontal wells include axial strength, tensile strength, and flexibility. Choices of these materials identified in sources consulted include:

- Fiber reinforced plastic (FRP);
- Fiberglass reinforced epoxy (FRE);
- High density polyethylene (HDPE);
- High temperature polyethylene (HTPE);
- Polyvinyl chloride (PVC);
- Stainless steel;
- Porous polyethylene well screen.

Screen packing materials identified for use with horizontal wells include:

- Natural pack;
- Pre-packed screen;
- Sand and/or gravel;
- Geotextile (filter fabric) (1, 2, 4).

4.0 TECHNOLOGY PERFORMANCE

4.1 GENERAL

Limited information was found concerning specific results associated with the use of horizontal wells to address environmental contamination. The following is a summary of general results from the application of horizontal well technology for air sparging/vacuum extraction at the Savannah River Site, in South Carolina (2):

- A 5-fold increase in contaminant removal rate was reported as compared to the use of vertical wells;
- 16,000 pounds of chlorinated solvents were removed over 20-week period, which was estimated to equal the results of pump-and-treat methods using 11 vertical wells at an extraction rate of 500 gallons per minute each;
- A 40% overall cost savings was predicted when compared to use of pump-and-treat methods.

The following is a summary of results of a 1993 market survey concerning horizontal wells for environmental purposes (2):

- Over 100 horizontal wells installed in the U.S. for environmental remediation since 1987;
- 25% used for groundwater extraction, 25% for soil vapor extraction, and 50% for other purposes (e.g., air injection, bioventing, petroleum recovery);
- 80% of horizontal wells installed at depths of 25 feet or less;
- Rate of installation of horizontal wells has increased rapidly since this survey due to increased recognition of applications/benefits and improvements in technology.

4.2 COST INFORMATION

The costs of horizontal well installation varies greatly depending on many site-specific factors, with estimates from $5,000 to $850,000 per well. Price per foot estimates range from $25 to $85 and per day from $1,500 to $15,000 (3).

5.0 TECHNOLOGY ADVANTAGES

Advantages of horizontal wells include:

- ***Treatment rate:*** Horizontal well screens contact a larger surface area of contaminated media thereby enhancing remediation of a greater volume of contaminated media per well.

- ***Cost-effectiveness:*** Even though horizontal well construction is more expensive per foot installed than vertical wells, fewer wells may be necessary, therefore, a horizontal well system may be less expensive than a vertical well system.

- ***Effectiveness:*** A horizontal well configuration allows better access to/contact with linear plumes ("laterally extensive and vertically restricted").

- ***Confidence:*** Minimizes "dead zones" that may occur between vertical wells.

- ***Integration:*** Installation can be completed with minimal disturbance to surface operations. A single collection and/or delivery system can be used to avoid disruptions to surface activities.

- ***Obstacle avoidance:*** Wells can be installed, in some instances, under buildings and other obstructions, under ponds, wetlands, lagoons, landfills, around utility lines, etc..

- ***Incorporation:*** The technology can be adapted to many *in situ* remediation techniques.

- ***Efficiency:*** Since horizontal transmissivity generally exceeds vertical transmissivity in aquifers, horizontal wells can deliver and recover gases/fluids and groundwater more efficiently than a vertically installed well.

- ***Productivity:*** Precise installation with respect to elevation and location allows efficient recovery of DNAPL pooled on aquitard (with less chance of puncturing confining layer) (1, 2, 4, 7, 9, 12, 17).

6.0 TECHNOLOGY LIMITATIONS

6.1 TRENCHED HORIZONTAL WELLS

Limitations of trenched horizontal wells include:

- Inability to be installed beneath buildings due to potential instability resulting from undercutting;
- Installation lengths may be limited by underground utility lines since precise steering around such obstacles is not possible;
- Well installation cannot proceed in hard rock cannot without pre-trenching (4, 7).

6.2 TRENCHED AND DIRECTIONALLY DRILLED HORIZONTAL WELLS

General limitations of horizontal wells:

- Not applicable for LNAPL recovery in areas with large water table fluctuations;
- Well installation depths can be limited;
- Vertical capture zone is limited by the vertical hydraulic conductivity, which is usually significantly lower than horizontal conductivity (1, 4, 6, 17).

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