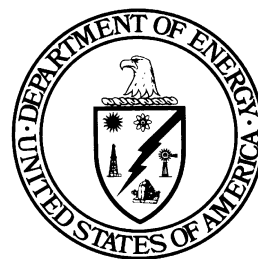


**INNOVATIVE  
TECHNOLOGY**  
Summary Report

# Horizontal Wells

Subsurface Contaminants  
Focus Area



*Prepared for*  
**U.S. Department of Energy**  
Office of Environmental Management  
Office of Science and Technology

September 1998

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# Horizontal Wells

OST Reference # 1927

Subsurface Contaminants  
Focus Area



*Demonstrated at*  
U.S. Department of Energy  
Savannah River Site  
Aiken, South Carolina  
Hanford Site  
Richland, Washington  
Sandia National Laboratories  
and Kirtland Air Force Base  
Albuquerque, New Mexico  
Other Commercial and Government Sites



## ***Purpose of this document***

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine if a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at <http://em-50.em.doe.gov> under "Publications."

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## SECTION 1

# SUMMARY

### Technology Description

Horizontal environmental wells have been demonstrated and deployed as an enhanced access method for treatment of contaminated soils and ground water. Directional drilling methods use specialized bits coupled with electronic transmitters in the drillhead to locate and steer as the borehole is advanced. Horizontal drilling was originally developed by industry for oil recovery, utility placement, mining, and construction. The United States Department of Energy's (DOE) Office of Science and Technology (EM50) adapted the technology for environmental remediation applications in the late 1980s and early 1990s.

A user survey for horizontal wells installed in the United States documented over 500 through 1996. Many wells are being installed by small companies that previously conducted directional drilling for the utility industry and as such have not been documented. It is likely that over 1,000 wells currently exist in the United States. Horizontal wells have been used primarily for ground-water extraction (33 percent), soil vapor extraction (35 percent), air sparging (21 percent), and other methods (11 percent) such as hydraulic control, free product recovery, and bioremediation/bioventing.

### Benefits

Horizontal well remediation systems are usually faster, cheaper, and more effective than the baseline technology of vertical wells. They provide:

- improved access to contaminants at sites with surface restrictions (e.g., buildings, tanks),
- improved hydraulic control along leading edge of contaminant plume or at property boundary,
- minimal surface disturbance because fewer wellheads may be required,
- ability to monitor beneath contaminant sources (e.g., tanks, pits, lagoons),
- increased surface-area contact with contaminants (see Figure 1),
- reduced operating expenses because fewer wells may be required, and
- access to off-site contamination to be treated by on-site operations.

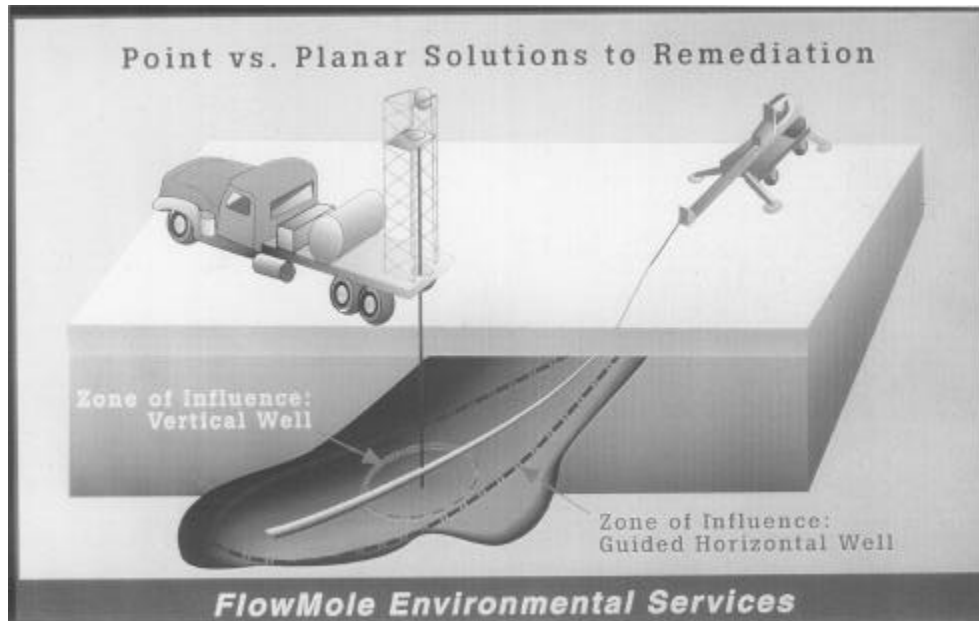


Figure 1. Horizontal wells can be installed to maximize access to contaminant plumes.

Horizontal environmental wells can be used for ground-water or soil-vapor removal for surface treatment; in situ treatment of ground water and soil; hydraulic control of ground water; and monitoring of soil vapor or ground water (e.g., beneath contaminant sources).

Horizontal wells can be installed by directional drilling or by trenching and backfilling (if specific site conditions allow it). Trenching and backfilling requires shallow depths and continuous surface access. Directional drilling can be used to install impermeable or permeable barriers and can be combined with fracturing technology in low permeability sediments.

Horizontal drilling concerns include reduced permeability of the geologic formation during well installation caused by compaction drilling tools or due to introduced drilling fluids (same as for vertical drilling); and potential for drilling fluids to foul uncontaminated areas, damage equipment, and interrupt utility services, or compromise soil stability beneath pavement and structures. Costs for disposal of contaminated backfill and drilling fluids/cuttings must be assessed during technology selection. For operators, experience in directional drilling is a must, and experience in drilling water well and hazardous waste sites is preferred.

Horizontal wells have been implemented at DOE's Savannah River Site (SRS) in Aiken, SC; Sandia National Laboratories (SNL) and Kirtland Air Force Base (KAFB), Albuquerque, NM; and the Hanford Site, Richland, WA. For a listing of commercial and other governmental implementation sites, see the 1996 survey noted above, available on the World Wide Web at <http://www.doejpo.com/ccem/et.htm>.

## Demonstration Summary

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DOE has supported development, demonstration, and applications of horizontal environmental wells as an enhanced access technology from 1988 through 1997:

- at SRS, where four directional drilling technologies were demonstrated. From 1988 through 1993, seven wells were installed and used to demonstrate innovative remediation technologies for treatment of volatile-organic contaminants (VOCs) in ground water and soils. Four of these wells have been integrated into the M-Area vapor extraction corrective action system. Two more wells were installed in 1997 to remediate ground water at the Sanitary Landfill.
- at SNL, where development and demonstration of directional drilling technologies were conducted from 1991 through 1995 in cooperation with Charles Machine Works (CMW), a utility directional drilling rig manufacturer. Field tests were conducted at SNL, KAFB, SRS, and Hanford.
- at the Portsmouth Gaseous Diffusion Plant (PORTS), where horizontal wells were installed to demonstrate and apply a recirculating ground-water treatment system using an innovative well-screen material, and for hydraulic recovery of ground water for iron-filings treatment.
- at Pinellas, where nine wells were installed for ground-water treatment of VOCs in 1995 through 1997. Seven wells were used for in situ air sparging, resulting in clean up of the site to drinking water standards and subsequent site closure. Two additional wells were used in conjunction with three surface trenches to establish a forced vertical gradient for in situ bioremediation.

## Key Results

Horizontal wells have been successfully installed at hundreds of sites across the United States and worldwide to treat and manage contaminated ground water and soils. Many of these projects have demonstrated that horizontal wells save overall remediation costs by cleaning up the site more quickly than vertical wells and by lowering maintenance and operating costs.

- Regulatory approval requirements for horizontal wells are similar to those for vertical wells. At the DOE Pinellas Plant, horizontal wells successfully remediated vinyl chloride in ground water, resulting in regulatory closure approval (at a site containing initial concentrations of ~40 ppb) after only approximately one year of operation.
- Horizontal wells have been shown to be more efficient than vertical wells. For example, at SRS a horizontal well used for vapor extraction was five times more efficient than a vertical well. Modeling studies have predicted more rapid cleanup (5 years versus 20 years) using horizontal wells as opposed to vertical wells.





- Directional drilling methods have been successfully modified for environmental applications, under a number of different geologic conditions, from unconsolidated sands, silts, and clays to consolidated rock at depths ranging from five to over 200 ft.
- The economics of using horizontal wells are enhanced if their application allows operating businesses to remain open while site remediation is occurring (e.g., gas stations and airports). At JFK Airport in NY, over 25,000 linear ft of horizontal wells were installed beneath runways to keep airport operations on schedule while cleanup operations were under way. At a chemical plant in Louisiana, over 30,000 linear ft of horizontal wells were installed for a pump-and-treat hydraulic control system to operate while plant operations continued.
- Horizontal wells are especially cost effective at low-permeability sites where numerous vertical wells would be required. For example, at Williams Air Force Base in AZ, the deepest horizontal environmental wells have been installed; at this site one horizontal well was predicted to replace 80 vertical wells. Horizontal environmental wells are also well applied in thin aquifers, in unconfined aquifers, and at sites with vertical fractures.

### **Commercial Availability**

Directional drilling rigs for drilling and installation of horizontal environmental wells are commercially available from a number of vendors, including Charles Machine Works who partnered with DOE to further develop the technology. Directional drilling services are available from a number of drilling companies. In addition, there are a number of consultants who specialize in the design and oversight of horizontal environmental well installations. A current list of these companies and individuals is available from the Technical Contact listed below.

## **Contacts**

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### **Other**

All published Innovative Technology Summary Reports are available on the OST Web site at <http://em-50.em.doe.gov> under "Publications." The Technology Management System, also available through the OST Web site, provides information about OST programs, technologies, and problems. The OST Reference # for horizontal wells is 1927.



## SECTION 2

# TECHNOLOGY DESCRIPTION

### Overall Process Definition

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*Demonstration Goals and Objectives:* Horizontal environmental wells are designed to enhance access to soil and ground-water contamination and to increase the remediation efficiency compared to the baseline technology (vertical wells) by vastly increasing the per-well zone of influence.

*Drilling System Description:* Directional drilling methods use specialized bits coupled with electronic transmitters in the drillhead to locate and steer as the borehole is advanced. Components required for directional drilling include a drilling rig, a mud system, drill bits, reaming bits, and a guidance system. Depending on the equipment used, bent sub assemblies and sophisticated surface locating equipment may be used.

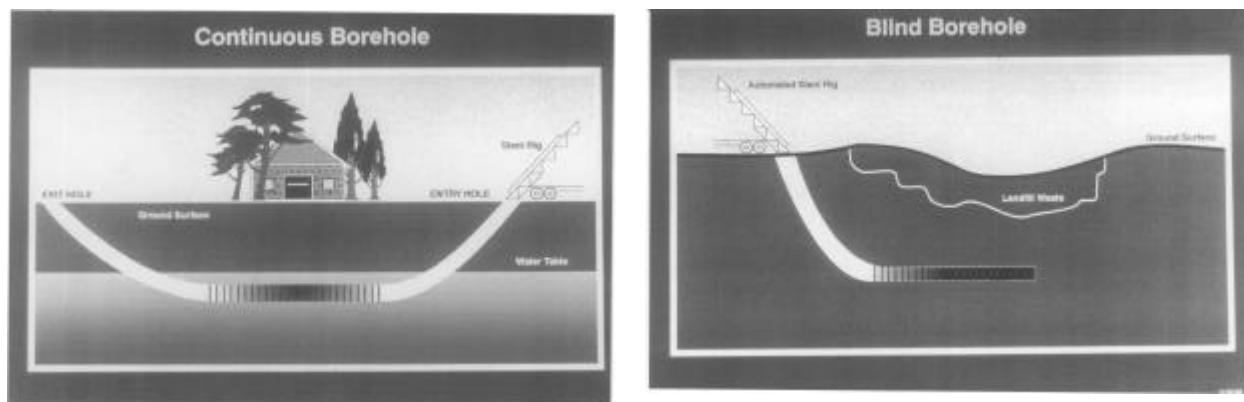
Directional drilling rigs typically consist of a carriage that slides on a frame and holds the drill rods at an angle of 0 to 45 degrees as shown in Figure 2. Drilling rigs are available in a wide range of sizes and are rated on their pullback capacity. Rigs range from less than 5,000 to over 1,000,000 pounds of pullback force. Small and mid-size rigs typically are used for environmental applications.



**Figure 2. The Charles Machine Works prototype X-810 drilling rig tested at SRS.**



*Basic Principles and Description of Major Elements:* Wells can be designed as either continuous (surface to surface) or blind (surface to end of horizontal section). Figure 3 illustrates the two types.



**Figure 3. Horizontal environmental well types.**

Continuous wells have both an entry and exit hole. Continuous wells are typically installed by drilling surface to surface. Well materials are then pulled from the exit hole back to the entrance hole as the hole is backreamed. Blind wells have only an entry hole; all drilling and reaming operations take place from the entry point. The most common method for drilling a short blind well calls for reaming the hole and installing the casing in the open-hole, maintaining its integrity with drilling fluid; longer holes however, may require the use of a washover pipe to enlarge the original pilot hole. Screen and casing are then installed inside the washover pipe to prevent caving during casing installation. The washover pipe is removed from the borehole after the well materials are installed.

Boreholes are created by cutting the formation with a rotating bit, water jet, hammer, or combination of these. Most commonly, bits are driven by downhole motors, jetting tools, and compaction tools.

- Downhole mud motor: Drilling fluid is pumped down the drill pipe into the cavity of the motor, which causes the motor and therefore the bit to rotate. The speed of the motor is controlled by the drilling fluid pressure.
- Jetting tool: Hydraulic pressure is used to cut the geologic formation. The force of the hydraulic jet is controlled with the drilling fluid pump.
- Compaction tool: A wedge-shaped tool is pushed into the geologic formation. The direction of the slant face of the wedge guides the direction of the tool. Compaction tools are generally used in unconsolidated geologic conditions at limited depths (<50 ft).

Drilling fluid is used to maintain hole integrity, remove cuttings from the borehole, cool the drilling tools, and possibly either drive a downhole motor or hydraulically cut the formation.

- Drilling fluids commonly used include organic polymers and bentonite with or without organic/inorganic polymers. Typically no drilling fluid or a small volume of water for cooling is used with a compaction tool.

The guidance tool supplies drilling tool orientation and the azimuth and inclination of the wellbore to the driller. The guidance system is typically located in the bottom-hole assembly behind the drilling tool and the bent sub-assembly and locates the end of the drill rod, provides the azimuth and inclination of the bottom assembly, and provides the orientation of the drill face. There are two basic types of guidance systems:

- Walk-over systems, which consist of a radio beacon-receiver, require surface location, and can be used to a depth of about 50 ft but are subject to interference; they are easy to use, rapidly collect data, and are the least expensive guidance system.



- Steering tool systems, which include either an inertial (gyroscope) system (the most expensive system) or a combination magnetometer-accelerometer (the most commonly used system, especially at depths > 40 ft) provide real-time information of greater accuracy at a higher cost than walk-over systems. They have built-in memory capacity and no depth limitations.

## System Operation

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*Operational Parameters and Conditions:* Operational requirements for directional drilling include one driller, one guidance technician, and one helper at a minimum. However, additional personnel (typically a project manager, construction engineer, geologist, health and safety officer, and/or health physics technician) are required when drilling at hazardous waste sites.

Horizontal well design considerations include geologic and hydrogeologic conditions; contaminant distribution; drilling methods (rig, fluids, etc.); survey tools; horizontal wellbore specifications (i.e., length and target depth of the well, borehole path); composition and design of well materials; and use of the well.

*Materials and Energy Considerations:* Well materials need to be flexible, have adequate tensile and compressive strength, have strong joints, and be compatible with the use of the well and the chemical composition of the ground water.

- Wells have been constructed using polyvinyl chloride (PVC), high-density polyethylene (HDPE), carbon steel, stainless steel, fiberglass, and porous polyethylene. The costs of these various materials range widely and highly influence the cost for installation of a horizontal well.
- Wells may use pre-packed screen if there is concern about formation infiltration. However, pre-packed screen may add greatly to the cost of the well and may be difficult to install, because of increased weight. Pre-packed screen should only be used if necessary at a specific site. Filter fabric is often used over HDPE screen to prevent infiltration of formation material into the screen, because of HDPE's lower limit on slot size (.020 in).
- According to the 1996 horizontal well survey report, there is a trend toward the use of HDPE as the well screen material of choice unless there is a concern about the well integrity due to the presence of aggressive chemicals (in which case, stainless steel is used), depth of installation, or length of materials to be installed.

Casing pull tests conducted by SNL indicated that selecting the appropriate casing includes considering loads on the equipment and materials. These loads include pulling the casing; the reamer, if used during pull back; the drill rig carriage drag; size and rotation of the pull back drill pipe; the casing pulling plug design; and bends (i.e., the radius of curvature) or irregularities in the wellbore.

*Personnel Skills and Training Requirements:* Experience in directional drilling is a must, and experience in drilling water well and hazardous waste sites is preferred.

*Potential Safety and Environmental Risks and Concerns:* Not significant. Please see Section 6.



## SECTION 3

# PERFORMANCE

### Demonstration Plan

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Directional drilling technologies were demonstrated at SRS, SNL, KAFB, and Hanford to test different systems under variable site conditions. These demonstrations were conducted under the then Office of Technology Development's SRS Integrated Demonstration: VOCs in Soil and Ground Water at Non-arid Sites and the Mixed Waste Landfill Integrated Demonstration at SNL. The Kirtland and Hanford demonstrations are considered part of the SNL demonstration.

#### **Savannah River Site Demonstration (1988–1993)**

*Demonstration Site Description:* Hydrologic investigations at SRS have shown contamination of the ground water with VOCs near the M-Area Settling Basin from the leakage of waste solvents from a tile process sewer into the vadose zone. A remedial action program consisting of ground-water pumping followed by above-ground air stripping has been implemented to address ground-water contamination in M-Area. A vapor extraction system has been installed to address the vadose zone contamination.

The geology in the M-Area is characterized by 200 ft of alternating units of permeable sands with low fines and significantly less permeable clayey sand and clay units. The water table is located at approximately 120 ft below ground surface (bgs).

The sand units range from fine-to coarse-grained and are generally moderately sorted with relatively little silt and clay. Interbedded with the sands are silty clay or clayey sand units, which exhibit relatively low permeabilities. Generally, the clays tend to be thin and discontinuous. The more permeable units were selected as target zones for the horizontal environmental wells.

*Demonstration Objectives and Elements:* The goal of the SRS demonstration was to test the feasibility of installing horizontal wells in unconsolidated sediments, using directional drilling technology. Four distinctly different systems of directional drilling and horizontal well installations were successfully demonstrated and evaluated at SRS:

- A short-radius petroleum-industry technology was used to install two wells, one at 65 ft bgs and one below the water table at a depth of 150 to 175 ft. The deeper well, which consists of perforated steel casing, was used for air injection; the shallower well, of stainless steel screen, for vapor extraction.
- A modified petroleum-industry technology was used to install two horizontal wells with the same configuration as the previous demonstration; wells were constructed of HDPE.
- A mini-rig utility-industry/compactional tool drilling technology was demonstrated by CMW to install a well in a 35 to 40 ft deep clay layer to test the effectiveness of radio-frequency heating enhanced soil vapor extraction. This well used slotted fiberglass casing.
- A mid-rig utility-industry technology was used to install two wells at a depth of about 100 ft to conduct soil vapor extraction beneath a closed seepage basin used for waste disposal. These wells were constructed of PVC screen and casing.

Seven wells were successfully installed at depths of 35 to 175 ft, with horizontal screen sections ranging from 150 to 400 ft, using the following materials: steel, stainless steel, PVC, HDPE, and fiberglass. The wells were utilized to demonstrate in situ air stripping, in situ bioremediation, and thermally enhanced soil vapor extraction. Four of the wells were later integrated into the M-Area vapor extraction corrective action.

Note: Innovative Technology Summary Reports on *In Situ Air Stripping Using Horizontal Wells* and *In Situ Bioremediation Using Horizontal Wells* are available online at <http://em-50.em.doe.gov>.



Evaluation of the horizontal well installation performance at SRS was based on (1) whether the wellbore was drilled in the proper location with minimum damage to the host formation, (2) whether the well materials were successfully installed in the wellbore, and (3) whether the well could meet the designated remediation objectives.

The SRS demonstrations identified two important factors for consideration during design of horizontal environmental wells: (1) trips in and out of the wellbore should be minimized to maintain wellbore stability, and (2) well materials should be adequately flexible to negotiate curves. Other lessons learned advanced the state of the technology. Of the four technologies demonstrated at SRS, the mini-rig and midi-rig utility technologies remain in use.

### **Sandia National Laboratories Demonstration (1991–1995)**

*Demonstration Site Description:* Testing was conducted at several locations as part of the SNL demonstration. The background and history of the various sites are briefly described below:

- The CMW experimental test range is located at Perry, OK northeast of the main CMW manufacturing facility. This site is a field with a slight elevation increase from south to north or from the selected entry toward the exit end of the test bed.
- The SNL Directional Boring Test Range (DBTR) is a clean site of six acres located in Albuquerque, NM.
- The KAFB RB-11 site was used for radiation effects testing during the 1950s and 60s. Several shallow open trenches were filled with low level contaminated post test debris.
- The M-Area at SRS is described above. An additional test was performed at the TNX Facility at SRS. This facility is located on a low bluff along the Savannah River, separated from the river by a marsh area.
- The Hanford test site was a clean test area located between Technical Areas 200-E and 200-W.

Testing was conducted at several locations as part of the SNL demonstration. The geology at the various sites is briefly described:

- The soils in Perry, OK are basically clay to about 14 ft bgs underlain by a 5 ft zone of shale then a deeper zone of more dense clay with some sand and small gravel.
- The geology at SNL is alluvial in origin containing caliche, sands, gravels, cobbles, and boulders distributed somewhat randomly, except that some cobbles are concentrated in layers of old river beds at least 30 ft bgs.
- The soils at KAFB are the same at SNL.
- The geology in the M-Area at SRS is characterized by 200 ft of alternating units of permeable sands with low fines and significantly less permeable clayey sand and clay units. The target zone of the horizontal wells was a clay layer.
- The geology at the Hanford test site is composed of glacial till with uncemented sand and multiple layers of semi-spherical cobbles ranging from baseball to basketball size.

Iterative technology testing and development by SNL resulted in high-quality, cost-effective access beneath waste sites while minimizing site impact.

*Demonstration Objectives and Elements:* Goals of the testing and development at SNL were to minimize environmental impact by the boring/drilling/thrusting method; and provide a low-cost but high-quality alternative to more expensive directional drilling methods for certain geologies. A no-cost industrial partnership between SNL and CMW (makers of Ditch Witch products) was established to enable testing of several existing types of machinery used in the shallow underground utilities industry.

Several pieces of commercial machinery manufactured by CMW for underground utilities installation were tested and evaluated at the CMW test range in Perry, OK, the SNL DBTR, KAFB, the SRS M-Area and TNX Facility, and Hanford. The machinery tested included the water-assisted Jet Trac Boring System, the air-assisted True Trac Boring System, the P-80 rod pusher, and the Pierce Airrow pneumatic hammer tool. After gathering information from initial testing of these machines, CMW began design and construction of a prototype machine (X-810).



As part of the testing conducted by SNL, the X-810, a pneumatic hammer and the P-80 hydraulic rod pusher were all tested at Hanford in glacial till composed of heterogeneous soils with rocks and cobbles (ranging from baseball to basketball size). Because the formation consisted of uncemented cobbles, horizontal drilling was unsuccessful regardless of thrust and torque capabilities. In addition, after approximately 3 h of pneumatic hammer testing, the hammer had penetrated approximately 50 ft horizontally. This indicated that the utility directional drilling may not be applicable to all geologies.

The SNL-CMW partnership also tested multi-samplers, a drill cuttings containment system (GUZZLER), and casing materials. As a result of this partnership, CMW developed a new line of machinery for environmental applications (X-810) and has hired ~400 employees for equipment production and sales worldwide.

#### **Other Demonstrations/Deployments**

A parallel pair of continuous horizontal wells were installed at PORTS to demonstrate a ground-water treatment system by establishing a recirculating flow field. Two wells were first installed at a clean test site for pilot-scale testing and then two wells were installed at a site contaminated with trichloroethylene and technetium-99. The wells were installed at 35 ft bgs with horizontal screen sections of 500 ft. An innovative well material, porous polyethylene from Germany called Schumasoil (shown in Figure 4), was installed in the wells.



**Figure 4. Assembling Schumasoil well screen at the DOE Portsmouth site.**

Additional deployment of horizontal environmental wells has been conducted at several DOE sites including PORTS one 1300 ft long well for ground-water collection; Pinellas seven wells to treat vinyl chloride in ground water using in situ air sparging and two wells to treat trichloroethylene, dichloroethylene, vinyl chloride, methylene chloride and toluene using in situ bioremediation; and SRS two wells, each over 1400 ft long and 60 ft deep, at the Sanitary Landfill for in situ bioremediation. The SRS wells are constructed of 6 in perforated steel lined with 4 in slotted HDPE. Volatile organic compounds in the ground water will be destroyed by stimulating indigenous bacteria with methane and nutrients, as was demonstrated in the M-Area.



## SECTION 4

# TECHNOLOGY APPLICABILITY AND ALTERNATIVES

### Competing Technologies

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The baseline technology for access to contaminated media is vertical wells. The well itself may be used for a variety of treatment technologies including ground-water extraction (e.g., pump and treat), soil vapor extraction, and air sparging.

In competition with horizontal wells as a means of enhanced access to contaminated media are induced fractures and interceptor trenches.

- Induced fractures are created by injecting fluid (pneumatically or hydraulically) into a wellbore. Typical dimensions are three times the depth for depth ranges of 5 to 16 ft (maximum dimension increases with increasing depth and decreasing permeability).

The primary application of induced fractures is to increase both the discharge of and the area affected by a well. Induced fractures may increase well discharge 10 to 50 times compared to conventional wells in rock or silty clay (relative increase in performance is greatest in tightest formations). Induced fractures may also be used to deliver solid compounds into the subsurface (e.g., nutrients to enhance bioremediation, reactants to oxidize or reduce organic compounds).

- Other than vertical wells, trenches are the most widely used method for controlling subsurface fluids and recovering contaminants. Trenches are installed using widely available standard construction equipment (e.g., backhoe) and more sophisticated continuous trenching machines. The primary application of trenches is for ground-water recovery (to intercept the migration of the ground-water plume) or to increase the rate of recovery in low permeability soils. Typically a cap is required over the trench to prevent surface water or air from entering the trench.

Both horizontal wells and trenches significantly increase the access (or exposure) to contaminants compared to vertical wells. The geometries of horizontal wells and trenches are similar. Trenches may be preferred for applications requiring shallow surface access, while horizontal wells may be preferred for deeper applications or in situations with surface access restrictions.

### Technology Applicability

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Horizontal environmental wells enhance access to soil and ground-water contaminants. They provide improved access to and potential monitoring of contaminants in areas with surface restrictions (buildings, tanks, utility lines, pits, lagoons, etc.); hydraulic control of a contaminant plume at the leading edge (when installed at the leading edge); and increased surface area contact with the contaminants.

- Horizontal environmental wells may also increase the remediation efficiency compared to the baseline technology by encompassing a larger zone of influence using long screen zones and by reducing operating expenses using fewer wells and therefore saving money on operation and maintenance (O&M).
- Limitations of horizontal environmental wells include a requirement for accurate drilling installation and minimal water table fluctuation for light non-aqueous phase liquid recovery; limited vertical influence of the well due to anisotropy; difficult drilling and installation conditions due to the presence of coarse gravels; and treatment of immobile non-aqueous phase liquid or strongly sorbed contaminants.





- Horizontal drilling concerns include reduced permeability of the geologic formation during well installation caused by compaction drilling tools or due to introduced drilling fluids (same as for vertical drilling); potential for drilling fluids to foul uncontaminated areas, damage equipment and interrupt utility services, or compromise soil stability beneath pavement and structures.

## **Patents/Commercialization/Sponsor**

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Information on patent and licensing issues, commercial involvement by private industry, and technology development sponsors, is available from the Technical Contact listed in Section 1.



## SECTION 5

# COST

### Methodology

Horizontal wells cost more to install but much less to maintain, and because each typically performs the work of several vertical wells, there is simply no doubt that, where they can be practically installed, they are the technology of choice. Horizontal wells, in short, in many places already are, and in most others will soon be, the new baseline.

Because horizontal wells are a mature technology, costs may be determined by standard accounting (for demonstrations) and by direct inquiry for various implementations and deployments.

- Not surprisingly, costs of horizontal wells range widely based on drilling method and size of rig; type of drilling tool, drilling fluid, and guidance system; vertical depth and total well length; site geology; well materials; and number of personnel on site.
- In general, cost and performance data outside DOE are not readily available because there is no compelling reason for private companies to track or report such data. Additional performance data are needed to compare costs of various horizontal environmental well applications.

### Cost Analysis

Based on past projects, the cost of a horizontal well (PVC or HDPE well casing) using a small to medium-sized utility-type drilling rig, a radio beacon/receiver guidance system, a simple drilling fluid system, and a compaction drilling tool is ~\$164/m (\$50/ft) (EPA, 1994).

More sophisticated directional drilling methods using a larger drilling rig, a magnetometer-accelerometer guidance system and a more advanced drilling fluid system and drilling tool or mud motor are approximately (assuming PVC or HDPE well casing):

- \$1036/m or \$316/ft (< 25 ft depth)
- \$602/m or \$183/ft (25 to 100 ft depth)
- \$744/m or \$227/ft (>100 ft depth)

The higher cost of the shallow wells is attributed to the shorter length and fixed mobilization and daily costs for equipment. Thus, the cost per unit length is less for longer wellbores where these costs can be minimized.

- Cost comparisons of the directional drilling technologies tested at SRS:

	<b>Short Radius Technology</b>	<b>Modified Petroleum Technology</b>	<b>Utility Technology</b>	<b>River Crossing Technology</b>
Demonstration cost	\$963,730	\$235,350	NA	\$230,000
Linear feet of well installed	768 ft	788 ft	–	1440 ft
Project cost/ft	\$1,255/ft	\$299/ft	NA	\$160/ft
Average industry cost/ft	\$150 - \$250/ft	\$150 - \$250/ft	NA	\$227/ft

NA - not available: work was performed by an industrial partnership, no drilling costs were available.



- Utility technology drilling costs determined in development testing by SNL were in the range of \$25 to \$75/ft, excluding the cost of the casing/screen materials.
- During well installation at Pinellas, the average cost for the horizontal wells was ~\$80/ft including the well materials which were built on-site.
- For horizontal wells installed at John F. Kennedy International Airport for air sparging (or soil vapor extraction), the installation of a single horizontal well to replace a row of eight to twelve vertical wells and associated trenching/piping, reduced installation costs by more than one half from \$270 per lin ft to \$110 per lin ft (Fournier and Pressly, 1996).

## Cost Conclusions

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Although drilling and installation of horizontal wells is more expensive compared to vertical wells, the increased efficiency (one horizontal well may replace several vertical wells) and increased performance (horizontal wells may remediate a plume faster because of the greater contact with contaminants by using longer well screens) of horizontal wells make the life cycle cost of horizontal wells less expensive (including installation, O&M, and remediation).

- Capital costs of one horizontal well were similar to five vertical wells, but the O&M cost for the horizontal well was less than 1/3 that of the five vertical wells (EPA, 1994).
- O&M costs for horizontal well systems are lower than for a vertical well field due to the lower number of pumps required, reduced time for routine sampling and lower power consumption. However, it may be more expensive to recondition horizontal wells compared to vertical wells.

Costs may be significantly reduced by minimizing investigative-derived waste and the associated waste management costs when horizontal wells are installed outside the main portion of the ground-water plume (e.g., below the plume).



## SECTION 6

# REGULATORY AND POLICY ISSUES

### Regulatory Considerations

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- Directional drilling technology requires the same permits as required for other drilling technologies.
- Hazardous waste drilling activities typically require that investigative-derived wastes (drilling fluids, cuttings, and equipment decontamination fluids) be handled according to the Resource Conservation and Recovery Act.
- When using an organic polymer-based drilling fluid, a chlorine additive is used in the drilling fluid makeup water and the development water. Degradation of the drilling fluid is due to increased microbial activity requiring a subsequent additive to inhibit bacterial growth. If a disinfectant cannot be introduced to the subsurface, then an alternate drilling fluid (such as a bentonite-based drilling fluid) should be used.
- Permit requirements are site specific and depend on the selected remediation and/or use of the horizontal well. All permits must be worked out with the appropriate regulators and may include:
  - an air permit for discharge of treated vapor extracted from the subsurface,
  - Comprehensive Environmental Recovery, Compensation, and Liability Act and/or Resource Conservation and Recovery Act permitting depending on site-specific requirements,
    - underground injection permits if injection of gases or fluids (e.g., air, nutrients) into the subsurface is required for the treatment, and/or
  - National Environmental Protection Act review for federal projects.

### Safety, Risks, Benefits and Community Reaction

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#### Worker Safety

- Potential worker safety risks include those associated with standard construction operations.
- Occupational Safety and Health Administration (OSHA) requirements must be reviewed because directional drilling, like all drilling methods, involves high noise levels and hazards associated with drilling near overhead or subsurface power lines or utilities.
- All field personnel must be 40 h OSHA trained as required in 29 Code of Federal Regulations (CFR) 1910.120 for hazardous waste operations.
- Other health and safety issues for horizontal environmental wells are essentially equivalent to those for conventional technologies such as ground-water extraction in a vertical well field.

#### Community Safety

- Directional drilling does not produce routine release of contaminants.
- Investigative-derived wastes (drilling fluids, cuttings, and equipment decontamination fluids) should be handled in a manner that prevents contact with the surrounding ground surface.
- No unusual or significant safety concerns are associated with transport of equipment or other materials associated with horizontal environmental wells.

#### Environmental Impacts

- Directional drilling and subsequent use of horizontal environmental wells minimizes clearing and other activities that would be required to install a comparable vertical well field.
- Investigative-derived waste are minimized when the horizontal well is installed outside of the main portion of the ground-water plume (e.g., below the plume).



- Visual impacts are minor and the ground surface is minimally disturbed by emplacement of horizontal wells.
- Operation of the drilling equipment creates moderate to high noise in the immediate vicinity.

#### **Potential Exposures**

- Potential exposures are equal to or less than those associated with vertical drilling.

#### **Socioeconomic Impacts And Community Perception**

- Directional drilling and horizontal wells have minimal economic or labor force impacts.
- The general public has limited familiarity with horizontal environmental wells; however, the technology can be explained to the public with ease similar to that of pump-and-treat technologies.



## SECTION 7

# LESSONS LEARNED

### Design Issues

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During the SRS demonstrations several pre-drilling activities that should be considered were identified.

- A thorough description of the target zone and surrounding geology/hydrogeology should be made available to the well designers and the drilling subcontractor.
- A description of the well completion requirements such as well screen size, filter pack size (if pre-pack screen is specified), and specifications of the well material should be made available to the well designers and the drilling subcontractor.
- A thorough design of the wellbore should be prepared. The design should include the locations of the entry hole and exit hole (if needed), the location of the well screen, and the radius of curvature required to place the well screen correctly.
- An engineering calculation brief that describes and sums the forces experienced by the well materials during well completion activities is required. The calculation brief should delineate the strength requirements of the well materials and evaluate the utility of the chosen well materials.
- The steering tool should be calibrated onsite by a qualified technician before each use.
- The drilling subcontractor should be procured and involved in the design process as early as possible. Pre-drilling meetings should be held, and all the above items should be discussed with the drilling subcontractor.

The project manager or the consultant must be experienced in designing horizontal wells, procuring horizontal well contractors, and performing horizontal well construction oversight.

### Implementation Considerations

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Complete characterization of the site hydrogeology for well placement and geology and geochemistry to understand the drilling conditions.

Careful and vigilant oversight during installation (e.g., checking for electromagnetic interference, poor calculations, and surface elevations) is required.

Drilling the pilot hole too quickly may result in sharp bends in the wellbore, putting unnecessary stress on the well materials (compared to the desired smooth, uniform curve).

Experience from the SRS demonstration yields the following recommendations:

- Well materials should be thoroughly inspected before well completion activities begin, with special emphasis placed on the pin and box of each piece if threaded joints are used.
- Well materials should be installed using a roller system to minimize bending at the surface.
- Surface-launched wellbores require that the drilling rig is anchored firmly to the ground and that the anchorage is able to resist maximum pushing and pulling capacity of the drilling rig.
- The steering system should be proven as an accurate survey tool or a secondary survey should be used to confirm the location of the downhole assembly.
- The drilling crew should be experienced in installing horizontal wells in conditions similar to those found at the proposed drilling site and use of all equipment required.
- The drilling crew should make every effort to control the loss of drilling fluid circulation. Lost circulation zones should be plugged when they are encountered.



## Technology Limitations/Needs for Future Development

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More experience with environmental horizontal drilling under a variety of subsurface conditions will ensure better well installations at reduced costs.

## Future Technology Selection Considerations

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Directional drilling of horizontal environmental wells has been demonstrated as an enhanced access method for treatment of contaminated soils and ground-water plumes. Remediation efficiency may be enhanced by increased surface area for reaction, similarity of well profile and contaminant plume geometry, wellbore access to areas beneath existing facilities, and drilling along facility boundaries to control plume migration.

Each site must be assessed for the utility of horizontal wells. Heterogeneous soils with rocks and cobbles may limit the ability to drill while soils with at least 15 to 20 percent clay may improve the drilling performance.







## APPENDIX A

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## APPENDIX B

### ACRONYMS AND ABBREVIATIONS

bgs	below ground surface
CFR	Code of Federal Regulations
CMW	Charles Machine Works
DBTR	Directional Boring Test Range
DOE	United States Department of Energy
EPA	Environmental Protection Agency
ft	foot (feet)
gpm	gallons per minute
h	hour (s)
HPDE	high-density polyethylene
KAFB	Kirtland Air Force Base
lin ft	linear foot
m	meter
O&M	operation and maintenance
OSHA	Occupational Health and Safety Administration
PORTS	Portsmouth Gaseous Diffusion Plant
ppb	parts per billion
PVC	polyvinyl chloride
SNL	Sandia National Laboratories
SRS	Savannah River Site
US	United States
VOCs	volatile-organic contaminants



