NATIONAL DRILLER

Horizontal Environmental Wells -- Part 1

June 1, 2002

The horizontal environmental well catalogue, which was created in 1993, provides a record of how the industry has evolved since the late 1980s.

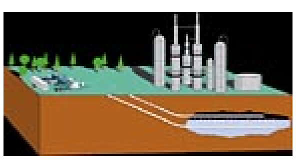
Since the late 1980s, directional drilling has been successfully modified and applied to environmental problems. Government and industry technology developers worked diligently to develop new approaches to access the subsurface for environmental remediation activities. In 1993, a survey of horizontal environmental wells in the United States was conducted. That survey catalogued 105 wells that had been installed as of July 1993. The horizontal environmental well catalogue has been updated approximately every other year since that time. This catalogue includes 1,142 horizontal environmental wells that have been installed in the United States through the end of the year 2000. While certainly not a complete listing, this catalogue provides a record of how the industry has evolved since the late 1980s.
The catalogue contains information provided primarily by the drilling contractors who installed the wells. Information is provided on the drilling contractor, location, use, construction, geologic conditions and borehole specifications for the wells. Cost and performance data were solicited, but have been provided on very few projects.

Summary points to be made using data from the most recent survey:

- The number of horizontal environmental wells installed each year in the United States increased rapidly beginning in 1988 and continuing through 1996. Since 1996, the number of wells installed annually has decreased slightly, likely due to market conditions in the environmental remediation arena. The total number of wells in the current catalogue is 1,142.
- Horizontal wells typically are installed in states where there is a champion, which can be either a directional-drilling contractor who typically installs horizontal wells, or an environmental consultant or site owner who understands the benefits of installing horizontal wells at certain contaminated sites. States with the more than 30 wells, in order of abundance, include Colorado, Louisiana, New York, California, North Carolina, Florida, Washington, Michigan, Ohio, Oklahoma.
- Horizontal wells have been installed for a number of different environmental applications: soil vapor extraction (34%), ground water or free-product extraction (28%) and air sparging (21%),

bioremediation (5%), characterization and/or monitoring (3%) and others, including hydraulic control (9%). Wells always have been installed for a multitude of uses. However, wells have been recently installed for characterization and monitoring.

- Most of the wells (83%) are installed at shallow depths (<26 feet) using utility installation contractors. The percentage of shallow wells always has been significant, but has increased over the last five years.
- Sixty percent of the wells are installed as continuous boreholes, and 40 percent are installed as blind wells. There are no changes in this statistic over the last five years.
- Horizontal wells are most commonly installed at sites with sandy/sandy silt targets (41%). Even though horizontal wells become more cost effective at lower permeability sites, wells are installed at clay-rich sites only 29 percent of the time. More recent installations have occurred at sites with cobbles present (21%). Two percent of the wells were installed in bedrock, and 6 percent are installed under other conditions, such as fill.
- Most wells are installed at private industry sites. Although the government was at the frontier of these installations in the late 1980s and early 1990s, governmental sites have not seen the growth evidenced at industrial sites.
- Forty-two percent of the wells are composed of high-density polyethylene (HDPE), 31 percent are composed of polyvinyl chloride (PVC), 12 percent of stainless steel, 6 percent steel, and 9 percent other or unknown. The number of installations with HDPE has increased over the last few years.
- In spite of the large number of installations, cost and performance data are very sparse. Sharing of this information in a public setting could encourage the use of horizontal wells for environmental applications.



This illustration, provided by Longbore Inc., Houston, depicts a dual horizontal well system for air sparging or soil vapor extraction.

Some History

Horizontal drilling technology, which originally was developed for oil recovery, river crossing and utility placement, has been transferred to the environmental remediation industry. Integration of these drilling technologies with water well installation techniques and materials has resulted in the creation of the horizontal environmental well industry, which had undergone strong growth in the environmental remediation market in the early 1990s.

Potential advantages of horizontal wells for petroleum recovery were recognized years ago, as the first recorded installation occurred in 1942. However, the technology for successfully drilling horizontal recovery wells was not adequately developed until the early 1980s. During the 1980s, as the technology advanced, there was a great increase in the number of horizontal recovery wells. Initially, horizontal wells were installed to increase petroleum recovery from low-yielding formations with vertical fracture systems, which can be more effectively intercepted by horizontal wells, and from offshore platforms to consolidate drilling and production at a single location. Since that time, their use has become more diversified and widespread depending on site-specific factors.

Boreholes drilled in the oil industry using mud rotary drilling techniques typically begin as vertical holes. The borehole path is deviated by the use of specialized drilling equipment and steerable downhole motors. This type of drilling technology was applied to environmental applications in the late 1980s, but no longer is used due to higher costs and poor borehole location accuracy at shallow depths as compared with river crossing and utility drilling technology.

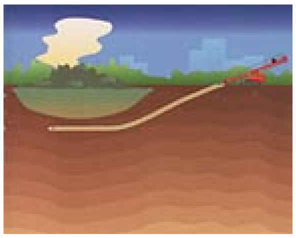
The utility installation industry, using technology originally modified from the directional drilling technology used for enhanced petroleum recovery, can be subdivided into river crossing and utility installation applications. River crossing technology has proven to be the technology of choice for long and/or deep horizontal well installations that require larger drilling rigs. Development and widespread use of river crossing drilling technology began in the 1970s as a method of installing utility conduits and pipelines under rivers. In general, river crossing projects require large drilling rigs, drilling fluid systems, sophisticated guidance systems, and specialty drill tools or downhole mud motors. River crossing boreholes have been as large as 60 inches in diameter, thousands of feet long and have had pipes as large as 48 inches in diameter installed in the boreholes.

Drilling rigs used for river crossing installations usually are custom-made and involve a slant-drilling platform for angled borehole entry. Directional drilling in unconsolidated sediments is accomplished using a bent subassembly and a downhole directional survey tool for steering the drill string and deviating the borehole path. In bedrock formations, a downhole motor typically is used for drilling.

Smaller rigs designed to install utilities in neighborhoods without trenching are very similar in design to the large river crossing rigs and account for approximately 75 percent of the installations catalogued in this report. The small rigs also utilize an angled borehole entry with a slant-drilling platform. Drilling usually is accomplished with total loss fluid systems that use minimal drilling fluid. For these systems, a hydraulic jet or compaction tool head may be used for advancing the borehole.

Beginning in 1988, U.S. Department of Energy's (DOE) Office of Science and Technology (formerly the Office of Technology Development) supported the development and deployment of directional drilling technology for environmental applications, i.e. horizontal environmental wells. From 1988 through 1993, funding supported the demonstration of four different directional drilling technologies at SRS in Aiken, S.C. DOE also supported further development of utility-based directional drilling technology via a cooperative research and development agreement between Charles Machine Works (CMW) and the Sandia National Laboratories from 1991 through 1995. As a result of this industry/government partnership, CMW developed a new line of manufacturing equipment.

On the industry side, Conoco Oil Co. led the way by installing the first horizontal wells to remove petroleum products floating on the water table beneath a residential neighborhood in Ponca City, Okla., using utility directional drilling technology.



Environmental Applications

For remediation of contaminant plumes, horizontal wells can offer significant advantages over vertical wells. Plumes that are under surface obstructions, such as buildings and runways, can be remediated using a horizontal well with the wellhead located in an adjacent open area. Plumes under buildings or landfills also can be monitored or characterized using horizontal wells. Horizontal wells also offer cleanup advantages as compared to vertical wells because of geometry. Contaminant plumes usually are horizontally extensive and relatively thin vertically. Therefore, horizontal wells better mimic this plume geometry and place more screen in contact with the target zone on a per well basis. Pilot testing at SRS, a sandy site, demonstrated that vapor extraction horizontal wells can remove up to five times more contaminant than vertical wells.
Horizontal wells may offer more significant advantages over vertical wells where the target is an unconfined aquifer with a small cone of depression, i.e. a low-permeability site. At Williams Air Force Base, models estimated that one horizontal well could replace 80 vertical wells, due to the low permeability of the formation. On the other hand, at a sandy site such as Savannah River Site, tests showed that one horizontal well could replace five vertical wells undergoing soil vapor extraction for removal of volatile organics in the unsaturated zone above the water table. Oil industry experience has shown that horizontal wells often are more efficient for recovering petroleum reserves and drain the reserves in a shorter time than do vertical wells. When evaluating the application of horizontal vs. vertical wells at a particular site, vertical and horizontal conductivities must be analyzed, as they definitely will affect the well's performance.

Horizontal wells may be utilized at locations where contamination has migrated off site. The horizontal well can then be installed off site, with the well head and above-ground remediation equipment present on the client's property. Other applications may locate the horizontal well along the property boundary where a remediation or containment system is installed to prevent further offsite migration of contaminants.

Even though horizontal well installations may be more costly than vertical well installations at some sites, costs for the life cycle remediation are likely to be less with the horizontal well system than for the vertical well system for a variety of factors, including a shorter remediation timeline. The cost of horizontal wells has declined as the technology has matured and experience in installing horizontal wells has increased. Upfront costs of well installation must be considered in conjunction with the life cycle costs for the entire remediation system. If horizontal wells can clean up a site more rapidly, and if fewer wells need to be installed, considerable savings can be incurred by using this innovative approach. For two of three treatment technologies, the initially higher cost of a horizontal-well system was more than compensated for by reduced maintenance and operating costs associated with a shorter cleanup schedule.

Horizontal wells must be considered carefully at some sites where the water table fluctuates greatly. If a horizontal well is installed at such a location, the well may change from saturated to unsaturated conditions, or vice versa, thereby causing problems with the remediation system as originally installed. Sites containing vertical fractures and thin aquifers are especially appropriate for horizontal well applications.

Horizontal wells have been used primarily for the following environmental applications:

- Ground water extraction for pumping and treatment -- A common remediation method is pumping of contaminated ground water from an aquifer, treating that water at a surface treatment system to remove contaminants, and injecting the water back into the aquifer or releasing it to a surface impoundment. If reinjection is utilized, it may create a hydraulic barrier that prevents plume migration. This is the baseline technology for ground water remediation.
- Soil vapor extraction -- This involves placing a vacuum on wells installed in the unsaturated zone to collect volatile compounds present in the intergranular pore spaces and adsorbed onto grain surfaces. The contaminated air is brought to the surface and usually treated to remove volatile compounds before it is released to the atmosphere. When used alone, soil vapor extraction only remediates soil in the unsaturated zone.
- Air sparging -- This involves injecting air into the subsurface to physically strip and chemically alter volatile compounds from the ground water and/or soil. Extraction wells connected to a vacuum are then commonly used in conjunction with an air sparging system to collect the vapors for treatment and removal of these compounds before release. Relatively thick plumes may be efficiently remediated using horizontal wells below and above the contaminated section in permeable formations. The lower well can be used for air injection and the upper well can be used for air extraction. In a pilot study at SRS where there was as much as 100 vertical feet between the lower and upper wells, inert tracers were utilized to demonstrate that good flow was achieved between the two wells.
- Free product recovery -- Fuels typically are lighter than water and are relatively insoluble. Therefore, these light non-aqueous phase liquids (LNAPLs) will float on the water table when released in

sufficient quantities. Solvents are heavier than water and may also be relatively insoluble. These dense nonaqueous phase liquids (DNAPLs) will sink in an aquifer until reaching a confining unit. When present at a site, recovery of LNAPLs and DNAPLs usually is the first priority because they provide a continuing source for ground water contamination.

- Bioventing/bioremediation -- This usually requires that low volumes of air (as compared with sparging) be injected into the formation to increase biological activity that results in contaminant degradation. Nutrients such as nitrogen, phosphorous, and lactate may be added to "feed" the microorganisms so they can multiply and increase the contaminant degradation rate.
- Other remediation technologies -- Horizontal wells have been utilized for introduction of chemical oxidants and heat to treat volatile organic compounds. At DOE's Portsmouth Gaseous Diffusion Plant in Ohio, two parallel horizontal wells were installed to create a circulation cell where ground water was pumped from one well, chemical oxidant was added to the ground water, which was then reinjected into the second horizontal well to treat volatile organic compounds. At SRS, a horizontal well was installed in a thin clay layer that contained volatile organic compounds that could not be treated effectively using soil vapor extraction due to low permeability. Radio frequency heating was then utilized within the well to enhance the soil vapor extraction system.
- Hydraulic containment -- Hori-zontal wells have been installed at a number of sites to create hydraulic containment by pumping of ground water, often along a site boundary or at the leading edge of a contaminant plume. Horizontal wells have also been installed for dewatering of hillsides.