Reconsidering Horizontal to Vertical Well Ratios for Site Clean-up

By W. Richard Laton, PhD. PG, CHg

California State University, Fullerton
Earth Forensics, Inc.

Directional drilling has been used for a variety of purposes; utilities, dewatering, and remedial activities. Cutting costs for remedial activities it is always of consideration. What the costs are to clean-up a site via traditional vertical extraction wells versus using a horizontal well system needs to be reconsidered based upon todays remedial challenges. Traditionally, it has been stated that a single horizontal well is worth 4-11 vertical wells. This seems arbitrary in that both depth of the system and hydrogeological conditions play a large role that does not seem to be considered. A better way to evaluate the cost benefit of one system over another is to base it on the number of vertical wells per linear foot of directional well and base it more on zone of influence of both designs.

BACKGROUND AND HISTORY

Horizontal or directional drilling (HDD) can be defined as any drilling activity that deviates from the vertical. Typically, this deviation is greater than 80 degrees from the vertical.

Directional or horizontal drilling is not new. The technique has been around for over 2,000 years. Some of the earliest examples are from Iran and north Africa (H. Mukherjee and M. Economides, 1991). The technique has been used throughout Europe for tunnels, water supply and drainage. The oil industry began using directional drilling in the early 1940's. However, it was not until the 1980's that horizontal drilling began to take off in North America for both the oil and environmental industry (Wilson and Kaback, 1993).

Improvements in locating and directing the drilling bit in loose unconsolidated soils improved greatly in the 1990's. It is then that the utility companies began to utilize the technique almost exclusively. This also coincided with the onset of fiber-optic cable and two new rig manufacturing companies; Vermeer and Ditch Witch (Farr, 2012). As the technology became more accepted in the 1990's for the environmental industry, more effort was put into understanding its potential in the evolution of site monitoring and clean-up.

There are several types of boreholes associated with HDD. Continuous boreholes, which have a starting point on the surface and end by returning to the surface. Whereas, blind boreholes enter from the surface but end in the subsurface. There are several different orientations associated with blind boreholes, these are dual, stacked, trilateral or herringbone configurations.

Within the realm of the environmental and industrial industries (mining, river crossing, utilities, etc.), HDD has been used for monitoring, extraction and injection. Wastewater has been disposed of via horizontal wells and water supply and dewatering have been utilized. Using horizontal wells for monitoring is relatively infrequent, but has been used for water and vapor pressures, water and vapor quality within the subsurface.

The use of HDD for the purpose of remediation or site clean-up has been used at many sites throughout the US and overseas (Concurrent Technologies Corp, 2002). HDD has been used in pump and treat, bio-venting and vapor extraction systems. They have been used to deliver chemicals to the subsurface both in the vadose zone and beneath the water table or used to simply air sparge a shallow groundwater system to aid in the removal of hydrocarbons. HDD wells also work well as barriers or hydraulic control systems.

VERTICAL VS HDD WELLS

What are the similarities between the more traditional vertical groundwater well and an HDD well? Both use a drilling rig to be installed. Like some vertical wells, usually HDD is drilled either with water or other drilling fluid. They both can be installed above or below the water table. There are little in the way of depth limits on the installation or drilling of the wells. Both end up with pipe and screen in the ground. Screens in both instances can be long or short. Boring diameters can be from inches to tens of feet. Both can be sealed from the surface. They have both been used for monitoring, extraction or injection. They can both be developed similarly. The wells can both be nested or have multiple areas of subsurface connection.

Most vertical monitoring wells have gravel or filter pack surrounding the well screen. This is used to aid in holding back the subsurface formation and help filter the fluid as it enters the screen. For HDD drilling, this is usually done as a natural gravel or filter pack. Meaning that no external material is added to the well bore.

It has been proposed that HDD wells can replace many vertical wells when it comes to monitoring, extraction or injection. The thought behind this proposal is the increased subsurface contact area with HDD wells. Since HDD wells can be placed within a single geological, hydrogeological or contaminant zone, you can essentially have an unlimited contact area. This is not the case with vertical wells. Vertical wells allow for you to screen a vertical section of the subsurface, but it would require multiple vertical wells to cover the same given zone or unit of interest.

Karlsson, 1993, stated that a single HDD well would replace between 5-10 vertical wells. Parmentier and Klemovich, 1996, stated it was as high as 30 to 1. Many others have attempted to quantify the number of vertical wells that a single horizontal well can replace (Wilson, Kaback and Oakley, 1990; Cleveland, 1994; Zhan and Coa, 2000 and Feleccia, 2015).

In all cases the results are based upon site specific examples. In order to fully understand this ratio, one needs to consider the following: geology, hydrogeology, depth, diameter and purpose. A better way to understand this ratio for the purpose of planning, would be to compare the number of vertical wells per linear foot of HDD well. This would allow for the determination of the zone of influence (capture area) for both designs and thus one could compare apples to apples.

Capture area or zone of influence refers to the area surrounding the screen. How far reaching away from the bore a given stress applied to this screened area can influence. This is calculatable based upon an understanding of the transmissivity, hydraulic conductivity and storage of the formation and rate of stress (i.e. pumping). Losonsky and Beljin, 1992, developed equations for both HDD and vertical well zone of influence. Their findings indicate that for a horizontal well to replace *n* vertical wells, its screen length must be *2n* or greater. *(A new application that allows the end-user to understand for planning purposes the actual site-specific ratio of HDD wells to vertical wells will is being developed. Expected to be release in spring 2019)*

There are multiple advantages to HDD over vertical wells. Both HDD and trenches significantly increase the access (or exposure) to contaminants compared to traditional vertical wells. The geometries of HDD wells and trenches are similar. Trenches may be preferred for some applications requiring shallow surface access, while HDD wells may be preferred for deeper applications or in situations with surface access restrictions exist. Additional advantages of HDD wells.

- The wellhead does not need to be directly over the well;
- The well can be placed under existing structures, landfills, roads, rivers, lakes, wetlands, etc.;
- Drilling can be conducted under an operational site, without disturbance;
- The screen orientation can coincide with the major axis of the contaminant plume;
- Increase in linear footage of well screen in contact with the contaminant zone, compared to vertical wells;
- The screen can be installed along the leading edge of a plume or at a property boundary for hydraulic control;
- The well can be used for monitoring and remediation;
- Can cross vertical fractures;
- Improved access to contaminants at sites with surface restrictions;
- Minimal surface disturbance because fewer wellheads may be required;
- Reduced operating expenses because fewer wells may be required; and,
- Access to off-Site contamination to be treated by on-Site operations.

Limitations of HDD 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. Additional disadvantages of HDD wells are:

- Difficult to place gravel/filter pack, may require pre-packed screen;
- Difficult to grout or segment individual sections;
- Difficult to develop;
- Can be affected by major water level changes; and,
- Costs

POTENTIAL ISSUES OR PROBLEM

Gravel Pack: The absence of an external gravel/filter pack. Many groundwater monitoring wells are installed without a gravel/filter pack. They use a natural filter pack instead. This is where the natural aquifer material around the screen is used, rather than introducing external materials. Additionally, soil and water sampling are routinely collected without a well or filter pack, such as CPT, direct push, simulprobe, hydropunch, etc. These samples technologies are routine and well accepted.

Well Development: All wells need to be developed after drilling. This is done such that the drilling fluid and or damage that is done to the formation during drilling can be eliminated. This is typically done through a surging or pumping manner. However, jetting or the introduction of cutting chemicals are used in some instances. Vertical water production wells are generally developed for over one hour per foot of screen. In the environmental industry, vertical monitoring wells are developed for a much shorter time and with much less energy. Commonly, HDD wells are developed much more intensely than their vertical well counterparts. This is due to the know issues with conductivity between the screen and formation and potential for drilling fluids to plug the formation.

Screen Length and Placement: Several studies talk about stratification within vertical groundwater monitoring wells (Britt, Parker and Cherry, 2010). This is something that you would not see in an HDD well. Additionally, HDD wells can be placed within a thin geological units or plume. This can't be accomplished with vertical well but rather only with mini piezometers. This leads to a much larger contact area for an HDD well over that of a vertical well.

Grout Seals: In 2009, the University of Nebraska-Lincoln published a study on grout seals. Their findings concluded that all seals leak and that if above the water table, bentonite grouts will dry out and shrink (Lackey, et. al., 2009). The placement of any grout seal is always difficult. The insertion of a grout seal within an HDD well is made even more difficult do to the orientation of the pipe. This still needs more attention to develop better methods of sealing.

GLOSSARY OF HDD

Bore - A hole made in the ground by drilling or pushing. The act of making a hole in the ground by drilling or pushing. borehole - drilling term – the elongated cavity created by the drilling process. Often the borehole is not a void, but rather a hole filled with drilling mud and cuttings.

Monitoring well - A well used to obtain hydrologic and water-quality data, usually installed at or near a known or potential source of ground water contamination.

Nested wells - Monitoring wells with intakes at different depths, with intermediate seals to isolate screen intervals, constructed in a single borehole.

Directional drilling – The type of drilling that involves advancing an intentionally non-vertical borehole, which is drilled at an angle in order to penetrate a formation that does not directly underlie the drilling rig. Directional drilling is commonly used in the oil industry to peneetrate different formation zones from a single off-shore drilling platform. It is also used frequently in mineral exploration to better penetrate the anticipated ore body. See horizontal drilling.

Horizontal drilling – Drilling that involves advancing a near-horizontal borehole, which is drilled a very low angle in order to penetrate a formation that does not directly underlie the drilling rig. Horizontal drilling is often used for environmental or geotechnical applications, such as sampling beneath water bodies, roadways, or buildings. See directional drilling.

Locator – drilling equipment – The above-ground component of a walkover locating system. The locator includes one or more antennae and a receiver to detect the signal

Transmitter – drilling equipment – The downhole component of an electronic locating system. Same as a sonde. transmitted by the downhole transmitter, and a microprocessor to decipher and display the downhole data.

Back reamer – drilling tool – a tool designed to enlarge a pilot hole. Typically employed by attaching to the drill string once it exits the ground (surface to surface installation). Can be used to forward ream a hole.

Compactor reamer – drilling tool – a tool used to enlarge the borehole by compressing the soil. Since this type of tool typically will decrease the permeability of the soil, it may not be suitable for horizontal wells.

Deflection – drilling term – the amount of flex exhibited by the drill rods. The drill head is typically steered by pushing it into the formation without rotation. There are limits to which the rods can be pushed before they deflect excessively.

Pitch – drilling term –The deviation from a horizontal plane is measured as pitch. When the drill is directed downward, the pitch is negative. When it is directed toward the surface, the pitch is positive.

Annular flow - Formation fluids are produced up through the tubing-casing annulus and recovered at the surface.

Mud filtrate - The liquid effluent of drilling mud that penetrates the wall of the hole.

Clean the hole – To circulate drilling fluids and possibly also to work the drill pipe upward and downward, to remove drilled cuttings, slough material, and bridges from the borehole.

Water based drilling fluid - Common conventional drilling fluids. Water is the suspending medium (continuous phase) for solids.

Drilling fluid - A fluid is circulated in rotary drilling to perform many downhole functions including carrying the cuttings of the borehole. The fluid, usually of water and clay or polymers along with or without chemical additives, is the most common drilling fluid (mud). Wells can also be drilled with air, with and without foamers and other additives, as a drilling fluid, and are often referred to as circulating fluid.

Drilling mud – The fluid that is used to remove cuttings from the borehole and stabilize the hole, by circulating the fluid throughout the borehole during drilling. Drilling mud typically consists of water, bentonite clay, and polymer. Other additives, such as soda ash, sodium bicarbonate, barite, and lost circulation materials may also be added to the drilling mud to adjust its chemical or physical properties.

Filter cake - Compacted solid or semisolid material remaining on the filter paper after pressure filtration of the drilling fluid in the standard (API) filter press. Thickness of cake is reported in thirty seconds of an inch. The layer of concentrated solids from the drilling mud that forms on the wall of the borehole opposite permeable formation; also called wall cake or mud cake.

Wall cake – The layer of drilling fluid solids (bentonite platelets) that form on the borehole wall, as the filtrate water from the drilling mud migrates into the formation. The wall cake serves to stabilize the hole, but can increase torque on the drill string or result in stuck pipe, if it gets too thick. The wall cake is measured in 1/32nds of an inch, and ideally should be very thin, and essentially impermeable. Also termed filter cake or mud cake.

Screen - A structural tubular retainer, usually metal or PVC, used to support the hole in unconsolidated material with openings which are selected on the basis of adopted standards, and which allows sand free water to flow freely into the well in ample quantities and with a minimum loss of head. In agricultural wells, slotted pipe is sometimes used as a screen. See Well Intake.

Well screen – A pre-manufactured perforated interval of a well that allows water to pass from the aquifer into the well through designed slots or perforations. The well screen also provides structural support to stabilize the borehole. Numerous types of screens are available, and selection of the appropriate screen type depends on the specific hydrogeologic conditions and the specific application for which the well is to be used. Casing perforations, such as mill slots or Mills knife cuts, provide the same function as well screen. Well screen types include wire-wrap screen, louvered screen, and bridge slot screen.

Filtration - The process of separating suspended solids from their liquid by forcing the latter through a porous medium. Two types of fluid filtration occur in a well: dynamic filtration while circulating and static filtration while at rest.

Filter pack - Sand, gravel or glass beads that are uniform, clean and well-rounded that are placed in the annulus of the well between the borehole wall and the well intake to prevent formation material from entering through the well intake and to stabilize the adjacent formation.

Gravel pack (artificial Filter pack) - see also Filter Pack. A term used to describe gravel or other permeable filter material placed in the annular space around a well intake to prevent the movement of finer material into the well, to stabilize the formation, and increase the ability of the well to yield water.

Gravel-packed well - A well in which filter material is placed in the annular space to increase the effective diameter of the well and to prevent fine-gained materials from entering the well.

Grout - A fluid mixture of cement and water (neat cement) of a consistency that can be forced through a pipe and placed as required to form a permanent impervious, watertight seal in the annular space, open hole or between two or more strings of casing. Various additives, such as sand, bentonite, and hydrated lime, may be included in the mixture to meet certain requirements. Bentonite and water are sometimes used for grout.

Well seal - An arrangement or device used to cap a water well or establish and maintain a junction between the casing or curbing or a water well and the piping or equipment installed therein. The purpose or function is to prevent pollutants from entering the water well.

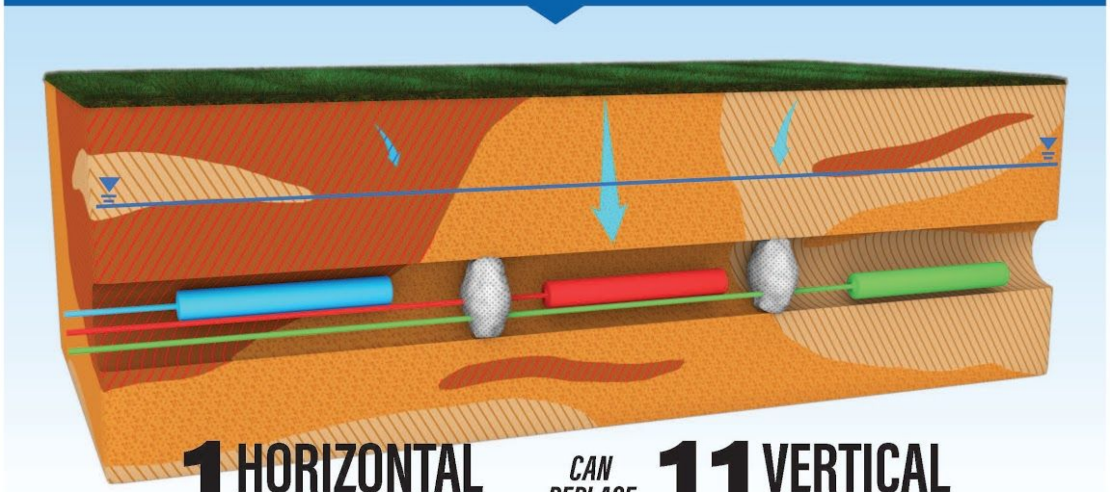
Well development - A procedure to facilitate the removal of fine solids and materials from the water-bearing zone of a water well to optimize production.

Packer - A downhole pneumatic, mechanical or hydraulic pressure device to shut off an annular opening such as between casing and borehole or concentric casings. A device for isolating a desired portion of a borehole.

Vertebrae™

HORIZONTAL NESTED WELL SYSTEMS

NEXT GEN Site Investigation & Remediation Technology



1 HORIZONTAL WELL SYSTEM *CAN REPLACE UP TO* **11 VERTICAL WELLS**

Depending on site specifics.

- **Patented system avoids preferential flow path distortions in sampling and reagent delivery.**
- **Individual segments are plumbed to the surface providing maximum operational flexibility; only treat where needed.**
- **In addition to conventional uses the systems have:**
  - *Technical/economic advantages for sub-slab depressurization.*
  - *Sustainable remediation features with finer control of processes.*
  - *Sensor interfacing with emphasis on leak detection applications.*

A Service-Disabled Veteran-Owned Company

Contact Us Today for a Free Site Evaluation!

877-747-ENRX (3679) ▪ www.enrxinc.com

DALLAS, TX | TAMPA, FL | DENVER, CO | IRVINE, CA