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Horizontal Directional Drilling: A Green and Sustainable Technology for Site Remediation

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Sustainability—maximizing the net benefit of human activities by reducing energy consumption, preventing or mitigating environmental damage, and addressing local economic and social factors—has become an important goal in nearly every facet of current business practice. Soil and groundwater remediation at contaminated sites has not been bypassed by this revolution. Many cleanup technologies have improved their energy efficiency, but the traditional methods for installing them have evolved only incrementally. Newer construction technologies, such as horizontal directional drilling (HDD) can facilitate the transition to more sustainable remediation practices both in remedy construction and operation.

In 2008, the Environmental Protection Agency published its technology primer, *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites.*[3] In this document, EPA outlined core elements of site characterization and remediation activities, suggesting sustainable practices to reduce their environmental footprint at affected sites. EPA has subsequently updated those elements[6] and developed additional methodology for quantifying the environmental footprint of site cleanup efforts. At least some regulators[1] have clarified that sustainability will become a key factor in their future approval of site Remedial Action Plans.

In 2011, the Sustainable Remediation Forum (SURF), an organization of industry, regulatory, and consulting professionals,[2] published a framework[5] for integrating sustainable practices into site remedies. The SURF framework stresses a holistic approach to all phases of site investigation and remediation for sustainable practices, in the context of the eventual future use of the site. By evaluating options at each phase of the project while considering future operations, optimized decisions can be made in selecting and implementing appropriate remedies.

In practical terms, high level policy must eventually be implemented in the field. Although a host of innovative technologies exist to treat contaminated soil and groundwater, constructing them in the field continues to rely on age-old, conventional methods: vertical drilling or excavation. Little guidance exists to improve the sustainability of these methods, other than generic suggestions to reduce emissions. Even less guidance is available to suggest newer construction methods to install cleanup technologies.

First commercially used for remediation in the early 1990s, HDD technology aligns well with emerging Green and Sustainable Remediation (GSR) practices. Compared to other methods, HDD can reduce energy consumption during construction, reduce collateral environmental damage, and enhance other sustainability metrics. Similarly, HDD wells offer benefits in energy conservation and reduced maintenance during operation.

HDD places relatively long well screens in contact with contaminated soil or groundwater along a linear or curved horizontal bore path. Well screens can extend for hundreds of meters, up to practical maxima approaching 775 m (2500 ft.) Wells can traverse beneath surface infrastructure, sensitive ecological areas, or even residential neighborhoods without disturbing them. Figure 1 depicts a typical horizontal well bore profile intercepting a contaminated zone.

This feature discusses the potential sustainability benefits where HDD can enhance, often substantially, key GSR metrics, compared with conventional technologies. The article is not intended to provide detailed technical discussion of proper horizontal well design, construction, or operation.

CORE SUSTAINABILITY ELEMENTS

In their guidance, the EPA[6] recognizes five core elements of cleanup projects where sustainable practices can provide a conservation benefit, while achieving the benefits of the cleanup itself. These include

- Total energy use and renewable energy use.
- Air pollutants and greenhouse gas emissions.
- Water use and impacts to water resources.
- Materials management and waste reduction.
- Land management and ecosystems protection.

Each of these elements will be discussed below.

TOTAL ENERGY USE AND RENEWABLE ENERGY USE

During construction, HDD can significantly reduce the time spent in constructing well networks, depending on well spacing, depth, and layout. A single horizontal well, installed in a week, can replace multiple vertical wells or large volumes of soil excavation that might take several weeks to complete; this equates to less equipment usage, fewer man-hours on site, and fewer trips to the site during construction. All of these factors reduce energy consumption.

Remediation systems that are based on horizontal wells can also significantly reduce site energy requirements and associated costs during operation. Many remediation systems make heavy energy demands to operate groundwater pumps, blowers, transfer pumps, ozone generators, and other equipment. A single horizontal groundwater extraction well can be hundreds of feet long, but requires only a single pump. Soil vapor extraction or air sparge systems that would require multiple blowers if constructed with vertical wells can often be designed with only one or two blowers if horizontal wells are employed.

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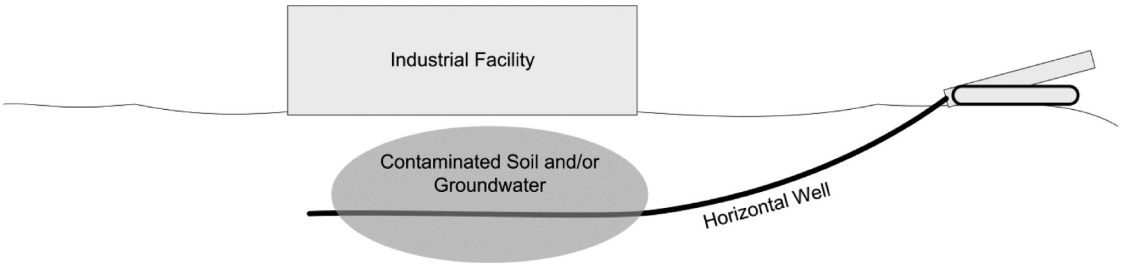

Figure 1. Typical horizontal well profile at contaminated site.

Horizontal wells generally reduce, often substantially, the quantity of nonproductive riser pipe and/or conveyance lines used in an extended remediation system, increasing system efficiency and often reducing treatment time. The combination of fewer, smaller pumps or blowers, and reduction in size or number of transfer pumps for conveyance lines also reduce energy consumption during operation.

AIR POLLUTANTS AND GREENHOUSE GAS EMISSIONS

EPA recommends several practices with the goal of reducing air emissions during construction. A few of these suggestions, including use of cleaner fuels, more efficient engines, and diesel particulate filters, are applicable to any sort of equipment intensive operation. However, by actually reducing the level of effort required to construct the remedy, HDD technology can result in overall air emissions reductions that favor the technology.

Drilling operations combine a variety of tasks and equipment operations that result in air emissions. There are obvious, direct sources, as well as "upstream" sources related to manufacturing and transport of project materials. During a project, sources may include direct on-site emissions from

- Drill rigs.
- Air compressors or drilling mud mixers or recyclers.
- Engine driven pumps and generators.
- Earthmoving and materials handling equipment.
- Crew and transport vehicles.
- Solvents for assembling well casing.

Less direct sources, that are still factored into the project's environmental footprint include emissions that result from manufacture of consumables, such as

- Well casing, well screen, and conveyance lines.
- Wellhead completion materials (e.g., bentonite or cement).

A key recommendation for reduction of emissions at the construction stage is obvious: minimize the use of heavy equipment. As noted previously, HDD provides ample opportunities to achieve this goal.

As GSR matures among environmental regulators, consultants, and industry, tools and guidance are being developed to facilitate the selection of options for site characterization and cleanup remedies. Notable among these tools is SiteWise, developed in cooperation by Battelle, the Army Corps of Engineers, and the U.S. Navy Naval Facilities Engineering Command.[4]

The SiteWise modeling tool provides a convenient way to directly compare the relative environmental footprints of alternative site remedies at different phases of a site remediation project. For this feature, the SiteWise tool was used to compare the air emissions of HDD versus a more traditional vertical drilling alternative in constructing a groundwater extraction system at a hypothetical site. The initial assumption for the example is a 310 m (1000 ft.) wide groundwater contaminant plume, with groundwater at 15 m (50 ft.). For this example, a single horizontal well, crossing the plume, is compared with a network of 12 vertical wells, spaced across the plume in a single line. Figure 2 illustrates the example.

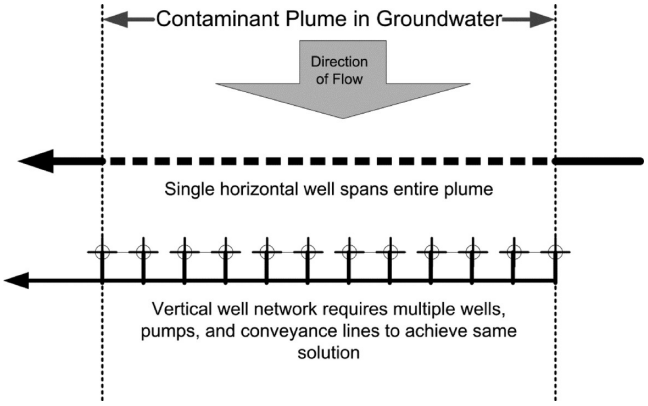

Figure 2. Plan view of horizontal vs vertical well network, crossing a contaminant plume.

The comparison is based on the assumed plume and well configurations that are provided in Table 1.

Table 1. Comparison of HDD vs. Vertical Wells for 310m Plume Capture

description	units	HDD	vertical
length of well network		310 m (1000 ft.)	310 m (1000 ft.)
depth to GW table	ft.	15 m (50 ft.)	15 m (50 ft.)
number of wells		1	12
well spacing	ft.	NA	26 m (83 ft.)
depth [length] of wells	ft.	455 m (1480 ft.)	21.5 m (70 ft.)
screen length (per well)	ft.	310 m (1000 ft.)	6.2 m (20 ft.)
total screen length	ft.	310 m (1000 ft.)	74 m (240 ft.)
combined riser length	ft.	148 m (480 ft.)	184 m (600 ft.)
combined well length	ft.	455 m (1480 ft.)	258 m (840 ft.)
well diameter	in.	10 cm (4 in.)	10 cm (4 in.)
well material		HDPE	PVC
bore diameter	in.	20 cm (8 in.)	20 cm (8 in.)

For this example, the hypothetical plume is traversed by either a single, double-ended horizontal well, or a string of 12 vertical wells. Horizontal wells enter the ground surface at an

angle, gradually leveling off near the target depth. To reach a target depth of 18.5 m (60 ft.) (3 m below the water table) in the example takes approximately 74 m (240 ft.). A horizontal well traversing the example plume would therefore include a 74 m entry section, 310 m of screen, and a 74 m exit section. For vertical wells in the example, 12 wells, spaced 26 m apart, are drilled and cased to a depth of 21.5 m, with 6.15 m of well screen in each well. The example includes the installation of trenched-in conveyance piping to transfer water from the vertical wells back to a central treatment facility. The horizontal well requires only a short length of transfer piping for this purpose.

A single horizontal well, up to 500 m long, can be installed in three to four days with a midsized horizontal drill rig, with a diesel powered mud system in support. In contrast, the installation of 12 auger-drilled vertical wells, would take about 15 days. Developing the horizontal well takes approximately one day, compared to 3–6 days to develop 12 vertical wells. Proper development of a horizontal well, drilled with drilling mud, generally takes a higher level of care than developing wells that were constructed using auger drilling technology. This effort assures that the drilling mud is fully removed from the bore, and that any potential damage to the formation is mitigated.

Although both auger and horizontal drilling are considered to be high-emissions activities, comparing the two operations with the SiteWise application confirms that air emissions can be reduced during well construction by using HDD. Reductions occur primarily due to the significantly reduced time on site and elimination of the conveyance line construction, although reduction in vehicle trips is a contributor. The graphs in Figure 3 compare air emissions between auger drilling and HDD for the example. For air emissions, the HDD footprint shows moderate reductions compared to conventional drilling.

WATER USE AND IMPACTS TO WATER RESOURCES

The EPA describes several core elements[1] related to water usage at remediation sites. The key points include

- Minimize fresh water consumption, and reuse water as much as possible for daily operations and treatment.
- Reclaim treated water for beneficial use.
- Use native vegetation that requires little or no irrigation, and
- Prevent impacts such as nutrient loading on surface water bodies.

Many vertical wells are installed using hollow stem augers, which minimize water use during construction. In contrast, most HDD installations use drilling mud, but the use of mud recyclers, which remove drill cuttings from the mud for subsequent disposal, enable a relatively small amount of mud (equal to the borehole volume plus a reserve) to be reused continuously during drilling operations. Recyclers also segregate the waste into a solid component that can be spread or landfilled, and a liquid fraction that is often treated on site, reducing transportation and disposal impacts. Mud use also reduces airborne emissions of volatile materials or dust, compared to alternatives such as air rotary drilling.

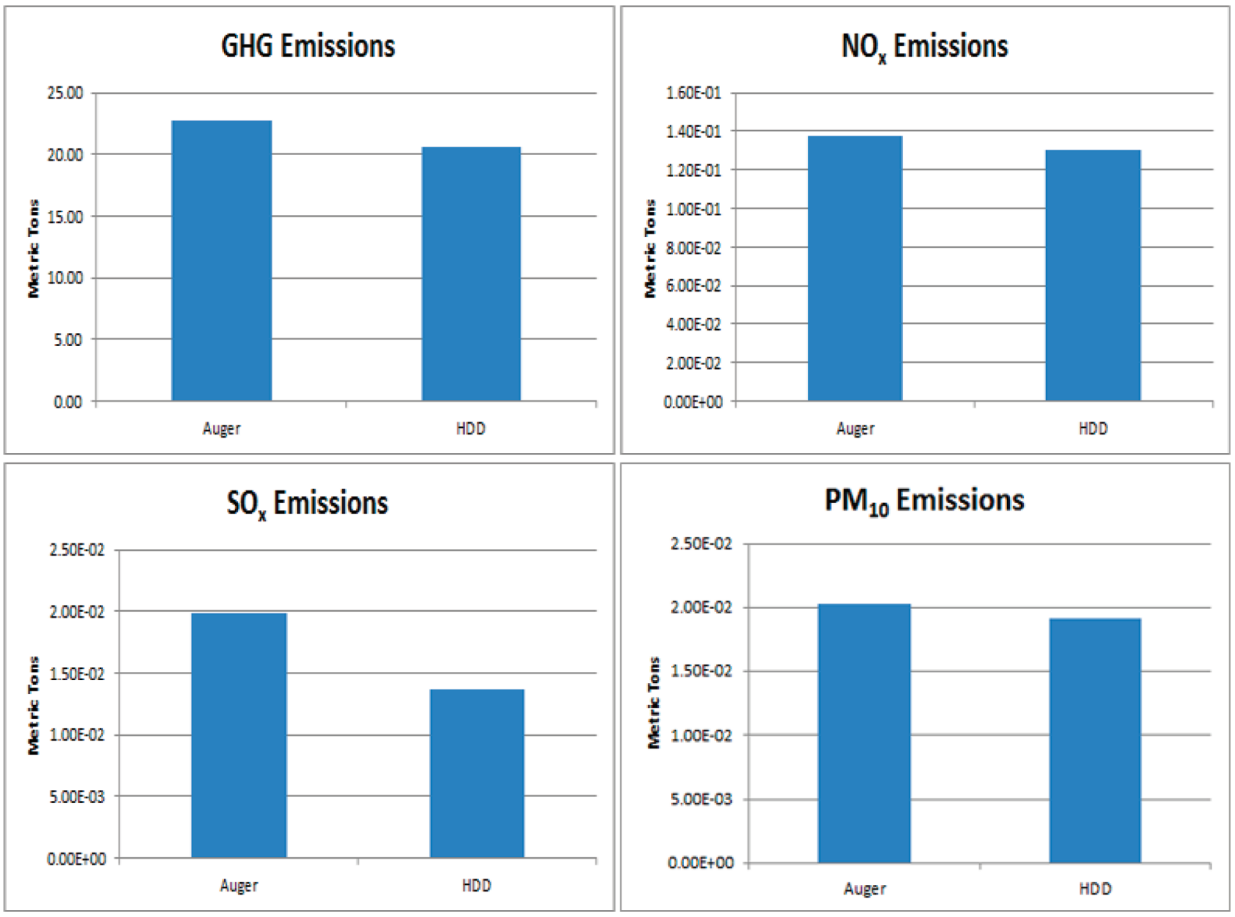

Figure 3. Various air emission comparison, auger drilling vs HDD.

Figure 4. Drill site on Monterey Bay, California. Well path extends for over 1000 feet in front of drill rig (right) through dune area to the horizon.

Horizontal directional wells are ideal for infiltration or injection of reclaimed or processed water from remediation projects back into affected aquifers. Horizontal wells can diffuse reclaimed water over an extended screen length, reducing the potential for local groundwater mounding or other adverse changes in groundwater gradient associated with shallow or deep vertical injection wells.

Horizontal wells can also be readily installed beneath existing vegetation, even in sensitive environmental areas. This eliminates the need to revegetate, and irrigate, large areas that may be disturbed by more invasive surface activities associated with vertical drilling at multiple locations, extensive trenching, or bulk excavation. This also reduces the costs associated with such activities.

By using infiltration wells that discharge treated water along a dispersed, subsurface zone, designers can also eliminate point source discharges to surface water bodies. In Sand City, California, situated on Monterey Bay, the waste brine from a 300 acre-foot desalination plant is routed to a 230 m (750 ft.) long infiltration well, installed 15 m (50 ft.) below sea level and parallel to the beach (Figure 4).The well was installed in a protected coastal environment, passing beneath habitat for the endangered California Black Legless Lizard (*Anniella pulchra nigra*) and the threatened Western Snowy Plover (*Charadrius alexandrinus*). Installation of the directional infiltration well avoided local marine salinity changes that could have occurred if the brine had been discharged directly to the ocean via a conventional outfall, as well as potentially extensive impacts on land habitat.

LAND MANAGEMENT AND ECOSYSTEM PROTECTION

In reducing the remediation footprint on the land and local ecosystems, EPA suggests several practices that may be beneficially achieved through the use of horizontal wells. These include:

Use of Minimally Invasive in Situ Technologies. HDD provides a distinct advantage when the ratio of the area area treated to the actual construction footprint is compared to conventional drilling. Horizontal wells are launched from a small excavation, only a few feet square. The entire footprint of a drill site may be less than 30 m (100 ft.) square, for one or several wells that may be over 500 m in length. Multiple vertical drill sites not only require the drill pads themselves, but pathways connecting them for rig and vehicle access, and intrusive wellheads and conveyance piping. For the prior example of a 1000 foot long treatment system, the construction footprint of an HDD well would require only 30% of the surface area (<0.05 hc) needed for a multiwell alternative (0.16 hc).

Use of Passive Energy Technologies. Horizontal wells are well suited to minimally invasive cleanup technologies, such as bioventing or bioaugmentation, which rely on in situ processes to stimulate natural contaminant cleanup. Wells may be designed for injection of a variety of chemical or biological agents to treat, sequester, or remove contaminants. A 1450 foot well was completed in 2009 at a Superfund site in Pensacola, Florida to intercept the contaminant plume from a wood treatment facility. The well, 30 m (100 ft.) deep, traversed beneath an asphalt recycling stockpile, an active railroad switch yard,

and the active Superfund surface cleanup activities, to install an oxygen injection system to remedy the plume.

Minimize Soil and Habitat Disturbance. In steep or highly vegetated terrain, directional wells and borings require minimal surface disturbance, to access terrain that would required extensive clearing, excavation, and road building to situate vertical rigs. Horizontal wells have been installed under streams and rivers, lakeshores, and protected coastal wildlife and plant protection zones, with virtually no direct impact on the protected habitats or the flora or fauna living above the wells.

In Santa Barbara County, California, directional drilling techniques developed for environmental cleanup were recently used for oil production from a shallow, dipping, oil-bearing sandstone formation on a hilltop. Three wells were drilled up the steep hillside, enabling gravity flow of the oil to catchment basins, while eliminating the need to construct multiple vertical drill pads and access roads in stands of the endangered Lompoc Yerba Santa (*Eriodictyon capitatum*) shrub that grows on the slopes there (Figure 5).

Figure 5. Endangered Lompoc Yerba Santa with protective cages at drill site, Santa Barbara County, California.

Minimize Bioavailability of Contaminants through Effective Source Control. HDD wells are proven to be highly effective for plume cutoff and source capture and control, or for dewatering in combination with other remedies. On a recent project at a USAF base in New Mexico, horizontal wells dewatered a 66 acre site prior to excavation of 12 m (40 ft.) of contaminated soil. A total of two, 330 m (1100 ft.) wells were installed, which removed approximately 16 000 000 gallons of contaminated groundwater in nine months of operation.

MATERIALS MANAGEMENT AND WASTE REDUCTION

A key element for sustainability in site cleanup is the reduction of waste materials generated during remediation activities. For sampling, EPA recommends the use of sonic drilling techniques, which can substantially reduce investigation derived waste (IDW) during characterization. However, sonic drilling methods are generally limited to small diameters, which are often not practical for remediation purposes. On a footage basis, the amount of soil waste generated by auger drilling is comparable to that generated by HDD. However, due to the advantageous well screen to riser ratio previously discussed, the amount of waste generated per volume of total treated area favors HDD. This benefit increases as the total volume of treated area increases on larger sites.

SOCIAL AND ECONOMIC METRICS

An analysis of GSR also requires an examination of social and economic factors associated with the remedy. From a safety standpoint, HDD is typically more protective of worker safety than alternative methods. Exposure to contaminants is typically reduced in HDD drilling operations, and less time on site reduces exposure to industrial accidents as well. The reduced construction footprint lessens neighborhood impacts, in some cases wells might pass beneath a residential area with no surface evidence at all.

Regarding local economic impacts, qualified HDD contractors are seldom local and bring their own crew when they arrive on site. However, traveling crews require lodging and logistical support, which provides income for the community.

SUMMARY

Although HDD is recognized as an effective method to achieve cleanup goals at many contaminated sites, its role as part of a sustainable remediation effort has not been deeply explored. Environmental HDD, examined from the perspective of GSR, can be an effective tool in meeting sustainability goals for remediation. When designing a remediation effort, it is worth the effort to compare the long-term economic and environmental costs of installation, operation, and maintenance between systems based on horizontal wells and other methods, in many cases, HDD may prove to be a superior choice.

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Notes

The authors declare the following competing financial interest(s): I am a geologist, employed by Directed Technologies Drilling, a horizontal directional drilling company. As a purveyor of the technology, I am enthusiastic about its application, however as an experienced environmental geologist I am also very aware that the technology is not universally applicable or desirable. My intent with this article was simply to raise awareness of the benefits of HDD as a GSR technology.

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