INTERSTATE TECHNOLOGY & REGULATORY COUNCIL

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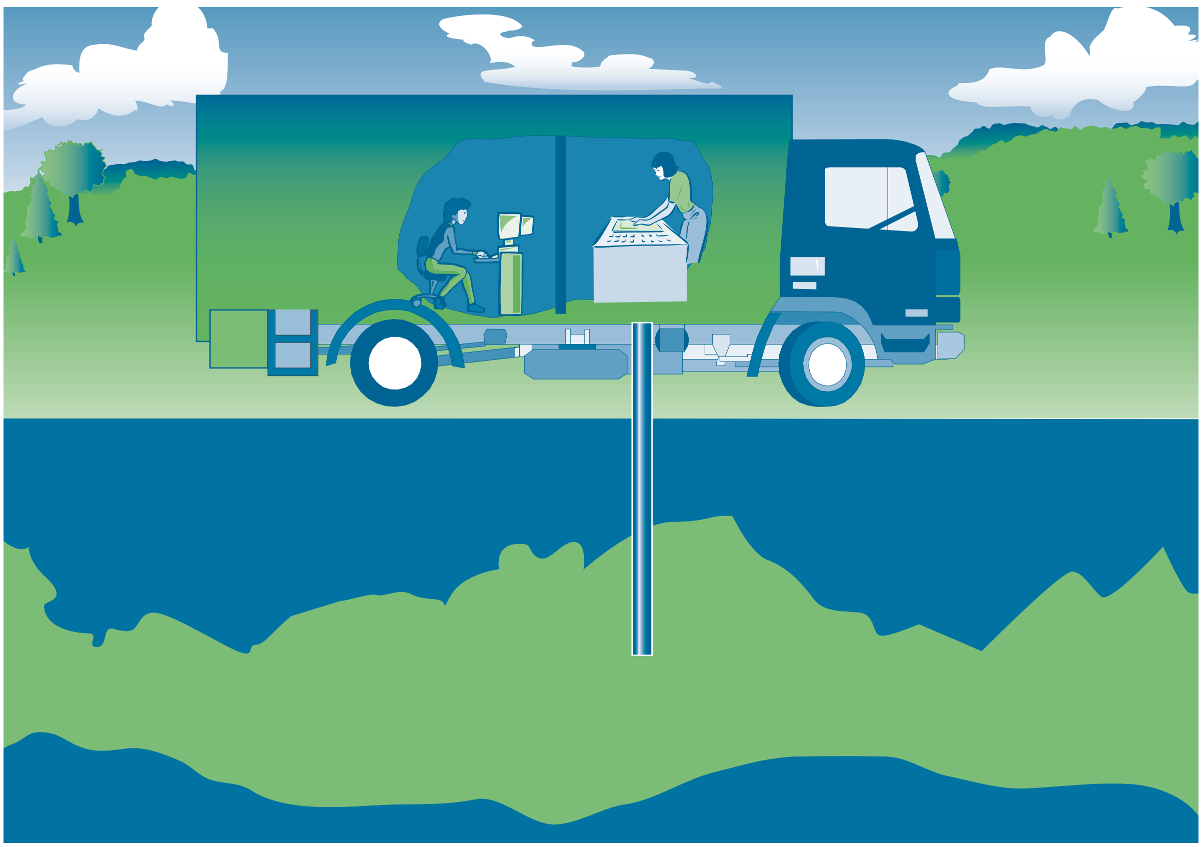
INTERSTATE TECHNOLOGY & REGULATORY COUNCIL

Technical and Regulatory Guidance

The Use of Direct Push Well Technology for Long-term Environmental Monitoring in Groundwater Investigations



March 2006

Prepared by
The Interstate Technology & Regulatory Council
Sampling, Characterization and Monitoring Team

ABOUT ITRC

Established in 1995, the Interstate Technology & Regulatory Council (ITRC) is a state-led, national coalition of personnel from the environmental regulatory agencies of some 40 states and the District of Columbia, three federal agencies, tribes, and public and industry stakeholders. The organization is devoted to reducing barriers to, and speeding interstate deployment of, better, more cost-effective, innovative environmental techniques. ITRC operates as a committee of the Environmental Research Institute of the States (ERIS), a Section 501(c)(3) public charity that supports the Environmental Council of the States (ECOS) through its educational and research activities aimed at improving the environment in the United States and providing a forum for state environmental policy makers. More information about ITRC and its available products and services can be found on the Internet at www.itrcweb.org**.**

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EXECUTIVE SUMMARY

This document provides technical and regulatory guidance concerning the use of Direct Push wells for long-term environmental groundwater monitoring. Direct Push wells offer the potential to save significant amounts of money and time for environmental groundwater monitoring. Equipment used to install such wells is usually smaller and lighter than conventional drilling rigs, so less damage is done to landowner's property. The quality of data from groundwater samples taken from Direct Push wells are comparable to those obtained from conventional wells. Despite these positive attributes, most states' regulations inadvertently prohibit their use for long-term groundwater monitoring and relegate their usage primarily to screening purposes. The basis of the prohibition on the use of Direct Push wells involves their lack of the relatively large volume of annular space that is required for the proper construction of conventional wells. Installation of wells by Direct Push technology is not new, and variances permitting the use of Direct Push wells for long-term monitoring are commonly granted in many states.

In the infancy of environmental ground water monitoring, regulatory agencies and advisory organizations relied upon established well drilling techniques when drafting regulations that would be protective of human health and the environment for the installation of environmental ground water monitoring wells. Those drilling techniques were primarily developed to access water and petroleum resources, and subsequently utilized to obtain environmental samples from aquifers to determine the identity and levels of contaminants present. The standard for environmental monitoring wells was typically based on two and four-inch diameter wells drilled and installed with a hollow-stem auger or other conventional installation techniques. The technologies used for installing ground water monitoring wells have advanced significantly since most of the regulations were written.

This ITRC technical/regulatory guidance document presents detailed information related to Direct Push well technology, including the following:

- a description of Direct Push well technology
- equipment and installation requirements
- known regulatory barriers and concerns
- technology advantages and limitations
- health and safety issues
- stakeholder involvement
- comparative data between Direct Push and conventionally drilled wells in the form of multiple case studies as they relate to contaminant detection and water level measurements

This document is intended to provide the information required to make an informed decision regarding the use of Direct Push wells for long term groundwater chemistry monitoring and for static ground water levels. In addition, links to further references related to Direct Push technology are provided, which may be referenced to address specific concerns and questions of the reader. This document does not address other potential applications for Direct Push well technology, such as temporary well points or site remediation injection wells. The primary conclusions of this report may be summarized in three key points as follows:

(1) Results from short-term and long-term groundwater monitoring studies have shown that samples taken from Direct Push wells are comparable in quality to those obtained from conventionally-constructed wells.

(2) Usage of Direct Push wells for long-term monitoring is prohibited in many states by existing regulations that require a larger annular space than can be obtained with Direct Push methods.

(3) Direct Push wells can be extremely cost-efficient.

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1. INTRODUCTION

Monitoring wells are fundamental to every ground water investigation. In pollution assessment and remediation, ground water monitoring wells often provide the only means for collecting representative ground water samples at a fixed location over time. These have traditionally been installed using drilling techniques and approaches that were developed for water resource and petroleum extraction applications. Over the past ten to fifteen years, several alternative installation techniques and devices have been developed. Most notably, Direct Push systems such as the hydraulic ram-based cone penetrometer and hammer-type devices have been used for installing ground water monitoring wells.

Direct Push wells are defined as wells that are installed by either a static push or dynamic push force. Hydraulic rams are typically used to provide a static pushing mechanism and hammer devices are used to provide a dynamic force. The primary distinction between a Direct Push well and a conventionally installed groundwater monitoring well is that a Direct Push well can be installed without first having to construct an open borehole. The primary advantage of Direct Push wells is the cost saving that is associated with the speed and ease of installation. Due to their lower costs, faster installation, decreased contaminant exposure, and decreased waste production, Direct Push wells are a desirable alternative to conventionally drilled wells.

Definition of Direct Push Wells
Wells that are installed by pushing or hammering the drive rods as opposed to drilling or augering.

However, regulatory barriers exist in most US states that prevent the use of Direct Push wells for long term environmental monitoring in groundwater. The primary barrier is the existence of regulations that require a larger annular space (between the well casing and the borehole wall) than is typically possible for Direct Push well construction. Another barrier is the misperception that groundwater chemistry data from Direct Push wells are inferior to that obtained from conventional wells.

Direct Push wells have been installed at numerous federal and state sites for uses that range from temporary wells for sample collection and groundwater level measurement to permanent installation. Often, these wells are used in place of conventionally drilled monitoring wells for long-term environmental monitoring or monitoring of contaminant migration.

Kram et al., 2003, note that Direct Push monitoring wells can lead to cost savings that range from 23% to 65%, depending on the total depth, screen length, filter pack selection, well diameter, and types of material penetrated. In addition, since several types of Direct Push systems are capable of installing wells, an additional mobilization step can be avoided when

Direct Push wells are incorporated into a field analytical program. For instance, sensors and tools used in Direct Push explorations are capable of soil type classification, chemical measurement, plume and lithology mapping, and can be used to collect soil and water samples. Operators can pre-select the number of monitoring wells desired and strategically incorporate these into the site delineation effort, leading to optimized well placement while reducing the time and level of logistical support typically required for multi-phased, multi-contracted efforts. In other words, Direct Push wells can be installed during the field characterization phase without requiring an additional mobilization.

The ability to dynamically alter a field characterization plan is an inherent concept of the Triad approach to environmental project management. The concepts embodied in the three legs of the Triad approach are as follows:

- systematic project planning
- dynamic work strategies
- real-time measurement technologies (ITRC SCM Team, 2003)

As an exploration tool, Direct Push wells aid dynamic work strategies by enabling rapid groundwater sampling.

The Triad Approach and Direct Push Wells
Direct Push Wells can be used as part of the dynamic work strategy component of the Triad approach.

The main construction differences between conventionally drilled wells and Direct Push wells depend on the installation method deployed, machinery involved, and available well construction materials. Direct push wells tend to be smaller in diameter than their conventionally drilled counterparts, leading to differences in annular space, casing, and sealing dimensions. Depending on screen depth, these differences can impact the sampling options available to the user. For instance, while smaller diameter Direct Push wells may preclude the use of larger diameter pumps, smaller diameter pumps are now commercially available and can be used in all but the deepest of wells. The same basic construction approach can be used for both drilled and pushed wells. Both types of wells can contain a screened area consisting of slotted casing surrounded by a filter pack, an annular seal, and a surface protection device. For drilled wells, a filter pack and annular seal are typically installed using gravity-fed tremie approaches. Pre-pack filter jackets and modular sealing devices have become available for Direct Push wells, effectively reducing the potential for bridging resulting from tremie approaches. Table 1-1 lists some of the relative attributes of Hollow Stem Auger (HAS) wells compared to Direct Push wells.

Direct Push monitoring wells have evolved from their initial use as temporary monitoring points to usage as permanent monitoring wells. Detailed comparisons of groundwater chemistry data from Direct Push wells with data from conventionally drilled hollow stem auger (HSA) monitoring wells were not available until recently. Because little was known about the ability of Direct Push wells to produce representative groundwater chemistry samples and the longevity of

Table 1-1. Comparison of hollow stem auger wells vs. Direct Push wells

Attribute	Hollow Stem Auger	Direct Push
Diameter	Larger	Smaller
Filter Pack	Placed by tremie	Pre-Pack or tremie
Annular Seal	Placed by tremie	Pre-Seal or tremie
Cuttings Generated?	Yes	No
Waste Exposure From Cuttings?	Yes	No
Depth	Depends on Formation	Depends on Formation
Waste Disposal Required	Yes	No

such wells, the majority of existing state regulations do not specifically address Direct Push technology.

Several studies have been conducted to determine the suitability of Direct Push wells. These studies have been sponsored by both private industry and the U.S Department of Defense (DOD). Most recently, this has included a demonstration sponsored by DOD's Environmental Security Technology Certification Program (ESTCP). This demonstration was conducted to determine the long-term performance of Direct Push wells at five test sites in different parts of the country. Earlier Direct Push well studies include a jointly sponsored study by the British Petroleum Corporation of North America and the U.S. EPA, and a study conducted by the Naval Facilities Engineering Service Center (NFESC) at Port Hueneme, California. The general conclusion from these studies was that Direct Push wells are comparable to conventionally constructed wells in regards to groundwater chemistry samples.

Later sections in this document discuss Direct Push well technology, regulatory issues, case studies, health and safety, and stakeholder issues.

2. TECHNOLOGY DESCRIPTION

Direct Push wells can be installed using either a static force system or a dynamic system. Static force systems consist of hydraulic ram units with a static weight of 20 – 30 tons, while dynamic systems consist of a percussion hammer and hydraulic rams mounted on a smaller truck or track unit. Throughout this section, comparisons are made between Direct Push wells and conventionally drilled wells since the reader may be more familiar with traditional well installation techniques. Direct Push well installation requirements, equipment requirements, and sampling considerations are also discussed in this section.

The main construction differences between conventionally drilled wells and Direct Push wells relate to the installation equipment, installation method, and construction materials. Figure 2-1 is a simple schematic illustrating some of the components of Direct Push wells versus a conventional well. In Figure 2-1, "DP" is used to abbreviate "Direct Push" and "S.S." is used to abbreviate "stainless steel."

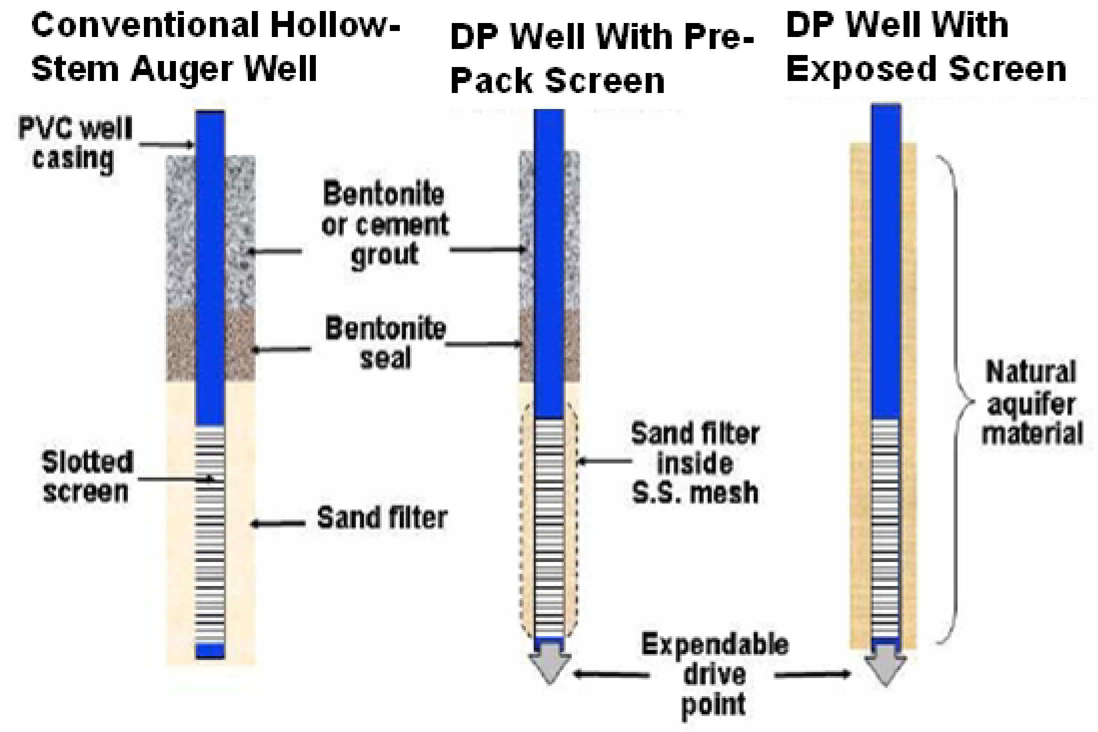

Figure 2-1. Diagrams of different well types

2.1 Direct Push Installation Equipment

Direct Push well equipment either pushes or hammers steel rods, sampling devices, geotechnical sensors, and/or analytical sensors into the subsurface. With this method no soil is removed, and only a very small borehole is created. In most cases, the steel drive rod is retracted and the riser pipe and screened section are exposed to the borehole. Filter packs can either be tremmied from the surface, or can be installed as pre-packs that surround the screened section and are emplaced with the screen and riser pipe materials.

The two major types of Direct Push installation equipment are the static force and dynamic force systems. Static force systems are sometimes known as cone penetrometer (CPT) systems and are generally the larger of the two. Static systems are usually mounted on a 10 to 30-ton truck. Unlike a dynamic system which uses a percussion hammer, static systems use a static reaction force to advance steel rods, a sampler, or an analytical device into the ground. The force used can be almost as great as the weight of the truck, which is supplemented with steel weights. Static systems that weigh 20 tons are common.

Dynamic systems typically consist of percussion hammer rigs mounted on pick-up trucks or tracks. A percussion hammer system uses a force generated both by the static weight of the vehicle on which it is mounted and a percussion hammer. Percussion hammer systems tend to be the most common and lowest cost system available.

Research to date has concentrated on developing new sensor technologies to allow the systems to produce continuous information on the geologic strata and contamination as the drive rod is pushed through the formation. Techniques such as laser induced fluorescence, soil gas sensors (Farrington and Bratton 1997), and gamma radiation detectors represent a few of the technologies being integrated with Direct Push that offer an alternative to traditional drilling and sample characterization techniques. While Direct Push systems have often been used as an alternative to drilling for the screening phase of an environmental site characterization, drilling or augering is still the most common method used to install long term monitoring wells.

2.2 Installation Methods

Direct Push wells can be installed using either an exposed-screen technique or a protected-screen technique. Diagrams of a conventionally installed HSA monitoring well and examples of Direct Push wells installed using an exposed-screen method and a protected-screen method can be found in Figures 2-1 and 2-2, respectively. Additional information on Direct Push well construction methods can be found in American Society for Testing and Materials (ASTM) Standards D 6724 and D 6725. ASTM D 6724 is a standard guide on the installation of Direct Push ground water monitoring wells and ASTM D 6725 is a standard practice for the installation of Direct Push monitoring wells with pre-packed screens in unconsolidated aquifers.

2.2.1 Exposed-screen Installation Technique

With the exposed-screen technique (often referred to as a well point), the riser and screen can be driven or pushed directly, or the riser and screen can be assembled and placed around the drive rod (on the exterior) that is connected to an expendable metal drive tip. Because the well screen is exposed to formation materials while being advanced, proper well development is important to remove sediment from the screen slots. The exposed screen method is faster and less expensive than other Direct Push installation techniques. Disadvantages associated with this method include the following:

- concerns with contamination of the target zone resulting from dragging down of NAPLs, contaminated soil and/or groundwater during the push
- clogging of the exposed screen by silts and clays
- the need for additional purging because of contamination and clogging concerns
- fragility of the screen because of the perforated open area
- the lack of an annular seal

2.2.2 Protected-screen Installation Technique

With the protected-screen well installation technique, the riser and screen are installed using one of the following methods:

- advanced within a protective outer drive rod that is driven to the target depth and then removed from the well
- advanced within a protective outer drive rod that is driven to the target depth and then retracted but left in the well to form an annular seal

- lowered into the drive rod or outer casing once the target depth is obtained

Most commonly, the installation is conducted by advancing the outer drive rod equipped with an expendable drive point or tip to the target depth, lowering the casing and screen into the well, and then attaching the screen to the drive point. This installation method protects the riser and screen from passing through potentially contaminated zones and protects the screen from clogging. This installation method is more consistent with conventional monitoring well installation techniques in that an annular seal and filter pack can be incorporated into the well design.

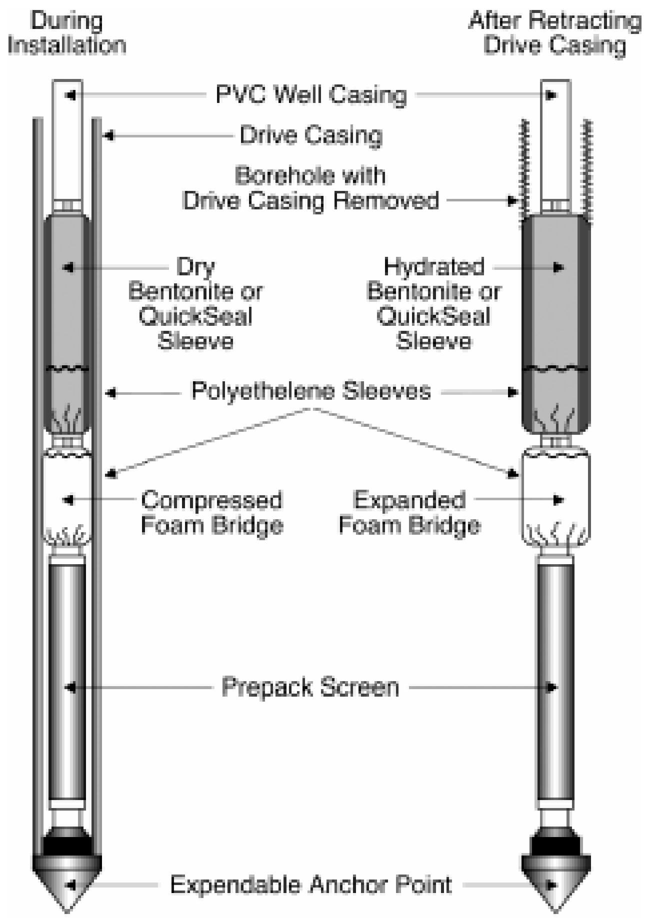

Figure 2-2. Example of protected-screen Direct Push well installation.

2.3 Construction Materials

2.3.1 Drive rods

For most installations, the drive rod is typically constructed of steel with threaded connections. For some exposed-screen and protected-screen wells, the drive rod doubles as the casing. The drive rods are hollow to allow for protection of the well components and insertion of sampling devices.

2.3.2 Expendable Drive Points

Expendable drive points are typically made of steel or aluminum and are commercially available.

2.3.3 Casings

Typically, schedule 40 or schedule 80 polyvinyl chloride (PVC) threaded or flush-jointed casings are used and installed inside an outer protective metal casing. Other materials such as stainless steel, Polytetrafluoroethylene (PTFE), or polyethylene, can be used if needed. The internal diameter ranges from ½ inch to two inches.

2.3.4 Screens

Slotted PVC screens with slot widths of 0.01 and 0.02 inches are commonly used, although wire wrapped and mesh stainless steel, polyethylene, polypropylene, and PTFE screens are also available.

2.3.5 Pre-pack filters

Pre-pack filters consist of an outer stainless steel mesh screen, and slotted PVC, polyethylene, or nylon mesh that contain the filter pack (graded silica sand), which is held against the inner screen (Figures 2-1 and 2-2). Pre-pack filters are typically installed using an outer protective metal drive casing. Typically the inner screen is slotted PVC, although all stainless and no-metal pre-pack filters are available.

2.3.6 Seals

Several methods can be used to seal a Direct Push well. The seal can be tremie grouted as the casing is withdrawn, using a grout of bentonite or cement (Figure 1). Grout machines for small-diameter Direct Push wells are commercially available. Prefabricated bentonite seals are also available and consist of a sleeve of dry granular bentonite that is wrapped around the riser (Figure 2). The bentonite sleeve expands when hydrated; these seals are designed to be used below the water table.

2.3.7 Grout barrier

Fine to medium sand is used as a grout barrier for those situations when it is possible to tremie material into place (Figure 1). When installing a direct push monitoring well using the protected-screen method, the grout barrier is installed on the casing prior to placing the well. These pre-installed grout barriers can take the form of foam bridges or plastic collars. A foam bridge type grout barrier is shown in Figure 2. The foam bridge expands after it leaves the drive casing and can be used with a pre-installed bentonite seal or a tremmied grout seal. The plastic collar operates in a similar manner.

2.4 Well Development

Monitoring well design, construction, and development procedures can greatly influence the quality and representativeness of groundwater samples. Proper well development is important to ensure that a good hydraulic connection exists between the well and the surrounding groundwater system. Proper well development is also essential to avoid or minimize turbidity in groundwater samples and is essential for ensuring representative samples. Well development removes artifacts created by the drilling process, such as disturbed fines near the borehole and silts and clays that have been "smeared" along the walls of the borehole. Unless these disturbed and smeared fines are removed by developing the well, the hydraulic connection between the well and the surrounding groundwater system will likely be poor. Techniques for developing a Direct Push well are similar to those used for a conventionally constructed well and include surge blocks, pumping, and jetting. Ideally, development should continue until all fines have been removed and relatively clear water is obtained.

Proper Well Development is Essential
Just like conventional wells, Direct Push wells must be properly developed to ensure representative groundwater samples.

2.5 Sampling Considerations

Direct Push monitoring wells can be used to obtain information related to the potentiometric surface of particular hydrologic units, water quality parameters, organic and inorganic contaminants, and migration characteristics of contaminants. Contaminants of concern may drive the sampling methodology and should be considered.

Samples from Direct Push wells can be collected with bailers, check-valve pumps, peristaltic pumps, or narrow-diameter bladder pumps. Several small-diameter bladder pumps (down to ½-inch in diameter) are commercially available. Because exposed-screen monitoring wells do not have an annular seal, caution is required for sampling contaminants if the well is pushed through NAPL or significant soil contamination. In addition to the methods mentioned above, methods have also been developed that do not require any purging. The passive diffusion bag method is one such method and is used for monitoring volatile organic compounds (ITRC, 2004). The Department of Defense is also experimenting with small containers with spring-loaded tops that can be triggered at the depth of interest. These are referred to as "snap samplers." The passive diffusion bags and snap samplers rely on the assumption that groundwater is sufficient through the well screen and that the water in the casing is representative of the surrounding groundwater.

Actual site conditions should be verified prior to employing sampling methods that rely on this assumption.

For non-passive sampling techniques, wells are purged prior to sampling so that standing water, which does not represent the true groundwater chemistry, is removed from the well. Water in the stagnant portion of the well (above the screen) can interact with the atmosphere. This interaction can result in loss of volatiles, change in the dissolved gas content (e.g., dissolved oxygen and CO2) of the well water, and can cause oxidation of some metals (e.g., precipitation of iron and manganese or co-precipitation of arsenic with iron hydroxide) (Summers and Gherini, 1987). However, these changes would most likely be less in smaller diameter Direct Push wells. As with any type of well, the stagnant water in the upper portion of the well casing can also be affected by sorption of analytes (although this is less of a concern because equilibrium will be reached in most cases (i.e., as long as the casing is not being degraded), leaching of constituents from the well casing (such as metals from stainless casings), corrosion, and degradation of the casing. The degree to which these reactions may occur will depend on the casing materials, the chemical environment in the well, and any biological activity in the well.

Three of the most common well purging techniques include the following:

- purging a specified number of well volumes
- low-flow purging and sampling using indicator parameters to determine when to sample
- well purging volume based on well hydraulics and aquifer transmissivity

Several procedures have been published with guidance on low flow purging and sampling, including Puls and Barcelona (1996), US EPA Region 1 (1996), Nielsen and Nielsen (2002), and ASTM (2003). For the definitive guidance, the reader is referred to these documents. The availability of small-diameter bladder pumps (as small as ½ inch in diameter) allows the use of low-flow purging and sampling in most instances.

2.6 Performance of Technology

There are many advantages associated with using Direct Push wells when compared with conventional monitoring wells, however, there are also limitations with using Direct Push wells. The advantages and limitations of Direct Push wells are listed in Table 2-1 and are discussed in the following paragraphs.

Table 2-1. Advantages and limitations of Direct Push wells

Advantages	Limitations
• Minimal waste "cuttings"	• Not applicable when cobbles or consolidated materials are present
• Fewer well development wastes	• Not accepted for long-term monitoring in most states
• Rapid installation and site characterization	• Debate remains regarding aquifer testing capabilities
• Less worker exposure to contaminants.	• Well diameter limitations
• Representative chemistry and field parameter measurements	• Cross-contamination of aquifers
• Minimal environmental disturbance	• Potential for higher turbidity in wells with no filter pack
• Improved landowner relations	
• Inexpensive to install, replace, and abandon	

2.6.1 Advantages

Installation of Direct Push wells is minimally intrusive and causes less disturbance of the natural formation than standard installation techniques. Percussion-hammer Direct Push systems are smaller and thus more mobile and have more access to a site than traditional drill rigs. Sampling and data collection are faster, reducing the time needed to complete an investigation and increasing the number of sample points that can be collected during the investigation. Additional advantages that result in substantial cost savings are listed below.

2.6.1.1 Minimal "cutting" wastes

Direct Push technologies produce minimal "cuttings" because very little soil is removed as the probe rods advance and retract. Consequently, the potential exposure to contaminated soils is greatly reduced and there is minimal material that must be disposed.

2.6.1.2 Fewer well development wastes

Due to the smaller diameter of Direct Push wells, development volumes are significantly decreased or reduced. For example, a 10-foot water column in a nominal two-inch monitoring well equates to a well casing volume of 1.63 gallons. Alternately, a 10-foot water column in a typical Direct Push monitoring well (e.g., ½-inch inside diameter) equates to 0.10 gallons. Stated another way, a 10-foot column of water in a conventional 2-inch well contains 16 times as much volume as the same 10-foot column in a ½-inch Direct Push well.

2.6.1.3 Rapid installation

Direct Push wells can be installed much more rapidly than conventionally drilled monitoring wells. Based upon case studies, Direct Push wells have been installed at a rate that is two-to-five times faster than conventionally drilled monitoring wells. In a heaving sand environment, cased Direct Push wells can be installed easier than conventional augered wells.

2.6.1.4 Rapid site characterization

In addition, the Direct Push well installation step can be integrated into a comprehensive dynamic characterization plan (e.g., the Triad approach) using chemical and lithologic sensors within a single deployment via in-situ emplacement of geophysical and analytical instruments. Also, closed sampling systems and on-board analytical instruments allow samples to be analyzed in the field, avoiding laboratory turnaround time, remobilization time, and associated expenses.

2.6.1.5 Less worker exposure to contaminants

Due to the decreased volume of development fluids and cutting wastes and the decreased installation time, workers receive significantly less exposure to potentially hazardous environments.

2.6.1.6 Representative chemistry and field parameter measurements

The results from a number of case studies that compared analyte concentrations taken from Direct Push wells with those collected from conventionally drilled monitoring wells are presented in more detail later in this document. Generally, these studies revealed there were relatively few instances where significant differences were found between the concentrations of analytes taken from Direct Push wells versus those from conventionally drilled monitoring wells. Analytes that were compared in these studies included organic contaminants, inorganic analytes present at the site, and purge parameters measured during the sampling process.

2.6.1.7 Minimal environmental disturbance

Direct Push wells are often installed using percussion-hammer rigs that are lighter than conventional drilling rigs. Consequently, there are fewer and shallower ruts created during off-road travel. Direct Push wells can be installed faster than conventional wells, so the crew spends less time occupying the site and is less apt to disturb the surrounding ecosystem.

2.6.1.8 Improved landowner relations

Direct Push wells are less destructive to property than conventional wells. They can be installed using smaller and lighter equipment than a conventional drilling rig; hence there is less damage from rutting. Because the equipment is smaller, it is more maneuverable than a larger drilling rig. Thus, wells can be installed in hard-to-access locations. This may allow for wells to be placed in out-of-sight locations that are requested by the landowner, when technically appropriate. Direct Push wells can be installed more quickly than conventional wells, thereby allowing the crew to vacate the landowner's property sooner.

2.6.1.9 Decreased costs associated with installation and abandonment

Data presented in the multiple case studies referenced later in this document indicate Direct Push wells can be installed at cost savings ranging from 23% to 65%, depending on the total depth, screen length, filter pack selection, well diameter, and type of geologic formation present at the site. An additional mobilization step can be avoided when Direct Push wells are incorporated into a field analytical program. Additionally, Direct Push wells are also less expensive in the event that abandonment or replacement is required.

Direct Push Wells Save Money

The primary advantage of Direct Push wells is the potential for significant cost savings as compared to conventional drilled or augered wells. Savings occur due to faster installations, less waste generation, and less material needed.

2.6.2 Limitations and Disadvantages

The primary physical limitation of Direct Push wells is that they are applicable only to unconsolidated materials. Other physical limitations and regulatory limitations are discussed in the following paragraphs.

2.6.2.1 Not applicable when cobbles or consolidated materials are present

The depth of penetration is controlled primarily by the reactive weight of the equipment or the type of hammer used (e.g., vibratory, manual, percussion). Consequently, Direct Push technologies are most applicable in unconsolidated sediments, typically to depths less than 100 feet. Penetration is limited in semi-consolidated sediments and is generally not possible in consolidated formations, although highly weathered bedrock (i.e., saprolite) is an exception for some equipment. Direct Push equipment may also be limited in unconsolidated sediments with high percentages of gravels and cobbles, or in caliche and dense, fine, saturated sands. As a result, other drilling methods are necessary in site assessment and remediation activities where geological conditions are unfavorable.

2.6.2.2 Not accepted for long-term monitoring in most states

Until relatively recently, there were no extensive, scientific case studies that evaluated the use of Direct Push wells for long-term monitoring. Consequently, states have been reluctant to recognize Direct Push wells in this context. In addition, most state regulations and/or guidance are written such that only conventional monitoring wells with a large annular volume are permitted for long-term monitoring. However, summaries of case studies related to the performance of Direct Push wells for long-term monitoring are presented in this document and indicate that Direct Push wells perform satisfactorily in this capacity.

2.6.2.3 Hydrogeologic characterization capabilities

Geologic strata can be characterized with Direct Push technology, but it differs from the methods used for conventional wells. Standard cone-penetrometer sensors can be used to ascertain soil properties. Dual-tube Direct Push systems allow for the collection of continuous soil cores to validate and confirm information generated with in-situ Direct Push sensor technologies. Groundwater samples can be collected using an exposed screen sampler.

2.6.2.4 Well diameter limitations

Direct Push wells are limited to a maximum diameter of casing that can be pushed or hammered by the equipment. As a rule of thumb, if it is necessary to install a well using casing greater than 2 inches in diameter, conventional drilling equipment should be used.

2.6.2.5 Cross-contamination of aquifers

Direct Push wells may be more apt to cause cross-contamination of aquifers by providing a vertical flow path if they are installed without using an outer casing. Also, it can be more difficult to install a proper seal above the screen in narrow diameter wells.

2.6.2.6 Potential for higher turbidity

Some practitioners still use screens without filter packs, which can result in higher turbidity and thereby compromise results. If a Direct Push well is not properly developed, samples taken from the well may also have a higher turbidity than a properly developed conventionally-constructed well would. Because of their smaller diameter, Direct Push wells require specialized tools to properly develop the well. However, properly installed and completed DP wells are capable of providing the same quality samples with reference to turbidity as conventional wells.

2.6.3 Hydraulic Conductivity

Recent research by Bartlett et al. (2004) compared the hydraulic conductivity values derived from conventional and Direct Push wells. The study was performed from March 9 to 20, 2003, at a test site at the Naval Facility, Port Hueneme, California. Over 296 pneumatic slug-in and slug-out tests and multiple steady and unsteady state pumping tests were performed. The tests were performed in five different well types and in 15 different wells. The five well types consisted of two-inch diameter conventional hollow stem auger wells, two-inch diameter Direct Push wells with pre-packs, ¾-inch pre-pack Direct Push wells with different types of pre-pack designs, and ¾-inch naturally developed pre-pack wells. The wells were screened between seven and 17.5 feet in fluvial-deltaic sediments consisting of medium to coarse-grained sand and gravel. The ground water table was five to seven feet deep and all the screens were fully submerged.

Conclusions from the study included the following points:

- The Direct Push wells had somewhat lower hydraulic conductivity values as compared to the wells installed using HSA.

- The hydraulic conductivity values in Direct Push wells were found to be independent of the pre-pack design, well radius, induced head, and test method (assuming the same screened interval).
- The variance associated with hydraulic conductivity tests in individual wells was many times smaller than the variance computed using the average hydraulic conductivity values from wells of the same type.
- The differences in hydraulic conductivity values observed amongst the wells were attributed to formation spatial heterogeneity rather than differences in well construction and installation or test method.

3. REGULATORY ISSUES, CONSIDERATIONS, AND BARRIERS

Throughout Section 3, the term "regulations" is used to describe any state law, regulation, statute, administrative code, rule, policy statement, or guidance of any sort that was discovered. This convention is used so as to be inclusive of all pertinent state-authored materials, because these terms may have different meanings to the various state governments, and because this document makes no effort to interpret the legal distinctions between the various terminologies. The primary regulatory issue concerning Direct Push wells is that most states require a minimum annular space for a monitoring well that cannot be met by the Direct Push installation technique.

Regulatory Barriers to the Use of Direct Push Wells
The primary regulatory barrier preventing the use of Direct Push wells is the requirement many states have for a minimum annular space between the well casing and borehole.

A review of state regulations suggests that at least 33 states may contain language requiring a greater annular space between the borehole and the casing than can be obtained using Direct Push methods. State regulations are commonly stated in a manner similar to the following paraphrased quote, "The annular space between the borehole wall and casing shall be a minimum of two (2.0) inches…" Direct Push technology commonly used today is capable of producing an annular space of 0.875 to 1.25 inches between the borehole wall and casing, which does not meet the requirement found in most states' regulations. Some Direct Push techniques do not require any annular space to produce an effective installation, while others only require a minimal amount. The annular space requirement commonly found in today's state regulations is based on practical considerations for the construction of conventional drilled or augered wells. When the existing regulations were developed, the minimum thickness for the annulus was determined based upon construction capabilities at the time and the desire to have an adequate filter pack. It was also assumed that Direct Push wells would not yield samples that were representative of groundwater chemistry. However, recent studies have shown that groundwater chemical samples obtained from Direct Push wells are comparable to those obtained from conventionally-constructed wells.

States commonly consider EPA guidance and ASTM standards when developing their regulations, and several states incorporate such by reference into their regulations. Hence, once such guidance or standard is published, it may become codified as an absolute requirement even though the original authors intended it only as “guidance.” The minimum annular space requirements found in most states’ regulations appear to be based on the assumption that monitoring wells would be constructed using drilling or augering methods. The magnitude of the annular space needed for conventional drilling techniques has been published in EPA manuals and ASTM standards as noted below in Table 3-1.

Table 3-1. Examples of legacy guidance documents that influenced state regulations

Document	Annular Space Requirement
USEPA 1986. *RCRA Ground-Water Monitoring Technical Enforcement Guidance Document*. p. 86	“A spacing differential of 3 to 5 inches should exist between the outer diameter of the casing and the inner diameter of the auger or the surface of the borehole to facilitate emplacement of filter pack and annular sealants.”
USEPA 1989. *Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells*. p. 81	“Additionally, larger boreholes are necessary for artificially filter-packed wells (e.g., suggested minimum of 6-inch borehole for a 2-inch inside diameter well or 8-inch borehole for a 4-inch well).”
USEPA 1993. *Solid Waste Disposal Facility Criteria Technical Manual*. p. 42	“At least 2 inches of filter pack material should be installed between the well screen and the borehole wall.”
ASTM D 5092-04 1990. *Standard Practice for Design and Installation of Ground Water Monitoring Wells*.	“The diameter of the borehole and the well casing for conventionally filter packed wells should be selected so that a minimum annular space of 2 inches (5 cm) is maintained between the inside diameter of the casing and outside diameter of the riser to provide working space for a tremie pipe.”

All of the above documents were quoted and incorporated by reference into state regulations. Subsequent to these documents being written, Direct Push methods of well installation have become more commonplace. The ASTM standard was first issued in 1990, and originally contained only the sentence quoted above regarding annular space requirements. However, at some point the following sentence was added and is included in the 2004 revision. “For naturally developed wells and pre-packed or sleeved screen completions, this annular space requirement need not be met.” Additionally, ASTM developed standards D 6724 and D 6725 specifically for Direct Push wells in 2001.

Acceptability of the data gathered through Direct Push wells is the other major issue within the environmental community. Direct Push wells have been considered as being useful only for screening purposes. Most states allow their usage on a temporary basis, but do not allow them to be used for long-term monitoring or for purposes of confirmation sampling. Case studies presented later in this document will show that, in fact, samples for groundwater chemistry taken from Direct Push wells are comparable to those obtained from conventionally-constructed wells.

A "Misperception" Barrier to the Use of Direct Push Wells
Another barrier preventing the use of Direct Push wells is the misperception that groundwater chemistry sample data from such wells are of lesser quality than similar samples taken from conventional wells.

3.1 Member State Survey

In preparation of this document, the ITRC SMC team distributed a survey through the ITRC Point of Contact Network to all ITRC member states. The survey was designed to elicit states' knowledge, use, and acceptance of Direct Push technology. States were asked to identify specific barriers related to the deployment of this technology and to identify what would aid regulators in considering this technology in their respective states. A copy of the survey distributed to member states is located in Appendix C.

Results from the state surveys were used to help develop the narrative in Sections 3.2 and 3.3.

3.2 Regulatory and Industry Concerns

Issues related to concerns from individual states fall into two major categories: well permitting and data acceptability.

The well permitting issues are mostly concerned with the procedures associated with the sealing of the well and the filter pack. These regulations were developed for conventional monitoring wells and reflect the typical annular space of such wells and the ability to design a graded filter pack when constructing conventional wells. Recent developments in Direct Push technology allow for effective seals and filter packs by utilizing pre-packed screens and either tremied or pre-fabricated bentonite seal sleeves. Most states allow Direct Push wells on a temporary basis through the variance process. However, only seven states currently allow Direct Push wells to be used for long-term monitoring without a variance.

The theory of sand pack design is based on mechanical retention of the formation particles. A pack thickness of only two or three grain diameters is all that's required to retain and control the formation materials (Driscoll, 1986). Since, in the past, it was impractical to tremie a filter pack in a drilled well annulus that was only a fraction of an inch thick and expect the material to completely surround the well screen, a four-inch (10.16-cm) annular requirement (beyond the outside diameter of the riser pipe) was used as a minimum criteria for many states (e.g., State of California, 1981). However, current technologies provide pre-pack Direct Push well screens (Figure 2-1) with "thin" filter packs. Thus, the existing requirement for a four-inch (10.16-cm) annular space is not necessary for Direct Push pre-pack screened wells. Developments in Direct Push technology have been acknowledged by some states. As an example, Oregon recently altered their well construction standards to allow for Direct Push pre-pack screened wells placed in boreholes a minimum diameter of one inch greater than the outside diameter of the well casing.

"Pre-Pack" Filters
Direct Push wells can be constructed with a thin sand filter "pre-pack" sleeve mounted in position prior to installation.

Acceptability of the data gathered through Direct Push wells is the other major issue within the environmental community. Use of Direct Push wells for water level measurements during pump tests and to detect the effect of remediation fluids injected in the ground has received greater acceptance by the regulator community. Groundwater chemistry data obtained from Direct Push wells have not been viewed as favorably. However, the case studies presented in Section 4 of this document indicate that groundwater chemistry data obtained from Direct Push wells are comparable to that obtained from conventionally drilled wells.

The drilling industry may have also been resistant to the use of Direct Push wells, because some contractors were not equipped to handle this relatively new technology. However, this is also changing and many specialized environmental drilling contractors are already equipped with such equipment. Anecdotal reports by state regulators indicate a wide spectrum of acceptance within the drilling community; while some states have experienced reluctance by the drilling contractors to utilize the new technology, others report lobbying efforts by the drilling contractors to permit use of Direct Push drilling.

3.3 State Regulations

The SCM team was not able to discover all possible rules, regulations, and guidance from every state that may be applicable to Direct Push wells. States differ in the manner they have assigned such responsibility to departments or agencies, and rules, regulations, or guidance that may pertain to Direct Push wells can sometimes be found in water resources, natural resources, environmental protection, geological, agricultural, health, or other state agencies. The SCM team members utilized internet research, the ITRC Point of Contact network, and personal contacts to develop the following materials. The following is not an exhaustive list, and because state regulations are re-written periodically, readers are cautioned to use the following materials only as a starting point for their own research.

A discussion of individual state regulations related to Direct Push wells follows below. Figure 3-1 depicts states where existing regulations appear to be a barrier to the use of Direct Push wells for long-term environmental groundwater monitoring, and it also shows the states where long-term usage is permitted. Figure 3-1 was compiled from research, telephone interviews, and email inquiries done by members of the SCM team. States that have regulations that appear to be a barrier to long-term monitoring by Direct Push wells are so indicated in Figure 3-1 by dark shading. States that allow long-term monitoring using Direct Push wells are so indicated by the cross-hatch pattern in Figure 3-1. It should be noted that all states can allow long-term monitoring with Direct Push wells through a variance procedure (or other state equivalent procedure to permit an exception), and that the states in the cross-hatch pattern are those where a variance is not required for long-term monitoring with Direct Push wells. As state regulations are continually updated, it is anticipated that Figure 3-1 and the discussion that follows will become outdated, so readers are cautioned to do their own research regarding current requirements. Because different state agencies and departments may have differing policies regarding usage of Direct Push wells, the reader is again cautioned to perform an independent verification prior to relying on any information contained in this document regarding a particular state's regulations or requirements.

Barrier States
The majority of states have regulations that act as a barrier to inhibit the use of Direct Push wells for long-term monitoring.

Figure 3-1 indicates that 33 states have minimum annular space requirements that effectively prevent Direct Push wells from being used for long-term monitoring without a variance. Seven states appear to allow Direct Push wells for long-term monitoring. The remaining 10 states fall into the "other" category and include states where the SCM team did not discover regulations, states that do not regulate wells, or states with regulations that were difficult to decipher regarding Direct Push wells. The data for Figure 3-1 were difficult to assemble because the maze of state regulations is not easy to discover and interpret. Figure 3-1 should be considered to be a dynamic figure that is undergoing constant change.

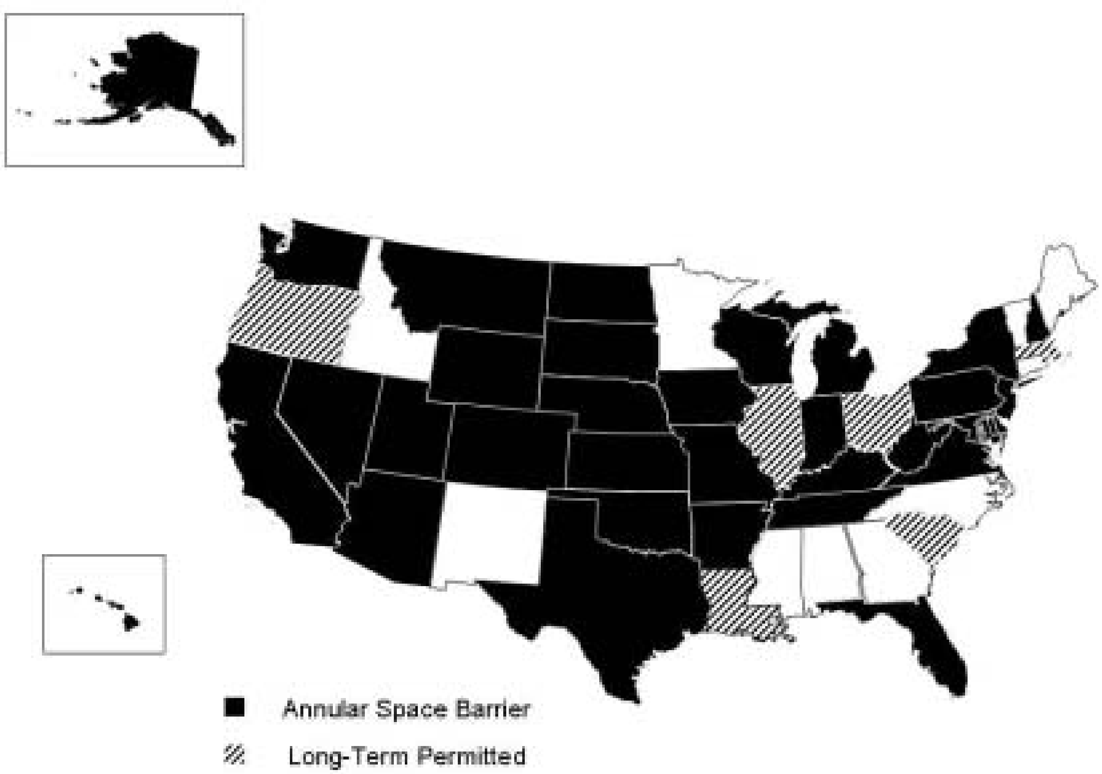

Figure 3-1. Map depicting state regulations regarding Direct Push wells

In the following subsections, a brief discussion is presented regarding the regulations that were discovered for each state. Excerpts from the actual state regulations or policy statements are provided. For the most part, the capitalization and formatting is left as it was in the actual document from which it was excerpted. The paragraph, section, and sub-section numbering routine is also left as it was found. To save space and focus only on those sections pertinent to this document, the excerpted regulation may be truncated in places by the use of a series of periods as follows; "…….." Readers are advised to consult the actual state regulations for greater clarity, and links are provided to assist in such research.

3.3.1 Alabama

No specific guidance for Direct Push wells was found in the Alabama Department of Environmental Management Administrative Code. Nothing was found that either prohibits or permits their use. The SCM team discovered sections that dealt with water wells. Pertinent excerpts found included the following:

> CHAPTER 335-9-1 LICENSING AND CERTIFICATION OF WATER AND WATER WELL CONSTRUCTION STANDARDS
>
> 335-9-1-.06 Construction Standards.
> (f) Special Cases.
> Any person desiring to construct a well in a manner not covered above, shall submit this information to the Board for approval before the work is started on the well.

Links of interest for Alabama regulations include the following:

- http://www.adem.state.al.us/WaterDivision/Ground/Hydrogeology/HydroUnitPage.htm
- http://www.alabamaadministrativecode.state.al.us/docs/adem/index.html
- http://www.adem.state.al.us/Regulations/Div9/Divi951988.pdf

3.2.2 Alaska

No specific guidance for Direct Push wells was found in the Alaska regulations. Minimum annular space requirements effectively prohibit their use. The Department of Environmental Conservation website contains a document titled *Recommended Practices for Monitoring Well Design, Installation, and Decommissioning*. Although this document is not a regulation, it is used as guidance and states: "Boreholes should have a minimum inside diameter at least four inches larger than the maximum outside diameter of the riser pipe and screen…"

Links of interest for Alaska regulations include the following:

- http://www.dec.state.ak.us/.
- http://www.dec.state.ak.us/eh/docs/sw/decom.pdf

3.3.3 Arizona

No specific guidance for Direct Push wells was found. Minimum annular space requirements effectively prohibit their use. Pertinent excerpts found in state regulations include:

> Arizona Department of Water Resources, WQARF Support Unit – Hydrology Division Special Well Drilling Requirements (For Wells Located Within Areas of Ground Water Contamination), Finalized November 1, 2002…
>
> Other Well Construction Considerations
> Additionally, there should be at least 2 inches of annular space between the casing and the borehole to allow for sufficient emplacement of grout, bentonite, or filter pack materials.

The above sentence contained a reference to page 86 of the March 1991 EPA *Handbook of Suggested Practices for the Design and Installation of GroundWater Monitoring Wells*.
Links of interest to Arizona regulations include the following:

- The Arizona Revised Statutes for Water
  http://www.azleg.state.az.us/ArizonaRevisedStatutes.asp?Title=45
- http://www.water.az.gov/adwr/
- http://www.water.az.gov/wqarf/content/WQARFInfo/Drill_guide.pdf

3.3.4 Arkansas

No specific guidance for Direct Push wells was found. By reference to EPA manuals and ASTM standards, minimum annular space requirements effectively prohibit their use.

In 1969 the Arkansas General Assembly passed the Arkansas Water Well Construction Act. This Act ordered the establishment of the Arkansas Water Well Construction Commission (AWWCC) to regulate drilling operations and pump installations through a water well contractor licensing program and to develop water well construction standards for the state. Currently, this commission operates under the Arkansas Soil and Water Conservation Commission (ASWCC).

Rules and Regulations developed by the AWWCC prescribe the minimum standards for the construction or repair of water wells in Arkansas. However, though the AWWCC retains the right to inspect all wells, Section 6.5 of these rules and regulations exempt monitoring wells from design and construction requirements. Instead, the regulations reference the EPA's "RCRA

Ground-Water Monitoring Technical Enforcement Guidance Document (TEGD)" as a guide for monitoring well construction.

This exemption and AWWCC's delegation of authority allows the Arkansas Department of Environmental Quality (ADEQ), which implements the state's environmental policies, to develop regulations specific to monitoring wells. In addition to following established EPA technical guidance documents and ASTM standards regarding installation of groundwater monitoring wells, ADEQ also relies on Regulation 22 to provide specific requirements for the State's Solid Waste Program and Regulation 23 for the Hazardous Waste Program. Regulation 22 references Section 5.7 of Solid Waste Disposal Facility Criteria, Technical Manual, EPA 530-R-93-017, November 1993, and ASTM D 5092 for well construction requirements.

In general, the Hazardous Waste Division of the ADEQ will allow the installation of Direct Push wells on a temporary basis during site investigations, but not for long-term monitoring. Design approval is provided through work plans and similar documents that describe procedures specific to each site.

Links of interest to Arkansas regulations include the following:

- http://www.arkansas.gov/awwcc/
- http://www.adeq.state.ar.us/default.htm
- http://www.aswcc.arkansas.gov/

3.3.5 California

Minimum annular space requirements effectively prohibit the use of Direct Push wells. However, San Diego County has developed its own guidance for Direct Push wells and has standardized and streamlined the process of applying for a variance for Direct Push wells. Pertinent excerpts from Department of Water Resources Bulletin 74-91, Section 9, B.5a include: "Gravel pack wells with casing: An oversized hole, at least 4 inches (100 millimeters) greater than the diameter of the conductor casing, shall be drilled to the depth specified…and the annular space…filled with sealing material."

Pertinent excerpts from the San Diego County SAM Manual Appendix B include:

> B. Standards
> 1. Well Construction…
>
> f. The following are minimum boring diameters for the respective casing sizes:

Casing I.D.	Minimum Boring Diameter
2 inches	6 inches
4 inches	8 inches
6 inches	10 inches

In general, casing sizes must have a minimum borehole diameter 4 inches greater than the proposed casing. Under prescribed conditions, a small diameter well variance may be permitted, refer to D. in this appendix…

D. Small Diameter Well Variance Guideline
1. Introduction

Small diameter wells cannot meet these prescribed construction standards because of the insufficient annular space created by the small diameter of the borehole. However, DEH has the authority to approve variance to the standards if the well design meets the intent of the State Well Standards. Therefore, DEH has established these guidelines to allow a variance for the construction of permanent small diameter wells…

Links of interest to California regulations include the following:

- http://www.sdcounty.ca.gov/deh/lwq/sam/index.html
- http://www.sdcounty.ca.gov/deh/lwq/sam/pdf_files/manual_2004/appendix/pdf/appendix_b.pdf

3.3.6 Colorado

Colorado's rules and regulations pertaining to the construction standards for monitoring and observation wells, and test holes are described in Rule 14 of the Water Well Construction Rules. The rules do not specifically address Direct Push wells. There is no minimum requirement for annular space between the casing and the borehole specified in Rule 14, but there are such requirements specified for water wells. However, Rule 14 contains a general clause that construction must comply with the construction standards specified in these rules, so it would appear that the minimum annular space requirement applies to monitoring wells. Pertinent excerpts found in state regulations include:

RULES AND REGULATIONS FOR WATER WELL CONSTRUCTION, PUMP INSTALLATION, CISTERN INSTALLATION, AND MONITORING AND OBSERVATION HOLE/WELL CONSTRUCTION (WATER WELL CONSTRUCTION RULES), 2 CCR 402-2, EFFECTIVE DATE, January 1, 2005

RULE 14
MINIMUM CONSTRUCTION STANDARDS FOR MONITORING AND OBSERVATION WELLS, MONITORING AND OBSERVATION HOLES, AND TEST HOLES

14.1.2 All monitoring and observation holes/wells and test holes shall comply with the construction standards and plugging, sealing and abandonment standards specified in these Rules.

Links of interest to Colorado regulations include the following:

- http://www.water.state.co.us/boe
- http://www.water.state.co.us/boe/rulesregs/constructionrules05.pdf

3.3.7 Connecticut

No specific guidance for Direct Push wells was found. No information was found that would either prohibit or permit their use. By practice, Direct Push wells are not used for permanent monitoring, but are considered useful for characterization.

Links of interest to Connecticut regulations include the following:

- http://www.epoc.org
- http://dep.state.ct.us/
- http://www.dph.state.ct.us/

3.3.8 Delaware

Well regulations in Delaware do not specifically address Direct Push wells. Minimum annular space requirements effectively prohibit their use. Pertinent excerpts found in state regulations include:

> DELAWARE REGULATIONS GOVERNING THE CONSTRUCTION AND USE OF WELLS…
>
> 4.07 Well Grouting
> A. All wells having annular spaces shall be grouted unless specifically exempted in this Section or otherwise approved by the Department.
> B. The annular space of all wells to be grouted shall be a minimum of one and one half (1.5) inches wide (diameter of bore hole = outside diameter of casing plus three (3) inches)…
>
> 5.01 Monitor and Observation Well Construction
> A. Unless otherwise approved by the Department, monitor and observation wells shall conform to standard well construction requirements and other general requirements as specified in these Regulations…
>
> General Requirements and Guidelines for the Construction of Monitor and Observation Wells…
>
> 9. Annular Space/Gravel Pack—The annular space of the screened interval must be at least 2 inches on both sides of the casing.

Links of interest to Delaware regulations include the following:

- Link to Delaware Department of Natural Resources and Environmental Control (DNREC)'s Well Permit Branch, http://www.dnrec.state.de.us/water2000/Sections/WatSupp/WellPermits/WSSWellPermits.htm
- Link to Delaware's regulations governing the construction and use of wells, http://www.dnrec.state.de.us/water2000/Sections/WatSupp/Library/97rgcuw.pdf
- Link to Delaware Guidance on Monitoring Wells, http://www.dnrec.state.de.us/water2000/Sections/WatSupp/WellPermits/MonitorWellGuidelines.htm

3.3.9 Florida

Some guidance for Direct Push wells was found. However, a one-inch annular space requirement effectively prohibits the use of most Direct Push construction techniques. Pertinent excerpts found in state regulations include:

> . . .in conjunction with field screening techniques (for example, use of temporary wells, piezometers or direct push technology to obtain groundwater samples for on-site analyses using gas chromatography) to optimize monitoring well placement. Citation: CHAPTER 62-770 ,PETROLEUM CONTAMINATION SITE CLEANUP CRITERIA , 62-770.600(3)c,k.

Analogous language appears in 62-782.600(4) for drycleaners and 62-785.600(4) for brownfields. In other documents outside the rules the Department has reportedly encouraged direct push techniques.

> Chapter 62-532.500, Florida Administrative Codes—Water Well Permitting and Construction Requirements: Casing with an outside diameter of less than 4 inches is to have minimum grout thickness of 1 inch (between casing and borehole.)

Links of interest to Florida regulations include the following:

- http://www.dep.state.fl.us/

3.3.10 Georgia

No specific guidance for Direct Push wells was found. No information was found to specifically prohibit or permit their use. Pertinent excerpts found in state regulations include:

> OCGA 12-5-120 GEORGIA WATER WELL STANDARDS ACT CODE SECTION 12-5-134 G…

> (5)(A) Wells and boreholes other than water wells shall be constructed:
> (i) So that no toxic or hazardous material is used in or introduced to the borehole,
> (ii) So that water-bearing formations that are, or are likely to be, polluted shall be sealed off, and
> (iii) To prevent water of different qualities from migrating between zones or aquifers…
>
> (D) Monitoring wells shall be constructed under the direction of a professional engineer or a professional geologist and shall be constructed in accordance with the following minimum requirements…
>
> (iv) The annular space around the well casing shall be grouted with impervious materials to prevent the entrance of interformational pollutants after due consideration of the local soil conditions, local geology, and the intended use of the well…

Links of interest to Georgia regulations include the following:

- http://www.ganet.org/cgi-bin/pub/ocode/ocgsearch?docname=OCode/G/12/5/134

3.3.11 Hawaii

Generally, Direct Push wells are not allowed in Hawaii as they are prohibited due to minimum annular space requirements. However, the Hawaii Department of Health, Solid and Hazardous Waste Branch, Underground Storage Tank Section, has made an exception that allows for the use of Direct Push wells at least for underground storage tank projects. The exception was made via a policy update to the *Technical Guidance Manual for Underground Storage Tank Closure and release response,* issued on December 21, 1995. The Department of Land and Natural Resources, Commission on Water Resource Management, revised the Hawaii Well Construction & Pump Installation Standards in February 2004. These revisions define monitoring wells and establish minimum annular space requirements that effectively prohibit the use of Direct Push wells. Pertinent excerpts from the Hawaii Well Construction & Pump Installation Standards include:

> Department of Land and Natural Resources, COMMISSION ON WATER RESOURCE MANAGEMENT, Hawaii Well Construction & Pump Installation Standards, Honolulu, HI, Revised Feb. 2004…
>
> 'Monitor well' means any cased permanent well drilled for the purpose of monitoring groundwater levels and salinity of ground water, or other flow properties of the aquifer. Cased permanent wells for the purpose of monitoring contaminants other than chloride are Test Borings…
>
> Part 2: WELL CONSTRUCTION…
> Section 2.5 Rock or Gravel Packing the Annular Space

> Rock or gravel packing shall consist of locally produced crushed basaltic aggregate, or preferably, commercially available rounded gravel…
>
> Section 2.6 Grouting the Annular Space…
> (d) Minimum Thickness of Grouted Annular Space
> The annular space of wells to be grouted must be a minimum of one and one half inches all around the maximum dimension of the casing if the grout is placed by positive displacement. If positive displacement is not used the minimum annular space is two inches for all wells except public water supply wells. Public water supply wells are required to have a three-inch annulus if the positive displacement technique is not used.

Links of interest to Hawaii regulations include the following:

- http://www.hawaii.gov/dlnr/cwrm/rules/hwcpis04.pdf

3.3.12 Idaho

No specific guidance for Direct Push wells was found in the Idaho regulations. No information was found to specifically prohibit or permit their use. Wells greater than 18 feet in depth are governed by the following well construction standards: Administrative Code, Department of Water Resources, Well Construction Standards Rules IDAPA 37.03.09. Pertinent excerpts include:

> 25.03.a Well casings shall be sealed to prevent the possible downward movement of contaminates surface waters in the annular space around the well casing. The seal material shall consist of cement grout, puddling clay, or bentonite grout. The use of well cuttings alone is not an approved seal.
>
> 25.03.c In wells where the above described methods of sealing wells do not apply, special sealing procedures can be approved by the Director upon written request by the well driller.
>
> 25.10 Monitoring wells. All monitoring wells shall be constructed and maintained in a manner that will prevent waste or contamination and as otherwise required by these rules.

Links of interest to Idaho regulations include the following:

- http://www.deq.state.id.us/

3.3.13 Illinois

Illinois allows installation of Direct Push wells with pre-pack filters for up to one year, or longer providing the overall integrity of the well is demonstrated.

Links of interest regarding Illinois regulations include the following:

- http://www.epa.state.il.us/land/publications/#permits-rcra
- http://www.ilga.gov/commission/jcar/admincode/077/07700920sections.html
- http://www.ilga.gov/commission/jcar/admincode/077/077009200001700R.html

3.3.14 Indiana

Specific guidance for Direct Push wells was found in the Indiana regulations, and it prohibits the use of Direct Push wells as monitoring wells. Direct Push wells must be approved by variance, and it appears that the intent is to approve them only for unusual circumstances. The following is an excerpt from the Indiana Department of Environmental Management's (IDEM) *Drilling Procedures and Monitoring Well Construction Guidelines—Nonrule Policy Document*, which was last updated in January 2003:

> Direct Push: At this time, Direct Push wells, without complete sediment removal, are not approved for use as monitoring wells. Using a four-inch drive point to compact material to the side of the hole is NOT acceptable, even if some, but not all, of the material was previously removed by a sampler. Exemptions for unusual circumstances, such as rig access in a building, may be made on a site-specific basis, only if written approval is obtained from the IDEM site manager or geologist before installation.

At press time for this document, it is known that a proposed revision to rule 312 IAC 13 has been developed that would allow for the use of Direct Push wells. As with all the discussion for the various states, readers are cautioned to do their own research to obtain the most current regulations.

Links of interest to Indiana regulations include the following:

- http://www.in.gov/idem/land/brownfields/pdffiles/guidance/monitoringwellconstrguidelines.pdf

3.3.15 Iowa

No specific guidance for Direct Push wells was found in the Iowa regulations. Annular space requirements effectively prohibit Direct Push wells, at least for some programs. Iowa's Department of Natural Resources administers the state's regulations governing the installation of monitoring wells. For solid waste disposal facilities, these regulations are specific and require a casing size of at least two inches in diameter and the installation of a seal in the annular space. The regulations for other programs in the department are less specific. Pertinent links include the following:

- http://www.legis.state.ia.us/IAC.html

3.3.16 Kansas

The Kansas Department of Health and Environment is responsible for administration of the water well regulations in the state of Kansas. Current water well regulations, which were last revised in 1993, do not specifically address the application of Direct Push technology for well installation. Annular space requirements prevent the installation of permanent monitoring wells using Direct Push technology. Pertinent excerpts found in state regulations include:

> 28-30-6 Construction regulations for all wells not included under section 28-30-5.
> (b) Grouting:
> (1) Construction or reconstructed wells shall be sealed by grouting the annular space between the casing and the well bore from ground level to a minimum of 20 feet or to a minimum of five feet into the first clay or shale layer, if one is present, whichever is greater…
> (2) To facilitate grouting, the grouted interval of the well bore shall be drilled to a minimum diameter at least three inches greater than the maximum outside diameter of the well casing.

Links of interest to Kansas regulations include the following:

- http://www.kdhe.state.ks.us/waterwell/download/article30.pdf

3.3.17 Kentucky

No specific guidance for Direct Push wells was found in the Kentucky Administrative Regulations, although there is a mention of "driven wells." Annular space requirements effectively prohibit Direct Push wells. Pertinent excerpts included the following:

> 401 KAR 6:310. Water well construction practices and standards. RELATES TO: KRS 223.400-223.460, 223.991, STATUTORY AUTHORITY: KRS 223.420, 223.435, 224.70-100…
>
> Section 6. Drilled Wells in Unconsolidated Formations…The driller shall fill the annular space between the casing and the drill hole. This may be accomplished by constructing an upper drill hole having a diameter four (4) inches greater than the inner diameter of the casing to be installed and extending to a depth of at least twenty (20) feet…

(6) In all wells where the casing is driven, the driller shall not use plastic casing.
(7) Plastic casing installations. When plastic well casing is installed, the drill hole shall be a minimum of two (2) inches greater than the inner diameter of the casing. …

(4) Driven well. The well point, drive pipe and joints shall be structurally suitable to prevent rupture or distortion during the driving of the well. The driller shall construct the top ten (10) feet of the hole to a diameter of at least two (2) inches greater than the inner diameter of the drive pipe. The driller shall fill the annular space around the drive pipe with impervious material.

Links of interest to Kentucky regulations include the following:

- http://www.lrc.state.ky.us/kar/401/006/310.htm
- http://www.lrc.state.ky.us/KRS/223-00/CHAPTER.HTM

3.3.18 Louisiana

The Louisiana Department of Environmental Quality and the Department of Transportation and Development prepared guidance titled *Construction of Geotechnical Boreholes and Groundwater Monitoring Systems Handbook*. Direct Push wells are discussed and are excluded from the annular space requirements. Pertinent excerpts from the Louisiana regulations include:

Title 70 (TRANSPORTATION) Part XIII (Public Works)…

L. Drilling and Construction
1. Geologic conditions in Louisiana permit the use of two methods of drilling: the rotary method and reverse circulation method. Regardless of the method used, every precaution should be taken to prevent ground water contamination during drilling operations…

12. Drilling of Monitoring Wells
a. Monitoring wells shall be constructed in accordance with the pertinent provisions of this Chapter in order to protect freshwater aquifers from surface contamination and to prevent movement of water of objectionable quality from one aquifer to another…

d. The entire annular space of the monitoring wells shall be sealed with cement-bentonite slurry, unless specified otherwise by the Department of Environmental Quality (DEQ)…

The *Construction of Geotechnical Boreholes and Groundwater Monitoring Systems Handbook* includes this excerpt:

5.0 MATERIALS AND CONSTRUCTI0N OF THE SYSTEM…

> The borehole created for the monitoring system should be of sufficient size as to provide a minimum annular space of two (2) inches for drilled boreholes. Wells without annular space, installed by direct push technology are excluded from this requirement.

Links of interest to Louisiana regulations include the following:

- http://www.deq.state.la.us/
- http://www.dotd.state.la.us/intermodal/wells/handbook.pdf

3.3.19 Maine

Maine reportedly has no policy or regulations on Direct Push wells. It is reported that Direct Push wells are commonly used.

Links of interest to Maine regulations include the following:

- http://janus.state.me.us/legis/statutes/32/title32ch69-Csec0.html
- http://www.geoexchange.org/pdf/CMR%20Chapter%20232-Well_Drillers_Rules_3_13_2002.pdf

3.3.20 Maryland

No specific mention of Direct Push wells was found in the Maryland regulations, but "driven wells" are discussed. Annular space requirements effectively prohibit Direct Push wells. Pertinent excerpts from the state regulations include:

> Title 26 DEPARTMENT OF THE ENVIRONMENT, Subtitle 04 REGULATION OF WATER SUPPLY, SEWAGE DISPOSAL, AND SOLID WASTE…
>
> Chapter 04 Well Construction, Authority: Environment Article, § 9-1305, Annotated Code of Maryland…
>
> M. Special Requirements For Specific Types of Wells.
> (2) Driven Wells.
> (a) 'Driven well' means any penetration of the ground made for water, or in exploration for water, in which the drill pipe is manually or mechanically driven into the ground with little or no material excavated during well construction.
> (b) Driven wells may not be used for a permanent public water supply, but may be used for domestic, small commercial, agricultural, dewatering, and observation wells. The casing shall be at least 11/4 inch (I.D.) and shall be at least 15 feet deep. An oversize hole for grout, at least 4 inches greater in diameter than the

> casing shall be constructed to a depth of at least 5 feet and the annular space between this hole and the casing shall be grouted to land surface.

Links of interest to Maryland regulations include the following:

- http://www.dsd.state.md.us/comar/subtitle_chapters/26_Chapters.htm

3.3.21 Massachusetts

In 1999, the Massachusetts Department of Environmental Protection published a chapter on applications of Direct Push wells. The state regulations are written so as to not preclude Direct Push use.

Links of interest to Massachusetts regulations include the following:

- www.mass.gov/dep/bwsc/files/sddw.htm

3.3.22 Michigan

Michigan's *Well Construction Code Administrative Rules* have annular space requirements that would seem to prohibit Direct Push wells. Pertinent excerpts from these regulations include:

> R 325.1633a Construction of wells; grouting…
> (3) A permanent casing shall be installed in a borehole that has a diameter of not less than 2 inches larger than the nominal size of the permanent casing, except as provided in subrule (4) of this rule and R 325.1635.
> (4) When grout is placed through a grout pipe outside the permanent casing, the borehole diameter shall be not less than 2 7/8 inches larger than the nominal casing size.

Links of interest to Michigan regulations include the following:

- http://www.michigan.gov/deq
- http://www.michigan.gov/deq/0,1607,7-135-3313_3675_3694-9194--,00.html#R%20325.1632a%20Construction%20of%20wells;%20driven%20well%20points

3.3.23 Minnesota

No specific guidance for Direct Push wells was found in the Minnesota Rules. Pertinent excerpts include the following:

> Subp. 2. Grouting of annular space. The annular space of a monitoring well must be grouted from ten feet or less above the screen or open bore hole to the

> established ground surface according to part 4725.3050, except that no cuttings from the bore hole must be added to the grout…

Links of interest to Minnesota regulations include the following:

- http://www.revisor.leg.state.mn.us/arule/4725/
- http://www.revisor.leg.state.mn.us/arule/4725/6650.html
- http://www.revisor.leg.state.mn.us/arule/4725/1830.html

3.3.24 Mississippi

The SCM team did not discover any information relating to Mississippi regulations that either permits or prohibits Direct Push wells. Direct Push wells of less than 50 feet in depth do not require a state well report. Pertinent excerpts from state regulations include:

> Mississippi Commission on Environmental Quality Regulation LW-3 Regarding LICENSING of WATER WELL CONTRACTORS…
>
> Construction Standards—The following construction standards apply to wells and boreholes penetrating water bearing strata including but not limited to, potable water wells, irrigation wells, monitoring wells, observation wells, underground discharge wells, dewatering wells, saline or brackish water withdrawal wells, contaminant recovery wells, heat pump water supply holes and vertical closed-loop system holes, industrial supply wells, cathodic protection wells, rig supply wells and geotechnical boreholes…
>
> e. The annular space on all wells covered by this section of the regulation shall be grouted from a depth of at least ten (10) feet below the surface to the surface, except as specified in paragraph…
>
> h**.** Wells located within one-quarter mile of a known existing area of contaminated aquifer shall be grouted from the top of the seal or filter pack to the ground surface, or the top of the casing for underground discharge wells…
>
> j. Monitoring wells shall be grouted from the top of the seal or filter pack to the ground surface, unless a more stringent requirement is mandated by other applicable regulatory programs. Specifics of monitoring well construction shall follow the most stringent requirements of the applicable regulatory programs…
>
> VIII. STATE WELL REPORTS—The State Well Report will include sections for a driller's log, a well completion report, and a well modification report. The driller's log portion of the report shall be completed by the licensed contractor and submitted to Mississippi Department of Environmental Quality (MDEQ) for all drilled wells and boreholes that penetrate water bearing strata. Water well contractors drilling irrigation wells into the Mississippi River Valley Alluvial

> Aquifer shall furnish a copy of the driller's log to the YMD Joint Water Management District at the same time the original report is submitted to MDEQ. Driller's logs will not be required for geo-technical boreholes less than twenty-five (25) feet in depth that do not encounter water bearing strata; environmental monitoring wells less than twenty-five (25) in depth that are regulated under other state and federal environmental programs; or small diameter wells or sampling holes less than fifty (50) feet in depth that are established with direct push (geo-probe) equipment….

Links of interest to Mississippi regulations include the following:

- http://www.deq.state.ms.us/MDEQ.nsf/page/L&W_Water_Well_Contractors_(Drillers)?OpenDocument
- http://www.deq.state.ms.us/MDEQ.nsf/pdf/L&W_WaterWellContractorsRegLW3/$File/WaterWellContractorsregs%20_LW-3_.pdf?OpenElement

3.3.25 Missouri

The *Missouri Well Construction Rules* were published in 1996 and last revised in 2001, but do not specifically address nor prohibit the use of Direct Push technology for the installation of permanent monitoring wells. The annular space requirements stipulated in the rules effectively prohibit the use of Direct Push wells. Pertinent excerpts from these rules include:

> Rules of Department of Natural Resources, Division 23. Division of Geology and Land Survey,
> Chapter 4. Monitoring Well Construction Code…
>
> 10 CSR 23-4.060 Construction Standards for Monitoring Wells…
>
> (2) Monitoring Well Borehole Preparation.
> Boreholes constructed for the installation of monitoring wells, including piezometers must be clean, free of obstructions, and must be at least four inches (4") in diameter larger than the outside diameter of the riser pipe, screen and/or surface casing that is used.

Links of interest to Missouri regulations include the following:

- http://www.sos.state.mo.us/adrules/csr/current/10csr/10csr.asp#10-23.
- http://www.sos.state.mo.us/adrules/csr/current/10csr/10c23-4.pdf
- http://www.dnr.mo.gov/alpd/swmp/fgrespj.htm .

3.3.26 Montana

No specific guidance for Direct Push wells was found in the Montana regulations but there is mention of "driven wells." Montana's regulations governing monitoring wells are listed under the Administrative Rules of Montana Title 36, Chapter 21, Subchapter 8, and Monitoring Well Construction Standards. The Montana Department of Natural Resources and Conservation provides oversight for these regulations. Annular space minimums are not required for driven wells, but are required for others. Pertinent excerpts from these regulations include:

> Exclusions from these construction standards include…
> 9) Monitoring wells installed under the authority of another governmental agency where the construction standards of that agency are more stringent than these rules…
>
> Seal/Materials…
> 3) For driven wells acceptable seals are granular or powdered bentonite…
>
> Installation of seals
> 1) In installing and developing a monitoring well, care shall be taken to preserve the natural barriers to groundwater movement between aquifers. All sealing shall be performed by adding the mixture from the bottom of the space to be sealed toward the surface in one continuous operation, except for driven wells.
> 2) The minimum sealing material thickness shall be 1 1/2 inches around the outside of the casing on all sides, except for driven wells.
> 3) For driven wells, granular or powdered bentonite shall be fed alongside the casing.

Links of interest to Montana regulations include the following:

- http://arm.sos.state.mt.us/36/36-4664.htm
- http://www.deq.state.mt.us/pcd

3.3.27 Nebraska

No specific guidance for Direct Push wells was found in the Nebraska regulations. Annular space requirements effectively prohibit their use. Excerpts from Nebraska Title 178 "Water Well Standards" include:

> 12-003.04 Well Casing: All wells other than test holes and closed loop heat pump wells must be cased…
>
> 12-003.04B Casing Placement: The casing must be centered in the borehole in areas of grout so there is a minimum 2-inch uniform annular space.

Links of interest to Nebraska regulations include the following:

- http://www.sos.state.ne.us/local/regsearch/Rules/Health_and_Human_Services_System/Title-178/Chapter-12.pdf

3.3.28 Nevada

No specific guidance for Direct Push wells was found in the Nevada Administrative Code. Annular space requirements effectively prohibit their use. Pertinent excerpts found included the following:

> CHAPTER 534 - UNDERGROUND WATER AND WELLS
>
> AC 534.4355 Monitoring wells: Casing; prevention of contamination. (NRS 534.020, 534.110)
> To ensure adequate space for the gravel pack and seals, the well bore of a monitoring well must, for the entire length of the casing placed in the well, be not less than 4 inches larger than the diameter of the casing…
>
> NAC 534.4367 Drive point wells. (NRS 534.020, 534.110)
> 1. A well driller may construct a drive point well without placing in the annular space of the well the gravel pack and seals required pursuant to NAC 534.4357.
> 2. The diameter of the casing used in a drive point well which is not constructed pursuant to the provisions of NAC 534.4357 must not be larger than 2 inches in nominal size.
> 3. A drive point well which is not constructed pursuant to the provisions of NAC 534.4357 must be abandoned within 60 days after the well is constructed. Upon abandonment, the casing must be removed from the well bore and the well bore must be plugged in the manner provided in NAC 534.4371. (Added to NAC by St. Engineer, eff. 12-30-97).

Links of interest to Nevada regulations include the following:

- http://www.leg.state.nv.us/NAC/NAC-534.html#NAC534Sec4351
- http://www.leg.state.nv.us/NAC/NAC534Sec4371

3.3.29 New Hampshire

No specific guidance for Direct Push wells was found in the New Hampshire regulations. Minimum annular space requirements effectively preclude their use. The following excerpts are from the state's rules on Groundwater Management:

> Env-Wm 1403.27 Groundwater Monitoring Wells.
> (a) Monitoring wells shall be designed, installed, and decommissioned in accordance with the practices described in:

(1) 'Standard Practices for Design and Installation of Ground Water Monitoring Wells in Aquifers,' American Society for Testing and Materials, Designation: D 5092 – 90, approved June 29, 1990, and published October 1990, readopted – 1995; and
(2) 'Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells,' document identification number EPA/600/4-89/034, USEPA, March, 1991.

Links of interest to New Hampshire regulations include the following:

- http://www.des.state.nh.us/orcb/doclist/wm1403.pdf

3.3.30 New Jersey

The use of Direct Push wells is described in New Jersey Department of Environmental Protection (NJDEP) document "Alternative Ground Water Sampling Techniques Guide", pages 26–30. Minimum annular space requirements effectively prohibit their use other than by variance. Excerpts from New Jersey Administrative Code 7:9D include:

> 2.2 General construction requirements for all wells
> (a) The following general construction requirements shall apply to the construction of all categories of wells pursuant to the State Act…
>
> 9. When casing is to be installed into an oversized borehole, the borehole diameter shall be at least four inches greater than the inside diameter of the well casing to be installed…
>
> 2.4 Requirements for the construction and maintenance of all Category 3 wells
> All annular space between the casing and the oversized borehole shall be sealed in accordance with the requirements in N.J.A.C. 7:9D-2.9 and 2.10.

Links of interest to New Jersey regulations include the following:

- http://www.state.nj.us/dep/
- http://www.state.nj.us/dep/srp/regs/agws/index.html#toc
- http://www.state.nj.us/dep/srp/regs/agws/agws_05.htm
- http://www.state.nj.us/dep/srp/dl/wcerta.pdf
- http://www.state.nj.us/dep/watersupply/NJAC7_9D.pdf

3.3.31 New Mexico

New Mexico has developed "minimum guidelines" for groundwater monitoring well construction and abandonment. Additional requirements or guidelines may also apply for other types of well construction, such as driven wells (Direct Push wells). Auger refusal due to boulders and gravel, and hard rocks is quite common and reduces the practicality of Direct Push wells. New Mexico has allowed the use of Direct Push wells in shallow perched water table situations on a case-by-case basis. Pertinent excerpts found in state regulations include this section from the *Ground Water Pollution Prevention Section Monitoring Well Construction and Abandonment Guidelines*:

> Purpose: These guidelines provide minimum construction and abandonment standards for drilled monitoring wells to be sampled for general chemistry analyses. There may be additional requirements if hydrocarbons or other chemicals are involved. Different guidelines may also apply for other types of well construction (eg., driven wells)…
>
> Well Specifications…
>
> The annular space above the sand pack shall be grouted or sealed at least 2 feet above the sand pack. Pressure grouting with bentonite or cement using a tremmie pipe is preferred. An alternative is to form a bentonite seal by emplacing and hydrating bentonite pellets (0.25 or 0.5 inch in size). Adequate time should be allowed for the bentonite/cement to cure before placing materials on top of the seal. The annular space above the bentonite/cement seal can be filled with uncontaminated drill cuttings, clean sandy clay or fine grained soil to within 10 feet of the ground surface. The remaining 10 feet must be sealed with a bentonite-cement grout seal (2 to 8% bentonite by weight) and allowed to cure for at least 24 hours before installing a surface pad.

Links of interest to New Mexico regulations include the following:

- http://www.nmenv.state.nm.us/index2.htm

3.3.32 New York

No specific guidance for Direct Push wells was found in the New York State Department of Environmental Conservation Rules and Regulations. Minimum annular space requirements effectively prevent their use other than by variance. Pertinent excerpts found included the following:

> Subpart 360-2, Landfills
> Section 360-2.11 Hydrogeologic report.
> (8) Monitoring wells and piezometers…(i) Construction in general…
>
> (i) Well borings must have an inside diameter at least two inches larger than the outside diameter of the casing and screen to ensure that a tremie may be properly used.

Links of interest to New York regulations include the following:

- http://www.dec.state.ny.us/website/dshm/sldwaste/wellpag2.htm
- http://www.dec.state.ny.us/website/regs/subpart360_02a.html
- http://www.dec.state.ny.us/website/regs/#endnav

3.3.33 North Carolina

No specific guidance for Direct Push wells was found for North Carolina. Nothing was found to either permit or prohibit their use. Pertinent excerpts found in the North Carolina Administrative Code include:

> 15A NCAC 02C .0108 STANDARDS OF CONSTRUCTION: WELLS OTHER THAN WATER SUPPLY…
>
> (c) Monitoring wells and recovery wells shall be located, designed, constructed, operated and abandoned with materials and by methods, which are compatible with the chemical and physical properties of the contaminants involved, specific site conditions and specific subsurface conditions. Specific construction standards will be itemized in the construction permit, if such a permit is required, but the following general requirements will apply…
>
> (4) The well shall be constructed in such a manner that water or contaminants from the land surface cannot migrate along the borehole annulus into any packing material or well screen area…
>
> (6) Grout shall be placed in the annular space between the outermost casing and the borehole wall from the land surface to the top of the bentonite clay seal above any well screen or to the bottom of the casing for open end wells. To provide stability for the well casing, the uppermost three feet of grout below land surface must be a concrete or cement-type grout…
>
> (f) Temporary wells and all other non-water supply wells shall be constructed in such a manner as to preclude the vertical migration of contaminants within and along the borehole channel.
> (g) For monitoring, sand-or gravel-packed wells, centering guides must be evenly distributed in the borehole.

Links of interest to North Carolina regulations include the following:

- http://ncrules.state.nc.us/ncadministrativ_/title15aenviron_/chapter02enviro_/default.htm
- http://gw.ehnr.state.nc.us/Acrobat%20Docs/2c0100.pdf

3.3.34 North Dakota

No specific guidance for Direct Push wells was found in the North Dakota regulations. Minimum annular space requirements effectively prevent their use other than by variance. Pertinent excerpts found in state regulations include this section from Chapter 33-18-02 in *Ground Water Monitoring Well Construction Requirements*:

> 33-18-02-06. Drilling methods…
>
> c. The nominal diameter of a borehole must provide a minimum annular space of 1.9 inches [48 millimeters].

Links of interest to North Dakota regulations include the following:

- http://www.state.nd.us/lr/information/acdata/pdf/33-18-01.pdf
- http://www.state.nd.us/lr/information/acdata/pdf/33-18-02.pdf
- http://www.health.state.nd.us/wq/

3.3.35 Ohio

Ohio permits the use of Direct Push wells for long-term groundwater monitoring, including compliance monitoring. Ohio's Technical Guidance Manual for Hydrogeologic Investigations and Ground Water Monitoring (TGM) was originally published in 1995. Chapter 7 of the guidance contains the following excerpt:

> Dimension of Artificial Filter Pack
> The distance between the casing and the borehole wall should be at least 2 to 4 inches to allow for proper placement of the filter pack and annular seal.

While the original guidance would appear to prevent the use of Direct Push wells due to the minimum annular size requirement, a new chapter was added in 2005. In February of 2005, Chapter 15 was added and provides guidance on the use of Direct Push technologies for soil and groundwater sampling. Chapter 15 contains the following excerpts:

> DPT technology can be used to collect compliance ground water samples if the data quality objectives are met…The sample point should be a permanent or temporary well. Samples from properly constructed DPT wells should be equivalent in accuracy to conventional ground water samples…Ohio EPA believes that the only way to achieve this level of data quality using DPT is with DPT wells installed using pre-packed well screens…

Links of interest to Ohio regulations include the following:

- http://www.epa.state.oh.us/ddagw/
- http://www.epa.state.oh.us/ddagw/Documents/tgmchapter15direct_push.pdf

- http://www.epa.state.oh.us/ddagw/Documents/chapter07DES.PDF

3.3.36 Oklahoma

No specific guidance for Direct Push wells was found in the Oklahoma regulations. The minimum standards for construction of monitoring wells and geotechnical borings are described in Section 785:35-7-2 of the Oklahoma regulations. Annular space requirements effectively prohibit Direct Push wells. Pertinent excerpts include:

> TITLE 785. OKLAHOMA WATER RESOURCES BOARD
> CHAPTER 35. WELL DRILLER AND PUMP INSTALLER LICENSING
>
> 785:35-7-2. Minimum standards for construction of monitoring wells and geotechnical borings…
>
> (b) Minimum standards for construction of monitoring wells.
> (1) Diameter of borehole.
> (A) The diameter of boreholes for monitoring wells, with the exception of boreholes for unsaturated zone monitoring wells, shall be at least three inches greater than the nominal diameter of the well casing and screen for the entire length of the casing.
> (B) The diameter of boreholes for unsaturated zone monitoring wells shall be at least one and one-half (1 1/2") inches greater than the nominal diameter of the well casing for the entire length of the casing.

Links of interest to Oklahoma regulations include the following:

- http://www.owrb.state.ok.us/
- http://www.owrb.state.ok.us/util/rules/pdf_rul/Chap35.pdf

3.3.37 Oregon

Specific guidance for Direct Push wells was found in the Oregon regulations. Direct Push wells with pre-pack filters up to 50 feet deep can be used for monitoring wells. Pertinent excerpts found in the Oregon Administrative Rules include:

> 690-240-0410, Monitoring Well Construction: General…
> (7) The borehole diameter shall be at least four inches larger than the nominal casing diameter except as noted in OAR 690-240-0525 concerning piezometers. If the monitoring well is constructed using a hollow stem auger drilling machine, the inside diameter of the auger must be at least four inches larger than the nominal diameter of the casing to be installed, except as noted in OAR 690-240-0525 concerning piezometers…"

690-240-0540, Direct Push Monitoring Wells and Piezometers…
(2) Monitoring wells and piezometers that are installed using direct push technology shall also comply with the following standards:
(a) Only pre-packed screens shall be used; and
(b) The outside diameter of the borehole shall be a minimum of one inch greater than the outside diameter of the well casing; and
(c) Granular bentonite shall not be used in the sealed interval below the static water level; and,
(d) Wells and piezometers shall not be constructed through more than one water bearing formation and shall not be greater than 50 feet in depth unless a special standard is obtained.

Links of interest to Oregon regulations include the following:

- http://www.wrd.state.or.us
- http://arcweb.sos.state.or.us/rules/OARS_600/OAR_690/690_240.html

3.3.38 Pennsylvania

Pennsylvania does not have regulations specific to Direct Push wells. Annular space requirements effectively prohibit Direct Push wells, so they must be approved by variance. Pennsylvania Department of Environmental Protection (PADEP) has approved push probe technologies on a case-by-case basis. This technology is most successfully used in the Southeastern portion of the state, where it is mainly a coastal plain environment. Pertinent excerpts found in the Chester County regulations are shown as an example:

CHESTER COUNTY HEALTH DEPARTMENT, RULES AND REGULATIONS, CHAPTER 500. WATER, WELLS, NUISANCES, SEWAGE AND LIQUID WASTE.

§50l. WATER WELL CONSTRUCTION, MONITORING WELLS, AND INDIVIDUAL, SEMI-PUBLIC AND PUBLIC WATER SUPPLIES, AND GEOTHERMAL BOREHOLES.

501.6.2. CONSTRUCTION…
501.6.2.1.3. Non-ferrous casings shall meet appropriate American National Standards Institute/ASTM or National Science Foundation standards for well casing applications as outlined in American Water Works Association Standard A100-84. Non-ferrous casing materials shall not impart any taste, odor, or toxic substances to the well water. Non-ferrous casing, if used, shall not be driven. The casing shall be placed a minimum of 5 feet into the consolidated formation with a minimum annular opening of 3 inches or larger so that the grout may be placed in accordance with the provisions of this section 501…

501.6.2.3.1.1. The minimum annular space of 1 1/2 inches around the entire outside of the casing shall be provided by drilling a borehole 3 inches larger than the outside diameter of the casing to be inserted.

Links of interest to Pennsylvania regulations include the following:

- http://www.dep.state.pa.us/dep/deputate/watermgt/wc/subjects/groundwaterprotection/default.htm
- http://www.dep.state.pa.us/eps/docs/cab200149b1126000/fldr200149e0051190/fldr200149e32221af/doc20026sb490900e/383-3000-001.pdf
- http://dsf.chesco.org/health/lib/health/regs/501.pdf

3.3.39 Rhode Island

The Rhode Island regulations do mention Direct Push wells and indicate that monitoring wells can be installed using this technology. The requirements differ for "single rod" and "two-tube" Direct Push wells. Pertinent excerpts found in state regulations include this section from the Office of Water Resources' *Rules and Regulations for Ground Water Quality*:

APPENDIX 1
Construction Standards for Monitoring Wells and Abandonment Procedures for Monitoring Wells, Piezometers and Other Subsurface Borings…

5. Drilled Wells…
5.1 Borehole Diameter: The borehole diameter in the overburden shall be a minimum of 4 inches greater than the diameter of the well casing…
5.5.2 Annular Space Seal: All monitoring wells shall be installed with an annular space seal using neat cement, neat cement-bentonite mixture, bentonite slurry or bentonite that is properly hydrated and set…

6. Single Rod Direct Push Wells: Wells installed using single rod direct push methods shall be installed in accordance with the requirements below:
6.1 Annular space seal: If the screen and riser are of the same diameter and are advanced such that they remain in contact with the formation during installation (exposed screen wells) no annular space seal is created. If the drive rod is smaller in diameter than the sampler body (protected screen wells) an annular space is created that must be sealed in accordance with Rule 5.5.2 above…

7. Two-tube Direct Push Wells: Monitoring wells installed using two-tube direct push methods create an annular space the length of the well, thus requiring a filter pack, seals and other provisions similar to conventional drilled wells. Two-tube direct push wells shall be installed in accordance with the requirements below (see Figure A1-2):
7.1 The outside diameter of the borehole shall be a minimum of one inch greater than the outside diameter of the well casing…

Links of interest to Rhode Island regulations include the following:

- http://www.state.ri.us/dem/pubs/regs/
- http://www.dem.ri.gov/pubs/regs/regs/water/gwqual65.pdf

3.3.40 South Carolina

Specific guidance for Direct Push wells was found in the South Carolina regulations. Direct Push wells are allowed without restrictions other than a statement dealing with cross-contamination. Pertinent excerpts found in state regulations include this section from the state's Well Standards Regulation 61-71:

> B. Definitions…
>
> 21. Monitoring Well—Any well constructed specifically to obtain a sample of groundwater for analysis, or any well used to measure groundwater levels. These wells include, but are not limited to, wells constructed using conventional drilling techniques and direct push methods…
>
> H. MONITORING WELLS…
>
> 3. Additional Requirements for Permanent Direct Push Monitoring Wells
> a. Direct Push Wells cannot be installed below a confining layer unless it can be demonstrated to the satisfaction of the Department that cross contamination of the aquifer systems can be prevented.
> b. Grouting.
> (1) These monitoring wells shall be grouted from the top of the bentonite seal to the land surface…
> (3) The diameter of the annular space shall be large enough to allow for forced injection of grout through a tremie pipe.

Links of interest to South Carolina regulations include the following:

- http://www.scdhec.net/water/regs/r61-71.pdf

3.3.41 South Dakota

No specific guidance for Direct Push wells was found in the South Dakota regulations. Minimum annular space requirements effectively prohibit their use. Pertinent excerpts found in state regulations include this section from the South Dakota Department of Environment & Natural Resources Plans & Specifications:

CHAPTER XVII, RECOMMENDED DESIGN CRITERIA FOR GROUND WATER MONITORING WELLS, *"ANIMAL WASTE MANAGEMENT SYSTEMS"…*

A. Recommended Design Criteria for Ground Water Monitoring Wells…

5. *Monitoring Well Design Components…*

b. Diameter
Monitoring wells can be constructed of casing and screen materials that are a minimum of two inches inside nominal diameter. The borehole into which the monitoring well is to be installed must be a minimum of four inches greater in diameter than the casing (i.e. a two-inch well must be installed in a six inch borehole).

Links of interest to South Dakota regulations include the following:

- http://www.state.sd.us/denr/des/P&s/designcriteria/design-17.html

3.3.42 Tennessee

No specific guidance for Direct Push wells was found in the Tennessee regulations. Tennessee's water well regulations contain annular space requirements that effectively prohibit Direct Push wells. These regulations indicate that construction standards for monitoring wells are regulated by other state agencies. Pertinent excerpts found in state regulations include this section from the Rules of Tennessee Department of Environment and Conservation Division of Water Supply:

CHAPTER 1200-4-9, WATER WELL LICENSING REGULATIONS AND WELL CONSTRUCTION STANDARDS…

(5) Casing…

(e) If cement-based grout is used for backfill, it shall be placed around the casing by one of the following methods:
1. Pressure
The annular space between the casing and the borehole wall shall be a minimum of one and five-tenths (1.5) inches, and grout shall be pumped or forced under pressure through the bottom of the casing until it fills the annular space around the casing and overflows at the surface; or
2. Pumping
The annular space between the casing and formation shall be a minimum of two (2) inches and grout shall be pumped into place through a pipe or hose extended to the bottom of the annular space which can be raised as the grout is applied, but the grout pipe or hose shall remain submerged in grout during the entire application; or
3. Other

> The annular space between the casing and the borehole wall shall be a minimum of three (3) inches and the annular space shall be completely filled with grout by any method that will insure complete filling of the space, provided the annular area does not contain water or other fluid. If the annular area contains water or other fluid, it shall be evacuated of fluid or the grout shall be placed by the pumping or pressure method…
>
> 1200-4-9-18 MONITOR WELL CONSTRUCTION STANDARDS.
> (1) Construction standards for monitor wells are not promulgated under this statute. Construction standards for monitor wells are regulated by the state agency requiring the monitor well to be placed into service. The Well Act only requires an individual to be licensed as a monitor well driller.

Links of interest to Tennessee regulations include the following:

- http://www.state.tn.us/sos/rules/1200/1200-04/1200-04-09.pdf

3.3.43 Texas

The State of Texas does not have rules specific to monitoring wells. Monitoring well requirements are currently scattered in the sections dealing with the "water well" requirements. No specific guidance for Direct Push wells was found in the Texas regulations. Annular space requirements effectively prohibit Direct Push wells. Texas rules are described in Section 76 of Texas Department of Licensing and Regulation (TDLR). Section 76.1011 (3) of TDLR goes into the details of annular space requirements. The annular space between the casing and the wall of the borehole is required to be three inches larger than the casing.

Links of interest to Texas regulations include the following:

- http://www.license.state.tx.us/

3.3.44 Utah

No specific guidance for Direct Push wells was found in the Utah regulations. Annular space requirements effectively prohibit Direct Push wells. The following excerpts are from the Utah Administrative Code R655-4, Water Well Drillers:

> R655-4-7. The approval process for Cathodic Protection Wells, Heating or Cooling Exchange Wells, and Monitor Wells: Only cathodic protection wells, heating or cooling exchange wells, and monitor wells constructed to a depth of 30 feet or greater below natural ground surface require approval from the state engineer…

> R655-4-13. (13.1.2) Monitor Well Construction Standards: These Standards are not intended as a complete manual for monitoring well construction, alteration, maintenance, and abandonment. These standards serve only as minimum statewide guidelines towards ensuring that monitor wells do not constitute a significant pathway for the movement of poor quality water, pollutants, or contaminants…
>
> 13.2.5 Annular Seal…The seal shall have a minimum diameter of four inches larger than the nominal size of the permanent casing, and shall extend from land surface to the top of the filter pack…
>
> The Utah Division of Environmental Response and Remediation publishes a *Customer Guide for Site Investigations and Monitoring Guidelines* which includes several pages on Direct Push sampling methods."

Links of interest for Utah regulations include the following:

- http://environmentalresponse.utah.gov/index.htm.
- http://www.hazardouswaste.utah.gov/

3.3.45 Vermont

Vermont does not have a permitting process for wells, so acceptance occurs by workplan approval on a case-by-case basis.

Links of interest for Vermont regulations include the following:

- http://www.anr.state.vt.us/dec/
- http://www.anr.state.vt.us/dec/wastediv/rcra/hazregs/fullregs.pdf
- http://www.anr.state.vt.us/dec/watersup/wsrule/WSFinalRuleJune192003.pdf

3.3.46 Virginia

No specific guidance for Direct Push wells was found in the Virginia regulations, although there is a mention of driven wells in the water well regulations. Annular space requirements effectively prohibit Direct Push wells, so they must be approved by variance. Well regulations can be found in Virginia Department of Health, Office of Drinking Water under private well regulation. Monitoring wells are covered under this regulation. The following excerpts are from these regulations:

> 12 VAC 5-630-410. Construction; general…
>
> c. Grouting…
>
> 5. Depth…

> e. Driven wells shall be grouted to a minimum depth of five feet by excavating an oversize hole at least four inches in diameter larger than the casing and pouring an approved grout mixture into the annular space…
>
> 7. Annular space. The clear annular space around the outside of the casing and the well bore shall be at least 1.5 inches on all sides except for bored wells which shall have at least a 3-inch annular space….
>
> 12 VAC 5-630-420. Observation, monitoring, and remediation wells…
>
> a. Except as provided in subsections B and C of this section, observation and monitoring wells are exempted from this chapter.
> b. Observation or monitoring wells shall be constructed in accordance with the requirements for private wells if they are to remain in service after the completion of the ground water study.
> c. Observation or monitoring wells shall be properly abandoned in accordance with 12 VAC 5-630-450 within 90 days of cessation of use.

Links of interest for Virginia regulations:

- http://www.vdh.state.va.us/formfeed/VDH87.PDF

3.3.47 Washington

Specific mention of Direct Push wells was found in the Washington regulations. Minimum annular space requirements effectively prevent their use other than by variance. Despite this, Direct Push wells are reportedly used as standard practice in the State of Washington. Direct Push has been used in several superfund sites for herbicide and pesticide contamination located in sandy and clay soils. Direct Push wells are also being used on the Department of Energy site located at the Hanford Reserve in Eastern Washington. Regulations can be found in the Regulatory Code of Washington RCW Chapter 18.104, as well as in the Washington Administrative Code WAC Chapter 173.160 and Chapter 173.162. Excerpts include:

> RCW 18.104.020 Definitions…
>
> (7) "Environmental investigation well" means a cased hole intended or used to extract a sample or samples of ground water, vapor, or soil from an underground formation and which is decommissioned immediately after the sample or samples are obtained. An environmental investigation well is typically installed using direct push technology or auger boring and uses the probe, stem, auger, or rod as casing. An environmental investigation well is not a geotechnical soil boring…
>
> WAC 173-160-410 What are the specific definitions for words in this chapter? …

> (5) "Monitoring well" means a well designed to obtain a representative ground water sample or designed to measure the water level elevations in either clean or contaminated water or soil…
>
> (10) "Resource protection well" means a cased boring used to determine the existence or migration of pollutants within an underground formation. Resource protection wells include monitoring wells, observation wells, piezometers, spill response wells, vapor extraction wells, and instrumentation wells….
>
> WAC 173-160-420 What are the general construction requirements for resource protection wells? …
>
> (6) All resource protection wells will be sealed in accordance with this chapter regardless of the method of installation. Except, resource protection wells that are properly decommissioned prior to the removal of any drilling equipment from the well location are exempted from the surface
> sealing requirements of this chapter. Provided the decommissioning process includes the removal of any conduit, tubing, probe, or other items inserted into the ground….
>
> WAC 173-160-450 What are the well sealing requirements? …
>
> (1) All resource protection wells constructed shall have a continuous seal, which seals the annular space between the borehole and the permanent casing. The seal shall be constructed to prevent interconnection of separate aquifers penetrated by the well, and shall provide casing stability. The seal shall have a minimum diameter of four inches larger than the nominal size of the permanent casing, and shall extend from land surface to the top of the filter pack.

Links of interest regarding Washington regulations:

- http://www.ecy.wa.gov/
- http://www.ecy.wa.gov/pubs/wac173160.pdf

3.3.48 West Virginia

The regulation that governs monitoring wells in West Virginia is 47CSR60 *Monitoring Well Design Standards.* It can be found under Title 47 Legislative Rule, Division of Environmental Protection, Office of Water Resources, Series 60. There is a guidance document titled "Monitoring Well Driller and Design Guidelines" by West Virginia's Water Resource Division. This document includes guidance for Direct Push wells under Guideline No. 19, Direct Push Drilling Requirements. It states that all requirements of monitoring wells apply with the exception that the two-inch annular space is waived providing that the well is not permanent. Installation of a temporary well needs approval by the regulatory agency and must be abandoned within 120 days. Excerpts of interest from these regulations include:

SERIES 59, MONITORING WELL RULES…

47-59-2. Definitions…

2.7
'Monitoring Well' means any cased excavation or opening into the ground made by digging, boring, drilling, driving, jetting or other methods for the purpose of determining the physical, chemical, biological or radiological properties of groundwater. The term 'monitoring well' includes piezometers and observation wells, which were installed for purposes other than those listed above, but does not include wells whose primary purpose is to provide a supply of potable water…

SERIES 60, MONITORING WELL DESIGN STANDARDS…

47-60-15. Borehole Diameter

15.1. Boreholes in unconsolidated geologic formations - For all permanent monitoring wells in unconsolidated geologic formations, the borehole diameter shall meet the following requirements:

15.1.1. If hollow stem augers are used, their inside working diameter shall be at least 2 inches greater than the inside diameter of the permanent well casing.

15.1.2. If solid stem augers are used, their outside diameter shall be at least 4 inches greater than the inside diameter of the permanent well casing.

Links of interest to West Virginia regulations include the following:

- http://www.dep.state.wv.us/
- http://www.wvdhhr.org/monwell/default.asp
- http://www.wvsos.com/csr/verify.asp?TitleSeries=47-60

3.3.49 Wisconsin

Minimum annular space requirements effectively prohibit the use of Direct Push wells in Wisconsin. Wisconsin has a fact sheet on "temporary wells" and includes Direct Push wells in that category. Pertinent excerpts found in Wisconsin regulations include:

DEPARTMENT OF NATURAL RESOURCES, Chapter NR 141, GROUNDWATER MONITORING WELL REQUIREMENTS…

NR 141.19(1)
(1) BOREHOLES IN UNCONSOLIDATED GEOLOGIC FORMATION. For all permanent groundwater monitoring wells in unconsolidated geologic formations,

the borehole diameter shall meet the following requirements:

NR 141.19(1)(a)
(a) If hollow stem augers are used, their inside working diameter shall be at least 2 ¼ inches greater than the inside diameter of the permanent well casing.

NR 141.19(1)(b)
(b) If solid stem augers are used, their outside diameter shall be at least 4 inches greater than the inside diameter of the permanent well casing.

NR 141.19(1)(c)
(c) If an air or mud rotary method is used, the borehole diameter shall be at least 4 inches greater than the inside diameter of the permanent well casing. If a temporary outer casing is used, the inside diameter of the temporary outer well casing shall be at least 4 inches greater than the inside diameter of the permanent well casing. The temporary outer casing shall be pulled as the annular space is being sealed.

NR 141.19(1)(d)
(d) If percussion methods, including the rotary wash, wash down and wash bore methods, with a temporary outer casing are used, in unconsolidated geologic formations, the inside diameter of the temporary outer casing shall be at least 4 inches greater than the inside diameter of the permanent well casing. The temporary outer casing shall be removed during the sealing of the annular space.

Links of interest for Wisconsin wells include the following:

- http://folio.legis.state.wi.us/cgibin/om_isapi.dll?clientID=93623&infobase=code.nfo&j1=ch.%20nr%20141&jump=ch.%20nr%20141&softpage=Browse_Frame_Pg
- http://www.dnr.state.wi.us/org/aw/rr/archives/pubs/RR647.pdf
- http://www.legis.state.wi.us/../rsb/code/index.html

3.3.50 Wyoming

No specific guidance for Direct Push wells was found in the Wyoming regulations. Minimum annular space requirements effectively prohibit their use. Pertinent excerpts found in Wyoming regulations include:

PART G, WELL CONSTRUCTION…

Section 65. Sealing the Annular Space.

(a) Minimum depths of seal below ground surface for various uses of wells will be…
Observation and monitoring: 20 feet…

> (b) Sealing conditions. Following are requirements to be observed in sealing the annular space…
>
> (i) Wells situated in unconsolidated, caving material shall have an oversized hole, at least four inches greater in diameter than the production casing, drilled. A conductor casing shall be installed. The space between the conductor casing and the production casing shall be filled with sealing material. The conductor casing may be withdrawn as the sealing material is placed.
> (ii) Wells situated in unconsolidated material stratified with significant clay layers shall have an oversized hole of at least four inches greater in diameter than the production casing drilled, with the annular space filled with sealing material. If a clay formation is encountered within five feet of the bottom of the seal, the seal should be extended five feet into the clay formation.
> (iii) Wells situated in soft consolidated formations shall have an oversized hole of at least four inches greater in diameter than the production casing. The annular space between the production casing and the drilled hole shall be filled with…

Links of interest to Wyoming regulations include the following:

- http://deq.state.wy.us/wqd/
- http://deq.state.wy.us/wqd/groundwater/downloads/Linked%20Documents/Rules%20and%20Regs/CHAPXI%20-%20Part%20G.pdf

4. CASE STUDIES

Several studies have been conducted to determine the suitability of Direct Push wells. These studies have been sponsored by both private industry and the U.S Department of Defense (DOD). Most recently, this has included a demonstration sponsored by DOD's Environmental Security Technology Certification Program (ESTCP) that spanned a 5-year time period. This demonstration was conducted to determine the long-term performance of Direct Push wells at five test sites in different parts of the country. Earlier Direct Push well studies include a jointly sponsored study by the British Petroleum Corporation of North America and the U.S. EPA, and a study conducted by the Naval Facilities Engineering Service Center (NFESC) at Port Hueneme, California. The University of Connecticut also recently conducted a study at Port Hueneme to determine if there are differences in the hydraulic conductivity in Direct Push and conventional wells. The findings from these studies are presented in detail below.

In addition, several states have used Direct Push technology to construct wells, and case studies of their experiences are also included below.

4.1 Summary of the ESTCP-sponsored Study

The purpose of this demonstration was to determine the suitability of Direct Push monitoring wells for long-term use. The investigators approach was to compare results from field and laboratory analyses conducted on samples obtained from Direct Push wells with analytical results from samples obtained from conventionally installed (drilled) HSA wells. Phase 1 of this effort included five sampling events over 15 months. Phase 2 included an additional eight sampling events over two years and fieldwork was only recently completed (in April of 2005).

Five field sites were selected to represent a variety of contaminants, geologic conditions, and regulatory domains (e.g. EPA regions and states). The test sites included the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, NH; the Dover National Test Site at Dover Air Force Base (AFB), DE; Hanscom AFB in MA; the NFESC at Port Hueneme, CA; and Tyndall AFB, FL. Table 4-1 presents the original number of wells used in Phase 1 and some general contaminant and hydrologic characteristics for each site.

Table 4-1. General test site characteristics

Location	Number of Wells	Geologic Character	Depth to Groundwater	Contaminants
CRREL	6	Glaciofluvial & Glaciolacustrine	87-128 ft	Chlorinated VOCS (TCE)
Dover	12	Marine Depositional	15-26 ft	Chlorinated & BTEX VOCs, MTBE
Hanscom	20	Glaciolacustrine	3-15 ft	Chlorinated & BTEX VOCs
Port Hueneme	32	Fluvial Deltaic	5-12 ft	MTBE
Tyndall	32	Marine Depositional	3-8 ft	Chlorinated and BTEX VOCs

New Direct Push wells were installed at all the sites except Hanscom AFB; the Hanscom Direct Push wells were installed in 1996 (Bianchi et al., 2000). Direct Push wells were installed adjacent to HSA wells to form either well pairs (a Direct Push and a HSA well) or well clusters (consisting of three or more well types, including one HSA well per cluster). Several Direct Push well design options were utilized in this demonstration including wells installed according to ASTM D 6724, pre-pack wells installed according to ASTM D 6725, and wells with no filter packs installed using an exposed-screen method. Conventional HSA monitoring wells were installed in accordance with ASTM D 5092. In each cluster or well pair, the Direct Push wells were installed so that the depth of the wells and the screened intervals matched those of the conventional wells.

In Phase 1, samples were obtained from four of the test sites (Dover, Hanscom, Tyndall, and Port Hueneme). During each sampling event, water levels and several purge parameters (conductivity, dissolved oxygen [DO], oxidation-reduction potential, pH, temperature, and turbidity) were measured and recorded. Groundwater samples were collected using a low-flow purging and sampling protocol (EPA Region 1 1996, ASTM D 6771) and sent to a contract laboratory for analyses of Volatile Organic Compounds (VOCs), including Methyl Tertiary Butyl Ether (MTBE) and geochemical analytes (metals). Duplicates of 10% of the samples were collected and sent to a separate laboratory for quality control assessment. A detailed description of the sampling approach is presented in Kram et al. (2001). Standard EPA methods were used for the chemical analyses.

A summary of the number and types of wells at each of the test sites is given in Table 4-2. At Tyndall AFB, there were eight clusters of wells. Five clusters had 10-foot screens, one cluster had 15-foot screens, and two clusters had 25-foot screens.

Table 4-2. Description of well types at each test site.

Test Site	Test Cell	# Well pairs or clusters	Well Types per cluster
Dover	N/A	6	2-inch HSA
			2-inch Direct Push
Hanscom	N/A	10	2-inch HSA
			2-inch Direct Push
Port Hueneme	A	4	2-inch ASTM HSA
			2-inch ASTM Direct Push
			3/4-inch ASTM Direct Push
	B	4	2-inch ASTM HSA
			2-inch ASTM Direct Push
			3/4-inch ASTM Direct Push
			3/4-inch Direct Push, conventional filter pack
			3/4-inch Direct Push, no filter pack
Tyndall	N/A	8	2-inch ASTM HSA
			1.5-inch Direct Push, no filter pack
			1-inch Direct Push, with pre-pack filter
			1/2-inch Direct Push, with pre-pack filter

Statistical analyses were conducted on the data from Phase 1 for each test site and each analyte separately to determine if there was a significant difference between the well types. Standard parametric tests were used whenever possible (i.e., on any data that was normally distributed and had homogeneous variances). In instances where the data were not normally distributed but the variances were homogeneous, the data were log-transformed and tested for normality. If the log-transformed data were normally distributed, then a standard parametric test was used. In instances where the data were found not to be normally distributed or the variances were not homogeneous, non-parametric tests were used to determine if there was a significant difference between the well types.

At the sites where there were well pairs and a parametric test could be used, a paired t-test was used to determine if there was a significant difference between the Direct Push well and the conventional HSA well. If a non-parametric test had to be used, then a Wilcoxon Signed Rank test was used. At the sites where there were clusters of wells and a parametric test could be used, a one-way Repeated Measures (RM) Analysis of Variance (ANOVA) test was used to determine if there was a significant difference between the various well types. In instances where a significant difference was found, a Tukey test was used to determine which well types were significantly different from the others. Whenever possible, these data sets were subjected to higher level ANOVAs to determine the effect of well location and if there was a significant interaction between well type and well location. These analyses allowed the researchers to better determine the effects of spatial heterogeneity. The results from the statistical analyses of the Phase 1 data were presented at the 2004 North American Field Conference and Exposition (Parker et al. 2004) and are given in more detail below.

At Dover AFB, Table 4-3 indicates that no significant difference was found for three of the six field parameters tested (specific conductance, pH, and temperature). For the temperature data, the difference in the mean value is largely due to one value that appears to be an outlier and when that value is removed from the data set, the difference in the mean values is less than 0.5°. For all three parameters where significant differences were found, the differences in the mean values were generally small in magnitude and would not impact any management decision at the site. For the inorganic analytes, there was no significant difference for the majority of the analytes tested. There also was no significant difference for the majority of organic analytes tested. Again, for the few analytes where there was a significant difference, the differences in the mean values were small in magnitude and would not have impacted the management decisions at the site.

Table 4-3. Mean values of analytes where a statistically significant difference was found—Dover AFB (from Parker et al. 2004).

Mean Concentrations		
	HS	DP (no pack)
Specific Conductance	0.18	0.252
pH	5.8	5.4
Temperature (°C)	16.2	15.3
Magnesium (mg/L)	7.0	9.5
Chloride (mg/L)	18.5	25.7
*Ethylbenzene (µg/L)	19.5	29.2

* There was a significant difference between the mean concentrations of this analyte in the Direct

Push wells vs. the conventional hollow-stem auger wells.

At Hanscom AFB, there was no significant difference for the majority of field parameters and inorganic analytes tested. In addition there were no significant differences for the eight organic analytes tested. Table 4-4 shows that the mean values for those analytes where there was a significant difference were small in magnitude and would not have impacted any management decision. For the sodium data, the high mean value is due to the presence of two values that appear to be outliers.

Table 4-4. Mean values of analytes where a statistically significant difference was found—Hanscom AFB (from Parker et al. 2004).

Mean Conc. (mg/L)		
	HS	DP (no pack)
Sodium	9.8	13.9
Dissolved Oxygen	3.5	4.9

In test cell A at Port Hueneme, there was no significant difference between the three well types for any of the five field parameters or any of the 12 inorganic analytes tested. In test cell B, there was no significant difference for the majority of the field parameters (4/5) and inorganic analytes (see Table 4-5). The higher mean value for turbidity was caused by a few high values that occurred earlier in the study when the pump was turned off after measuring field parameters prior to collecting the samples. Once this practice was discontinued (i.e., the pump was kept running), this was no longer an issue. For the other analytes, the differences in magnitude are again small and no management decision would be affected. For MTBE (the only organic contaminant present), there was no significant difference between the five well types in test cell B. In test cell A; the mean concentration was significantly higher in the ¾-in. Direct Push well than it was in the 2-in. HSA well. However, again the magnitude of this difference is small and no management decision would be impacted by this small difference.

Table 4-5. Mean values of analytes where a statistically significant difference was found–Port Hueneme (from Parker et al. 2004).

Mean Concentrations					
	2-in. HS ASTM	**2-in. DP ASTM**	**¾-in. DP ASTM**	**¾-in. DP Conventiona l**	**¾-in. DP No Pack**
Manganese (mg/L)	2.21	2.24	2.24	2.35	2.39*
Potassium (mg/L)	7.52	6.38*	6.73	6.99	6.99
Alkalinity (mg/L)	415	399*	404*	405*	410
Turbidity (NTU)	45	19	6.0*	4.3*	8.3
Chloride (mg/L)	74	68*	68	70	70
MTBE (µg/L)	34.6	40.4	41.5*	N/A	N/A

*Values significantly different from 2-in HSA well.

At Tyndall AFB, Table 4-6 shows there was no significant difference between any of the three Direct Push well types and the conventional HSA well for the majority of the field parameters and inorganic analytes. The differences in the sulfate values were also small in magnitude and would not have impacted any management decision. Although there was a significant difference between the turbidity values for the one-inch pre-pack Direct Push well (vs. the conventional HAS wells) and the other two Direct Push wells, this difference was small in magnitude. Because all the turbidity values were higher in these wells than the desired range for low-flow sampling, all these wells were redeveloped prior to starting Phase 2 of this demonstration. The concentrations of manganese were significantly higher in the two pre-pack wells and may reflect the elevated turbidity values in these wells.

However, the findings for the organic contaminants were very different from those at the other three test sites because there was a significant difference for the majority of the organic contaminants. For the most of these contaminants, concentrations were significantly higher in the 1.5-inch Direct Push wells with no filter pack than in the conventional HAS wells. When the data were examined on a cluster-by-cluster basis, it was clear that at two clusters (MWD-9 and MWD-11) concentrations were often more than a factor of 10 times higher in the 1.5-inch Direct Push wells. These two clusters were the only clusters with 25-foot screens and, more importantly, the well construction logs indicated that at both locations the screened interval of these Direct Push wells was more than a foot higher than that of the conventional wells. This suggests that sampling occurred from different parts of the aquifer at these two sites. When the data for these two clusters were removed from the data set and the data were re-analyzed, no significant differences between the concentrations in the Direct Push wells and the conventional wells were found for the majority of the contaminants.

Table 4-6. Mean values of analytes where a statistically significant difference was found–Tyndall AFB.

	Mean Concentrations (ug/L)			
		1.5-in DP	**1-in. DP**	**0.5-in. DP**
	2-in. HS	**No pack**	**Pre-pack**	**Pre-pack**
Turbidity (NTU)	22	37	43*	36
Manganese (mg/L)	0.11	0.1	0.37*	0.39*
Sulfate (mg/L)	17	13*	16	15
Ethylbenzene	30	71*	40	43*
o-Xylene	30	104*	49	28
p-Dichlorobenzene	18	54*	22	18
TCE	54	127*	96	55
Toluene	5.5	54*	27	4.6

* Values significantly different from the values for the 2-in HSA well.

For the sandy and sandy/silty soils used in this study, the preliminary findings from Phase 1 indicate that for the majority of cases, there was no significant difference between the concentrations of analytes and field parameters in samples collected from the various types of Direct Push wells versus those collected from conventionally installed HSA monitoring wells. Where significant differences did exist between Direct Push and HSA monitoring wells the magnitude of this difference was generally small and no management decision would be impacted by this difference. Additionally, where significant differences existed there was no consistent trend that could be associated with Direct Push wells; i.e., concentrations being consistently greater than HSA wells or vice versa.

In Phase 2 several identical (duplicate) conventional drilled wells were installed in some of the clusters, or well pairs, to allow the investigators to better determine the amount of variability between duplicate HSA wells within a well cluster or well pair. In addition, several duplicate Direct Push wells were installed within some of the well pairs, or well clusters, to better determine the variability between identical Direct Push wells in a well pair or cluster. These additional wells allow the researchers to better determine the spatial heterogeneity within a well cluster. The fieldwork for this demonstration was completed in April 2005. A final report will be generated in 2006 and will be available through ESTCP technology transfer instruments. A summary of the findings for the organic analytes was given recently at the North American Environmental Field Conference and Exposition by Parker et al. (2006).

4.2 Summary of the BP/EPA Study

A study by the BP Corporation of North America and the Underground Storage Tank Programs of the EPA Regions 4 and 5 (2002) was conducted to determine if measurements of groundwater parameters obtained from Direct Push wells were comparable to those obtained from conventional monitoring wells. The study was conducted at four fuel stations with dissolved-phase hydrocarbon plumes; two sites were in Ohio and two sites were in Georgia. More information on the soil type and terrain at each site is given in Table 4-7. The one-inch diameter (schedule 80), PVC Direct Push wells contained no filter pack and were installed through an open borehole after single tube soil sampling was completed to the desired depth. Conventional wells were either two-inch or four-inch PVC wells, with 10- or 15-foot screens, and were installed in accordance with state-approved methods. The screened intervals of the Direct Push wells were set at depths that were equivalent to those of the conventional wells. The wells were sampled quarterly for one year. The measured parameters included groundwater levels, Total Suspended Solids (TSS), analyte concentrations of contaminants (such as benzene, toluene, ethylbenzene, and xzylene compounds, or BTEX, MTBE, and Naphthalene), natural attenuation parameters, and hydraulic conductivity measurements.

Typically the data were transformed, using a natural log function or some other function (e.g., square root, fourth root, etc.), until a normal distribution was obtained. A General Linear Model was then used to determine what factors or combinations of factors influenced the results. Factors included the site, well, and well type. If the correlation coefficient was 0.75 or higher, the linear model was determined to describe the data well (i.e., was a good fit of the data) and the F-test statistic indicated whether well type was significant.

No difference was found in MTBE concentrations measured in the Direct Push and conventional wells. There also was no significant difference in BTEX concentrations at three of the sites. However, for one site (Granville), the concentrations were significantly higher in the samples obtained from the Direct Push wells. They felt that this suggested a systematic error and felt it might have been due to the borehole becoming contaminated during installation.

For the geochemical parameters indicative of natural attenuation (dissolved oxygen, carbon dioxide, ferrous iron, nitrate, methane, alkalinity, and sulfate), the authors found no significant difference in the concentrations measured in samples obtained from Direct Push wells versus those from conventional wells. However, they did note that there was only a small amount of data and it exhibited considerable variability.

In contrast, it was noted that the hydraulic conductivity was more than four times higher in the conventional wells than in the Direct Push wells. The authors also found the TSS concentrations significantly higher in the samples from the Direct Push wells and that the Naphthalene concentrations significantly higher in the Direct Push wells at the Granville site but not at the other locations.

The lower hydraulic conductivity and higher TSS concentrations in the Direct Push wells and the differences in the BTEX and Naphthalene concentrations in the Direct Push wells at the Granville site were attributed to poor development of the Direct Push wells. The authors noted that the Direct Push wells had been developed simply by purging the well and recommended that a surge block technique should be considered for developing these wells in the future. (It was noted that Henebry and Robbins [2000] had found that undeveloped Direct Push wells had hydraulic conductivities of 3.2 to 9.6 times lower than those that had been developed using a surge block technique.) They concluded that if the wells are properly developed, there is good reason to believe that all measurements obtained from Direct Push monitoring wells would be comparable to those obtained from conventional monitoring wells.

Table 4-7. Site characteristics.

Site	Physiographic Province	Sediment Type	Mean depth to Water
Brunswick, Georgia	Barrier Island Sequence Coastal Plain	Permeable silty & clayey, Fine to medium sands	5.1 ft.
Marietta, Georgia	Piedmont Central Uplands	Fine-grained soils & saprolite that mantle bedrock	13.0 ft.
Toledo, Ohio	Interior Plains, Central Lowlands	Clayey silt with very thin, Discontinuous laminae of clay	8.8 ft.
Granville, Ohio	Till Plain	Sandy silt over sand & Gravel outwash	17.9 ft.

4.3 Summary of the NFESC Study

A comparison between the performance of Direct Push wells and conventionally installed monitoring wells was conducted by the Naval Facilities Engineering Service Center (NFESC) at two MTBE contaminated sites at Port Hueneme, CA (Kram et al. 2001). The purpose of this effort was to determine whether representative chemical and water table data could be generated using Direct Push wells.

The MTBE plume was located in a semi-perched aquifer that consists of fluvial deltaic sediments approximately 25 feet thick. The upper most silty sands graded into more sand and silty sand at depths ranging from 6 to 25 feet below the ground surface (bgs). The unconfined water table ranged from 5 to 12 feet bgs. The two sites selected for this study were test cells A and B. At the beginning of this study, test cell A was located downgradient of the plume but in the direction of its migration. However during the course of this study, the plume reached the test cell. Test cell B was located in a moderately contaminated portion of the plume.

Each test cell contained four clusters of PVC monitoring wells. At test cell A, each well cluster consisted of a 2-inch diameter HSA well with a tremmied filter pack, a 2-inch diameter Direct Push well with a pre-pack filter, and a ¾-inch Direct Push well with a pre-pack filter. All three wells were built to ASTM guidelines, including the filter pack and screen slot size selection. Piezocone measurements were used to determine candidate sampling zones, with the goal being to screen wells across high permeability strata. Laboratory determinations of permeability were used to select the appropriate screen zone, while grain-size distribution of corresponding soil core samples were used to determine the correct filter pack and slot size according to ASTM D5092 design guidance. At test cell B, each cluster contained the same three types of wells already mentioned plus two additional ¾-inch Direct Push wells; one with no filter pack and one with a conventional filter pack design (consisting of a 20-to-40-sized sand pack surrounding a 0.010-inch screen). All the wells within a cluster were constructed with the same length screen and were placed at the same depth. Within each test cell, two clusters of wells contained 2-foot screens and two clusters contained of 5-foot screens.

Four sampling rounds were conducted between March and August of 2000. MTBE concentrations and several geochemical parameters (metals) were monitored. A low-flow sampling protocol was used to collect the samples. Within a cluster, the various well types were sampled in a random order. The wells were purged at a flow rate of ~470 mL/min and then sampled for the geochemical parameters at a flow rate of ~150 mL/min. The flow rate was then slowly reduced to ~100 mL/min and samples for turbidity measurements and MTBE analyses were collected. The trace metals analyses for the geochemical parameters were by EPA method 200.7 and MTBE analyses were by EPA method 8260B. Other analyses methods also utilized standard EPA methods and are given in detail in Kram et al. (2001).

Extensive statistical analyses were conducted on the various analyte concentrations. For each test cell, each analyte was analyzed separately. ANOVA tests were used to determine whether there was a significant difference between the performance of the Direct Push and HSA wells and to determine the major source of variability in the data. Sources of variability included the sampling date, well cluster, well type, depth of well, and screen length.

In all cases (for each of the analytes in both test cells), the variability in the data among the different well types was less than that displayed by spatial heterogeneities associated with well screen differences (depth and length of the screen) and temporal variability (i.e., sampling date).

For the MTBE data in test cell B, a three-way ANOVA test that evaluated the main effects (i.e., well type, sample date, and depth) found that there was no significant difference between the various well types. In contrast, both sample date and depth were highly significant. A higher level ANOVA test was also conducted that evaluated the significance of the main effects and all the two-way interactions (e.g., well type and depth or well type and date). This analysis showed that although there were significant differences between the mean concentrations of MTBE in the Direct Push wells and the HSA well at the various depths, these differences were not consistent with depth. This explains why the simple model (that only tested the main effects) showed no significant difference. This can be seen more clearly in Table 4-8. For example, if one compares the mean MTBE concentrations in the ¾-in. ASTM-designed Direct Push wells with the conventional wells, one can see that the mean concentration of MTBE was higher in the ¾-inch Direct Push wells at the 12.5-to-17.5-foot depth than in the HSA well (by 41µg/L) but was lower than the conventional well at the 10-to-12-foot depth (by 14µg/L). Clearly, there is no consistent trend that can be associated with any well type. The findings were similar when a 4-way ANOVA test was used to further elucidate the effect of "depth" by separating it into two factors, screen length and screen depth. In this analysis, both the interaction of well type and screen length and of well type and screen depth were significant.

Table 4-8. Differences between the mean concentrations of the various Direct Push wells with the conventional 2-inch HSA well. (units are µg/L)

Screen Depth	3/4-in. DP No Pack	3/4-in. DP ASTM	3/4-in. DP Conventional filter	2-in. DP ASTM
7 to 12 ft.	0.22	3.37	-15.7	10.9
10 to 12 ft.	-4.66	-13.9	-38.1	-46.7
12.5 to 17.5 ft.	1.89	41.4	57.0	58.8
16 to 18 ft.	2.55	-24.1	-3.21	-21.0

For the MTBE data in test cell A, the 3-way ANOVA test that evaluated the main effects (i.e., well type, sample date, and depth) found that there was a significant difference only between the ¾ inch Direct Push Well and the 2 inch HSA well. However, the higher level ANOVA test showed a significant interaction between well type and screen depth. Again, this means that although there were significant differences between the concentrations of MTBE in the Direct Push wells and the HSA well at different depths, these differences were not consistent at all the depths. The findings were also similar when a four-way ANOVA test was used to determine the effect of screen length and screen depth separately.

The geochemical parameters monitored in this study included boron, calcium, iron, magnesium, manganese, potassium, and sodium. For all the analytes, there was no significant difference between the mean concentrations of these analytes in any of the Direct Push wells and the conventional HSA wells. This was true for both test cells.

Although a comprehensive hydraulic evaluation was not conducted, water level values generally yielded comparable results for the various well designs.

It does not appear that any management decision would have been adversely affected by obtaining samples from any of the Direct Push well types, as compared to obtaining samples only from the conventional wells.

4.4 Summary of Individual State Experiences

Delaware, Missouri, South Carolina, Vermont, and Wisconsin (and likely others) have all used Direct Push wells as permanent monitoring wells. It is probable that every other state has at least utilized them for temporary monitoring wells. In particular, the ITRC SCM team is aware of the following states that have used Direct Push wells for temporary monitoring wells: Arizona, Kansas, Kentucky, New York, Nebraska, North Dakota, Oklahoma, and South Dakota. Case study experiences from four states that have used Direct Push wells are listed in the following sections.

4.4.1 Delaware

Direct Push wells have been used in the CERCLA, Brownfield, Voluntary Cleanup, HSCA (State equivalent of CERCLA) UST, and Solid waste programs. The RCRA program will allow Direct Push wells but hasn't done one yet. A methane gas survey was performed using Direct Push points. Direct Push wells have been used in different phases of investigations such as site inspections, removal assessments and remedial investigations.

Direct Push wells have been used for both permanent and temporary installations to determine dissolved-phase contaminant levels and water level measurements in groundwater aquifers using pre-packed wells. In Delaware, the wells have been installed from eight to 45 feet below ground surface and used to monitor volatile organics (chlorinated solvents, petroleum constituents), metals and methane gas.

The primary geological conditions where Direct Push wells have been installed include sandy alluvium, silts, clays, and weathered bedrock.

The primary usage in Delaware has been for temporary Direct Push wells to collect groundwater samples for a single sampling event. Recently, permanent Direct Push wells with pre-packed screens with one- to two-inch diameter have been used. The pre-packed screen eliminated the problem with turbidity and made it suitable for dissolved contaminants including metals.

Technical limitations were observed as indicated in the list below:

- The depth of the 1-inch wells was limited by the depth peristaltic pumps can be used for sampling.

- The 2-inch pre-packed screen was difficult to install because of the narrow clearance between the well and the push tube.
- The driller's lack of experience installing Direct Push wells can be a challenge.
- Slow recovery occurred when purging.
- Borehole collapsing created limitations during installation of filter pack.
- Casings shattered during installation.

The well regulations in Delaware do not specifically address Direct Push wells. Direct Push wells are treated like observation and monitoring wells, and must be installed by a licensed driller and include installation of a protective cover with a locking cap.

4.4.2 Missouri

Direct Push wells have been used in multiple CERCLA/SARA investigations (site inspections, removal assessments, remedial investigations), petroleum storage tank investigations, and methane migration studies at multiple landfills.

Direct Push wells have been used for both permanent and temporary installations to determine dissolved-phase contaminant levels and the presence of free-phase product in groundwater aquifers. In Missouri, the wells have been installed from 15- to 70-feet below the ground surface, and used to monitor volatile organics (chlorinated solvents, petroleum constituents) and methane gas.

The primary geological conditions where Direct Push wells have been installed include sandy alluvium, loess, silts, clays, residuum (chert/clay), and glacial till (silts).

The Missouri Department of Natural Resources (MDNR) has installed both temporary and permanent Direct Push wells at several sites during varying stages of the Superfund investigation process as well as for other departmental programs. Wells have been installed in many geological settings, with the limiting factor being the inability to push into consolidated bedrock. Samples collected from Direct Push wells have been comparable in turbidity from conventionally drilled wells. Dissolved-phase contaminants have been detected in samples collected from Direct Push wells.

It is common that a crew can install up to two permanent Direct Push wells in a work day, including pressure-grouting via a tremie pipe, a bentonite seal and annular seal, and including a protective casing with a locking cap set in concrete per Missouri Well Regulations. Due to minimum annular space requirements specified in Missouri Well Regulations, a variance has been required for each permanent Direct Push well installed, which has been a relatively small administrative barrier.

During an extensive comparative study started in 1994 and conducted by the MDNR Solid Waste Management Program, Direct Push wells were installed side-by-side with conventionally drilled wells at multiple landfill sites. Analysis of the data generated during the comparative study indicated Direct Push wells could be installed at an average savings of approximately 69% as compared to conventionally drilled 2-inch monitoring wells.

4.4.3 South Carolina

Direct Push wells have been used in federal and state CERCLA/SARA investigations, Underground Storage Tank investigations, drycleaner sites, Targeted Brownfield Assessments, and other sites in different program areas.

Direct Push technologies have been used for both permanent and temporary well installations to determine contaminant levels in groundwater aquifers, collection of soil samples, installation of piezometers, and determination of lithology. In South Carolina, the wells have been installed from four to 100 feet below the ground surface, and used to monitor volatile organics (chlorinated solvents, petroleum constituents), semi-volatile organics, and inorganics.

The primary geological conditions where Direct Push wells have been installed include saprolite and residuum in the Piedmont Province. The saprolite is normally composed of a mixture of sand, silt, and clay and may contain small fragments of rock. Direct Push wells have also been installed in sediments of the Coastal Plain province including sand, clay, silt or mixtures of these constituents.

Direct Push wells have been used at several sites across South Carolina (SC). They have been instrumental in various investigations at Federal and State Superfund sites, Drycleaner sites, Targeted Brownfield Assessments, and at other sites in different program areas. Specifically, the SC Drycleaner Restoration Trust Fund has a protocol involving the use of Direct Push technologies. Direct Push wells help to determine the vertical and horizontal extent of primarily perchloroethylene plumes typically found at drycleaners. A Direct Push well (without a filter pack) is pushed into the subsurface, a groundwater sample is collected, and the sample is screened onsite using Colormetric tubes. Based on the results of the field analysis, additional wells can be placed in other strategic locations. At one drycleaner in Mt. Pleasant, the combination of Direct Push wells and real time analysis led to the determination of the extent of a PCE plume in two months. The plume is located in a heavily commercial and residential area and is about 1200 feet long. The targeted zone of contamination is between 25 and 30 feet below the ground surface. After the initial screening, permanent Direct Push wells were installed with pre-pack filters. SC has seen success with finding volatile organic compounds using Direct Push technologies. However, if a filter pack is not used during an investigation of the nature and extent of a metals plume, elevated concentrations of metals will be seen (due to turbidity), as compared to wells with filter packs.

4.4.4 Wisconsin

Direct Push wells have been used in the Wisconsin Department of Agriculture, Trade and Consumer Protection, Agricultural Chemical Cleanup Program (ACCP), multiple CERCLA/SARA investigations (site inspections, removal assessments, remedial investigations), petroleum storage tank investigations, and for research on wetlands and groundwater/surface water interaction.

Direct Push wells have primarily been used for temporary wells to determine the degree and extent of contamination. Usage as permanent wells has occurred where access for installation of conventional wells is limited. The ACCP has seen fairly widespread use of Direct Push technology for “grab” groundwater sample collection and for temporary well installations. Temporary wells have been used to help determine groundwater flow direction and the degree and extent of pesticide and nitrate contamination at historic and current agri-chemical dealerships. Temporary wells are typically pulled after short-term use and permanently abandoned or replaced with permanent monitoring wells. Permanent monitoring wells installed on ACCP sites have been predominantly installed using conventional drilling methods (not Direct Push). However, with the advent of pre-manufactured/pre-packed well casings and screens for use with Direct Push equipment, the ACCP is giving greater consideration to Direct Push technology for permanent monitoring well installations. In the past year, two sites have had permanent monitoring wells installed using Direct Push. In a recent example, six Direct Push permanent monitoring wells were installed to depths of 12–15 feet and one Direct Push piezometer was installed at 32 feet bgs in one day of fieldwork.

In Wisconsin, the wells have been installed from 25–30 feet, however, some wells as deep as 45 feet bgs (below ground surface) have been installed. Typical contaminants monitored include pesticides (e.g. organonitrate/organophosphate), fertilizers (e.g. ammonia/ammonium and nitrite/nitrate—nitrogen), and volatile organics (e.g. chlorinated solvents and petroleum constituents).

The primary geological conditions where they are installed include unconsolidated, sandy, high transmissivity environments, and glacial deposits (till and moraine deposits, loess, outwash deposits—sands, silts, clays).

As a general rule, Wisconsin only allows Direct Push wells to be used as temporary monitoring wells. Direct Push technology has commonly been used on ACCP sites for collection of grab groundwater samples and for installing temporary monitoring wells. Only recently has the ACCP seen the use of this technology for installing permanent monitoring wells.

4.5 Conclusions—All Case Studies

Direct comparison of groundwater chemistry data obtained from Direct Push wells to the same data obtained from conventional wells has been done in separate studies sponsored by ESTCP, British Petroleum in partnership with EPA, and NFESC. All of these studies arrived at the same general conclusion and determined that there were generally no statistically significant differences between the comparative samples. In cases where there was a statistically significant difference, the magnitude of the difference was relatively small and the difference would not have affected any management decisions. Greater detail is available in the individual sections discussing these studies.

Case Study Conclusions
Groundwater chemistry data from Direct Push wells are comparable to that obtained from conventional wells. Significant cost savings are possible with Direct Push wells.

Delaware, Missouri, South Carolina, Vermont, Wisconsin, and likely many other states have used Direct Push wells for permanent monitoring wells. Missouri participated in a study that found significant cost savings are possible. The South Carolina section includes an example of Direct Push wells being utilized in a Triad-like manner to facilitate rapid field characterization.

5. HEALTH AND SAFETY ISSUES

At a minimum, a site-specific Health and Safety Plan (Plan) is required for any work conducted at sites where hazardous wastes are present. The Plan should be part of a comprehensive written safety and health program developed in accordance with the Occupational Safety and Health Administration's Hazardous Waste Operations and Emergency Response Standard, Title 29 Code of Federal Regulations (CFR) Part 1910.120.

Operations related to the installation of Direct Push wells have inherent safety issues, which should be addressed in the Plan. Any personnel involved with Direct Push well installation operations should be thoroughly trained on the equipment being employed, including familiarity with the specific Direct Push platform manufacturer's recommended safety guidelines. Personal protective equipment should include hard-hat, steel-toed boots, safety glasses, hearing protection, and heavy work gloves, at a minimum. Table 5-1 identifies some health and safety issues that may be encountered with Direct Push well installations, and includes potential remedies for these issues.

Table 5-1. Health and safety issues for Direct Push wells

Safety issue	Remedy
Hidden (subsurface) obstacles/utilities	Request/conduct a utilities locate prior to initiating work
Loud noise related to percussion hammering	Adequate hearing protection
Flying dust/debris during hammering	Adequate eye protection (safety glasses)
Head injury	Adequate head protection (hard hat)
Feet becoming trapped under probe foot and/or derrick	Keeping feet clear of equipment and wearing steel-toed boots.
Hands becoming trapped in equipment	Keeping hands clear of equipment and wearing heavy work gloves.

Exposure to hazardous substances	Air monitoring Appropriate respiratory protection Adequate decontamination procedures Adequate personal protective equipment

Direct Push well technology involves installation methods that employ percussive hammers and/or static weight provided by hydraulic cylinders to advance the well as opposed to rotary auger or drilling techniques employed in conventional well drilling. From a health and safety perspective, a key advantage of Direct Push wells is that the procedures used to install them do not generate as large a volume of drill cuttings as conventional wells. These drill cuttings may contain hazardous chemicals from the site being explored. Minimizing the quantity of waste generated also reduces the amount of waste needed for disposal. This waste minimization aspect of the Direct Push approach limits the exposure of both investigators and local residents to potentially harmful chemicals, thereby reducing the risk to these populations.

6. STAKEHOLDER INPUT

Stakeholders often have valuable information about site characteristics and history that can enhance the evaluation process and improve the quality of remediation and monitoring decisions. Sampling, evaluation, and deployment decisions need to take into account the usage of the site and the community's planned future use of the site.

Stakeholders, for the purpose of this document shall include affected tribes, community members, representatives of environmental and community advocacy groups, and local governments, have shown great interest in environmental contamination problems, in remediation efforts, and in the cost of the restoration. Given the financial, technical, and regulatory complexities inherent in the remediation and monitoring processes, it is important that affected stakeholders be involved in all decisions pertaining to these processes. Only through meaningful and substantial participation will the stakeholders support the difficult policy, budget, and technical choices that will have to be made (DOIT Project Demonstration Resource Manual, 1994).

It is important to note that affected stakeholders are not necessarily limited to abutters. For instance, those who live downgradient of a site may be affected even if they are not in the immediate vicinity of the site. Furthermore tribes may have treaties or other pacts with the federal government that grant them fishing, hunting, or access rights in places that are not necessarily near their present-day reservations; this is an especially important consideration in the identification of affected tribes. Individual states and the Indian community recognize tribes that are not necessarily recognized by the federal government. A list of federally recognized tribes can be found at the following URL:

http://www.ihs.gov/generalweb/webapps/sitelink/site.asp?link=http://
www.artnatam.com/tribes.html

A list of tribes that are not federally recognized can be found at the following URL:

> http://www.ihs.gov/generalweb/webapps/sitelink/site.asp?link=http://www.kstrom.net/isk/maps/tribesnonrec.html

All interested stakeholders must have access to critical information and have the opportunity to provide input to technology development decisions at strategic points in the remediation and monitoring processes. It is particularly important at the site level to involve stakeholders in collaborative decision-making. Using a coordinated team approach for identifying and planning opportunities for stakeholder and regulator interactions with the technology developers increases the credibility of data and demonstration results and decreases the likelihood that barriers to the demonstration and implementation of a technology will be encountered (DOIT MWWG Final Report, 1996). Effective stakeholder participation can promote a more accurate understanding of the relative risks of various technologies and remediation options. Participants gain a greater understanding of the regulatory requirements and process, as well as a greater understanding of the technologies and/or remediation techniques that can lead to less costly environmental solutions. At Oxnard Plain, for example, the Restoration Advisory Board members recommended a less expensive remediation alternative than originally proposed by the Navy (DOIT Assessment of Local Stakeholder Involvement, 1996).

The stakeholder involvement process that is appropriate at one site may be inadequate at another. The necessary level of participation needs to be defined on a site-by-site basis by the stakeholders involved. Additionally, state and federal agencies and site operators need to recognize the varying levels of involvement: What makes each situation different? What process is most appropriate according to the affected tribes and stakeholders? What roles are appropriate within that process? The roles of tribes and communities may vary dramatically in situations where tribes have regulatory oversight (DOIT A Guide to Tribal and Community Involvement in Innovative Technology Assessment, 1995).

If Direct Push wells are proposed for use in an application that has not been permitted previously, the question may be raised about its technical effectiveness. It is essential to present the facts about the technical merit of the proposal. Stakeholders have historically supported cost-saving solutions if the data support their technical merit. If mutual trust and respect have been established through open and honest communication from the beginning, consensus can be reached in favor of a scientifically meritorious solution.

7. CONCLUSIONS

The primary conclusions of this report may be summarized in three key points as follows:

(1) Results from short-term and long-term groundwater monitoring studies have shown that samples taken from Direct Push wells are comparable in quality to those obtained from conventionally-constructed wells.

(2) Usage of Direct Push wells for long-term monitoring is prohibited in many states by existing regulations that require a larger annular space than can be obtained with Direct Push methods.

(3) Direct Push wells can be extremely cost-efficient.

Direct Push methods are widely accepted for temporary monitoring wells but regulatory acceptance for usage as permanent monitoring wells occurs in only a few states.

Direct Push wells can be constructed with pre-installed filter packs and the well annulus can be sealed with a pre-installed bentonite sleeve or grout can be placed via tremie. They can be developed with techniques similar to those used for conventional wells. Other than being smaller in diameter and having a smaller annular space between the well casing and geologic formation, Direct Push wells can be constructed similarly to conventional monitoring wells, and ASTM standards on the construction of Direct Push wells are available. Several comparison studies conducted by the federal government and by private industry all indicate that groundwater monitoring samples taken from Direct Push wells are comparable in quality to those obtained from conventionally-constructed wells. Cost savings on the order of 50% are possible for site conditions appropriate for the technology. Existing regulations in most states present a barrier to the deployment of this innovative technology.

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Additional Resources:

- A list of federally recognized tribes can be found at the following URL: http://www.ihs.gov/generalweb/webapps/sitelink/site.asp?link=http://www.artnatam.com/tribes.html.
- A list of tribes that are not federally recognized can be found at the following URL: http://www.ihs.gov/generalweb/webapps/sitelink/site.asp?link=http://www.kstrom.net/isk/maps/tribesnonrec.html
- USEPA, Technology Innovation Office: http://fate.clu-in.org/dpp_main.asp.

Appendix A

Acronyms

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ACRONYMS

APC	air pollution control
ARAR	applicable or relevant and appropriate requirement
ASTM	American Society of Testing and Materials
BNA	base/neutral/acid
BTEX	benzene, toluene, ethylene, xylene
CAMU	corrective action management unit
CEM	continuous emissions monitor
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
CLP	Contract Laboratory Program
CO	carbon monoxide
CPT	cone penetrometer
DCA	dichloroethane
DCE	dichloroethene
ECOS	Environmental Council of the States
EPA	Environmental Protection Agency
ERIS	Environmental Research Institute of the States
ESTCP	Environmental Security Technology Certification Program
GC/ECD	gas chromatograph/electron capture detector
GC/MS	gas chromatograph/mass spectrometer
ITRC	Interstate Technology and Regulatory Council
LEL	lower explosive limit
LTTD	low temperature thermal desorption
MTBE	methyl tert-butyl ether
NFESC	Naval Facilities Engineering Services Center
NPL	National Priority List
OSHA	Occupational Safety and Health Administration
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCE	perchloroethylene
PIC	products of incomplete combustion
POC	point of contact
POP	proof of process
POTW	publicly owned treatment works
QA/QC	quality assurance/quality control
RCRA	Resource Conservation and Recovery Act
SCM	Sampling, Characterization, and Monitoring Team (ITRC)
SERDP	Strategic Environmental Research and Development Program
TCE	trichloroethylene
TDU	thermal desorption unit
TPHC	total petroleum hydrocarbons
TRPH	total recoverable petroleum hydrocarbons
TSCA	Toxic Substances Control Act
TSD	treatment, storage and disposal
VO	volatile organic

VOC	volatile organic compound

Appendix B

Glossary

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GLOSSARY

annular space. Annulus; the space between the drill string or casing and the wall of the borehole.

borehole. A hole bored or drilled in the earth: as (a) an exploratory well (b) chiefly British: a small-diameter well drilled especially to obtain water.

bridge. An obstruction within the annulus that may prevent circulation or proper emplacement of annular materials.

casing. A pipe or tubing of appropriate material, of varying diameter and weight, finished in sections with either threaded connections or beveled edges to be field welded, lowered into a borehole during or after drilling in order to support the sides of the hole and thus prevent the sides of the hole from caving, to prevent loss of drilling mud into permeable strata, or to prevent fluids from entering or leaving the borehole.

confining unit. A term that is synonymous with "aquiclude", "aquitard", and "aquifuge"; defined as a body of relatively low permeable material statigraphically adjacent to one or more aquifers.

contaminant. An undesirable substance not normally present in water or soil.

Direct Push monitoring well. A type of monitoring well constructed by pushing casing into the subsurface so as to construct the well without drilling or augering. Little or no annular space is created using this method.

drill cuttings. Fragments or particles of soil or rock, with our without free water, created by the drilling process.

d-10. The diameter of a soil particle (preferably in millimeters) at which 10% by weight (dry) of the particles of a particular sample are finer; synonymous with the effective size or effective grain size.

d-60. The diameter of a soil particle (preferably in millimeters) at which 60% by weight (dry) of the particles of a particular sample are finer.

filter pack. An artificial filter material that is placed in the annular space around the well screen; typically a clean silica sand or sand and gravel mixture of selected grain size and gradation that is installed in the annular space between the borehole wall and the screen, extending the appropriate distance above the screen for the purpose of retaining and stabilizing the particles from the adjacent strata; synonymous with gravel pack; see pre-pack screen for additional information.

grout. A low permeability material placed in the annulus between the well casing or riser pipe and the borehole wall (that is, in a single-cased monitoring well) to maintain the alignment of the casing and riser and to prevent movement of ground water or surface water within the annular space.

monitoring well. Any well constructed specifically to obtain a sample of groundwater for analysis, or any well used to measure groundwater levels. These wells include, but are not limited to, wells constructed using conventional drilling techniques and Direct Push methods.

pre-pack screen. A manufactured well screen that is assembled with a slotted inner casing and an external filter media support. The external filter media support may be constructed of a stainless steel wire mesh screen or slotted PVC that retains filter media in place against the inner screen. The filter media is usually composed of graded silica sand.

screen. A filtering device that serves as the intake portion of a well that allows water to enter the well while preventing sediment from entering the well; usually a cylindrical pipe with openings of a uniform width, orientation, and spacing.

temporary monitoring well or well point. A monitoring well placed or constructed in such a fashion that it is not intended for long-term monitoring.

tremie. The use of a small diameter pipe inserted into the borehole through which the filter pack or grout is placed at the desired depth to either complete construction of the well or to abandon the boring.

Appendix C

Direct Push Survey Form

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DIRECT PUSH SURVEY FORM

Initial feedback from respondents indicates this survey takes approximately 15 minutes to complete. In some instances, there may be more than one answer applicable – feel free to circle all responses that apply and to expand as necessary on any of your responses.

It would also be helpful to provide your contact information should we need to conduct any follow-up questions. Please provide information about the program you work in (Superfund, Brownfields, etc).

Name/State ____

Program Area ____

*Contact Information (Phone/Email)*____________________________

1) Please attempt to accurately describe your state's cumulative awareness and acceptance towards Direct Push monitoring well technology (Check appropriate response and provide further details as warranted).

a.____Regulators are knowledgeable of this technology; it is currently used and widely accepted.
b.____Regulators are knowledgeable of this technology; its use has been approved on a limited basis.
c.____Regulators are knowledgeable of this technology; it has not been implemented at any sites.
d.____Regulators are generally aware of this technology; its use has been approved on a limited basis.
e.____Regulators are generally aware of this technology; it has not been implemented at any sites.
f.____Regulators are unfamiliar with the technology; its use has not been approved at sites.
g.____This technology is expressly prohibited in your state.

____
____
____

2) Are there any specific technical barriers/concerns or contaminant-specific concerns regarding the use of Direct Push wells in your state of which you are aware?

____
____
____

3) Have consultants, responsible parties, or other government entities approached regulators in your state to allow the use of Direct Push wells at sites?________

(How have the regulators been approached? Presentations, in corrective action proposals, sells pitches? For instance, if it's a sells pitch, it may have been done poorly and the regulator won't allow push technology since he has a first bad impression. Or if it's in a proposal and it's not presented well, the regulator may reject it because he didn't get enough info on Direct Push. This is just a suggestion)

a. If so, were Direct Push wells allowed?

____

____

b. Are there any specific programs within your state, which allow or restrict the use of Direct Push wells? (e.g. UST allows for Direct Push wells; Superfund does not – please specify)

____

____

4) Has your state ever used Direct Push wells for environmental assessments/ monitoring at any state-led sites?_____

a. If so, were they used in place of conventional drilled wells?_______

b. If so, please list the projects where they were used, or if that is not possible please estimate the number of projects where they were used. Please also specify state programs, if applicable, that have allowed/employed Direct Push wells (Brownfields, RCRA, Superfund, UST, Voluntary cleanup).

____

____

____

5) If your state has experience with the use of Direct Push wells (either at state-led sites or by a consultant/responsible party), please indicate all uses for which they are/were allowed.

___Piezometers (either temporary or permanent)
___Temporary wells (Ex. one-time sampling during initial assessments/RIs)
___Slug tests
___Observation wells during pump tests
___Compliance monitoring
___Long-term monitoring
___Short-term monitoring
___Other (please specify)

____

____

____

6) Does your state's appropriate authority have any formal policy/regulations/acts, which address the installation/use of Direct Push wells for environmental monitoring?_____

a. If so, please indicate the statute, regulation, variance, or memo that is the basis for the policy. (include a copy and/or website that specifies the exact regulations or policy/guidance)

____
____
____

b. If so, does the policy/regulation/act place any express restrictions on the installation/use of Direct Push wells (please provide specifics)? (include a copy and/or website that specifies the exact regulations or policy/guidance)

____
____
____

c. If so, does the policy /regulation/act expressly prohibit Direct Push wells for environmental monitoring (please provide specifics)? (include a copy and/or website that specifies the exact regulations or policy/guidance)

____
____
____

7) Has your state's appropriate authority incorporated in part, or in its entirety, ASTM D5092 "Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers" into any of its formal policy/regulations concerning the installation of monitoring wells?_____

a. If so, has incorporation of this standard presented a barrier within your state for the implementation/use of Direct Push monitoring wells (please provide specific regulatory reference)?

____
____
____

8) Is your state aware/familiar with ASTM D6724-01 "Standard Guide for Installation of Direct Push Ground Water Monitoring Wells in Unconsolidated Aquifers"?________

a. If so, has your state incorporated this standard into any official policy/ guidance regarding Direct Push wells? (please provide specific regulatory reference)

____
____
____

b. If you're aware, and your state has not incorporated this standard into any official policy, would this practice be acceptable in your state?_____________
(why would it be acceptable?)

c. If you're aware of this standard, do you have any concerns with this standard or are there any regulatory/policy/act that would prohibit or limit this standard's acceptance? (please specify)

____
____
____

9) Prioritize the following list of potential regulatory concerns regarding Direct Push wells (1=no concern, 5=highest concern)

___Annular Space Requirement
___Turbidity
___Annular Seal Integrity
___Filter Pack Requirement
___Hydraulic Conductivity
___Sample Representativeness
___Long term performance
___Reliability of Static Water Level Measurements

10) Is your state aware/familiar with ASTM D6725-01 "Standard Practice for Direct Push Installation of Pre-packed Screen Monitoring Wells in Unconsolidated Aquifers"?_______

a. If so, has your state incorporated this standard into any official policy/ guidance regarding Direct Push wells? (please provide specific regulatory reference)

____
____

b. If you're aware, and your state has not incorporated this standard into any official policy, would this practice be acceptable in your state?_________ (why would it be acceptable?)

c. If you're aware of this standard, do you have any concerns with this standard or are there any regulatory/policy/act that would prohibit or limit this standard's acceptance? (please specify)

____
____
____

11) Are you aware of any studies currently underway by states, EPA, DOD, DOE, or others concerning the use of Direct Push wells for environmental monitoring? If so, please list the complete reference.

____
____
____

12) If the results of a multi-year study of Direct Push wells conducted at various locations throughout the country indicated that they were as reliable and accurate as conventional drilled wells for environmental sampling, would this influence your consideration for their use?______Why would it influence your consideration?

13) Please check the most accurate response:

_____We strongly recommend the use of Direct Push wells where appropriate.
_____We recommend the use of Direct Push wells where appropriate.
_____We have not yet developed an opinion concerning the use of Direct Push wells.
_____We do not recommend the use of Direct Push wells.
_____We expressly prohibit the use of Direct Push wells.

14) If your state has experience with this technology, please check the response that most closely represents your state's cumulative experience:
_____Direct Push wells have functioned appropriately and saved project funds compared to conventional wells
_____Direct Push wells have functioned appropriately but there was no cost savings over conventional wells
_____Direct Push wells did not function as expected (please provide specifics)

15) If your state does not have experience with this technology, what information would you deem most beneficial in being able to adequately evaluate this technology's value, applicability, and acceptance in your state? (Examples might include Internet training, classroom training, ITRC document, in-depth case studies, etc.)
____
____

Are you aware of any current resources for information regarding this technology?_______

a. If so, please identify those sources.
____
____
____

b. If so, have you been able to adequately evaluate this technology based upon the information you've found?
____
____
____

Feel free to provide additional comments with regards to Direct Push wells, particularly with respect to how they are used and/or restricted in your state and listing what regulatory barriers, if any, may be present.

APPENDIX D

ITRC Team Contacts, Fact Sheet, and Product List

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