Guidance Manual for Environmental Boreholes and Monitoring Systems

Prepared by:

Louisiana Department of Natural Resources and Louisiana Department of Environmental Quality

November 2021

PREFACE

The *Guidance Manual for Environmental Boreholes and Monitoring Systems* will serve as the primary reference document for those licensed by the State of Louisiana to work in the construction, installation, repair, and proper abandonment of such structures. It replaces the heavily utilized but now outdated “Green Book” as the primary reference for such licensed environmental drillers and associated professionals working in the state.

Much has changed in the field since the initial publication of the “Green Book” in the early 1990s, and even since its last revision in 2000. Seeing the need for a major revision and this new document’s eventual incorporation within the Louisiana Office of Conservation’s Title 56 rules and regulations, Commissioner of Conservation Richard P. Ieyoub authorized staff in the agency’s Ground Water Resources Program (GWRP)/Environmental Division to undertake this task in the fall of 2016. After completing an initial draft, the agency later organized a Work Group, with the concurrence of the Advisory Committee for the Regulation and Control of Water Well Drillers, to assist in further revisions. This Work Group included representatives from the Louisiana Department of Natural Resources (DNR) and Louisiana Department of Environmental Quality (DEQ) as well as licensed well drillers and associated professionals.

The document that these individuals further developed and revised consequently reflects not only a deep knowledge of current best management practices in the field but also a nuanced appreciation of the regulatory framework which governs this work for the larger purpose of environmental protection and conservation. In crafting the *Guidance Manual*, Work Group members drew upon their own experience and professional judgement, as well as a wide array of technical resources including, but not limited to:

- Current Federal and State of Louisiana regulations and guidance documents;
- National standards promulgated by the American Society for Testing and Materials (ASTM), National Ground Water Association (NGWA), and other trade associations and organizations;
- Widely distributed scientific and technical publications;
- Manufacturer documents and similar resources, including Standard Operating Practices (SOPs), guidelines, and instructions.

Recognizing the complexities of the type of work in which environmental drillers are engaged, DNR and DEQ strongly encourage the utilization of the *Guidance Manual* by water well contractors and associated professionals in the planning, construction, documentation, and plugging-and-abandonment of subsurface penetrations for environmental projects in Louisiana. DNR, through the Office of Conservation (DNR/OC), has licensing authority over well drilling contractors operating in the state, while assorted rules and regulations from various agencies including DNR/OC and DEQ govern work on the types of wells and boreholes discussed in this document. **The use of procedures or materials that deviate from the *Guidance Manual*, agency rules and regulations, and/or approved work plans without prior approval may result in work not being accepted.**

<u>A Note on the "Green Book"</u>: As noted above, the *Guidance Manual* is replacing the old "Green Book"—known officially as "The Construction of Geotechnical Boreholes and Groundwater Monitoring Systems Handbook"—as the primary reference for licensed environmental drillers working in Louisiana. Originally published in 1993 by DEQ and the Louisiana Department of Transportation and Development (DOTD), the handbook quickly earned its nickname in the industry due to the front cover's green color, in contrast to the "Blue Book" containing DOTD's 1985 water well regulations. A revised version was published in December 2000. As indicated in its foreword, the handbook was "intended to serve as a reference" and was "not intended to present any specific regulation or regulatory program." Nonetheless, the "Green Book" served for many years as the *de facto* guidance document for the applicable portions of Louisiana Administrative Code (LAC) Title 56 and LAC Title 33 regulations. With technological advances and changes in the regulatory scheme, both licensed environmental drillers and government regulators saw the need for a comprehensive replacement, now found in this document.

Guidance Manual Work Group Members

Industry Representatives

Dave Angle, Pisani & Associates
Scott Bergeron, Professional Technical Support Services
Warren Brady, GeoSnytec Consultants
Brian Carter, GHD
Lonnie Gaudet, Devonian
Lloyd Hoover, ATC Group

Government Representatives

Bob Harris, DEQ
Bill Schramm, DEQ/Member-at-Large
Gary Snellgrove, DNR/OC

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

Tables

Figures

LIST OF ABBREVIATIONS AND ACRONYMS

Agencies and Organizations

ARA	Appropriate Regulatory Authority
ASTM	American Society for Testing and Materials
CPRA	Louisiana Coastal Protection and Restoration Authority
DOTD	Louisiana Department of Transportation and Development
EPA	U.S. Environmental Protection Agency
DEQ	Louisiana Department of Environmental Quality
DNR	Louisiana Department of Natural Resources
DNR/OC	Louisiana Office of Conservation
DNR/OCM	Louisiana Office of Coastal Management
LAC	Louisiana Administrative Code
LDH	Louisiana Department of Health
NGWA	National Ground Water Association
NSF	National Sanitation Foundation
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

Technical Terminology

BMP	Best Management Practice
CPT	Cone Penetration Testing
CUP	Coastal Use Permit
DNAPL	Dense Non-Aqueous Phase Liquid
DPT	Direct Push Terminology
GPS	Global Positioning System
GW&W	Groundwater and Wells
ID	Inner Diameter
IDW	Investigation-Derived Waste
LIDAR	Light Detection and Ranging
LNAPL	Light Non-Aqueous Phase Liquid
NAPL	Non-Aqueous Phase Liquid
NGVD	National Geodetic Vertical Datum
OD	Outer Diameter
P&A	Plug & Abandonment, Plugging & Abandonment
PVC	Polyvinyl Chloride
SONRIS	Strategic Online Natural Resources Information System
SOPs	Standard Operation Practices/Procedures
SPT	Standard Penetration Tests
USCS	Unified Soil Classification System
USDW	Underground Source of Drinking Water
VOC	Volatile Organic Compound
WBU	Water Bearing Unit

STATEMENT ON RELEVANT DEFINITIONS AND FORMS

Depending upon particular statutory interests, regulatory authorities in Louisiana often utilize similar but nonetheless different definitions for the same technical and scientific terms encountered in the field of water well contracting and especially in environmental borehole and monitoring system work. Each of these regulatory authorities likewise may require the completion of unique forms or documents as requirements for this work under state law and their agency rules and regulations.

In light of this, all work completed under LAC Title 56, LAC Title 33, the *Guidance Manual*, or another recognized regulatory scheme should be compliant with the appropriate terminology, definitions, and document requirements utilized by the Appropriate Regulatory Authority (ARA) approving or sanctioning the work. In short, it is the absolute responsibility of the individual well driller, contractor, or associated professional to be thoroughly familiar with the regulatory framework under which each specific project is completed and to ensure that the work meets all requirements of the ARA.

1.0 INTRODUCTION

As noted in the Preface, the *Guidance Manual* has been developed under the authority of DNR and DEQ to serve as a reference document for licensed Louisiana water well contractors, affiliated professionals, and regulators in the planning, construction, documentation, and plugging-and-abandonment of subsurface penetrations for environmental projects in Louisiana. Consequently, the *Guidance Manual* shall serve as the main reference for subsurface environmental field investigations completed within the context of the regulations provided in LAC Title 56 (DNR) and LAC Title 33 (DEQ).

The purpose of the regulations pertaining to the construction of water wells is to reduce the potential for contaminating the state's groundwater resources via improperly constructed wells and boreholes. Notably, two of the most critical tasks relating to well construction are: 1) grouting of annular spaces, and 2) plugging-and-abandonment (P&A) of boreholes and wells. Consistent with the mission of the state Ground Water Resources Program within DNR's Office of Conservation (DNR/OC), the *Guidance Manual* includes detailed discussions on the topics of sealing, grout materials, grout mixtures, grouting techniques, and P&A of environmental boreholes, monitoring wells, and related subsurface environmental systems. These boreholes, monitoring wells, and related subsurface environmental systems are intended to be completed in such a manner so as not to adversely impact the quality of groundwater, provide an avenue for contaminants to be introduced from the surface, nor allow such an avenue of contamination between aquifers. Consequently, best management practices (BMP) must be observed to maintain cleanliness and restrict potential contamination during the drilling, well installation, and P&A processes.

1.1 Existing Regulatory Framework

The mission of DNR is to ensure and promote sustainable and responsible use of the natural resources of Louisiana so that they are available for the enjoyment and benefit of citizens now and in the future. Louisiana's groundwater is one such natural resource. The Office of Conservation, an agency within DNR, has the statutory authority through its Ground Water Resources Program, to ensure aquifer sustainability and groundwater resource conservation. DNR/OC also has the authority and responsibility under LAC 56 to regulate the construction of water wells in Louisiana. This authority includes environmental "monitoring wells" as defined in the code. Specifically, monitoring wells, geotechnical boreholes and test holes must be drilled by a licensed contractor/driller. Effective beginning in 2010, DNR/OC obtained authority for water well construction and water well driller licensure from DOTD. Other divisions of DNR/OC also maintain relevant authorities and responsibilities relating to environmental boreholes and subsurface injections, including the Injection and Mining Division (injection for environmental aquifer remediation) and the Environmental Division (Exploration & Production—Part 29B).

The mission of DEQ is to provide comprehensive environmental protection to promote and protect the health, safety and welfare of the citizens of Louisiana (LAC Title 33). DEQ regulates and monitors the activities of operations that may pose a threat to the subsurface environment of the state of Louisiana. An important element of this regulatory activity is the monitoring of groundwater quality and consequential actions that would impact groundwater, such as remediation and restoration activities. DEQ requires boreholes, monitoring wells and environmental systems to demonstrate comprehensive environmental protection under multiple programs described in LAC Title 33 (hazardous waste landfills—Part V Subpart 1; solid waste landfills—Part VII; UST Trust Fund—Part XI; RECAP).

The missions of DNR and DEQ overlap with respect to boreholes, water wells (monitoring and related environmental wells), and similar environmental systems, resulting in the need for guidance as provided in this document, while maintaining the flexibility of licensed drillers to adapt to unique circumstances, including subsurface geological circumstances and Louisiana's environment.

While it is recognized that other Louisiana agencies may have relevant authorities and responsibilities stemming from drilling activities, such as the Louisiana Department of Wildlife & Fisheries (DWF) and Louisiana Department of Health (LDH), they generally have not been considered within the context of the *Guidance Manual*. It is broadly understood that in all instances, licensed Louisiana water well contractors and affiliated professionals should consult with the Appropriate Regulatory Authority (ARA) that retains the authority and responsibility to approve (or disapprove) of Work Plans and similar documents relating to specific projects and actionable matters.

1.2 Applicability

This document is not intended to override, usurp, replace or otherwise change regulations set forth in LAC Title 56 and LAC Title 33. Rather, it is intended to supplement and complement the regulations, particularly where additional guidance/instruction is warranted. In particular, the *Guidance Manual* provides additional direction for soil sampling boreholes, electronic/instrument logging technologies, temporary groundwater sampling points, installation of monitoring and other wells, well development, aquifer remediation injection, related technologies, and P&A activities affiliated with subsurface environmental projects. Water well contractors and affiliated professionals shall consult the relevant regulatory definitions for each agency as needed for specific projects.

Further, the *Guidance Manual* is intended to serve as a reference and guide to environmental contractors, consultants and regulators for project-specific efforts, many of which include the development of an ARA-approved Work Plan (or similar document) and execution by a contractor. In fact, most applicable environmental projects are completed using Work Plans approved by DEQ or DNR, which serve as the ARA. Two exceptions are a Phase II environmental investigation completed for a commercial buyer and a litigation-based effort completed for a private party. Absent ARA approval, all aspects of such subsurface environmental projects shall be governed by the appropriate regulations, namely LAC Title 56 and LAC Title 33, and the guidance offered by this document.

2.0 PRIOR TO CONSTRUCTION

Proper safety precautions should be considered prior to field activities. There are numerous regulatory bodies (*e.g.*, Occupational Safety and Health Administration) and recognized safety guidelines applicable to drilling activities. The drilling contractor has a responsibility to understand all applicable guidelines and regulations and to field adequately trained personnel to prevent accidents or exposures. Depending on the complexity of a particular site, additional training and medical surveillance may be required. Proper recordkeeping protocols should be established to document the monitoring well design, construction, and installation process prior to the initiation of field activities so that requisite information can be recorded and provided to DNR/OC as part of the well registration process. The following subsections identify the major activities anticipated to be performed prior to field activities.

2.1 Drilling Approvals

As noted previously, the requirements of a DEQ- or DNR-approved Work Plan may supersede the guidance suggested within this Manual. It may also be necessary to obtain pre-approvals/permits from DNR, the U.S. Army Corps of Engineers (USACE), or other ARA to install soil borings and monitoring wells in the Louisiana Coastal Zone and or near USACE-maintained levee systems. These pre-approvals/permits are discussed in the following subsections.

2.1.1 Pre-Approvals/Permits – Injection Wells

DNR/OC's Injection and Mining Division requires prior approval for the installation and use of injection wells within the State of Louisiana under LAC 43:XVII.Chapter 1, Statewide Order No. 29-N-1. DNR classifies wells that are used to inject nonhazardous fluids into or above an underground source of drinking water as Class V wells. Additional information on Class V wells is provided in Chapter 8.0 of this document. In addition to the DNR/OC permit, an approval from the Environmental Protection Agency (EPA) or DEQ is required prior to submitting a Class V permit application. DNR/OC issues the following permits:

- **Permit to Construct**–includes administrative, technical and geologic review;
- **Permit to Inject**–includes administrative, technical and geologic review to verify well construction as proposed, prior to operation of the well.

DNR/OC has streamlined the permitting process for Class V Remediation Wells associated with EPA- or DEQ-approved remediation projects. For temporary injection points, as described in Chapter 8.0, the DNR/OC requires a permit waiver and associated fee. This waiver requires an EPA- or DEQ- approved Work Plan and much of the information required for a Class V injection well. Additional information on the Class V permitting process and waivers for temporary injection points can be obtained from DNR/OC.

2.1.2 Pre-Approvals/Permits – Extraction Wells

Extraction wells may require 60-day prior notification to DNR/OC using the appropriate agency water well notification form (available on-line). This form identifies the requirements, exemptions, and other information relevant to the extraction of groundwater. The design and installation of extraction wells for groundwater dewatering or remediation purposes requires approval of DNR and/or DEQ prior to their installation and operation. Specific regulations regarding water wells are included in LAC Title 43 and LAC Title 56.

2.1.3 Pre-Approvals/Permits – USACE Levee Systems

All subsurface work within 1,500 feet of a USACE river levee/floodwall and within 300 feet of a hurricane levee/floodwall requires a levee district permit. The levee districts will not issue a permit without receiving a letter of no objection from both the USACE and the Louisiana Coastal Protection and Restoration Authority (CPRA). An email and/or letter must be sent to the three offices (levee district, USACE, and CPRA) describing the proposed work including location (latitude/longitude and address), dimensions, depth, and distance from the levee or floodwall, with drawings and map attached.

If the proposed work is on the levee, it might require Section 408 permission from the USACE as well as a levee district permit. If that is the case, the USACE must be contacted directly. A drilling program plan will be required if the borings or drilling location is in the levee section or within a 1:1 zone of the levee toe. For example, a boring 75 feet deep must be a minimum of 75 feet from the levee or a drilling program plan will require approval by the USACE local office and the USACE Risk Management Center in Denver. The USACE can provide more information for such projects as needed.

2.1.4 Pre-Approval/Permits – Louisiana Coastal Zone

A Coastal Use Permit (CUP) must be obtained from DNR's Office of Coastal Management (OCM) prior to the installation of any soil boring or monitoring well utilizing motorized drilling equipment (*e.g.*, track, rubber tire, airboat, etc.) in the Louisiana Coastal Zone. The CUP application process provides a single point of contact for work within the Coastal Zone, as well as a single public notice. The application is then circulated among a wide array of interested state and Federal agencies for comment and potential modification.

2.1.5 Alternative Technologies

As a general rule, deployment of alternative technologies will require ARA approval.

2.2 Utility Locate (Louisiana One Call)

The location of any underground lines potentially present in the vicinity of any borehole or monitoring well must be identified prior to field activities through the use of the Louisiana One Call system. Important factors associated with utility locating and Louisiana One Call are as follows:

- Louisiana One Call may not identify all lines potentially present, especially underneath commercial and industrial facilities and in locations where the utility providers are not Louisiana One Call system members;

- Contact with person(s) knowledgeable with the underground utility system in the vicinity of the borehole or monitoring well location is recommended (*e.g.*, inside a chemical plant);
- The Louisiana One Call system requires 48-hour notice prior to breaking ground; and,
- The use of a T-handle probe at least five or six feet long to probe each boring/well location in a triangular pattern as a final check prior to the initiation of any drilling activities is a BMP.

In some situations, additional utility locating measures (*e.g.*, air-knife, pot-holing, or geophysical method) should be considered. Examples of these situations include: work within a plant; work near a roadway with fiber-optic lines; work in areas of high methane; and work in older developed areas where records are sparse.

2.3 Selection of Well Location

Careful selection of the well location in the field is important for many reasons that include but are not limited to: future accessibility for monitoring and sampling, especially for long term monitoring programs; preventing potential cross contamination from flooding; avoiding other potential surface contamination sources; siting considerations for current use (*e.g.*, installation of wells in agricultural fields). Due to Louisiana's high rainfall, the location of monitoring wells should be selected to avoid low-lying areas that are subject to flooding. Publicly available topographic maps and ground surface elevation data can be readily obtained from the United States Geological Survey (USGS) and the Louisiana Statewide Lidar Project. Historical aerial photographs can be obtained/viewed for free through Google Earth and USGS.

2.4 Design of the Well (Filter Media and Well Screen Selection)

Well construction materials should be selected based upon the goals and objectives of the proposed monitoring program and the geologic conditions anticipated. The design of the well filter media (filter pack) and selection of the well screen are an important, but oftentimes overlooked, component of the well construction planning process. An improperly sized filter pack and well screen slot size may result in a well that will not yield an adequate supply of water or result in excess sediment entry into the well.

The majority of shallow monitoring wells in Louisiana installed for environmental purposes are screened in water bearing units (WBUs) that consist of clays, silts and sands of various combinations. These shallow WBUs are not typically used for drinking water supply. Domestic and/or public supply wells are typically screened deeper in sand-and-gravel aquifers. The filter media and well screen slot size will differ significantly depending upon the grain size of the WBU or aquifer and the ultimate purpose of the well. Specific design information for the selection of an appropriate screen and filter media are provided in Chapter 6.0.

2.5 Potable Water

Potable water should be used for drilling, grouting, sealing, filter pack placement, well installation or equipment washing. Potable water should be from a source of known water quality and should not adversely impact the chemical and biological quality of the groundwater. In some cases, the quality of the water should be quantified through analytical testing and/or obtaining data from the supplier prior to use at a site.

The contractor should procure, transport and store the water required for the project in a manner that avoids potential contamination or degradation of the water. The tanks or tank trucks used for transport of the water should be free of loose rust, scaling, or any other materials that might alter the properties of the water.

2.6 Cleanliness of Materials and Equipment

Cleanliness of materials and equipment (drilling and sampling equipment) is a quality control measure required prior to drilling and installation of soil borings and monitoring wells. Special care must be taken to minimize or prevent inadvertent cross-contamination between borehole locations. As such, equipment, tools, and well materials must be properly cleaned (decontaminated) between locations. Single use, factory pre-cleaned materials are considered a BMP for well screens, risers, sand filer pack and related items.

Decontamination is the process of washing and rinsing equipment that has or may come in contact with subsurface material or groundwater that is known or suspected of being contaminated. The purpose of the decontamination process is to prevent introduction of contaminants, potential "cross-contamination" between boreholes, or the drag-down of contaminants to deeper WBUs or aquifers. A decontamination program should be designed prior to field activities and should consider: the location where the decontamination procedures will be conducted; the types of equipment that will require decontamination; the decontamination frequency; the cleaning techniques and solutions; containment of decontamination residuals; and quality control measures to evaluate the adequacy of the decontamination program. Methodologies for cleaning and decontamination may include but are not limited to:

- Pressure washing (cold or hot potable water);
- Liquinox/Alconox wash with potable water rinse;
- Triple rinsing with potable water;
- Acid, hexane or other cleaning agents and rinsing;
- Combination(s) of the above.

All equipment used in the construction of wells and boreholes performed for environmental purposes shall be free of contamination. Such equipment includes: drill rig, augers, drill stem, samplers, tools, water tank, recirculation tanks, pumps, and any other auxiliary equipment. All cleaning and decontamination should be performed in areas and in a manner where fluids can be effectively managed. Before leaving the site, all construction equipment shall be decontaminated.

2.7 Investigation-Derived Waste Containment

The method to manage investigation-derived waste (IDW) should be identified with specific procedures prior to field activities. IDW consists of the soil cuttings and groundwater generated during the installation of soil borings and monitoring wells and the well development and purging process. IDW should be properly containerized to prevent the potential for spreading contaminants potentially encountered during the drilling and sampling process. Typical IDW containers consist of drums, bagged waste, roll-off boxes, and tanks. Upon completion of drilling and sampling activities, containers should be properly managed in accordance with the appropriate regulatory requirements.

2.8 Licensing Requirements for Drillers and Contractors

Anyone intending to drill, install, or P&A a borehole or well in Louisiana shall meet the licensing requirements for a "contractor or driller" as set forth in LAC Title 56.

TABLE 1
PRIOR TO DRILLING FIELD GUIDE SUMMARY

Utility Locates

- **Louisiana One Call**–notified and lines marked (currently 2 business days AFTER day of notification)
- **Identify other utility-locating measures**–private locate, tile probing, hand-auger, air-knife, pot-holing

Pre-Approvals & Permits

- Contactor licensed in State of Louisiana
- Work Plan approved by ARA
- Permits obtained for type of boring or well to be installed (extraction or injection wells)
- USACE and local levee district permit obtained if boring or well to be installed within 1,500 feet of levee/floodwall
- Coastal Use Permit (CUP) obtained if boring or well is to be installed (or access to the desired location) within a Coastal Use Area

General Considerations

- Objectives and Scope of Work defined (and contingencies identified)
- Drilling and well installation methods defined
- Depth and quantity of borings and well locations identified
- Sampling frequency identified for soil borings
- Sampling objectives of borehole logging & practices
- Knowledge of past borings and well installations provided to field team (*e.g.*, geology, successful methods, etc.)
- Health and safety plan in-place and reviewed by field team
- Safety meeting(s) format, frequency, and documentation for daily operations identified
- Personal Protective Equipment (PPE) in-place for field team
- Access to all boring and well locations is suitable via scheduled equipment (present and future if appropriate); special requirements identified (*e.g.*, boat, marsh-buggy, matting, etc.)
- Access to all boring and well locations is available via existing property owner agreements
- Potential flooding considerations made as appropriate
- Potable water source identified on-site (or scheduled to be brought to project)
- Field equipment operational and clean
- Investigation-Derived Waste (IDW) Plan in-place

3.0 CONSTRUCTION OF BOREHOLE

3.1 Borehole Completion Methods

The following subsections provide a summary of the most common currently used borehole advancement techniques in Louisiana. The common methods are summarized as follows:

Figure 1: Borehole Completion Methods

Method	Typical Application	Advantages	Disadvantages
Mud Rotary	Geotech Borings	Range of Diameter	Large IDWs, “Messy” Wells
Hollow-Stem Augering	Monitor Well (MW) Installations	Good Monitor Wells	Depth & Sand Limitations
Rotary Sonic	Monitor Well (MW) Installations	Fast in Sands	Rig Size, Water Usage
Direct Push Technology	Environmental	Small Diameter, Small Rigs, Efficient for Shallow	Inefficient at Depths

3.1.1 Mud Rotary Drilling

Rotary drilling methods advance a drill bit on extension rods into the soil while pumping water, with or without additives, through the bit to remove soil cuttings from the borehole. The fluid additives may include National Sanitary Foundation (NSF) approved bentonite mixtures or artificial polymers and related chemicals.

A BMP for drilling through impacted and non-impacted permeable zones is to install a permanent casing through any impacted zone and advancing deeper boreholes with a smaller diameter bit through the center of the casing. Special emphasis should be made to ensure proper sand and bentonite placement through the mud column and verified through downhole measurements. For environmental applications, the drilling fluid and cuttings must be contained for proper disposal.

Rotary drilling remains popular due to its simplicity and universal availability of rigs. Typical diameters of environmental applications of rotary drilling are:

Sizes	Typical Application
3- to 4-inch diameter	Soil Boring
6- to 16-inch diameter	2- and 4-inch MWs
>8-inch diameter	Surface Casings

Figure 2: Typical Diameters, Rotary Drilling

3.1.2 Hollow-Stem Augering

The borehole is traditionally advanced with five-foot "flights" of hollow augers that maintain the integrity of the borehole while providing a central access pathway to acquire soil samples, as required. When used in tandem with direct push technology (DPT), the augers typically are used only to install a monitor well so that a plug is frequently installed and the augers are used to expand the borehole diameter in order to install the monitor well.

Hollow stem augers provide a physical barrier to soils caving into the borehole although they may not prevent fluids from entering. The BMP for completing a monitor well through multiple permeable zones would include installing permanent casings through impacted zones and drilling through underlying materials with a smaller diameter auger or DPT. This BMP typically limits hollow-stem augers to be used only in the uppermost WBU depths. Well installation using this method may also have difficulties with heaving sands where fine-grained native material is fluidized and forced up the auger central port due to high hydraulic head. A sacrificial plug at the bottom of the lowest auger may prevent sands from entering the augers.

During well installation special emphasis should be made to ensure filter pack sand and bentonite seal materials are properly placed in the auger boring. These materials may bridge across the annulus within the augers and the well casing and prevent uniform distribution of filter pack sand and/or bentonite seal materials. Common diameters (in inches) of hollow stem augers are: 2¼, 3¼, 4¼, 6¼, 8¼, 10¼, and 12¼ Inner Diameter (ID). This range of IDs facilitates numerous applications within the environmental industry.

3.1.3 Rotary Sonic

The rotary sonic (rotosonic) rig advances a core barrel using rotation and very strong vibrations of the core bit. The sonic core barrel is advanced with extension rods and is usually accompanied by advancing an outer casing that is used to maintain the integrity of the borehole and widen the borehole, as needed, to install monitor wells. The outer casing may be advanced with a water flushing technique, drill mud or dry. The BMP for rotosonic drilling is the use of multiple casings to telescope and isolate potentially contaminated zones. Typical diameters of environmental applications of rotary sonic drilling are: 4-, 6-, 8-, and 10-inch nominal diameters.

3.1.4 Direct Push Technology

The DPT method is used to obtain soil cores by advancing a core barrel with hydraulic pressure and hammering. An outer casing may be advanced to keep the borehole open. Typically, the method is just used for soil sampling but is sometimes used to install monitor wells. The method is not recommended for installing monitor wells in cohesive soils, because the core barrel will compress the soils during the advancement of the device leaving the zone of completion with a significantly reduced permeability. The DPT method is prone to experience tool refusal in dense sands/gravels.

DPT rigs vary from very small units that will fit within a standard 36-inch wide door, to very large and powerful tracked units, and several sizes in between. The smallest units typically deploy smaller diameter tools to shallow depths, while the largest units deploy largest diameter tools to deeper depths, and the intervening units in between. Due to the nature of the DPT method, the larger the diameter, the larger the dynamic force required for penetration. Current rod packages include:

Figure 3: Current Rod Packages (Diameters, Applications)

Diameter (inches)	Application(s)
1	Hand DPT
1.25	Small Units
1.5	Small to Mid-Sized Units, CPT
1.75	MiHPT, Groundwater Profiler
2.125	Small Units, Shallow Installations
2.25	Mid to Large Units
3.25	Mid-Sized Units
3.5	Mid to Large Units
3.75	Large Units, Large Diameter Sampling
4.5	Large Units, Large Diameter Sampling
6.0	Large Units, Installations

3.1.5 Others

Advancements in technology have resulted in drill rigs that offer combined drilling methods. There are a variety of hand tools that may be used to advance soil borings including hand augers, post-hole diggers, and hand advanced direct push devices. Typically, these methods are used to clear the subsurface to a specified depth before advancing the borehole with mechanical techniques, as described above. Shallow borings may be installed with hand tools if access prevents the use of mechanical techniques.

3.2 Soil Sampling and Borehole Logging

3.2.1 Direct Push Technology

DPT sampling is presently the most common method for obtaining soil samples for environmental applications in Louisiana. The method has limitations in cohesive soils, where the soils may bridge in the bottom of the core barrel/liner during advancement and portions of the soil column may be displaced. In coarser-grained soils, core catchers are frequently utilized to retain granular soils in the core barrel when the core is retrieved from the ground. Although this method frequently recovers representative samples of the soil, depending on soil conditions, the soil samples may or may not be considered undisturbed for geotechnical purposes.

Two basic DPT sampler types are the Piston and the Dual-Tube. Piston samplers enable use at greater depth but have the potential for contaminant drag-down. Dual-Tube samplers have reduced drag-down but can only be used at shallower depths

3.2.1.1 Large-Bore and Macro-Core Piston Sampling

Large-bore and macro-core piston sampling can be accomplished either using an "open barrel" or a discrete piston rod system. Soil volume is based on the size of the acetate liner and tool string selected; current options range from 1-inch to 3-inch ID, with larger diameters envisioned in the future. This process does require the entire tool string to be removed as each soil sample interval is collected. Open-barrel core sampling works well at depths of less than 20 ft bls and is limited due to formation collapse. Soil sample quality may be impaired as depth increases due to overburden entering the system. Discrete piston rod sampling depths can be greater than 100 ft bls and are limited by "refusal" or sand entering the tool string. Discrete piston rod sampling reduces overburden entering the system, allowing for greater soil sample accuracy at depth.

Open-barrel sampling is performed utilizing an acetate liner, which is placed into the core barrel. The acetate liner is locked into place with a bottom-cutting shoe and on top with a drive head. The core barrel containing the acetate liner is driven to the desired depth and retrieved. This process is repeated until the desired depth is achieved by adding additional drive rods as necessary.

Discrete piston rod sampling is performed by adding a piston rod to the above system. The piston rod is held at the bottom of the core barrel with a drive point that sets within the bottom cutting shoe and a stop pin that is threaded into the drive head. The assembly is driven to the top of the sampling depth, the stop pin is unthreaded from the drive head and removed, the tool string is driven to the desired depth, and the discrete sample and entire tool string is retrieved.

3.2.1.2 Dual-Tube Sampling

This process does not require the entire tool string to be removed as each soil sample interval is collected. Dual-tube sampling is useful in areas of known impacts or where multiple water bearing zones are encountered. Dual-tube sampling does require a larger diameter tool string, which causes a limitation of penetration depth. In areas that contain "flowing/heaving" sands, the system does not perform well. Soil volume is based on the size of the acetate liner and tool string selected; current options range from 1-inch to 3-inch ID, with larger diameters envisioned in the future.

Dual-tube sampling is comprised of an outer casing that is driven simultaneously with an inner tool string that contains the core barrel for soil sample collection. Based on the length of the core barrel, the outer casing and inner tool string is driven as one. At depth, the inner tool string containing the core barrel/acetate liner is retrieved. This process is repeated by lowering the inner tool string to the base of the outer casing, adding additional casing/inner tool string, and advancing to target interval. The outer casing remains in the subsurface until final depth is achieved and completion actions (grouting, well installation) are performed.

Dual-tube samplers have been designed to match many of the DPT rod package sizes, and additional sizes likely will be developed to accommodate ever-expanding project needs. Current samplers include:

Model	Rod Size (OD in inches)
DT22	2.125/2.25
DT325	3.25
DT35	3.5
DT37	3.75
DT45	4.5
DT60	6.0

Figure 4: Current Dual-Tube Samplers

3.2.2 Shelby Tubes and Split-Spoons

Shelby tubes are the standard device for recovering undisturbed cohesive soils for geotechnical analyses and split-spoons are the standard device for recovering disturbed non-cohesive soils for geotechnical analyses. These devices may be advanced by any of the above referenced drilling techniques, typically at the end of extension rods.

ASTM D1587 is typically followed for Shelby tubes. Common sizes deployed are 2-, 3-, and 5-inch. Methods should follow the ASTM but may be adjusted due to subsurface conditions. Notably, this is an undisturbed, thin-wall sampler that was designed to be pushed. ASTM D1586 is typically followed for split-spoons, which are thick-walled samplers, designed to be hammered-in as part of Standard Penetration Tests (SPT).

3.2.3 Rotary Sonic

Depending on the soil type, the typical sonic core may retain a nearly complete soil column that is representative of the soil stratigraphy, but does not typically result in an undisturbed soil sample, due to both the method for core advancement and extrusion. Soil samplers and techniques that recover undisturbed soil samples may be used with sonic equipment. However, unless specific tools or techniques are used, sonic drilling can result in soil cores that are heated and reduced to a slurry, resulting in the destruction of loss of volatile organic compounds (VOC) or semi-VOC.

Consequently, in sampling for VOC or semi-VOC, drillers must seek approval from the ARA on a case-by-case basis and/or consider guidance on using rotary sonic techniques found in the EPA's "Design and Installation of Monitoring Wells" (Jan. 29, 2013) to insure that soil cores are not heated or disturbed.

The most prevalent rotary sonic sampling models and sizes are as follows, with larger sizes available for specialty applications:

Model	**Size (Nominal, in inches)**
SDT45	4.5 OD Sonic Dual-Tube
SDT60	6.0 OD Sonic Dual-Tube
4x6	4x6
6x8	6x8
8x10	8x10

Figure 5: Common Rotary Sonic Sampling Models and Sizes

3.2.4 Others

The soil samplers referenced in sections above are not intended as an exhaustive list of samplers suitable for use in Louisiana soils but represent those more commonly used for environmental boreholes. Other samplers include piston and pitcher samplers, typically associated with geotechnical investigations. These and other tools should be evaluated by the drilling team and utilized as designed for the appropriate subsurface conditions.

In addition, hand tools are used occasionally to advance borings when access for mechanized boring equipment is an issue. A hand auger or posthole digger by their nature can only retrieve disturbed soil samples. There is, however, hand-advanced DPT sampling equipment that can retrieve cores of soil that are representative. In situations where sampling of VOC or semi-VOC is required, drillers must seek approval from the ARA on a case-by-case basis as to the tools and techniques utilized.

3.3 Logging of the Borehole

Soil types and condition of the soils encountered during the boring operation should be described in detail. Logging of these boreholes should be done by an individual such as a soil technician, geologist or engineer with sufficient experience to identify soil types and the presence of contaminants and other relevant information to document subsurface conditions.

The following information typically is documented on the boring log or attached to it:

- The name of the drilling company, driller and individual logging the boring;
- The latitude, longitude and surface elevation of the borehole and the method used to obtain the data, for instance, Global Positioning System (GPS), topographic map, Light Detection and Ranging (LIDAR) professionally surveyed to the North American Vertical Datum of 1988 (NAVD 88), etc.;
- The depths at which soil types change or groundwater is encountered;

- The soil types encountered in the boring, described in sufficient detail for the soils to be classified by the visual/manual procedures described using the Unified Soil Classification System (USCS, equivalent to ASTM 2487 and 2488);
- Rock or similar lithified or semi-lithified materials described by generally acceptable terms;
- Identification of the depths where soil samples were submitted for laboratory or geotechnical analysis: Moisture content (ASTM D-2216), Liquid Limit, Plastic Limit and Plasticity Index (ASTM D-4318), Organic Content (ASTM D-2974), Particle Size Analysis of Soils (ASTM D-422 or ASTM C-136);
- Identification of special problems and their resolutions on the log (*e.g.*: hole caving, recurring problems at a particular depth, sudden tool drops, excessive grout takes, drilling fluid losses, casing installation problems, etc.);
- Dates and times for the start and completion of the boring;
- The first encountered free water with the depth recorded on the log;
- Any special abbreviations used on the log defined where they are used, or in a general legend;
- All information associated with the logging of a borehole legible and indelibly transcribed; corrections made on the log should be done by a single line drawn through the error followed by the correction, date of correction and the initials of the person making the correction.

4.0 ELECTRONIC PROFILING TECHNOLOGIES

Electronic profiling technologies have been available for many years, providing *in-situ* subsurface data to environmental and geotechnical professionals. Tool technologies, computers, and software have expanded the offerings from traditional engineering sensors (pressure transducers and strain gages) to robust hydrostratigraphic, trace chemical, and pure product *in-situ* vertical profilers. Notable advantages of electronic borehole completion technologies include:

- Real-time field screening of the physical and chemical characteristics of soil;
- Faster, one-trip-in/one-trip-out of the borehole;
- Typically, reduced volumes of IDW;
- Smaller, lighter than traditional drilling tools;
- Commonly deployed with smaller footprint rigs;
- Safer to deploy from a health and safety perspective (smaller, lighter, with less operator fatigue);
- Electronic data sets are suitable for transmission from field (internet/Wi-Fi), computer analysis, and graphical presentation.

Large quantities of subsurface data have resulted in the development of High-Resolution Site Characterization (HRSC) approaches that deploy multiple desirable technologies for environmental projects. Most of these completion technologies are relatively small diameter and include sensitive instrumentation, which are typically pushed in-place or driven in-place using DPT (small-diameter boreholes). The subsurface conditions in Louisiana, coupled with challenging surface conditions (*e.g.*, wet, swamp, marsh, etc.) have resulted in the development of alternative pushing and DPT platforms such as: air boat, marsh buggy and barge carrier vehicles. The alternative pushing and DPT platforms complement electronic borehole completions.

Although most electronic borehole completions do not include permanent installations, these boreholes require grouting upon termination of testing operations. Retraction grouting is an available option on some completions and is generally considered the BMP. Re-driving rods to total depth and subsequent grouting is the principal grouting method currently employed when using small-diameter tool packages.

The below descriptions are intended to guide readers of this Manual of the available technologies, their typical application, and known considerations for use. Other electronic tool technologies are available and applicable for environmental and geotechnical use.

Some of the more common electronic borehole logging applications are:

Method	Primary Purpose	Comments
CPT	Soil Engineering Properties	Push-Only
Soil EC	Lithology	Simple Robust Tool
Hydrostratigraphic	Lithology and Hydraulics	*In-Situ* K-Values
MIP	Low Level Contamination	Phase Delineation
Fluorescence	Gross Contamination	LNAPL, DNAPL
Gamma/Wireline	Lithology	Wireline in Borehole or Well

Figure 6: Common Electronic Borehole Logging Applications

4.1 Cone Penetration Testing

The cone penetration testing (CPT) tool is an *in-situ* technique used to determine soil stratigraphy and geotechnical engineering properties of unconsolidated soils. The CPT method was developed in the 1950s and initially consisted of mechanical measurements. Contemporary CPTs typically have conical tips of either 10 or 15 cm^2 cross-sectional area (diameter 3.5 and 4.6 cm, respectively), and are pushed at a controlled pace of 1 to 2 cm/second. The penetration resistance to pushing the conical tip is known as the "tip friction" or "tip resistance." The penetration resistance to pushing on the outer surface of the tool is known as the "local friction" or "sleeve friction." The piezo CPT includes measurement of pore water pressure. In addition to being capable of measuring the hydrostatic surface within the subsurface, dissipation tests can be performed to determine hydraulic conductivity/permeability of soils below the water table. CPT systems collect this data (tip resistance, sleeve friction, and pore water pressure) electronically.

CPT tool penetration typically is advanced by pushing the tool with a heavy or anchored vehicle to develop an appropriate reaction force. Penetrations are advanced to target depth, refusal (total resistance = total reaction force), tool declination, or other operator reactions to cease penetration. With the CPT tool system, a near continuous profile (log) of soil parameters is developed. There are numerous researchers/authors on the topic and manufacturers of CPT data and systems. Standardized CPT testing procedures include ASTM D3441, 6001, and 6067; these and similar standards, along with BMPs, should be utilized when performing CPT tests. Soil borings completed using CPT penetrations are typically grouted using a retraction grouting attachment, or by re-driving to total depth with blank rods fitted with an expendable point, filling the rods with grout and subsequently retracting the rods.

4.2 Soil Electrical Conductivity Probing

The Soil Electrical Conductivity (Soil EC) tool is an *in-situ* technique used to determine lithologic properties of unconsolidated soils. Soil EC is the ability of soil to conduct electrical current in millisiemens per meter (mS/m). Soil EC is inversely proportional to particle size (clays have higher conductivity than sands). Soil EC values beyond the range of natural soils may be indicative of salinity or other contaminants.

The Soil EC tool penetration is most commonly advanced by driving the tool with a DPT machine. The Soil EC tool is considered "robust" and can be heavily hammered by DPT machines. Penetrations are advanced to target depth, refusal (total resistance = total reaction force), tool declination, or other operator reasons to cease penetration. With the Soil EC tool system, a near continuous profile (log) of soil electrical conductivity is developed.

There are numerous researchers/authors on the topic and manufacturers of Soil EC data and systems. Standardized Soil EC testing methods are available from the manufacturers in the form of SOPs and should be combined with BMPs. Soil borings completed using Soil EC penetrations are typically grouted by re-driving to total depth with blank rods fitted with an expendable point, filling the rods with grout and subsequently retracting the rods.

4.3 Hydrostratigraphic Testing

Hydrostratigraphic testing techniques are used to determine *in-situ* characteristics of groundwater flow within unconsolidated soils. In Louisiana, this technique effectively supplements the engineering and lithologic data that can be collected via CPT and Soil EC techniques. The systems inject a very small amount of fluid (typically potable water) into the subsurface, measuring pressure (via transducer) and controlling the flow rate of the fluid injection. In addition to being capable of measuring the hydrostatic surface within the subsurface, dissipation tests can be performed to determine hydraulic conductivity/permeability of soils below the water table.

The hydrostratigraphic tool penetration most commonly is advanced by driving the tool with a DPT machine. The Hydraulic Profiling Tool (HPT) manufactured by Geoprobe® is considered "generally robust" compared to EC probing and can be hammered modestly by DPT (with a hammer dampener in place). The sensitivity of the downhole transducer, along with electrical and water connections, requires some dampening of the hammering. Penetrations are advanced to target depth, refusal (total resistance = total reaction force), tool declination, or other operator observations to cease penetration. These systems provide a near continuous profile (log) of soil hydraulic properties.

There are numerous researchers/authors on the topic and manufacturers of these systems, including but not limited to: HPT by Geoprobe®, Dye-enhanced laser-induced fluorescence (DyeLIF) by Dakota Technologies, and the Waterloo Advanced Profiling System (WaterlooAPS™). Most manufacturers of hydrostratigraphic tools include a Soil EC measurement on their tool string. Standardized testing methods are available from the manufacturers in the form of SOPs and should be combined with BMPs. Soil borings completed using Hydro-Stratigraphic penetrations are typically grouted by re-driving to total depth with blank rods fitted with an expendable point, filling the rods with grout and subsequently retracting the rods.

4.4 Membrane Interface Probe (MIP)

Membrane Interface Probe (MIP) testing is used *in-situ* to determine the relative concentrations of volatile organic compounds (VOCs) in unconsolidated soils at trace levels (ppm and sub-ppm levels). For some environmental investigations, this can be a particularly valuable supplement to the soil borings, hydrostratigraphic, lithologic, and engineering data collected via traditional borings and *in-situ* techniques. The MIP tool is used to semi-quantitatively screen for VOCs, using a semi-permeable hydrophobic membrane within a 120°C heater block, promoting diffusion across the membrane. A carrier gas brings the diffused VOCs up the tool string to gas chromatograph detectors (typically PID, FID, EC/XSD) located at the surface, which perform the semi-quantitative screening (non-speciating).

The MIP tool most commonly is advanced by driving the tool with a DPT machine. The MIP tool is considered "generally robust" and can be hammered modestly by DPT (with a hammer dampener in-place), limited by the sensitivity of the downhole components, along with electrical and gas connections. Penetrations are advanced to target depth, refusal, tool declination, or other operator reasons to cease penetration. These systems provide a near continuous profile (log) of VOCs in soil.

There is one commercial manufacturer of these systems: Geoprobe®. Most applications of the MIP tool include a Soil EC measurement on the tool string. Standardized testing methods are available from the manufacturer in the form of SOPs and should be combined with BMPs. Soil borings completed using MIP penetrations are typically grouted by re-driving to total depth with blank rods fitted with an expendable point, filling the rods with grout and subsequently retracting the rods. A retraction grouting attachment is available, but is not effective or practical in many situations in Louisiana.

4.5 Fluorescence Tools

Fluorescence tools are used to develop vertical profiles of hydrocarbon, chlorinated, and polycyclic aromatic hydrocarbons (PAHs) contamination in non-aqueous form (LNAPL and DNAPL). For some environmental investigations, this can be a particularly valuable supplement to the soil borings, hydrostratigraphic, lithologic, and engineering data collected via traditional borings and *in-situ* techniques. The general principals of operation of most tools use a wavelength-tunable, ultraviolet laser source coupled with an optical detector to measure fluorescence via optical fibers. The measurement is made through a window on the tools. Some commonly available fluorescence tools are ROST™, LIF, UVOST®, OIP, DyeLIF, and TarGOST®.

The fluorescence tools most commonly are advanced by driving the tool with a DPT machine. They are considered "generally robust" and can be hammered modestly by DPT machines (with a hammer dampener in-place), limited by the sensitivity of the downhole components. Penetrations are advanced to target depth, refusal tool declination, or other operator reasons to cease penetration. These systems provide a near continuous vertical profile (log) of LNAPL or DNAPL in soil. Soil borings completed using these tools are typically grouted by re-driving to total depth with blank rods fitted with an expendable point, filling the rods with grout and subsequently retracting the rods.

4.6 Gamma and Other Wireline Logging Tools

The miniaturization of selected wireline logging tools has resulted in the ability to log within DPT rodsets. Notably, slim gamma logging (< ¾-inch diameter) can be performed within 2.25-inch OD DPT rodset upon reaching terminal depth. Temperature and conductivity logging are also readily available. These boreholes typically are grouted by filling the rods with grout, and retracting the rods. Gamma logging measures the amount of natural gamma radiation emitted by geologic materials surrounding the well/borehole through which the tool is advanced. In general, clay and shale-containing rocks emit relatively high natural gamma radiation, while sand and caliche do not.

4.7 Other Electronic Logging Technologies

Technological advancement has also resulted in the integration of multiple technologies (stacked tool strings). Many of the above electronic logging tools can be simultaneously deployed, yielding high-density, high resolution data sets. Modern computers and software can now manage, analyze, and visually present the large, comprehensive data sets.

Other logging technologies exist that are not described within this Manual; no doubt new ones will be developed through innovation and technological advances. While the use of innovative technologies is encouraged, Work Plans should be submitted to the ARA for approval prior to implementation for those technologies not generally recognized by the professional community. Utilization of such should always promote BMPs relating to plugging-and-abandonment and grouting, so that the subsurface natural resources of Louisiana are protected.

5.0 TEMPORARY GROUNDWATER SAMPLING POINTS

Temporary groundwater sampling points have become increasingly popular due to advances in tooling and pre-packed well screen design. Advancements have also included a wide array of supporting products designed for small diameter sampling points, including:

- Foot Valves for development;
- Swabs for development;
- Wireline Gamma Logging (¾-inch);
- Water Level Probes;
- Pneumatic Slug Testing;
- Bailers;
- Bladder Pumps;
- Transducers.

Temporary groundwater sampling points can be installed manually, using DPT, sonic drilling methods, and rotary drilling methods. The following guidance is specific to temporary sampling points. This guidance should be applied with the following BMPs to prevent the migration of impacts:

- No registration is required if the temporary groundwater sampling point is plugged within 60 days. Chapters 10.0 and 11.0 contain guidance for plugging and registration;
- A bentonite seal may not be necessary if groundwater samples are collected within the same mobilization event or the temporary sampling point contains a surface seal. A surface seal is a BMP;
- Extending the sand pack above the well screen may not be necessary if groundwater samples are collected within the same mobilization event or the temporary sampling point contains a surface seal;
- Annular grouting of temporary well boreholes may not be necessary if groundwater samples are collected within 60 days of completion and the temporary sampling point is properly plugged-and-abandoned (see Chapter 10.0);
- Pre-packed bentonite sleeves may be used during the construction of temporary sampling points;
- Surface completions are not required for temporary sampling points. Protection and/or flagging surrounding or on the well-point is a BMP;
- A slip-on or threaded cap should be maintained on the temporary sampling point.

Should the temporary sampling point be converted to a permanent monitoring well, the well should be completed and registered as described in Chapters 6.0 and 10.0, respectively.

5.1 Drive Points

A slotted screen drive point is a steel rod that contains machined slots that allow the groundwater to enter the rod assembly at a given depth. The driven slotted screen is not encased within an outer casing and is exposed to soil/groundwater conditions as it is driven to depth. This temporary sampling method works best in soils with high permeability and where surface impacts are not present. The advantages to the drive point sample include: its speed in the right conditions; the fact that the grouting can be completed using the downhole tool string; and collection of groundwater samples from multiple intervals (top/bottom). Potential disadvantages include: its slowness in wrong conditions; possibility of upper rods leaking; limited to small-diameter wells with no filter pack surrounding the well screen; and the ability of clayey materials to plug the screen.

5.2 Retractable Screen Samplers

Stainless steel and polyvinyl chloride (PVC) drop screens are often used for the collection of groundwater samples. In the case of the drop screen, the screen is located inside of a larger rod (sheath) and driven to the desired depth. The drop screen is held in place by an expendable point at the base of the sheath and engineered drive head. Once the depth is reached, the tooling is retracted (length of screen), thus exposing the well screen. The advantages of retractable screen samplers include: its speed in the right conditions; the fact that the grouting can be completed using the downhole tool string; common 10- and 4-slot screen sizes; collection of groundwater samples from multiple intervals (top/bottom WBU); and the screen is not in contact with upper soil/groundwater zones while being driven to depth. Potential disadvantages include: its slowness in wrong conditions; possibility of upper rods leaking; and the fact that small-diameter wells might have no filter pack surrounding the well screen.

5.3 Temporary Sampling Points/Wells

The following sections contain guidance on temporary sampling points/wells (and piezometers). In most cases the temporary sampling point contains many of the same materials as a permanent monitoring well but is normally used for a single groundwater sample and then is removed from the subsurface and the borehole plugged-and-abandoned.

5.3.1 Standard Installations

In cases where standard screens and casing are used, the suggested borehole sizes are based on nominal DPT rod package diameters. When a standard screen is utilized, the filter/seal materials are to be installed as the outer casing is removed from the subsurface. The advantages include: accurate depth/filter pack placement; possible conversion into permanent monitor well; re-sampling if needed; and quicker development time. Disadvantages include: use on smaller diameter well points and the danger that when adding the filter pack and/or seal, these materials can bridge within the rods.

5.3.2 Pre-Packed Screen Installations

Temporary monitoring wells are typically constructed of PVC risers with pre-packed screens. The pre-packed screens are usually 3- or 5-foot sections with selected inside and outside diameters. The inner component of the pre-packed screen consists of a PVC screen with the appropriate slot size and diameter. The screen component is usually PVC 0.010-inch slotted screen, while the outer component is a stainless steel wire mesh. The screens are typically pre-packed with 20/40 grade silica sand between the PVC screen and wire mesh by the manufacturer. Larger pre-packed screen assemblies may be field-packed with sand, due to shipping considerations. The following table contains the suggested borehole diameter for the given well diameter:

Figure 7: Suggested Borehole Diameters

Well Diameter (inches)	Outer Screen Diameter (inches)	Borehole Diameter (minimum, in inches)
0.5	1.4	2.5
0.75	1.4	2.5
1.0	2.4	3.5
1.5	2.5	3.5
2.0	3.4	4.5

Advantages include: very accurate depth/filter pack placement; works well in "flowing/heaving sand"; may be used in fine grain formations; may be converted into permanent monitor wells; allows for re-sampling if needed; and quicker development times. The primary disadvantage of pre-packed screens is there use in typically smaller diameter well points, which precludes some specialty instrumentation.

5.4 Open Boreholes

This process entails inserting the temporary well screen and riser into the open borehole created during soil sampling processes. When implementing this installation method, the temporary sampling point should be placed (never driven) to the desired depth as drilling often leads to well failure, both structural and in yield. The major advantage of open boreholes is their ease of installation in certain soil types; they are typically best suited for the first WBU. Disadvantages include: no filter material; longer development times; low well yield in most cases; allows perched water to enter the borehole; and provides a conduit for residual soil impacts to vertically migrate.

5.5 Other Temporary Sampling Point Constructions

The above sections outline guidance for the most commonly used temporary sampling point installation methods. Some other methods currently being used are multi-port temporary well points and the Geoprobe® groundwater profiling tool. The guidance listed above should be referenced when using these temporary sampling methods.

Multi-port temporary well points enable the collection of multiple depth-discrete groundwater samples from a single temporary well. The multi-port temporary well point consists of an outer tube that contains several inner ports. At each port a small screen can be inserted to collect a groundwater sample from a specific interval. Should a multi-port temporary well point be converted to a permanent construction, it should be completed and registered as described in Chapters 6.0 and 11.0, respectively.

The Geoprobe® groundwater profiling tool allows for the collection of groundwater samples at discrete depths using the dual-tube soil sampling system. As tooling systems advance, new methods for groundwater collection will follow. While the use of innovative sampling techniques is encouraged, Work Plans should be submitted to the ARA for approval prior to implementation for those techniques not generally recognized by the professional community.

6.0 MONITORING WELL SYSTEMS

6.1 Overview and Sequencing

Monitoring well systems should be designed and installed under the supervision of a qualified professional with relevant knowledge in installation experience. The qualified professional should be available for consultation during the installation of the monitoring well system. The basic steps to well construction are as follows:

- Complete the borehole;
- Select the screen interval and filter pack;
- Install the screen and riser pipe in the borehole;
- Backfill the annular space around the screen with the appropriate filter pack;
- Backfill the annular space above the screen/filter pack with a bentonite seal grout (typically one foot);
- Grout annular space above the bentonite seal;
- Seal the surface and complete the well head.

All well installations envisioned by this Manual are assumed to be regulated by LAC Title 56. Deviations from this Manual's guidelines or LAC Title 56 require a Work Plan with ARA concurrence. Applicable BMPs are provided on a task-by-task basis in this chapter. Emphasis is placed in this chapter on sealing the well screen (typically bentonite seal above filter pack), selection and emplacement of grout to seal the annular space from overlying soils, and placement of a surface seal that is as good or better than the native ground conditions. The objective is to ensure that the well is constructed in a manner that effectively provides protection of groundwater and is consistent with the intended use (*e.g.*, monitoring, remediation).

6.2 Screen Interval Selection and Well Materials

Well screen lengths should be selected based on the well purpose. Some wells are designed to determine the general presence or absence of contaminants. Others are designed to monitor a discrete zone for a particular contaminant type. Design of screen length should take into consideration the hydrostratigraphy, temporal considerations, environmental setting, constituents of concern, fate and transport of contaminants, and/or regulatory requirements. Typically, monitoring wells serve a dual role as groundwater quality sampling points and as piezometers to measure hydraulic head at a particular location and depth. The length of well screens in permanent monitoring wells should be long enough to effectively monitor the interval or zone of interest. Monitoring well screen lengths may range from as short as two feet to greater than 20 feet. Typically, well screen lengths are five or 10 feet, and rarely exceed 20 feet.

Previous assessment activities and historical information gathered can help identify whether NAPL is present in the subsurface soils and/or groundwater. If NAPL was observed during previous field activities, then a determination should have been made whether the NAPL is dense or light (heavier or lighter than water). A qualified professional logging the borehole should document the top of the groundwater-bearing zone to be monitored and/or remediated. If LNAPL was observed at the soil/groundwater interface, then the well screen should extend from the bottom of the boring to at least two feet above the soil/groundwater interface. If a smear zone was identified due to groundwater elevation changes, then the well screen may need to extend more than two feet above the soil/groundwater interface. However, the total length of the well screen should not exceed 10 feet without ARA approval.

If the NAPL is determined to be DNAPL, then the screen must be placed at the bottom of the borehole. There should be no filter pack beneath the base of the screen as this construction may provide a place for the DNAPL to sink and not be detected. If DNAPL is observed, the well screen should be placed at the bottom of the saturated zone or just above a confining layer. Screen lengths should be as short as possible.

In the event particularly shallow monitor wells are required which result in the top of the screen being very near the ground surface, Table 3 ("Monitor Well Systems Field Guide Summary") offers examples to accommodate non-typical surface seal and grout intervals.

6.2.1 Materials

All new well screens must be commercially fabricated, slotted or continuously wound, and have an ID equal to or greater than the ID of the well casing. An exception may be warranted in the case of continuously-wound screens. No fitting should restrict the ID of the joined casing and/or screen. The end plug should be composed of the same material as the well screen. The screen assembly must be able to withstand installation and development pressures without collapsing or rupturing.

Riser casing and well screen materials selection should consider compatibility with constituents monitored and the potential for over or under estimation of constituent concentrations. Rigid PVC materials meeting NSF Standard 14 type WC (Well Casing) are generally acceptable but other materials may be used with prior ARA approval. Materials should be selected that will be rugged enough to endure the anticipated lifespan of the monitoring well. Stainless steel (304 or 316) or rigid PVC meeting NSF Standard 14 (type WC) are materials typically used for monitoring well casing or screen. There are other materials used for well riser and screens such as HDPE, black iron, carbon steel, galvanized steel, and fiberglass, but these materials are less common and not often recommended. In cases where a driven casing is used, or a high strength outer casing is needed, carbon steel may be acceptable in non-corrosive groundwater-bearing zones. The well casing should be secured to the well screen by flush-jointed threads.

6.2.2 Size

The ID of the well screen should be based on anticipated uses of the well. The actual inside diameter of a nominally sized well is a function of screen construction and the wall thickness/schedule of the screen, casing, and joints. In the case of continuously-wound steel screens, their interior vertical supporting rods may reduce the full inside diameter. Additionally, the welded couplings on 2-inch ID stainless steel well pipe frequently reduces the inside diameter to slightly less than two inches. This consideration is critical when sizing pumps, bailers, surge devices, etc.

The most common nominal casing size for permanent monitoring wells is two inches, though smaller sizes (0.5-inch, 0.75-inch, 1-inch) are commonly used in many applications. The historical preference for 2-inch ID well has been primarily due to the sufficient diameter available for sampling with most types of devices such as bailers or low-flow samplers). Sampling and purge methods have improved and thus smaller wells, as identified above, may provide groundwater quality and potentiometric data that meets project objectives. If the well may be used as part of a remediation system, a greater ID may be considered (likely 4-inch or 6-inch).

6.2.3 Filter Pack and Slot Size

The grain size distribution of the screened formation and the filter pack gradation are the primary parameters that should be used when selecting a slot size for the well screen. Therefore, the grain size of the groundwater-bearing zone lithology should be the determining factor in selecting well screen slot size. The largest practical slot size that is compatible with the groundwater-bearing zone and available filter material should be used. This will allow maximum intake volume per unit screen length. The slot size should retain at least 90 percent (preferably 99 percent) of the filter pack material.

In formations consisting primarily of fines (silts and clays), the procedures for water well screen design may result in requirements for filter packs and screen slot sizes that are not available. The selection of 0.010 inch screen slots with a 20/40 sand filter pack or 0.005-inch screen slots with 100-sand filter pack for very fine formations is generally acceptable for most environmental monitoring applications. ASTM D5092 (*Design and Installation of Ground Water Monitoring Wells in Aquifers*) may be consulted for further guidance on specifications for appropriate applications.

The filter pack materials should consist of clean, rounded to well-rounded, hard, insoluble particles of siliceous composition. The required grain-size distribution or particle sizes of the filter pack materials should be consistent with the selected slot size of the well screen. In practice most filter pack materials consist of 20/40 sand, which is compatible with a 0.010 slot (ten-slot). A BMP for filter pack materials is to perform a sieve analysis conducted on the soil samples collected from the aquifer materials and/or the formation(s) to be monitored. The filter pack grain size is based on the smallest formation material.

The following chart provides a comparison of typical filter pack mesh sizes and appropriate screen slot size:

Figure 8: Typical Filter Pack Mesh Sizes and Screen Slot Sizes

Screen Slot Size (in inches)	Screen Slot Size Number	Typical Sand Pack Sieve Size Number
0.005	5	100
0.010	10	20 to 40
0.020	20	10 to 30
0.030	30	10 to 20

Filter pack materials should not be accepted unless proper documentation can be furnished as to the composition, grain-size distribution, cleaning procedure, and chemical analysis. If a data search reveals that there is enough existing data to adequately design the well screen and filter pack, then it may not be necessary to conduct a sieve analysis on the formation materials to be monitored.

6.3 Screen, Casing and Centralizer Placement

Install the well screen, casing and centralizers (well materials) within the borehole. If hollow-stem augers or rod packages like sonic or DPT are used, install the well materials within the augers/rods. BMPs for well material placement include:

- Field personnel handling the well materials should wear new, clean gloves to prevent contaminating the well materials;
- Centralizers are often used for wells greater than 50 feet deep and are generally placed below the screen, above the screen, and mid-riser; special care should be taken to ensure that the centralizer does not affect the placement of the filter pack, well seal, and grout;
- Silt traps or sumps attached by a threaded connection and of the same composition as the screen are often used below the screen as a collection point for sediment; these shall not exceed two feet in length, unless otherwise approved by the ARA;
- If DNAPL is present, the well screen should be placed directly on the bottom of the borehole; no sump will be used in such cases;
- Hold or hang well materials in tension, which ensures a straight and vertical alignment;
- Lubricating oils or grease should not be used on casing threads;
- Glue of any type should not be used to secure casing joints;
- O-rings are recommended to insure a tight fit and minimize leakage;
- Environmental well casings typically utilize flush-jointed threads.

The augers/rod packages should be slowly extracted as the filter pack and bentonite pellet seal are tremied and/or poured into place, as described below.

6.4 Filter Pack Placement

Filter packs are placed in the borehole and around the well screen to prevent natural formation material from entering the well screen. The filter pack typically extends two feet above the top of the well screen to allow for settling and to isolate the screened interval from the grouting material. In open boreholes, the filter pack should be placed by the tremie or positive displacement method. Placing the filter pack by pouring the sand into an open drill stem is acceptable with the use hollow stem augers and other methods such as sonic or DPT where the borehole is temporarily cased down to the filter pack. The augers/rods should be slowly extracted as the filter pack is tremied and/or poured into place at a rate equal to the auger/rod extraction rate. The gradual extraction of the augers/rods will allow the materials being placed in the augers to flow out of the bottom of the augers into the borehole displacing the borehole fluids. If the augers/rods are not gradually extracted, the sand will accumulate at the bottom of the augers causing potential bridging problems.

The final depth to the top of the granular filter should be measured directly and recorded in the field logbook. Final depths must not be estimated based on volumetric measurements of placed filter sand. A fine-grained sand such as 30/65 may be used as a secondary filter pack in deeper wells. The objective of a secondary filter pack is to supplement the bentonite seal, which reduces the potential for vertical grout migration into the filter pack.

In the event particularly shallow monitor wells are required which result in the top of the screen being very near the ground surface, Table 3 ("Monitor Well Systems Field Guide Summary") offers examples to accommodate non-typical surface seal and grout intervals.

6.5 Bentonite Seal

The objective of an annular seal is to prevent intrusion of the annular grout into the filter pack. This is particularly critical in thin, fully penetrated WBUs common in Louisiana environmental wells. This seal may become less critical in thick, partially penetrated WBUs as the filter packs may extend significantly above the screen and annular grouts will be in contact with the natural sand formation. Seals are typically designed to be 1- to 3-feet in thickness above the filter pack. Bentonite is the most common material used for the annular seal. Bentonite has the ability to expand when completely hydrated to form a dense clay mass with very low permeability, thereby providing an effective barrier to water migration. However, bentonite is not effective when improperly hydrated, allowed to desiccate in place, or placed in high or low pH environments. To allow for adequate hydration and avoid desiccation, bentonite seals must be placed at a depth below the lowest anticipated static ground water level in the well.

Bentonite used as an annular seal may be coated or uncoated pellets/tablets, chips, powders, and pre-packed assemblies. Pelletized or chipped bentonite should be used for bentonite seals, whereas powdered or granular bentonite should be used when preparing slurries. The materials must be a 100 percent pure sodium bentonite (montmorillonite) supplied in sacks or plastic buckets. The bentonite must be free of any additives or other material that may adversely impact water quality in the resulting environmental well.

Types and application of bentonite seals include:

- **Coated compressed pellets/tablets**–typically used as a seal for deeper applications with extended water columns; comes in multiple sizes (0.25-, 0.375-, 0.5-inch, etc.); the coating dissolves slowly, minimizing sticking and bridging;
- **Uncoated compressed pellets/tablets**–typically used for shallow applications; comes in multiple sizes (0.25-inch, 0.375-inch, etc.);
- **Chips**–typically used for shallow applications; comes in multiple sizes (crumbles/granular, medium chips, and large chips);
- **Powders**–typically high solids grouts are blended to make a slurry (soft grout);
- **Pre-packed bentonite assemblies**–typically consists of pre-molded granular bentonite that is formed to well casing immediately above the screen with packaging cover of usually brown paper designed to dissolve in water.

Since bentonite products begin hydrating rapidly, they can be very difficult to place properly. The preferred method of placing bentonite pellets or chips is by positive displacement or by use of a tremie pipe. The tremie method minimizes the risk of pellets or chips bridging in the borehole, as they are placed by tremie pipe and flushed into place with potable water. Pouring of uncoated pellets/tablets is acceptable in shallow boreholes, while coated pellets/tablets are a BMP for deeper and long water column applications.

To provide accurate measurement of bentonite thickness in the well boring, a tamper can be used to ensure that the material is being placed properly and to rapidly break up any bentonite bridging that occurs. If casings are used, the thickness should be verified after casing removal to account for the void space. Where cement grouts are to be used, the bentonite should be hydrated according to manufacturer specifications. Where the water table is temporarily below the bentonite seal, potable (or higher quality) water should be added repeatedly to hydrate the bentonite prior to grouting. Bentonite seals should be measured during and immediately after placement, without allowance for swelling.

Hydration may extend the height of the bentonite seal. A secondary filter pack (sugar sand–100-sieve) can also be used above the bentonite seal to compress the bentonite into the borehole wall and to further prevent potential intrusion of the grout into the filter pack and represents a BMP that may be used to reduce the hydration period for the bentonite.

The final depth of the top of the bentonite seal should be directly measured (by tape or rod) and recorded. Final depths should not be estimated based on volumetric measurements of placed bentonite.

In the event particularly shallow monitor wells are required which result in the top of the screen being very near the ground surface, Table 3 (“Monitor Well Systems Field Guide Summary”) offers examples to accommodate non-typical surface seal and grout intervals.

6.6 Grouting of the Well Annulus

Once the bentonite seal has been given sufficient time to hydrate, the annulus of the well can be sealed by pumping the grouting material down the annulus. Important considerations in grouting include grout selection, grout mixing, and grout placement, as discussed below. Grouting is the most critical component of environmental well installations for two key reasons, namely the protection of the state’s natural resources and the collection of representative groundwater data. The objective of this procedure is to remove excess produced fluids (water) and drill cuttings from the annulus.

In the event particularly shallow monitor wells are required which result in the top of the screen being very near the ground surface, Table 3 (“Monitor Well Systems Field Guide Summary”) offers examples to accommodate non-typical surface seal and grout intervals.

6.6.1 Grout Selection

Thirty years of grout experience in Louisiana under LAC Title 56 have helped identify the optimum methods for selecting grouts that: protect groundwater from potential surface contamination; increase the life of the well by protecting the casing against exterior corrosion; and prevent the introduction water of objectionable quality from one aquifer to another. Based on this long field experience, cement-bentonite grouts have been the most commonly used grouts in the state. However, a careful review of published reports and studies on grouting from other states and/or industry groups shows that other grouts meet the objectives stated above. The Nebraska Grout Study, for instance, compared multiple grout materials under varying subsurface settings and applications to build an evaluative framework for professionals in the field. It is possible that some of these less-utilized grouts may be of value for specific projects here in Louisiana.

LAC Title 56 currently allows for the following grout materials/types:

- **Cement-bentonite slurry**–composed of Portland cement, bentonite and water;
- **High-solids bentonite grout**–consists of predominantly sodium bentonite;
- **Neat cement**–composed of Portland cement and water.

The Nebraska Grout Study and others demonstrated that cement-bentonite grouts do not perform as well as other grout mixtures due to non-adherence to the casing, shrinkage, heat of hydration, and cracking. These same studies showed that high-solids bentonite grout, however, generally performed well in humid areas analogous to Louisiana. To date, these grouts have been infrequently used in Louisiana. Neat cement has also been infrequently used in Louisiana but also performed well under certain conditions in these studies. In summary, the grout studies indicate that other grout mixtures may be more effective than the materials/types identified in LAC Title 56 when used under the appropriate conditions, according to geology, climate, depth to water, and with proper placement.

Grouts identified in these studies that would meet the design objectives under LAC Title 56, if installed and applied correctly, would include:

- Cement/sand grout mixtures;
- Bentonite chips;
- High-solids bentonite grout;
- Neat cement;
- Bentonite pellets;
- Cement-bentonite grout.

The use of grouting materials not identified in LAC Title 56 should be determined on a site-specific basis and will require ARA approval prior to implementation. As noted above, high-solids bentonite grout is identified in LAC Title 56 but is rarely used though these materials have beneficial applications, as described above. Examples of where grouting materials not identified in LAC Title 56 may be appropriate include: installation of a shallow monitoring well in an area with a shallow water table (bentonite chips or pellets); installation of a monitoring well in a deep

WBU (cement/sand mixture); installation of a monitoring well in the first WBU with a deeper water table (bentonite chips or pellets if there is sufficient soil moisture).

The grouting material selected should not contain any additives that may compromise analytical data indicative of the actual condition of the groundwater. The cement must not contain lumps indicating storage under wet conditions prior to use. The cement should be low alkaline (0.6% total alkalis or less) Portland cement Type I/II or API Class A. The water should be potable or of the same quality as used for the construction of the borehole. There is a definite relationship between the amounts of each component in a cement-bentonite grout mix. The most critical factor is the cement-to-water ratio. Excessive water thwarts the bonding ability of the cement and may lead to micro-annular features around the well casing.

The high-solids (25+%) bentonite grouts are composed of 90% sodium montmorillonite clays, specially designed as a grouting material for well boreholes and well annuli seals. These mixtures should be free of any polymer additives and must achieve a density of at least 9.4 pounds per gallon (lbs/gal). High-solids bentonite grouts are readily available from multiple manufacturers and distributors in Louisiana. Grouts consisting of attapulgite clay instead of bentonite may be used for installation of wells in saline aquifers. Bentonite is not effective when improperly hydrated, allowed to desiccate in place or placed in high or low pH environments. For contaminated groundwater sites, the compatibility of grouting materials with contaminants should be considered during work plan development.

6.6.2 Mixing

Mixing of the grout material should be done by a mechanical paddle device or recirculation with a grout pump in accordance with manufacturer instructions. Manual mixing is discouraged and recirculation is inappropriate for some mixtures due to shearing. Mixing activities should continue until a smooth, lump-free consistency is achieved. Once a uniform blend is achieved, the grout weight should be determined with a calibrated mud balance (ASTM-D-4380). The weight of the mixture should be +/- 0.2 lbs/gal of the appropriate target weight. The weight of the pumped mixture should be recorded on the well construction log.

6.6.3 Placement

All pumped grout materials should be placed by a rigid, side-discharge tremie pipe using a pump specifically designed and manufactured to pump grout materials. The use of pumps associated with the recirculation system of the drilling equipment is not the BMP, as rig pumps may not be able to accommodate the weight or viscosity of the grout and may contaminate the grout unless decontaminated after each use.

Proper grout placement requires an open borehole (the boring remains open at depth once augers or drill rods are removed) or a cased borehole (augers, sonic casing, DPT rods removed as the well is being constructed) utilized to maintain borehole integrity with depth during the grouting process. For an open borehole, the side discharge tremie pipe is typically placed a few feet above the bentonite seal and, if applicable, slowly withdrawn as the grout is pumped. The rate of tremie pipe withdrawal should ensure that water and cuttings return to the surface, and that there is minimal downhole dilution of the grout. Pumping of the grout should continue until undiluted grout exits the annulus at the surface. The grout returns at the surface should be sampled and weighed with the mud balance. When the unit weight of the pumped grout equals the original grout, grouting activities may stop. The objective of this procedure is to remove excess water and drill cuttings from the annulus.

Grout placement within cased boreholes should proceed similar to above. However, grouting is performed in stages as portions of the casing/augers are removed. This is typically achieved by grouting within the casing, removing a string of casing, allowing for grout displacement of the space previously occupied by the casing/auger/borehole fluids, adding additional grout, and repeating the procedure until all casing/augers are removed and the grout is returned to the surface.

Gravity placement of grout within the annular space of a well is acceptable only under certain conditions, such as when the grout addition is limited to a few feet or a limited amount of water columns are present. The total volume of the grout pumped into the annulus should be recorded on the well construction log. The annular grout should be inspected for settlement and additional grout added as needed. The volume of additional grout should be recorded on the well construction log. The protective casing for the well is typically set into the grout column, resulting in the protective cover being integrated into the annular grout seal. Care should be taken to properly perform the final construction steps to maintain seal integrity.

6.7 Surface Casings and Multi-Cased Wells

Multi-cased wells should be constructed when there is reason to believe that interconnection of two groundwater-bearing zones by well construction may cause cross-contamination or when flowing sands make it impossible to install a monitoring well using conventional methods. A highly contaminated surface soil zone also may be cased-off so that continued drilling below the casing will reduce the chance of cross contamination.

Outer well casing used as a permanent part of the installation when multi-cased wells are installed must be composed of new material. The casing must be free of interior and exterior protective coatings and must be steam cleaned or washed with a high-pressure water device (if appropriate for the selected material) using approved water immediately before installation. The type of material and wall thickness of the casing must be adequate to withstand the installation process. Surface casing must consist of steel meeting ASTM Standard A53/A53M-06 or Schedule 40 or 80 PVC, and shall have a minimum wall thickness of 0.25 inches, unless otherwise specified. The ends of each casing section are typically flush-threaded or beveled for welding.

A pilot borehole should be bored through the overburden and/or the contaminated zone into the clay-confining layer. An outer casing (sometimes called surface or pilot casings) should then be placed into the borehole and sealed with grout. The borehole and outer casing should extend into tight clay, typically 2 feet. The total depths into the clay will vary, depending on the plasticity of the clay. The final depth should be approved by a qualified professional. The size of the outer casing should have sufficient inside diameter to contain the inner casing of the future monitor well and typically a 2-inch annular space. In addition, the borehole for the surface casing should be of sufficient size to contain the outer casing and the 2-inch outer annular space, if applicable.

The outer casing should be grouted using the tremie or displacement method from the bottom of the pilot borehole to the ground surface. The grout should be pumped into the annular space between the outer casing and the borehole wall. A minimum of 24 hours should be allowed for cement-bentonite grout plugs (seals) to cure before attempting to drill through it. The grout mixture used to seal the outer annular space and the seal or plug at the bottom of the borehole should be consistent with the materials and placed as identified previously.

When drilling through the seal, care should be taken to avoid cracking, shattering, or washing out the seal. If caving conditions exist such that the outer casing cannot be sufficiently sealed by grouting, the outer casing should be driven into place and a soft grout seal placed in the bottom of the casing.

TABLE 2
RECOMMENDED MIX DESIGNS FOR CEMENT-BENTONITE GROUT

Materials		**4% Mix**		**5% Mix**		**6% Mix**		**7% Mix**	
Cement Sacks	Pounds Cement	Pounds Bentonite	Gallons Water	Pounds Bentonite	Gallons Water	Pounds Bentonite	Gallons Water	Pounds Bentonite	Gallons Water
1	94	3.8	7.8	4.7	8.5	5.6	9.1	6.6	9.8
2	188	7.5	15.6	9.4	17.0	11.2	18.2	13.2	19.6
3	282	11.3	23.4	14.1	25.5	16.9	18.2	19.7	29.4
4	376	15.0	31.2	18,8	34.0	22.6	27.3	26.3	39.2
5	470	18.8	39.0	23.5	42.5	28.2	36.4	32.9	49.0
6	564	22.6	46.8	28.2	51.0	33.8	45.5	39.5	58.8
7	658	26.3	54.6	32.9	59.5	39.5	54.6	46.1	68.6
8	752	30.1	62.4	37.6	68.0	45.1	63.7	52.6	78.4
9	846	33.8	71.2	42.3	76.5	50.8	72.8	59.2	88.2
10	940	37.6	78.0	47.0	85.0	56.4	81.9	65.8	98.0
Slurry Weights		**14.1 lbs/gal**		**13.8 lbs/gal**		**13.5 lbs/gal**		**13.3 lbs/gal**	

6.8 Surface Completion – Well Protection, Labeling and Identification, Surveying

A protective casing is typically installed around each monitoring well the same day as the grout placement. Any annulus formed between the outside of the protective casing and the borehole or between the monitoring well and protective casing should be filled to the ground surface with grout as part of the overall grouting procedure. ASTM D5787 provides guidance for monitoring well protection described in the following paragraph. Although not exhaustive, the guidance identified components and considerations for a good surface completion. All protective casings should be clean prior to placement; free of extraneous openings; and devoid of any asphaltic, bituminous, encrusted, and/or coating materials, except the paint or primer.

The material type of the protective casing should be adequate to protect the completed monitoring well. The protective casing materials need to be selected such that they provide adequate protection against physical destruction, tampering, natural degradation, and the environment. Protective casing materials may conform to the following:

- Locking 16-gauge steel or aluminum protective well cover, round or square and 5-feet in length, or flush-mounted 22-gauge steel, water resistant, welded box with 3/8-inch steel lid;
- Cement consisting of one of the five Portland cement types specified in Standard C 150;
- Brass, corrosion resistant, keyed-alike padlock, available from monitor well supply vendors and locksmiths; note that harsh conditions such as humidity and flooding may require replacement of these locks over time;
- Protective bumper posts constructed of 4-inch diameter and minimum 5-foot long steel or aluminum pipe (four per well). Each post must be set into concrete outside the corners of the concrete pad and filled with concrete;
- Paint that matches existing monitoring wells at the installation. Where no wells exist, it is recommended to use high visibility yellow epoxy paint;
- A well identification tag.

The metal identification tag should be attached to the protective casing of each monitoring well or placed square on the protective concrete pad. The tag typically contains the following:

- Well Designation/Name/ID;
- Depth;
- Screen Interval;
- Date of Installation;
- Top-of-Casing, Top-of-Screen, and Concrete Pad Elevations.

Each boring and/or well installation should be topographically surveyed to determine its location referenced to either a Universal Transverse Mercator (UTM) grid or the State Plane Coordinate System (SPCS). If the project is an area remote from UTM or SPCS benchmarks and such horizontal control is not warranted, then locations measured from an alternate system depicted on project plans may be acceptable.

Elevations for a designated or marked measuring point on the rim of the uncapped well casing (not the protective casing) and concrete pad for each well shall be surveyed to within +/- 0.01 foot and referenced to the NGVD 1988. Prior to surveying the elevation of the top of casing, a designated measuring point is typically marked. Some example markings include: indelible ink mark; “V-notch”; or cutting the top of casing at an angle so that the surveyor rod only rests properly on the high side. In the absence of a marked measuring point, many samplers measure depth to water from the north side of the casing. The purpose of the designated measuring point is to guide the monitor well sampling team to a consistent measuring point for use at each well. For any special circumstances or environmental conditions, the driller should consult with the ARA for case-by-case guidance.

Elevations for the natural ground surface at the well site (not the top of the concrete pad) should be within +/- 0.10 foot and referenced to the NGVD 1988. These surveys should be connected by third-order leveling to the NGVD in accordance with the Standards and Specification for Geodetic Control Networks. If the project is in an area remote to NGVD benchmarks and such vertical control is not warranted, then elevations measured from a project datum may suffice.

Temporary benchmarks may be installed to perform survey work. Temporary benchmarks typically consist of one or more of the following:

- Iron pin (#4 rebar minimum, 24 inches in length);
- Benchmarks identified in the Monitoring Well Design and Construction Guidance Manual (2008);
- Railroad spike in utility pole or tree;
- Masonry nail driven in pavement;
- Chiseled square on a concrete structure;
- Painted portion of a fixed object, such as a specific part of a fire hydrant.

Permanent benchmarks may be required to provide future control at a site. Permanent benchmarks will consist of a concrete monument a minimum of five inches square and two feet in depth with an iron pin imbedded full depth of the concrete and set flush with the top of the concrete, or a brass marker set in a five-inch square, two-foot deep concrete monument.

6.8.1 Above-Ground Completions

A ¼-inch diameter hole (or weep hole) should be drilled in the protective casing immediately above the concrete pad to allow water to drain from the inside of the protective casing. Vent holes should not be used for flush-mounted well completions. Enough clearance, usually two to six inches, may be left between the lid of the protective casing and the top of the vertical riser to allow the introduction of sampling equipment and/or pumps.

Additional design details for a typical above-ground protective casing include the following:

- A 5-foot length of steel or aluminum protective casing shall extend approximately 2.5 feet above ground surface and set into the protective apron (aluminum or schedule 80 PVC may be used in environments due to its corrosion resistant characteristics);
- The protective casing inside diameter is typically at least 4 inches greater than the nominal diameter of the well riser;
- An aluminum-hinged cover or loose-fitting telescopic slip-joint-type cap may be used to keep precipitation and cap runoff out of the casing;
- All protective casing covers/caps are commonly secured to the protective casing by means of a padlock at the time the protective casing is installed;
- If practical, all padlocks at a given site should be keyed alike;
- Typically, no more than a 2-inch clearance should be left between the top of the protective casing and the top of the well riser. This spacing may be required for installation of monitoring and/or pumping devices. If, however, other equipment will be used for water-level determinations, a smaller spacing (two inches or less) may be necessary. In cases that may require a larger clearance (more than two inches), the driller should consult with the ARA on a case-by-case basis as part of the overall plan;
- Only the outside of the protective casing, hinges (if present), and covers/caps are typically painted with a paintbrush (no aerosol can). Paint shall dry prior to initially sampling that well.

6.8.2 <u>Flush-Mount Completions</u>

Monitoring wells located in high traffic areas should be completed as flush-mounted whenever possible. Such installations are inherently harsh environments that require special consideration due to enclosed humid conditions and possible flooding with water. If a well cannot be flush-mounted in high traffic areas or areas where heavy equipment normally operates, the well should be protected with four steel bumper posts. This type of protection may not be necessary at all monitoring well locations.

Where monitoring well protection must be flush-mounted with the ground, a locking security internal cap is typically on top of the riser within the steel manhole or vault. This cap must be leak proof so that if the vault or manhole should fill with water, the water will not enter the well casing. A bolt-down manhole cover is commonly adequate for security. The manhole cover should be installed into a 6-inch thick, 2-foot square, concrete pad, sloped (one inch per foot) to provide water drainage away from the well, and finished flush to existing grade. Ideally, the manhole cover should also be leak-proof. For any special circumstances or environmental conditions, the driller should consult with the ARA for case-by-case guidance.

6.8.3 <u>Surface Completion Repairs and Modifications</u>

A properly installed, routinely maintained monitoring well can remain in service for many years; 30 plus years is not uncommon. Nonetheless, circumstances change and mishaps do occur, resulting in the need for repairs or modifications. The following discussion is not intended to be exhaustive, but merely describing some common damage and resulting repairs. Some common examples of damage include: a wellhead hit by a vehicle or heavy equipment (bush-hogging); damage resulting in misalignment/declination of the well, rendering passage of bailer or pump impracticable; a cracked well pad; rusting of the security cover or hinges; soil shrinkage resulting in voids around/under the well pad; adjacent surface fill resulting in a need to raise/elevate the well pad; varmint digging; etc.

In the event repairs or modifications are needed, a professional familiar with monitoring well construction and site activities or history should evaluate the root cause(s) of damage and the prospect for successful repair or modification. Revisit the original well design and make appropriate changes to restore the surface completion. In the event the surface completion/well cannot be repaired or successfully modified to its intended use, a P&A job is in order. Importantly, the well pad and cover are integral components of annular grouting and surface sealing which must be taken into consideration with repairing or modifying a surface completion.

Below are some common examples of damage and repair:

- **Cracked or broken well pad**–If the crack/break is minor, this can often be repaired by pouring a concrete laminate over and around the existing pad. If major, the well pad should be broken-out, removed, and replaced to meet the intended use of the well. If the cracked or broken well pad includes a flush-mount surface completion, consideration should be given to adding steel reinforcement, tie-in to surrounding concrete with rebar, and deeper/stronger flush-mount road boxes.

- **Voids around edge of well pad**–This commonly is caused by shrinkage of soils, settlement, or digging varmints. Minor voids often can be repaired by placement of a form around the perimeter of the well pad, followed by mixing and pouring of a flowable grout to fill the voids. More severe voids may require shoring/blocking of the well pad prior to grouting. A surface dressing of crushed stone around the well pad is often helpful, particularly with pads that are elevated several inches above grade.

- **Rusted-out security cover**–If the well pad is intact, often the best repair consists of cutting or grinding-off of the rusted cover, followed by affixing a larger security cover that is anchored to the intact well pad. If the well pad has been compromised, break out the pad, remove and replace the security cover, and re-pour a new well pad.

- **Misalignment/Declination**–If misalignment is near ground surface (within a few feet), the problem can often be resolved by breaking-out the well pad, removing the surface completion, digging out the annular space to a depth below the misalignment, cutting off the bent well riser, and re-building the upper components of the well to the original specifications. Oftentimes, this type of repair requires re-surveying of the top of casing.

- **Need to raise well pad and security cover**–The need to raise a well pad and security cover most often arises due to the adjacent ground surface being “filled,” such as adjacent to a landfill side slope. This type of modification is typically more complicated and should be evaluated more carefully by the responsible parties. The complexity is most often driven by the amount of elevation change that is required, and consequently the amount of customization required to modify the surface completion while maintaining the intended use of the well. The modification should consider soil compaction, steel reinforcement and other matters relating to the integrity of the well.

- **Protection of well or pad**–If root cause analysis indicates damage by vehicular traffic (truck, bush-hog, etc.), take into consideration all available options. If the well has been damaged repeatedly, consider a P&A and re-location; if only isolate damage, consider additional bollard protection, visible coloring/flagging, etc. Note that bollard protection should be installed most often outside of the well pad.

TABLE 3
MONITOR WELL SYSTEMS FIELD GUIDE SUMMARY

- Defined Work Plan with established well design methods
- Knowledge whether LNAPL or DNAPL has been observed in past or is anticipated in current field activities
- Proposed design maintains proper surface seal
- Materials being used are comparable and compatible
- Filter pack correctly sized for well screen selected
- Filter pack placed up to two feet above screened interval
- Methods in-place to establish filter pack placement
- Seal component approved for use along with correct product
- Seal component placed up to two feet above filter pack
- Sufficient time allowed for hydration of seal according to manufacturer's specifications
- Annulus filled with a lump-free mixture of either grout and/or bentonite
- Gravity placement of grout or bentonite mixture only if limited amount of water in annulus
- Surface casing needed if there are interconnected water bearing units
- Understanding the type of surface completion needed
- Employees and contractors equipped with appropriate PPE

Examples of Recommended Shallow Well Designs of Varying Depths and Intervals

Well Depth (ft.)	Screen Length (ft.)	Screen Interval (ft.)	Filter (ft. bgs)	Seal (ft. bgs)	Grout (ft. bgs)
10	5	5-10	4-7	2-4	0-2
10	10	ARA Approval	---	---	---
11	10	1-11	1-11	0-1	n/a
12	10	2-12	2-12	1-2	0-1
13	10	3-13	2-13	1-2	0-1
14	10	4-14	3-13	2-3	0-2
= or > 15	10	5-15	4-15	2-4	0-2

7.0 WELL DEVELOPMENT AND REHABILITATION

Well development and redevelopment ensure the well utilized for environmental purposes is operating as designed, whether for monitoring, recovery, injection, or some other purpose. Well development is generally performed to:

- Remove additives associated with the initial well drilling;
- Provide unobstructed flow through the well commensurate with the intended well design;
- Purge stagnant water within the well during sampling to collect representative groundwater samples.

Well rehabilitation is performed when the well is not performing as intended due to deleterious deterioration such as sedimentation, biofouling, or precipitation. The most common development techniques and methods employed on environmental wells in Louisiana are:

- Bailing;
- Pumping/Over-Pump;
- Surge Block;
- Swab;
- Air-Lift;
- Chemical Treatment;
- Brush;
- Flush;
- Jet.

Other methods are described in the following sections of this chapter. Well development should be performed AFTER the annular grout has properly cured.

7.1 Well Development Objectives

The purpose of a well development program for environmental monitor wells is to restore the area adjacent to the well to its indigenous condition by correcting damage done to the formation during the drilling process. This process is required to provide a well that is a “transparent” window into the aquifer from which samples can be collected that are truly representative of the quality of water moving through the formation. In order to return the water-bearing zone to indigenous conditions, the formation must be stressed around the screen so that mobile artifact particulates or additives are removed. Often environmental wells installed in Louisiana cannot be developed to drinking water standards as they may be installed in finer-grained WBUs. They should however be developed to a consistent and reproducible quality that is representative.

Development of the well after installation should begin after a sufficient time has elapsed to allow the grout to set. The EPA recommends at least 48 hours after grouting has been completed, however, this is oftentimes not feasible. The selected development method should be accomplished in a manner that does not damage the well screen, filter pack, or formation. The well development plan should provide a process for achieving reproducible measurements.

7.2 Well Development Techniques and Methods

7.2.1 Mechanical Development

Mechanical development of an environmental well is typically accomplished with a pump, surge block, swab, or jetting and may be supplemented with a bottom discharge/fill bailer (for sediment removal). The pumping method and rate should be sufficient to stress the water bearing zone and sufficiently dislodge and remove the effects of drilling and well installation commensurate with the intended use of the well.

Numerous over-the-counter products consisting of swabs or surge blocks for ¾-inch to 6-inch wells are readily available and their use is encouraged. Generally, the well is pumped and the screen is agitated utilizing the selected method(s). This pumping and screen agitation continues until the development objectives are achieved.

Air lifting is encouraged if a dual-tube system is utilized to prevent direct air entry across the screened opening. If air equipment is used, an oil free compressor or a compressor equipped with an air filtering system capable of removing possible contaminants from the compressed air is a BMP. Unimpeded air lifting is not encouraged.

7.2.2 Chemical Development

The chemical development of a well should only use approved National Sanitation Foundation (NSF) dispersing agents, acids, disinfectants or other chemical additives intended for potable drinking water wells. Other chemicals may be utilized with prior approval from the ARA. For the development of horizontal wells, dispersing agents or acids may be necessary to break the drilling fluid. These additives shall be specified in the work plan submitted to the ARA for approval and manufacturer instructions should be utilized.

The addition of water to the well (jetting) may be necessary for development. The water added must be potable and may not adversely impact the chemical nature of the groundwater. The amount of water lost to the formation should be determined and a greater amount recovered than added. Well development should continue until the development objectives are achieved.

7.3 Well Rehabilitation

Well rehabilitation addresses the treatment of a well to recover loss in yield caused by intrusion or clogging of the screen, filter pack, and/or water-bearing strata adjoining the well. Well rehabilitation methods that may be acceptable include mechanical surging, backwashing, or surging by alternately starting or stopping a pump, surging with air, water jetting, sonic cleaning, chemical treatment, mechanical swabbing, or a combination of these methods.

Rehabilitation methods should be performed with care to prevent damage to the well while addressing the cause of restricted groundwater movement within the well. Rehabilitation methods should be compatible with the use of the monitoring well and well materials. Special care should be given to the selection of rehabilitation methods for water-quality monitoring wells. No residual effects of the rehabilitation should remain once the well is back in service.

A workplan may be submitted to the ARA for well rehabilitation unless procedures have already been established in a groundwater sampling and analysis plan or previously ARA-approved document. No permit will be required if the workplan has agency approval. If rehabilitation is needed on a regular basis, a schedule may be developed as part of the plan, with proper notification then the only requirement after the plan and schedule are approved.

7.3.1 Causes of Well Yield Loss and Typical Rehabilitation Chemicals

Efficient well rehabilitation is more likely if testing is performed before rehabilitation activities to identify the cause for loss in yield in the well. BMPs for pre-rehabilitation activities include inspecting the well by downhole camera and/or sampling the screen area to determine the source of the problem. Examples of commonly used tests for biologicals include the Biological Activity Reaction Test (BART®) that identifies the presence of iron, sulfate, and heterotrophic bacteria that may be present in a well.

For iron bacteria and slime, a liquid bacteria acid is effective. For clogs with carbonate scale, sulfamic acids are used with inhibitors and modifiers. If the bacterial problem persists, more aggressive chemicals like muriatic acid and hydroxyacetic acid may be required.

7.3.2 Rehabilitation Techniques

For typical well rehabilitation the treatment chemicals are placed in the well and agitated frequently for 24 to 72 hours. The well is then developed to remove rehabilitation chemicals before a pumping test is performed to ensure the well system is ready to be put back in service. Chemicals used for rehabilitation must be removed from the well, filter pack, and water-bearing strata accessed by the well immediately after rehabilitation operations are completed. Chemicals, water, and other waste should be disposed of in accordance with applicable Federal, state, and local requirements. The ARA should be contacted regarding the proper disposal of waste from rehabilitation operations.

Mechanical rehabilitation with or without the addition of chemicals may be achieved by high-pressure jetting where a tool with an adjustable, multi-head, water-powered jet is lowered into the well and water is injected at high pressure to dislodge debris from the well. The water removes debris from the clogged perforations in the screen and can crack the formations underground to create new sources of water. Well surging is the repeated injecting and flushing-out of water in a well system. With repeated flushing, the debris is washed away. As stated previously, well development and rehabilitation should be performed in a manner such that the integrity of the well is maintained. If high-pressure jetting is utilized, the pressures should be compatible with the well’s construction and materials.

TABLE 4
SUMMARY OF WELL DEVELOPMENT AND REHABILITATION

Purposes/Objectives

- Restore area adjacent to well to its indigenous condition (correcting damage done to formation during drilling)
- Remove drilling additives (muds, water, chemicals, etc.)
- Provide unobstructed flow through screen commensurate with design (sampling, recovery, injection, etc.)
- Purge sedimentation and stagnant water from well

Notable Criteria

- **Pre-Development**–a light pre-development during sand/filter pack placement (prior to adding bentonite seal) may help settle the filter materials, resulting in a better well installation
- **Timing**–well development should be performed AFTER the annular grout has properly cured

Common Development Techniques

- **Purge**– removes fluids and sedimentation (subject to intake location and/or surging)
- **Surge**–application of energy such that the well and water bearing zone is stressed
- **Cleaning (physical)**–literally clean the interior casing, interior screen, and possibly the screen slots/openings
- **Cleaning (chemical)**–utilization of chemicals to clean the interior casing, interior screen, screen slot/openings and possibly into the sand/filter pack (and natural formation); always used in addition to other development techniques

Common Development Methods

- **Air-Lifting**–dual-tube air-lifting is a modestly simple means of effectively purging & surging an environmental well. Contractors sometimes refrain from Air-Lift development due to the need for a source of compressed air/nitrogen (compressors, cylinders). The materials needed are readily available, inexpensive and can be disposable or re-used. Oil-less air compressors and compressed gas cylinders are available for rent.

- **Bailing**–bailing, particularly aggressive bailing, can remove sedimentation via purging and surging if the energy associated with sloshing a bailer is adequate for a particular well (generally limited to shallow wells and/or short water columns). Bailers are readily available, inexpensive (disposable and re-useable), and simple to use, hence their widespread application in the environmental industry. Bailers are available in diameters from ½-inch through 4-inch for environmental applications, with many lengths and many materials (*e.g.*, LDPE, HDPE, PVC, stainless, Teflon etc.).

- **Brush**–used to manually scratch/remove sediment and encrustation on the interior of well casing and screen; always used in addition to other development techniques. This is a simple, readily available, easy-to-use method. It is typically deployed using DPT rods or pipe (PVC, steel) along with a swivel to reduce the chance of pipe joints unthreading.

- **Chemical**–use of NSF approved chemicals is strongly encouraged; always use with caution and consistent with manufacturer instructions and dosing; always used in addition to other development techniques.

- **Flush**–flushing has limited applications for environmental wells: typically, immediately following well installation to flush bentonite drilling muds and sediments. Flushing should always be used in addition to other development techniques; as a general rule, at least three times the amount of water lost during flushing should be purged during subsequent development.

- **Foot Valve**–foot valves are typically a simple ball valve device that is manually or mechanically oscillated up/down using inertia energy to pump/purge water. Inertia pumping inherently produces surge energy that may be adequate in some instances. Foot valves are most often deployed using tubing (installed on the bottom of the tubing, hence the name "foot" valve). These are simple devices, and are commercially readily available for most sizes of environmental wells. They are inexpensive, typically made of Delrin or stainless steel. Deployment using disposable LDPE, HDPE or PVC tubing makes it suitable for environmental applications, particularly shallow Louisiana wells. Mechanical actuators that oscillate the surge block up/down are available for rent.

- **Jetting**–used to mechanically scratch/ remove sediment and encrustation on the interior of well casing and screen; always used in addition to other development techniques. Like flushing, as a general rule, at least three times the amount of water lost during jetting should be purged during subsequent development.

- **Peristaltic Pumping**–most often used for small diameter temporary sampling points. It can remove bottom sediments during purging; in some instances, may adequately surge. Peristaltic pumps are vacuum lift pumps; as such the depth to water must generally be less than 25 feet below TOC. The method is readily available and inexpensive disposable tubing makes it suitable for environmental applications

- **Pumping, bladder (air)**–a number of submersible bladder pumps exist that fit within ¾-inch through 4-inch diameter environmental wells. The advantage of submersible pumps is the total dynamic head of the devices are typically capable of lifting water greater distances (when the depth to water is greater than 20 feet). Pumping is purging; the nature of bladder pump operation is cycling is required to fill and empty the submerged chamber, consequently surging is inherent; the surge energy may be adequate in some instances. Submersible bladder pumps are designed to remove some sediments, which would be limited to the pump intake placement and effects of surging. Bladder pumps for the environmental industry are infrequently utilized for development in the environmental industry due to the need for a source of compressed air/nitrogen (compressors, cylinders) and control panels. They are generally available for rent.

- **Pumping, diaphragm (air)**–seldom used for environmental wells, primarily due to the need for a source of compressed air/nitrogen. Can remove bottom sediments during purging; in some instances, may adequately surge. Diaphragm pumps are vacuum lift pumps; as such the depth to water must generally be less than 25 feet below TOC. The method is readily available, including many small sizes, and inexpensive disposable tubing makes it suitable for environmental applications.

- **Pumping, submersible**–numerous submersible pumps exist that fit within 2-inch and 4-inch diameter environmental wells. The advantage of submersible pumps is the total dynamic head of the devices are typically capable of lifting water greater distances (particularly when the depth to water is greater than 20 feet). Pumping is purging; rapidly turning a pump on/off can create some limited surging energy. Submersible pumps are not inherently designed to remove sediments, although they are frequently used to do so. Submersible pumps for the environmental industry are available in 12V and 110V configurations. Some models require the utilization of expensive controllers.

- **Surge Block**–a surge block is typically a disc that is manually or mechanically oscillated up/down using inertia energy to displace the water column and consequently thru the screen and into the formation. Surge blocks can be deployed using tubing, pipe, drilling rods, wirelines and similar methods. These are simple devices, and are commercially readily available for most sizes of environmental wells. They are inexpensive, typically made of Delrin, PVC, steel and other materials. Deployment using disposable tubing makes it suitable for environmental applications, particularly shallow Louisiana wells. Mechanical actuators that oscillate the surge block up/down are available for rent.

- **Swab**–a swab is simple flexible device that fits snugly within the well casing and is manually or mechanically oscillated up/down within the water column using inertia energy to surge water. Inertia inherently produces significant amounts of energy which displaces the water column and consequently thru the screen and into the formation. Swabs are deployed using tubing, pipe, DPT rods and wireline. These are simple devices, and are commercially readily available for most sizes of environmental wells (¾-inch through 6-inch). They are inexpensive, typically made of thin layer(s) of Teflon, LDPE, HDPE or similarly flexible materials. Deployment using disposable LDPE, HDPE or PVC tubing makes it suitable for environmental applications, particularly shallow Louisiana wells. Mechanical actuators are available for rent.

- **Swab/Surge Block Combinations**–a combination of both methods integrated into a single device. Readily commercially available for most sizes of environmental wells (¾-inch through 6-inch). They are inexpensive, typically made of thin layer(s) of Teflon, LDPE, HDPE or similarly flexible materials. Deployment using disposable LDPE, HDPE or PVC tubing makes it suitable for environmental applications, particularly shallow Louisiana wells. Mechanical actuators that oscillate the surge block up/down are generally available for rent.

Diameter (inches)	Volume (gal/ft)
0.25	0.00
0.375	0.01
0.5	0.01
0.75	0.02
1	0.04
1.25	0.06
1.5	0.09
2	0.16
3	0.37
4	0.65
6	1.47
8	2.61

Nominal Tubing and Casing Volumes (per linear foot)

8.0 INJECTION WELLS/POINTS FOR AQUIFER REMEDIATION

Aquifer remediation is typically facilitated through the use of injection wells that deliver amendments to the subsurface to reduce the concentration, toxicity, or mobility of a contaminant. Typically, this is accomplished through the use of Class V injection wells regulated by the EPA and the states through the Underground Injection Control (UIC) Program (in Louisiana, housed in DNR/OC). The EPA banned the use of Class IV injection wells in 1984 and these wells may only be operated as part of an EPA or state-authorized groundwater clean-up action. Class V injection wells currently are regulated by DNR's UIC program under the authority of the Safe Drinking Water Act.

The design and construction of Class V injection wells is highly dependent on the compatibility of the well construction materials and proposed injection amendments, the design pressures the injection well will be required to withstand to adequately distribute the amendment, and many other factors (*e.g.*, sand pack, grouting, etc.) discussed previously. Further, Class V wells may only inject fluids that will not endanger underground sources of drinking water. Because there are such a wide variety of Class V well applications in addition to aquifer remediation, such as storm water drainage wells, agricultural drainage wells, septic system leach fields, etc., there is no "one-size-fits-all" guidance for injection well construction. Consequently, the design of Class V wells for aquifer remediation should be based on the factors and considerations identified above and throughout the *Guidance Manual*. To reach remedial objectives, injection wells must be able to effectively distribute amendments.

Temporary injections points converted to permanent monitoring well(s) and injections wells should be completed and registered as described in in Chapters 6.0 and 11.0, respectively. These points will also require proper sealing.

Preliminary matters requiring attention prior to injection include:

- DNR/OC Injection & Mining–obtain permit or waiver;
- Work Plan approval by ARA;
- Injection mixture(s) that will NOT endanger USDW;
- Well/temporary point design compatible with injection mixture and formation;
- Injection formation/zone clearly identified;
- Field plan to control injection flow rate and pressure;
- Field plan to monitor for "daylighting";
- PPE suitable for mixtures;

8.1 Remediation Injection Well Design and Development

Injection wells for amendment delivery are commonly constructed with PVC or stainless-steel materials, ¾-inch to 4-inches in diameter. The larger the diameter the well screen, the greater the surface area opening of slotted pipe and the greater ability to insert tools and probes into the wells. Smaller injection wells (¾- and 1-inch wells) may be installed using DPT as described previously, while the traditional drilling techniques may be used for small and large diameter injection wells. It should be noted that because installations using DPT involves compressing of the formation during drilling, there may be implications on the ease of injection of amendments based on the technique used. Injection wells are best suited for projects in which the injection reagents and substitutes do not contain large quantities of solids (aqueous solutions).

The well screen and filter pack are designed to allow the amendments to easily flow from the well while preventing the well from becoming plugged with naturally occurring silt and sediment or products created by the reaction of the amendments with the constituent of concern (COC) or the aquifer material. In cases where the amendment is being added to a low hydraulic conductivity formation through small injection wells, continuous or "wire-wound" screens should be considered as they have a higher burst pressure than standard slotted screens. These screens may also double the available opening space for a given treatment interval. For PVC pipe installations, Schedule 40 or 80 commonly are used, with Schedule 80 typically recommended for higher injection rates due to its higher burst pressure and general durability for multiple injections.

Wedge wire screens (Vee-Wire®, etc.), which consist of a slotted screen with a larger slot size on the outer portion of the casing and smaller slot size on the inner casing, are commonly used to prevent clogging in pumping wells and should not be utilized for injection. This well screen configuration adversely affects injections as the wider slot screen size is present for the outer casing and these well screens types are particularly susceptible to solids build up and/or bio-fouling during injection. In addition to the well installations described previously, recommendations for injection well design are as follows:

- Install well screens within the contaminated zone;
- Ensure that all materials and seals are compatible with COCs and the reagents and substrates that will be introduced into the aquifer;
- Do not screen injection wells across multiple zones; doing so may reduce the likelihood of preferentially distributing amendments;
- Consider continuous or wire-wound screens as opposed to slotted screen, because these types of screens provide a greater surface area and reduce fouling;
- Ensure that all materials and seals are compatible with the design operating pressure as well as reagents, substrates, and COCs'
- Design well screens so that injection and extraction well entrance velocities do not exceed 1.5 and 2.0 cm/s, respectively;
- Consider grain size of formation to properly design screen and filter pack size.

The well should be properly developed as soon as possible to remove fine solids and any drilling material to prevent clogging during injection and reduction of optimal injection rates.

8.2 Remediation Injection Well Operation

Injection of amendments into the saturated zone through injection wells results in the mixing and displacement of groundwater causing a localized rise in the water level (called “mounding”). The force impacted by the pull of gravity on the mounded groundwater and amendments is referred to as the hydrostatic pressure. As the initial water is displaced the mounding dissipates, which relieves the temporary buildup of hydrostatic pressure. The rate of mounding dissipation is primarily dependent on the hydraulic conductivity of the aquifer matrix. Aquifers with more permeable material like sands and gravels will generally respond by accepting amendments at low application backpressures. Conversely, the injection of amendments into a more fine-grained unit like silt and clayey silt will respond with a higher backpressure.

The use of a recirculating system, where amendment is added and groundwater is extracted, amended, and reinjected, is one method to minimize mounding and/or take advantage of this affect to optimize amendment delivery. The degree of mounding may be exacerbated as the amendment reacts with the aquifer solids resulting in bio-fouling or precipitation in the area of the injection wells.

Continued buildup in backpressure may result in the fluid finding its way to the surface (path of least resistance) resulting in “surfacing” or “daylighting.” If fluids “daylight” in an uncontrolled manner, or in a sensitive area such as a roadway, stream or offsite property, the drilling injection operation must be stopped until it is controlled. Excessive buildup of hydrostatic pressure can be avoided by proper injection well design, injection methods, and tooling. Surfacing may be managed through monitoring of backpressure and adjusting injection parameters (pressure, flow rates, and number of injection points). Methods to control daylighting and/or decrease injection inefficiencies over time include:

- Perform pre-injection assessment of site condition by assessing locations that may serve as daylight points, such as utility manholes, outfalls, vaults, cracks, etc.;
- Equip injection wells with pressure gauges; even gravity injection can result in high well pressure if reagents and substrates produce gas as a byproduct of the reaction;
- Monitor for daylighting during injection, especially if injection of reagents is performed under pressure; if daylighting is observed reduce the injection flow rate, consider intermittent (pulsed) injection to allow potential mounding of water to dissipate, or consider recirculation;
- Monitor for bio-fouling (including specific capacity tests prior to and during injections to identify changes from baseline, use of a down-hole camera, evaluation of key groundwater quality indicators pre-injection and during injection) and apply mitigation/restoration measures as necessary such as surging or brushing, hot water injection, hydrogen peroxide, shock chlorination, or acid treatment;
- Carefully control flow rate into each well and injection interval when simultaneously injecting into multiple points; use flow control valves (globe or gate);
- Consider using bag filters to remove any particulates prior to injecting fluids into injection wells, since particulates can clog the injection well screen and filter pack.

8.3 Temporary Injection Points

The use of temporary injection points is also commonly used for the injection of both aqueous and solid amendments for groundwater remediation. Typical solids injection consists of completing soil borings to the target groundwater unit and backfilling the boring and/or injecting amendments (iron, oxygen release compounds, etc.) into the borehole. More advanced applications utilize elevated pressures to induce fracturing of the target unit for enhanced amendment delivery. As discussed above, daylighting should be considered during the design phase and actively managed/monitored during implementation. Further, these temporary injection points should be properly grouted once complete. Like injection wells, the use of temporary injection points must be approved by the state UIC program prior to implementation. Some of the more commonly used temporary injection methods and processes are as follows.

8.3.1 Direct Push Technology

The expendable tip DPT amendment delivery method consists of advancing a DPT boring with an expendable tip. The expendable tip is "dropped" or knocked out of the end of the lead rod at the target depth. The amendment is then injected via the open rod. This method is simple and is appropriate for target zones that are reasonably homogenous. This method is potentially limiting because the amendment must be applied in a "bottom-up" fashion, meaning that the reagent is being pumped out the end of the lead rod at a known rate while slowly raising the rods. This method provides less flexibility (bottom-up only) and may tend to focus the injected amendment downward rather than outward.

The DPT rig may also utilize horizontal injection tooling that contains a modified section of the lead rod known as a drop-screen. This section of the lead rod is typically equipped with a sleeve that covers a set of injection ports. Upon reaching the desired depth the injection of amendments takes place through the injection ports in the rod. The horizontal injection method allows for "top-down" as well as a "bottom-up" injection and provides greater flexibility and outward injection of the reagent than the expendable tip method.

8.3.2 Fracturing

Fracturing commonly is performed for shallow applications via hydraulic or pneumatic means. Hydraulic fracturing involves injecting amendments into the subsurface at a pressure that initially exceeds the combined lithostatic pressure, hydrostatic pressure, cohesive strength of the formation, and other sources of resistance such as pressure loss through the injection tooling. Clays generally have significantly greater cohesive strength than sands. Other pressure losses, such as friction from the sidewalls of the injection rods, will create additional resistance that must be overcome. Once this pressure has been overcome and a fracture has been created, the pressure required to continue the injection will be lower.

In a hydraulic fracturing injection application, the reagent is pumped into the formation at a rate and pressure that exceeds the ability of the formation to accept the reagent via permeation. Fracturing occurs when there is a sudden and significant drop in the injection pressure while the flow rate remains constant or increases. After fracturing occurs, the injection flow rate of the reagent is maintained to propagate the fractures out from the injection borehole. Typically, a biodegradable slurry comprised of a small amount of guar gum is cross-linked to create a viscous gel that suspends solid amendments and helps maintain the fracture integrity as the fracture is propagated from the injection point. The fracture radius of influence will depend on several factors such as soil type, application method, injection rates, injection depth, and reagent viscosity, where more viscous reagent slurries enhance fracture propagation.

Pneumatic fracturing uses gas to fracture the media and inject the reagent, with or without the use of packers to isolate the injection depth. The injection method is completed in two sequential steps, pneumatic fracturing and pneumatic injection. Pneumatic fracturing is accomplished with controlled bursts of high-pressure gas at pressures exceeding the natural in situ geostatic pressures and at flow volumes exceeding the natural permeability of the subsurface. The type of gas used depends on the reagent. For oxidative reagents, compressed air can be used. For reducing reagents, nitrogen gas is used to avoid injection of oxygen into the aquifer.

9.0 OTHER TECHNOLOGIES AND INSTALLATIONS

Other technologies, such as directional drilling, multi-level wells, and gas wells, commonly deployed in Louisiana, along with associated installations, are continually developing. All these are expected to be implemented using an ARA approved Work Plan and are required to follow applicable LAC Title 56 regulations, such as licensure, registration (if an installation), grouting, plugging and abandonment, etc. Permanent installations of the technologies described herein should also include consideration for decommissioning of the system. It is recommended that the plugging and abandonment and other decommissioning activities be documented to the appropriate ARA in a Work Plan. Illustrations and descriptions of these technologies are provided below.

9.1 Lysimeters

Lysimeters are employed for use when conditions do not allow for the installation of monitoring wells, such as for investigations of shallow contaminant plumes, at depths typically less than 6 feet below ground surface. Lysimeters may be employed in the saturated zone, and used in the determination of the soil pore quality in the unsaturated zone. The use of lysimeters are anticipated to be implemented using an ARA approved Work Plan, which should describe the installation process in detail. Permanently installed lysimeters should be registered as wells, consistent with LAC Title 56.

9.2 Horizontal Directional Drilling (HDD) and Horizontal Wells

Horizontal wells are used in applications such as: water removal; pump and treat, air sparging/soil vapor extraction; injection; bio-sparging; and free product removal. In many facets, HDD and Horizontal well methods are substantially similar to vertical mud rotary drilling methods and installations. HDD is at an angle above horizontal (example: 10 to 20 degrees), and the bit is steered. Typical placement consists of a constant depth for the screened portion of the HDD. The typical HDD borehole is successively reamed to reach the final design diameter, drilling thru and back. The two most common types of well installations are continuous (through-and-through) or blind (dead-end).

Environmental applications of Horizontal Directional Drilling (HDD) and horizontal wells within Louisiana are anticipated to be implemented using an ARA approved Work Plan. Work Plans should describe the installation process in detail. Work Plans should specify drilling method, well materials, seal material, grout materials and grout placement methodology; their designs should be in conformance with other installations described within this Manual. Permanently installed horizontal wells should be registered as wells, consistent with LAC Title 56. HDD boreholes commonly utilize bentonite-based fluids during drilling and installation.

However, other NSF-approved drilling fluids/additives may be used based on site conditions and applications. The Work Plan typically sets forth the drilling plan. The borehole size for horizontal well installation should be a minimum of two inches larger than the outside diameter of the casing. One of the most common problems encountered during HDD is a “frac out” (or inadvertent return of the drilling fluid to the ground surface along the pathway of the borehole). Frac outs can occur at any depth and are caused by natural fractures in the subsurface formation and elevated drilling fluid pressures. The HDD contractor must be aware of the potential for drilling fluids to vent to the surface. If fluids frac out in an uncontrolled manner, or in a sensitive area such as a roadway, stream or offsite property, the drilling operation must be stopped until the frac out is controlled.

Common Horizontal Well materials include: PVC; high-density polyethylene (HDPE); stainless steel; carbon steel; and fiberglass. The well materials will be specified within the Work Plan should be consistent with BMPs for the project. The well screens should be designed to accommodate maximum open flow area compatible with the required strength (tensile and compressive forces) needed for installation, with consideration for perpendicular or parallel slot pattern (to pipe axis). Due to the difficulty in placing a gravel/filter pack around the screen in a horizontal borehole, either prepacked screens or no additional filter materials are used for well completions (the formation material is used to make the filter pack).

In many instances, filter material is not required due to the extremely slow flow rate and relatively long screen section. Annular grout should be placed from the ground surface as deep as possible using a tremie pipe with the pump down method. At least the top 30 feet of measured depth (pipe length) should be grouted using the same grout mixtures as described for vertical wells. The surface completion for horizontal wells should be designed to prevent unauthorized entry of personnel, rain/flood water, insects or dust/dirt into the casing. A surface concrete slab or flush mount road box as specified for vertical wells should be constructed for the horizontal well. Well development for horizontal wells typically includes a combination of washing, jetting, surging and NSF-approved chemical development compatible with the drilling mud and site conditions.

9.3 Soil Gas/Vapor Sampling, Soil Vapor Extraction, and Sparging Wells

Soil vapor sampling is the actual effort of collecting a sample of soil vapor from unsaturated soil for subsequent analytical testing. Soil vapor extraction (SVE) is a remedial process in which VOC contaminants in the unsaturated zone are removed using SVE wells. Air Injection wells are used to pump air into the ground, Air Vent wells are passive vents, while Air Sparging (AS) wells are used to pump air into the saturated zone to facilitate flushing/upward bubbling of VOC/SVOC contaminants. The bubbling is a simple process which facilitates exchange of contaminants into the vapor phase.

All permanent Soil Vapor and Air Sparging installations within Louisiana are anticipated to be implemented using an ARA approved Work Plan. Work Plans should describe the installation process in detail, along with the anticipated plugging and abandonment procedures. Work Plans should specify drilling method, well materials, seal material, grout materials and grout placement methodology; their designs should be in conformance with other installations described within this Manual.

Screen design and installation must account for seasonal variations in groundwater levels. Special attention should be taken in the design and installation of the surface seal to ensure that it is as tight as possible. Operation of the system should have a process for identifying and remedying short-circuiting/channeling. Permanent Soil Vapor installations and related wells should be registered as wells consistent with LAC Title 56.

SVE Systems are designed to remove contaminants such as VOCs that have a tendency to volatilize or evaporate easily from soil in the unsaturated zone. By applying a vacuum through a system of wells, contaminants are pulled to the surface as vapor or gas. While the SVE wells remove contaminants, Air Injection and Air Sparge wells are installed to increase airflow and improve removal rates of the contaminants and/or to stimulate bioremediation of some compounds. SVE may consist of interim vacuum events (vac truck) or permanent installations. Applications for AS/SVE systems are commonly at UST sites, although many sites with chlorinated organic compounds have installed these remediation systems.

9.4 Multi-Level Monitoring Wells

A Multi-Level Monitoring Well (M-L MW) is a groundwater sampling point that allows the monitoring of a number of discrete groundwater zones within a single borehole. The system typically consists of seals and ports that are placed at varying depths along a casing string, to isolate and provide access to each monitoring interval. Multi-level installations have increased in reliability, particularly with improvements in the integrity of seals. The principal benefits of the depth-discrete data that M-L MWs provide include:

- Effective vertical profiling and monitoring over large vertical intervals;
- More efficient determination of vertical contaminant distribution (single or multiple WBUs);
- Ideal for monitoring of natural attenuation or remediation processes;
- More accurate risk assessments;
- Minimizes risk of additional contaminant pathways;
- Vertical hydraulic head data for model calibration.

At the time of this document there is one identified commercial manufacturer of these permanently installed systems: Solinst, which offers the CMT and Waterloo multi-level systems. Standardized installation methods are available from the manufacturer, in the form of SOPs and should be combined with BMPs such as those prescribed within this Manual.

All permanent M-L MW installations within Louisiana are anticipated to be implemented using an ARA approved Work Plan. Work Plans should describe the installation process in detail and should specify drilling method, well materials, seal material, grout materials, and grout placement methodology; their designs should be in substantial conformance with other installations described within this Manual. Permanent M-L MW installations and related wells should be registered as wells consistent with LAC Title 56.

9.5 Vibrating Wire Transducers

The vibrating wire transducer/piezometer is used to monitor *in-situ* water levels. In addition to geotechnical applications, the implanted transducer(s) is used to monitor *in-situ* water levels in subsurface water-bearing units. The implants are typically grouted in-place using a standard grout mixture specified by the manufacturer or project designer.

9.6 Thermal Treatment Systems and Wells

Thermal Conduction Heating (TCH) and Electrical Resistance Heating (ERH) are two examples of subsurface *in-situ* thermal remediation systems that include soil borings and well installations regulated under LAC Title 56. These systems typically consist of a series of subsurface electrode installations, along with vapor recovery points and temperature monitoring points. *In-situ* thermal treatments raise the subsurface temperature to treat contaminants, often using: steam injection and vapor extraction; groundwater viscosity reduction; and destruction of contaminants.

ERH generally consists of electrical current flow between electrodes; the electrodes are not heaters although heat is generated *in-situ* due to electrical resistance of the soil and groundwater. When the subsurface reaches the boiling temperature, continued system operation results in steam generation. TCH generally consists of heater wells through which heat is transferred by temperature differential. Soils nearest the heater wells become desiccated by the heat (200-300^{o}C), and the high temperature provides the basis for the thermal gradient.

All thermal treatment systems and wells installed within Louisiana are anticipated to be implemented using an ARA approved Work Plan. Work Plans should describe the installation process in detail and should specify drilling method, well materials, seal material, grout materials, and grout placement methodology; their designs should be in substantial conformance with other installations described within this Manual. Permanently installed thermal treatment system wells should be registered as wells consistent with Title LAC 56.

9.7 Phytoremediation

Phytoremediation is a remedial technology that has been used since the 1980s to degrade, extract, contain, or immobilize contaminants by using plants. Phytoremediation occurs through various mechanisms, including phytoextraction (translocation of dissolved phase contaminants from groundwater to plant tissue), and hydraulic control (using trees to intercept water and control the migration of contaminants). For VOCs, phytoremediation mechanisms may also include phytovolatilization (transfer of contaminants or their metabolites to the air through plant respiration), rhizosphere degradation (degradation in the soils surrounding plant roots), and phytodegradation (degradation within the plant tissue).

There are several considerations for phytoremediation. Types and concentrations of COCs and hydrogeological and soil conditions must be understood to choose the appropriate plants and locations for implementation. Some concentrations of VOCs and salts may be phytotoxic to specific plant species. Soil properties that influence phytoremediation success include available nutrients, particle size, bulk density, salinity, redox potential, pH, cation exchange capacity, organic matter content, and the presence of soil microorganisms for degradation. The depth of COCs requiring treatment is another consideration.

All tree-remediation wells installed within Louisiana are anticipated to be implemented using an ARA approved Work Plan. Work Plans should describe the installation process in detail. Work Plans should specify drilling method, well materials, seal material, grout materials, and grout placement methodology; their designs should be in substantial conformance with other installations described within this Manual. Piezometers and wells associated with tree-remediation applications should be registered consistent with LAC Title 56.

9.8 Other Innovative Technologies

Other innovative technologies exist that are not described within this Manual and new technologies are anticipated to be developed through innovation and advances. While the use of innovative technologies is encouraged, Work Plans approved by the ARA should be obtained for new technologies prior to implementation. Utilization of such should always promote BMPs relating subsurface installation and plugging and abandonment and grouting, such that the subsurface natural resources of Louisiana are protected.

10.0 PLUGGING AND ABANDONMENT (P&A)

Abandonment procedures are intended to permanently seal a boring or well that has been abandoned or is permanently no longer needed. Any environmental groundwater monitoring system, recovery well, piezometer, or investigative borehole that no longer serves a purpose, that is damaged beyond repair, or is to be abandoned due to closure of the monitored unit shall be plugged by a Louisiana-licensed water well contractor.

As described in Chapter 6.0, the grout seal is intended to protect the groundwater of Louisiana from surface contamination, prevent movement of groundwater from one aquifer to another, prevent the entrance of objectionable water (materials or wastes) into aquifers via open or improperly sealed boreholes or wells, and to minimize the health and safety hazards associated with abandoned wells. P&A of environmental boreholes and wells is to be completed consistent with LAC Title 56, LAC Title 33, and other appropriate ARA requirements. Many boreholes are P&A'd without specific Work Plan approval, while wells are more commonly P&A'd under an ARA approved Work Plan. Environmental borings are typically defined within LAC Title 56, LAC Title 33, and other ARAs as a form of a Geotechnical Borehole.

Prior to P&A of a well, Louisiana's Strategic Online Natural Resources Information System (SONRIS) should be used to confirm well construction information and registration. If the well to be abandoned was not previously registered or cannot be identified in SONRIS and there is limited information on construction available from the well owner, more exhaustive research is recommended. If not previously registered, the well must be registered contemporaneously with the P&A documentation as described in Chapter 11.0. An unregistered well is not considered administratively P&A'd until the corresponding form for registration is complete and submitted to DNR/OC with the P&A form.

Grout materials and grouting procedures were discussed in Chapter 6.0. Substantially similar materials and approaches are applicable to the P&A of environmental boreholes and wells. Notably, liquid grouts are typically emplaced via a tremie line or similar conduit as previously described. Some examples of tremie pipe or conduit for placement of grout are: direct placement of tremie line into an open borehole; rods driven in-place with an expendable point at the bottom; the interior of hollow-stem auger flights; the interior of rotosonic rods; and similar means of grout transmission to the target depth. Typically, the tremie line/conduit is placed to a depth at least equal to the base of the deepest confining layer fully penetrated during drilling (depth of grouting a borehole should be substantially similar to the depth of grouting a substantially similar well).

Importantly, the near surface seal should have equal or better sealing properties than native surface materials. Always consider the existing settings and conditions, taking precautions to retain existing good, properly-functioning seals and grouts. If appropriate, re-check the grout of environmental boreholes or wells for settlement; top-off as necessary. DNR/OC requires the documentation of all P&A activities.

10.1 Boreholes

Environmental boreholes typically require full borehole length seals and/or grout to ensure protection of subsurface resources. Shallow environmental boreholes such as those of less than 10 feet deep that do not penetrate below the first WBU should be backfilled with a material of equal or less permeability of the material removed from the borehole. To prevent the creation of conduits, deeper environmental boreholes that do not penetrate the first WBU should be backfilled with a seal or grout material using a placement method consistent with those outlined previously in Chapter 6.0. BMPs and site knowledge should be utilized to determine the appropriate method to effectively seal the surface for these applications. The following provides a summary of common borehole P&A scenarios:

- **Boreholes that do not penetrate a WBU**–typically, backfill with a seal as good or better than the native ground conditions. The use of soil cuttings as backfill is not acceptable without ARA approval, as these un-compacted materials may not be "as good or better than the native conditions."

- **Boreholes penetrating ONLY the first WBU**–backfill with a seal as good or better than the native ground conditions. Typically, cement-bentonite grout, other grout or bentonite chips (or crumbles), as described in Chapter 6.0 may be used. Gravity poured grout is acceptable if the borehole is open and only a nominal column of water is present. Gravity poured solid bentonites are acceptable, and if used, the BMP would be to tamp and hydrate the bentonite in lifts.

- **Boreholes penetrating multiple WBUs**–backfill with a seal as good or better than the least permeable confining layer. The grout should be placed at or below the deepest confining unit fully penetrated using some form of tremie line or conduit with grout placement from the bottom up to at least the base of the shallowest WBU. Backfill materials above this should be as good or better than the native ground conditions.

P&A of boreholes used for electronic profiling, including CPT, EC, and MIP, is typically accomplished by re-driving a conduit with expendable point to target depth, followed by sealing or grouting. Injection and retraction grouting tools are integrated onto some tools and present an alternate BMP. The seal or grout requirements pertaining to the depth of boreholes discussed above apply for electronic profiling technologies (shallow, first WBU, or multiple WBU penetrations).

For temporary groundwater sampling wells, the seal or grout requirements described above are applicable. Knocking off the bottom plug (or knocking a hole into the well bottom) prior to grouting is a recommended BMP. An attempt should be made to remove all well materials from temporary sampling point installations. If the well materials are anticipated to break-off in the subsurface, including pre-packed screen bridges within the borehole, the sampling point should be grouted prior to attempting to pull. Should the temporary well materials break-off in the subsurface, the remaining well materials are to be utilized as an in-place tremie line. As noted above, the near surface seal should have equal or better sealing properties than native surface materials for all of the borehole applications described above.

10.2 Wells

Environmental wells typically require full borehole length grouting and at a minimum at or below the base of the deepest, fully penetrated confining layer encountered during drilling. **Always consider the existing settings and conditions, taking precautions to retain existing good, properly functioning seals and grouts. The P&A design should yield a better seal, otherwise grouting in-place should be strongly considered.**

Remove all appurtenances, pumps and obstructions. Typically break-out surface completion pad and security cover, if this is possible to do without adversely impacting the well and annular grout. If the well is likely to be damaged during the break-out of the surface completion (pad and security cover), consideration should be given to grouting the well (tremie-grouting) before demolition of the surface completion. Once grouting is complete, the well is cut off below-grade and a surface seal of a quality equal to or better than native soils should be applied; typically, the near-ground surface seal consists of 100% sodium bentonite high-solids seal (pellets or chips).

If it is the intention of the owner to remove all physical presence of the abandoned monitor well/borehole, the location of the environmental borehole or wells should be accurately confirmed. In areas subject to farming or other work, to prevent damage to plows or other machinery, the casing may be cut below the ground surface before sealing the surface.

If an attempt to pull the well will be made immediately after grouting, and the well is constructed of PVC or other readily breakable material, consideration should be given to knocking out the bottom of the well, thus creating a path for grout to flow into the borehole as the well materials are pulled. In the event that the materials break during pulling, this also allows the voids to be filled with grout.

The following provides a summary of common environmental well P&A scenarios. However, if the well integrity is questionable, completing a cement bond log or other integrity test would be advisable as a BMP.

- **Example 1: Post-1985, Properly Constructed and Registered Well (Typical)**–this is generally defined as a "modern era" well, without a surface casing. If the monitoring well was installed after November 1, 1985, in accordance with the provisions and registration requirements of LAC Title 56, removal of the well casing may not be required. The typical procedure would consist of breaking the well pad, removing the security cover, attempting to pull the well, and grouting the well in-place or the resulting borehole, followed by sealing the surface.

- **Example 2: Post-1985, Properly Constructed and Registered Well (Over-drill)**–this is generally defined as a "modern era" well, without a surface casing as above, but occasionally an ARA approved Work Plan may dictate that over-drilling is required. The typical procedure for handling an over-drill consists of breaking the well pad, removing the security cover, over-drilling a portion of the vertical depth of the well (typically to the top of the screen), and grouting the resulting borehole, followed by sealing the surface.

- **<u>Example 3: Post-1985 well that has NOT been registered, Shallow, first WBU</u>**–review available documentation. If properly constructed, typically proceed as outlined in Example 1. If no documentation is available, or is unsatisfactory, typically proceed as outlined in Example 2.

- **<u>Example 4: Pre-1985 well that has NOT been registered, that appears intact and properly constructed (based on records or visual inspection), Shallow, first WBU</u>**–review available documentation. If property constructed, typically proceed as outlined in Example 1. If no documentation is available, or is unsatisfactory, typically proceed as outlined in Example 2.

- **<u>Example 5: Pre-1985 well that has not been registered, that does NOT appear intact</u>**–review available documentation, and typically proceed as outlined in Example 2 (break the well pad, remove the security cover, over-drill, grout the borehole, seal the surface).

- **<u>Example 6: Properly constructed well installed into a Deeper WBU, and wells with a surface casing</u>**–review available documentation. If properly constructed, typically proceed as outlined in Example 1. This method is preferred to maintain the good grout seal (or good grout seal within the surface casing, if present) during P&A activities.

- **<u>Example 7: Improperly constructed or poorly documented well installed into a Deeper WBU, with or without a surface casing</u>**–review available documentation. Typically proceed as outlined in Example 2. This method is required to ensure a proper seal between the shallow WBU and subsequent deeper WBUs. Over-drilling should be completed through the shallow WBU to an underlying confining layer or to a minimum of 15 feet.

The above examples of the most common well situations encountered, although other conditions may dictate alternative P&A methods that meet subsurface and near-seal objectives. Consultation with the ARA is encouraged in considering facets of a satisfactory P&A. Importantly, the near surface seal should have equal or better sealing properties than native surface materials. Unregistered wells that are P&A'd require both registration and P&A documentation.

TABLE 5
PLUGGING-AND-ABANDONMENT (P&A)
FIELD GUIDE SUMMARY

- Final objective is to provide a seal equal to or better than current
- Use SONRIS to confirm well construction and installation date
- Liquid grouts are typically emplaced via tremie pipe
    - Direct placement of tremie line
    - Rods driven in-place with expendable point
    - Interior of hollow stem auger
    - Interior of rotosonic rods
    - PVC well, if bottom of well has been knocked out
- Shallow boreholes that do not penetrate below the first WBU, can be backfilled with material of equal or less permeability of material removed. Soil cuttings not acceptable without ARA approval.
- Boreholes greater than 10 feet that do not penetrate below the first WBU, should be backfilled with a seal or grout using a tremie line.
- Always consider the existing settings and conditions, taking precautions to retain existing tools and properly functioning seals and grouts. The P&A design should yield a better seal, otherwise grouting in-place should be strongly considered.
- If well is likely to be damaged during removal of surface structures, consideration should be made to grout the well before damage can occur.
- If an attempt is made to pull the well after grouting, the bottom of the well should be knocked out.

Sealant Use

Type of Sealant	Emplacement <25 feet	Emplacement >25 feet	Soil Hydration Low	Soil Hydration High
Cement/Bentonite	Y	Y	Y	Y
Neat Cement	Y	Y	Y	Y
High Solids	Y	Y	N	Y
Bentonite Pellets	Y	N	N	Y
Bentonite Chips	Y	N	N	Y
Cement/Sand	Y	Y	Y	Y

P&A Methods for Properly Constructed Wells and Borings*

Type	Plug In-Place	Over-Drill	Remove Casing	Pressure Grout	Destruction
Temp Wells	Y	Y	Y	Y	ARA Approval
Pre-Packed Wells	Y	Y	Y	Y	ARA Approval
Monitor Wells	Y	Y	Y	Y	ARA Approval
Dual Cased	Y	Y	Y	Y	ARA Approval

* Regardless of method selected there should be a mechanical attempt made to remove the casing/screen from the subsurface. BMP's for abandonment procedures are intended to permanently seal a boring or well and for the seal to have equal or better sealing properties than native surface materials.

11.0 CONSTRUCTION DOCUMENTATION

A variety of documentation is required for boreholes and wells proposed and completed in Louisiana. This section highlights the submittals required under LAC Title 56 regulations after construction has been completed. The SONRIS database of wells and the DNR website provide information and resources for the completion of required construction documentation. Other ARAs (DEQ, DNR Injection & Mining, LDH, etc.) may require additional submittals and documentation on a case-by-case basis. A number of the pre-construction (prior to field activities) approvals and documentation are provided in Chapter 2.0. For purposes of health and safety, observations of subsurface natural gas or other gaseous substances during drilling and construction of wells must be reported to DNR within 24 hours.

DNR/OC has issued reminders regarding expectations and obligations for reporting non-compliance with water well regulations. The purpose of the reporting is to build goodwill with the public and promote professional integrity within the water well industry by encouraging practices in pursuit of compliance with the regulations.

11.1 Determination of Well Location and Top of Casing Elevation

The location of the wells should be ascertained using a GPS location in latitude/longitude coordinates. Notably, GPS did not exist during prior regulatory versions, and it was customary to provide latitude/longitude coordinates derived from viewing USGS 7.5 minute Quadrangle maps, although these coordinates were not as accurate as GPS today. Additionally, the location of Section, Township & Range of a monitoring well should be determined.

11.2 Well Registration & Documentation

All wells completed under LAC Title 56, LAC Title 33 and the *Guidance Manual* require registration with DNR, which currently compiles and manages the publicly available SONRIS database. Registrations should be submitted within 30 calendar days after the well has been completed and include a copy of Well Registration Short Form DNR-GW-1S. All required sections of the form must be completed.

There are a number of required and suggested attachments to the registration forms. Required attachments are: an area map; a detailed map or sketch of the area identifying the well location, including nearby wells and other notable site features; and a sketch or other documentation of well construction details. Some suggested attachments are: a soil boring log; well construction diagram; geophysical log; and other data and information suitable for placement in the permanent record maintained by DNR. The attachments can be submitted as a supplement to a registration AFTER the 30-day requirement.

11.3 Plugging & Abandonment of Boreholes and Wells

A copy of DNR's P&A Form DNR-GW-2 must be completed and submitted within 30 days after a well has been P&A'd. All required sections of the form must be completed. Importantly, the drilling contractor should make every attempt to identify the well within the SONRIS database, and document the DNR Well Number on the P&A Form.

In the event the drilling contractor cannot determine the identity of a well within the SONRIS system, a well registration form should be completed and submitted contemporaneously with the P&A form. The registration should provide all available information (on the form and via required and suggested attachments). An unregistered well is not considered administratively P&A'd until the corresponding form for registration is complete and submitted to DNR with the P&A form.

As a general rule, most environmental boreholes completed under LAC Title 56, LAC Title 33 and this Manual do not require registration. One exception would be a "Test Hole" as defined under LAC Title 56. **Proper P&A methods must be utilized regardless of whether or not it is registered.** There are a number of required and suggested attachments to the P&A form, similar to those for the well registration form. One additional suggested attachment is the P&A Work Plan, if one exists. As above, the attachments can be submitted as a supplement AFTER the 30-day requirement.

11.4 Deviations from Approved Methods or Construction Plans

Deviations or variances from established rules and regulations require approval from the ARA, usually DNR in the case of well and boreholes.

Louisiana Department of Natural Resources
Office of Conservation
P.O. Box 94275
Baton Rouge, LA 70804