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WORK PLANS

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Comprehensive Site Plan
Salty Dog Brine Station
Lea County, New Mexico

Prepared for **New Mexico Energy, Minerals and Natural Resources Department**
Oil Conservation Division, Environmental Bureau

September 5, 2008

Daniel B. Stephens & Associates, Inc.

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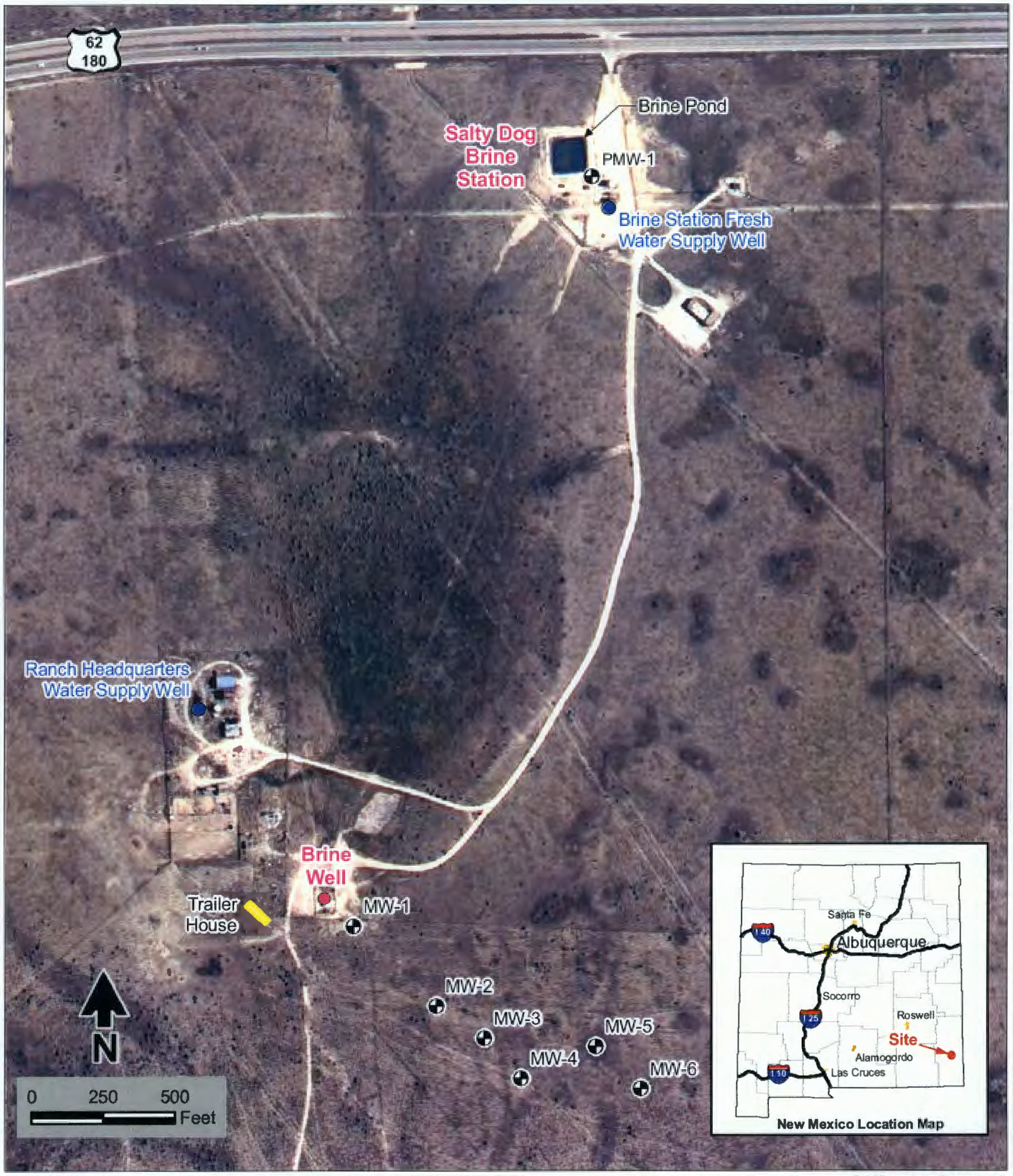
Appendix

1. Introduction

On behalf of PAB Services, Inc. (PAB), Daniel B. Stephens & Associates, Inc. (DBS&A) is pleased to submit this Comprehensive Site Plan (Plan) to the New Mexico Oil Conservation Division (OCD) Environmental Bureau in response to the requirements set forth in Sections 15b, 15e, and 15f of the OCD Settlement Agreement & Stipulated Revised Final Order (Order) for the Salty Dog brine station (Site). The Order requires PAB to complete certain actions to address environmental compliance-related issues at the Site in accordance with the timeline established by the OCD. The Site is located approximately 12 miles west of Hobbs on the south side of the Hobbs/Carlsbad Highway in the J Unit of Section 5, Township 19 South, Range 36 East, NMPM, Lea County, New Mexico (Figure 1). As required, this draft Comprehensive Site Plan is being submitted within 30 days of the Stipulated Agreement. A final Comprehensive Site Plan will be submitted to the OCD subsequent to receipt of comments on this draft document.

The Plan discusses the proposed project tasks to be completed in fulfillment of the requirements of the Order. Rather than submitting separate, individual specifications/proposals for each task, DBS&A has included all of the specifications/proposals required by the OCD in this Plan.

This Plan discusses the required elements as set forth in Sections 15b, 15e, and 15f of the Compliance Order (which were not listed in the order of due dates for project deliverables as detailed in Section 2 of this Plan) in the order in which the tasks will be performed. Section 2 presents a proposed project schedule for meeting the timeline established by the OCD in the Order. Section 3 presents individual specifications/proposals for each task, outlining the specific approaches to be used for addressing the environmental compliance-related issues at the Site. Table 1 cross references Order Requirements with the Plan section in which they're discussed.



Explanation

- Existing monitor well
- Water supply well

Source: RGIS aerial photograph dated July 2005

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SALTY DOG BRINE STATION
Site Location Map

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Figure 1

Table 1. Cross Reference Between Compliance Order Requirements and Comprehensive Site Plan Discussion

Order Section	Requirement	Plan Section
15.b.i	Specification/proposal for removal of existing brine pond	3.8
15.b.ii	Specification/proposal for construction of new tank battery	3.6
15.b.iii	Specification/proposal for coating concrete pad and sump	3.7
15.b.iv	Specification/proposal for survey of ground and top of monitor well casing elevations at the brine pond area; installation of five new monitoring wells and one recovery well; specification of how wells are to be constructed	3.1 3.3
15.b.v.	Specification/proposal for survey of ground and top of monitor well casing elevations at the brine well area; installation of three new monitoring wells and one recovery well; specification of how wells are to be constructed	3.1 3.3
15.b.vi	Specification/proposal for aquifer pump tests	3.4
15.b.vii	Closure report regarding removal of contaminated soil/soil staining and analytical data results at the brine well	3.8. 3.9
15.b.viii	Specification/proposal for installation of a single boring and collection of soil and water samples in the playa lake area	3.2
15.b.ix	Specification/proposal for installation of additional density gradient monitor wells at both the brine pond and brine well locations; specification of how wells are to be constructed and their location	3.1
15.e	Submittal of a copy of the SOPs used by the contract entities performing any and all sampling, collection, testing and/or analysis relating to the site	3.11
15.f	Quarterly monitoring reports	3.5.3 3.10

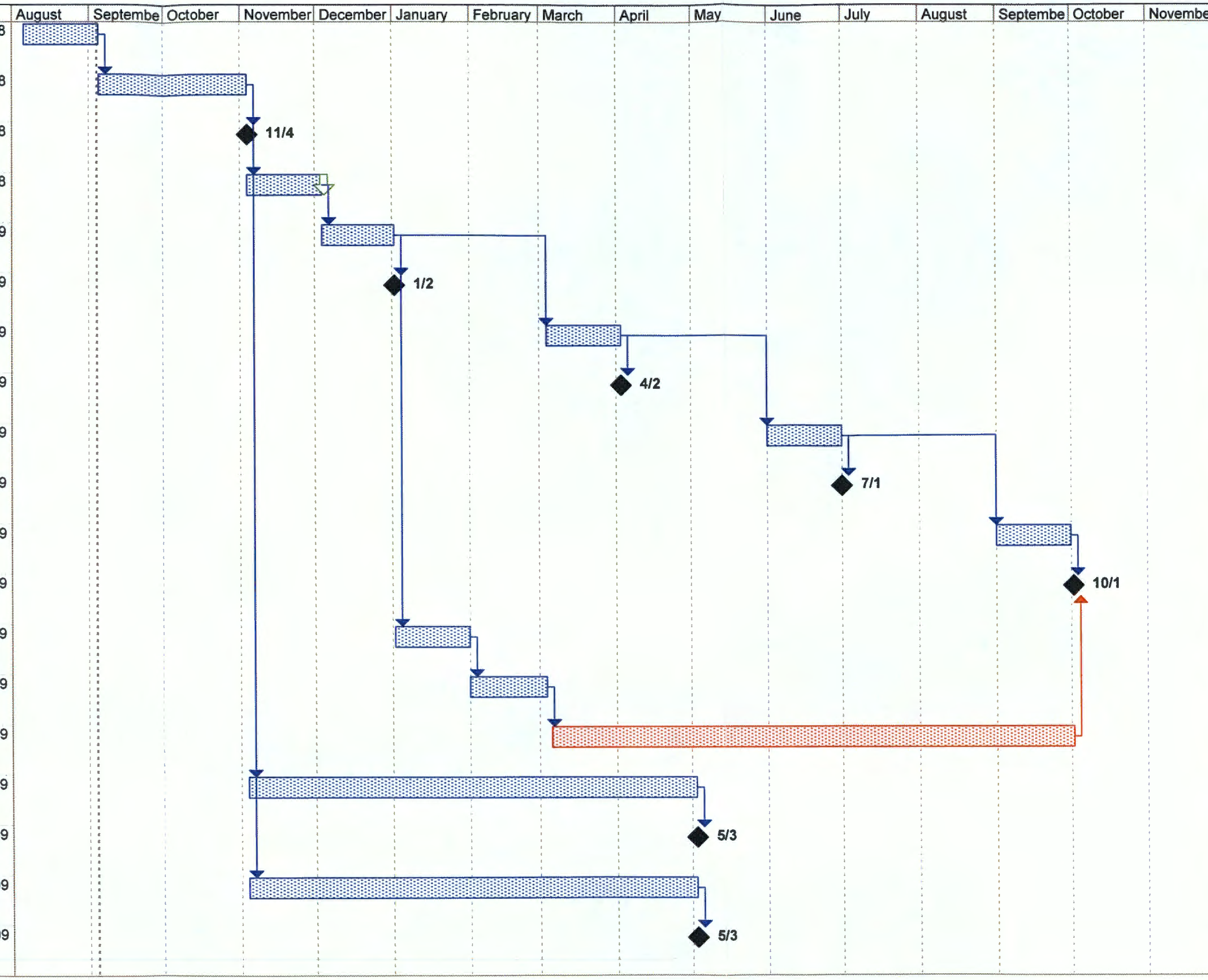
2. Project Schedule

Table 2 summarizes the project deadlines imposed by the OCD in Sections 15b, 15c, 15d, 15e, and 15f of the Order. Figure 2 presents a proposed schedule for completing the project tasks required by the Order. The schedule is based on the assumption that OCD will approve the final Plan on November 4, 2008, which is 60 days after the draft Plan is submitted for review (30 days for OCD review and 30 days for DBS&A to prepare the final Plan). If the date of approval of the final Plan changes, either earlier or later than November 4, 2008, the schedule will be adjusted accordingly.

Table 2. Project Deadlines Defined in the Order

Order Section	Requirement	Deadline
15b	Submit draft Comprehensive Site Plan	Within 30 days of the date of the signed Order
15c	Submit final Comprehensive Site Plan	Within 30 days of receipt of OCD's comments on the draft Plan
15d(i)	Remove existing brine pond; construct new loading pad; install new tank battery	Within 180 days of OCD approval of Plan
15d(ii)	Coat concrete pad and sump at brine loading/unloading station with epoxy	Within 60 days of OCD approval of Plan
15d(iii)	Complete a survey of ground and top of monitor and recovery well casings at both the brine well and brine pond areas; install 5 monitor wells and 1 recovery well at the brine pond area; install 3 monitor wells and 1 recovery well at the brine well area	Within 30 days of OCD approval of Plan
15e	Submit a copy of the SOPs	Within 30 days of the date of the signed Order
15f	Implement quarterly monitoring schedule	Once monitoring wells have been installed
15f(i)	Conduct baseline groundwater monitoring	Once monitoring wells have been installed
15f(ii)	Submit baseline groundwater monitoring report	Within 30 days of completing baseline groundwater sampling
15f(iii)	Submit quarterly groundwater monitoring reports with a Conclusions section	Within 30 days of the quarterly sample event
15f(v)	Submit a potentiometric surface map to assess cones of depression from the dynamic pump systems	At the onset of installation and activation, and upon achieving a steady-state pump rate condition in the recovery wells at the brine well and brine pond areas

ID		Task Name	Duration	Start	Finish
1		Comprehensive Site Plan Draft & SOPs to OCD	30 days	Wed 8/6/08	Fri 9/5/08
2		Plan Review & Final Submittal to OCD	60 days	Fri 9/5/08	Tue 11/4/08
3		OCD Approval of Plan	0 days	Tue 11/4/08	Tue 11/4/08
4		Installation of Monitor and Nested Wells & Soil Boring	30 days	Tue 11/4/08	Thu 12/4/08
5		Baseline Sampling	29 days	Thu 12/4/08	Fri 1/2/09
6		Submittal of Baseline Sampling Report	0 days	Fri 1/2/09	Fri 1/2/09
7		Second Quarterly Sampling	30 days	Tue 3/3/09	Thu 4/2/09
8		Submittal of Second Quarter Report	0 days	Thu 4/2/09	Thu 4/2/09
9		Third Quarter Sampling	30 days	Mon 6/1/09	Wed 7/1/09
10		Submittal of Third Quarter Report	0 days	Wed 7/1/09	Wed 7/1/09
11		Fourth Quarter Sampling	30 days	Tue 9/1/09	Thu 10/1/09
12		Submittal of Fourth Quarter Report	0 days	Thu 10/1/09	Thu 10/1/09
13		Installation of Recovery Wells & Pump Test	30 days	Fri 1/2/09	Sun 2/1/09
14		Pump Test Report	31 days	Sun 2/1/09	Wed 3/4/09
15		Begin Groundwater Remediation with New Recovery Wells	210 days	Thu 3/5/09	Thu 10/1/09
16		Design & Construction of New Tank Battery and Loading Pad	180 days	Tue 11/4/08	Sun 5/3/09
17		Complete Construction of Tank Battery & Loading Pad	0 days	Sun 5/3/09	Sun 5/3/09
18		Pond, Shed Excavation & Existing Pad Demolition	180 days	Tue 11/4/08	Sun 5/3/09
19		Final Closure Report(s)	0 days	Sun 5/3/09	Sun 5/3/09



Project: Salty Dog Project.mpp
Date: Thu 9/4/08

Task | Milestone | Rolled Up Critical Task | Split | Group By Summary
Critical Task | Summary | Rolled Up Milestone | External Tasks | Deadline
Progress | Rolled Up Task | Rolled Up Progress | Project Summary

Figure 2. Proposed Schedule for Project Tasks

The proposed project milestones are shown in Table 3. The dates that are shown in the table for completion of each milestone are projections based on the date of approval for the final Plan, as discussed above, and will change based on that date.

Table 3. Project Milestones

Project Milestone	Date
OCD approval of Comprehensive Site Plan	November 4, 2008
Installation of monitoring wells, nested wells, and soil boring	December 4, 2008
Submittal of baseline groundwater monitoring report (first quarterly report)	January 2, 2009
Recovery well installation, pump test, and report	March 4, 2009
Initiation of groundwater remediation with new recovery wells	March 5, 2008
Submittal of second quarterly groundwater monitoring report	April 2, 2009
Completion of new tank battery and loading pad construction	May 3, 2009
Submittal of final closure reports for brine pond and brine well areas	May 3, 2009
Submittal of third quarterly groundwater monitoring report	July 1, 2009
Submittal of fourth quarterly groundwater monitoring report	October 1, 2009

3. Project Tasks

Section 15b of the Compliance Order requires the preparation of a Comprehensive Site Plan that includes a number of elements (referred to as specifications/proposals) that are required to be addressed in the Plan. Additional requirements are specified in Sections 15e and 15f of the Order. These specifications/proposals are discussed, in the order in which they will be completed, in Sections 3.1 through 3.11. For reference purposes, Table 1 of this Plan cross references each of these tasks to the Compliance Order section that specified their completion.

All field work performed during this project will be conducted in accordance with standard operating procedures (SOPs) developed by DBS&A as part of its quality assurance (QA) program. A discussion of the SOPs is provided in Section 3.11 of this Plan.

3.1 Installation of Monitor Wells, Nested Wells, and Recovery Wells

A total of eight monitor wells, two nested wells, two recovery wells, and one temporary well will be installed during this drilling program. Table 4 summarizes the drilling program.

Table 4. Summary of Drilling Program

Location	Monitor Wells	Nested Wells	Recovery Wells	Soil Borings/ Temporary Wells
Brine Pond Area	DBS-1 DBS-2 DBS-3 DBS-4 DBS-5	DBS NW-1	DBS RW-1	—
Shed and Brine Well Area	DBS-6 DBS-7 DBS-8	DBS NW-2	DBS RW-2	SB-1

Prior to the performance of fieldwork, DBS&A will develop a site-specific health and safety plan (HASP) to address health and safety issues associated with the proposed project activities. New Mexico One-Call and PAB will be contacted so that underground utilities can be marked in the proposed drilling locations. Subcontractor services will be negotiated and agreements will be obtained for drilling, surveying, and laboratory analysis.

DBS&A will subcontract with a New Mexico licensed drilling company to complete the installation of monitor wells, nested wells, and recovery wells at both the brine pond area and the shed and brine well area. The wells will be installed using air rotary drilling technology. All of the wells will be constructed in accordance with the New Mexico Environment Department (NMED) Ground Water Pollution Prevention Section Monitoring Well Construction Guidelines, Revision 0.0, dated January 2007. A discussion of the well installation at the brine pond area and the shed and brine well area is provided in Sections 3.1.1 and 3.1.2.

3.1.1 Brine Pond Area

3.1.1.1 Monitor Wells

Five groundwater monitor wells (DBS-1 through DBS-5) will be installed at the brine pond area. Based on regional groundwater data and information contained in previous site reports provided by PAB, the direction of groundwater flow (without pumping) is assumed to be to the southeast. The monitor wells will be installed in upgradient, downgradient, and cross-gradient locations (Figure 3) to delineate the extent of the dissolved-phase chloride contaminant plume:

- DBS-1: approximately 200 feet downgradient (southeast) of the brine pond
- DBS-2: approximately 200 feet cross-gradient (east) of the brine pond
- DBS-3: approximately 200 feet cross-gradient (south-southwest) of the brine pond
- DBS-4: approximately 400 feet downgradient (southeast) of the brine pond
- DBS-5: approximately 300 feet upgradient (northwest) of the brine pond

The soil borings for the monitor wells will be advanced to the water table at approximately 60 feet below ground surface (ft bgs). Soil samples will be collected at 10-foot intervals during drilling and submitted to Hall Environmental Analysis Laboratory (HEAL) in Albuquerque, New Mexico for chloride analysis using U.S. Environmental Protection Agency (EPA) method 300.0 to quantify the chloride concentration profile with depth in the unsaturated zone. Each boring will then be advanced approximately 20 feet below the water table and completed as a 2-inch-diameter groundwater monitor well. A schematic of the proposed monitor well construction is shown in Figure 4.

Explanation

- Existing monitor well
- Water supply well
- Proposed monitor well
- Proposed nested well
- Proposed recovery well

Source: RGIS aerial photograph dated July 2005

SALTY DOG BRINE STATION

Proposed Well Locations

Brine Pond Area

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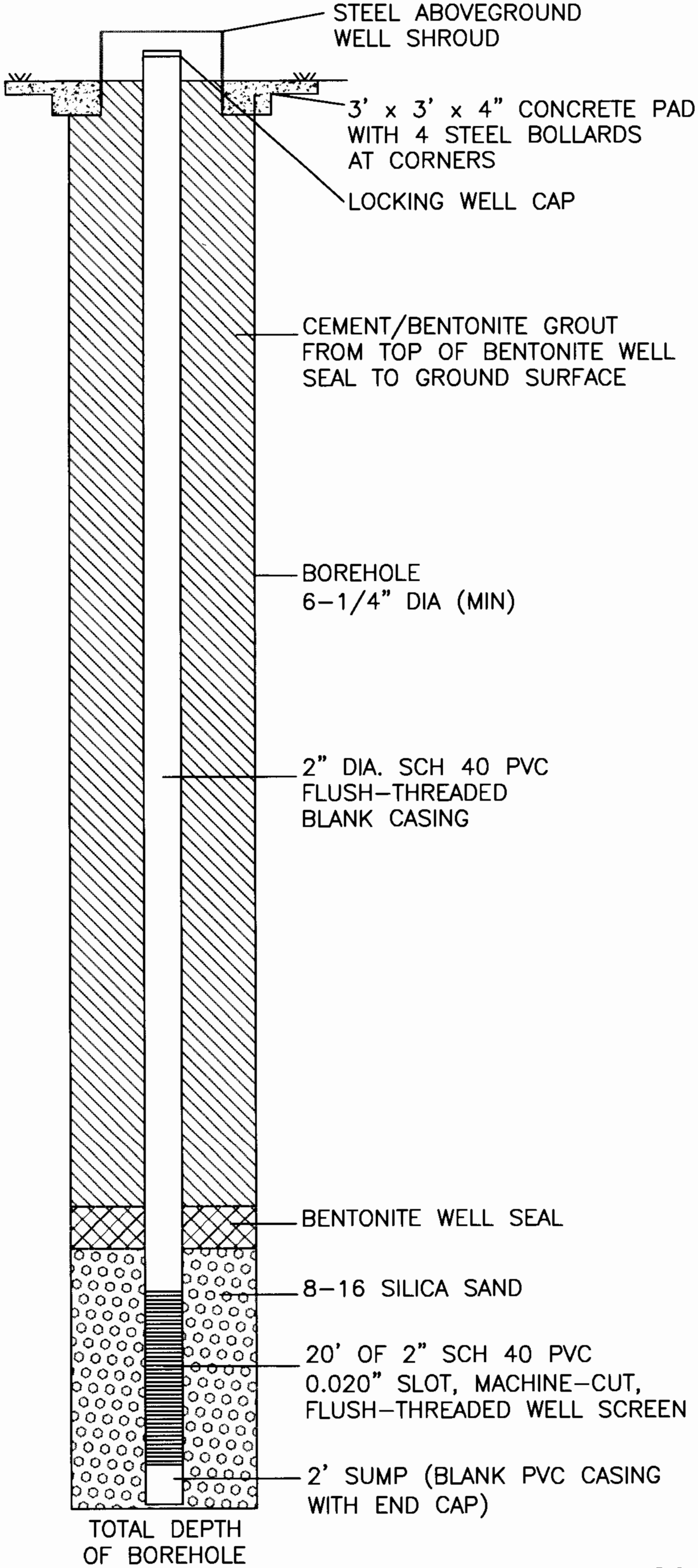
08/25/2008 JN ES08.0118.01

Figure 3



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SALTY DOG BRINE STATION

Typical Monitor Well Construction Detail

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Figure 4

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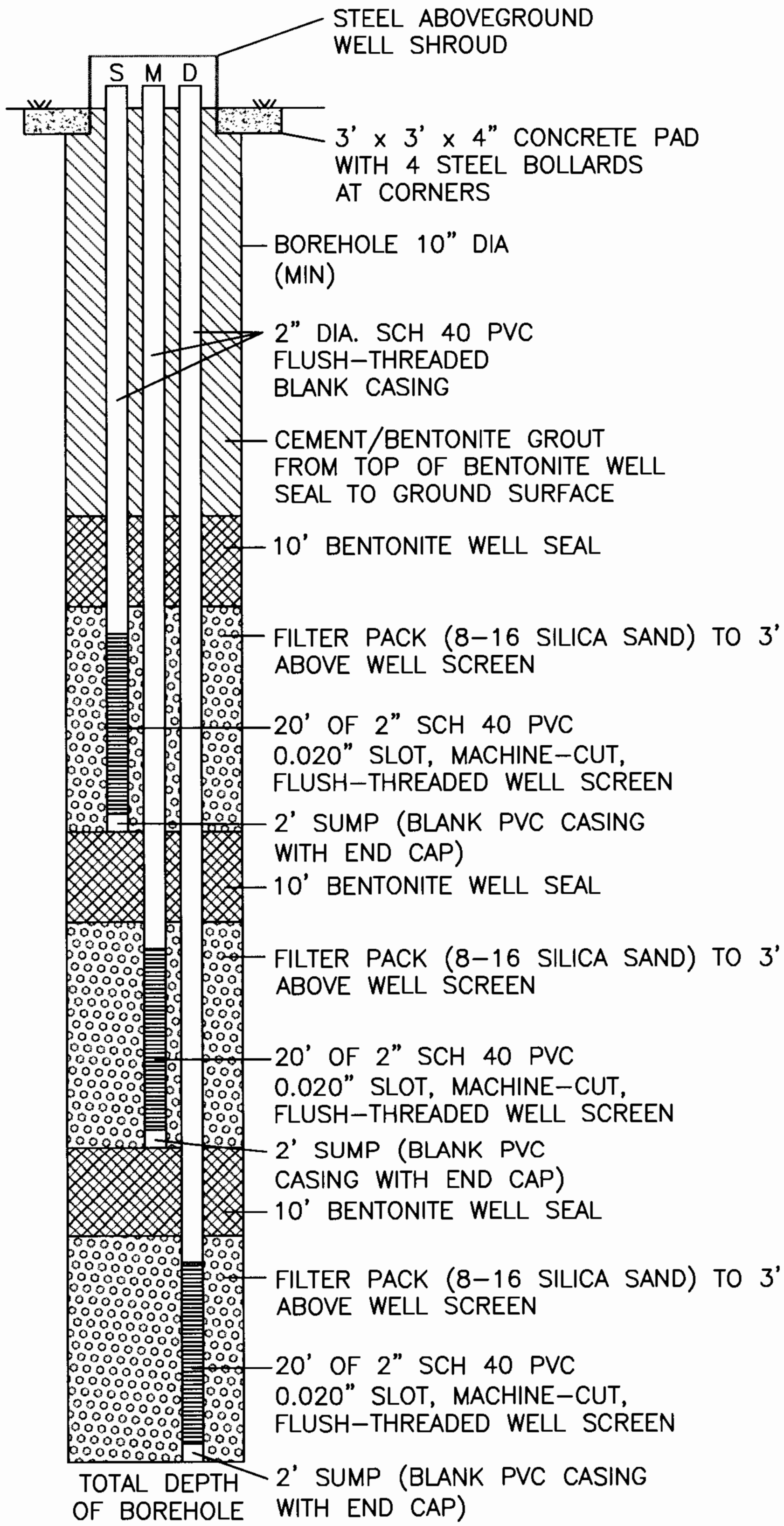
The wells will be constructed of 20 feet of 2-inch-diameter, 0.020-inch slot, flush-threaded, machine-cut, Schedule 40 (SCH 40) polyvinyl chloride (PVC) well screen with a 2-foot sump. Blank 2-inch-diameter, SCH 40 PVC casing will extend to approximately 2.5 feet above the ground surface. The well screen will extend from 5 feet above the water table to 15 feet below the water table. The filter pack will consist of 8-16 silica sand, placed by a tremie pipe, and will extend from the bottom of the boring to 3 feet above the well screen. The well will be surged or bailed to settle the sand pack, and additional sand will be added if necessary prior to placing the bentonite seal. A minimum 3-foot bentonite pellet seal (hydrated) will then be placed above the sand pack, and the annular space above the bentonite seal will be filled with a cement/bentonite grout to the surface. The surface completions for the monitor wells will consist of a locking, stickup steel well shroud with a 3-foot by 3-foot by 4-inch concrete pad and bollards at each corner.

3.1.1.2 Nested Well

One nested well (DBS NW-1) will be installed approximately 60 feet south of existing monitor well PMW-1 in the brine pond area (Figure 3) to determine the chloride density gradient with depth in the saturated zone. The nested well will enable DBS&A to evaluate vertical hydraulic and concentration gradients at a single location. The nested well will consist of three 2-inch-diameter monitor wells installed in one 10-inch-diameter soil boring.

The soil boring for the nested well will be advanced to the water table. Soil samples will be collected at 10-foot intervals during drilling and submitted to HEAL for chloride analysis using EPA method 300.0 to quantify the chloride concentration profile with depth in the unsaturated zone. The boring will then be advanced to the redbeds (base of the Ogallala Formation), which occurs at approximately 150 ft bgs beneath the Site based on previous Site reports provided by PAB. The screened intervals of the three wells will be located in the upper, middle, and deep portions of the saturated zone and will be adjusted in the field based on the depth to water. A schematic of the proposed nested well construction is shown in Figure 5.

The deep well will consist of 20 feet of 2-inch-diameter 0.020-inch slot, flush-threaded, machine-cut, SCH 40 PVC well screen with a 2-foot sump. Blank 2-inch SCH 40 PVC casing will extend to approximately 2.5 feet above the ground surface. The filter pack will consist of 8-16 silica



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Note: S = Shallow-screened well
M = Middle-screened well
D = Deep-screened well

SALTY DOG BRINE STATION

Typical Nested Well Construction Detail

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Figure 5

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The middle well will be constructed of 20 feet of 2-inch-diameter 0.020-inch slot, flush-threaded, machine-cut, SCH 40 PVC well screen with a 2-foot sump. Blank 2-inch SCH 40 PVC casing will extend to approximately 2.5 feet above the ground surface. The filter pack will consist of 8-16 silica sand placed by a tremie pipe and will extend from the top of the bentonite seal for the deep well to 3 feet above the well screen. The well will be surged or bailed to settle the sand pack, and additional sand will be added if necessary prior to placing the bentonite seal. A 10-foot bentonite pellet seal (hydrated) will then be placed above the sand pack.

The shallow well will be constructed of 20 feet of 2-inch-diameter 0.020-inch slot, flush-threaded, machine-cut, SCH 40 PVC well screen with a 2-foot sump. The screen will extend from 5 feet above to 15 feet below the water table. Blank 2-inch SCH 40 PVC casing will extend to approximately 2.5 feet above the ground surface. The filter pack will consist of 8-16 silica sand placed by a tremie pipe and will extend from the top of the bentonite seal for the middle well to 3 feet above the well screen. The well will be surged or bailed to settle the sand pack, and additional sand will be added if necessary prior to placing the bentonite seal. A 10-foot bentonite pellet seal (hydrated) will then be placed above the sand pack, and the remaining annular space above the bentonite seal for the shallow well will be filled with a cement/bentonite grout to the surface.

The surface completion for the nested well will consist of a locking, stickup steel well shroud with a 3-foot by 3-foot by 4-inch concrete pad and bollards at the corners.

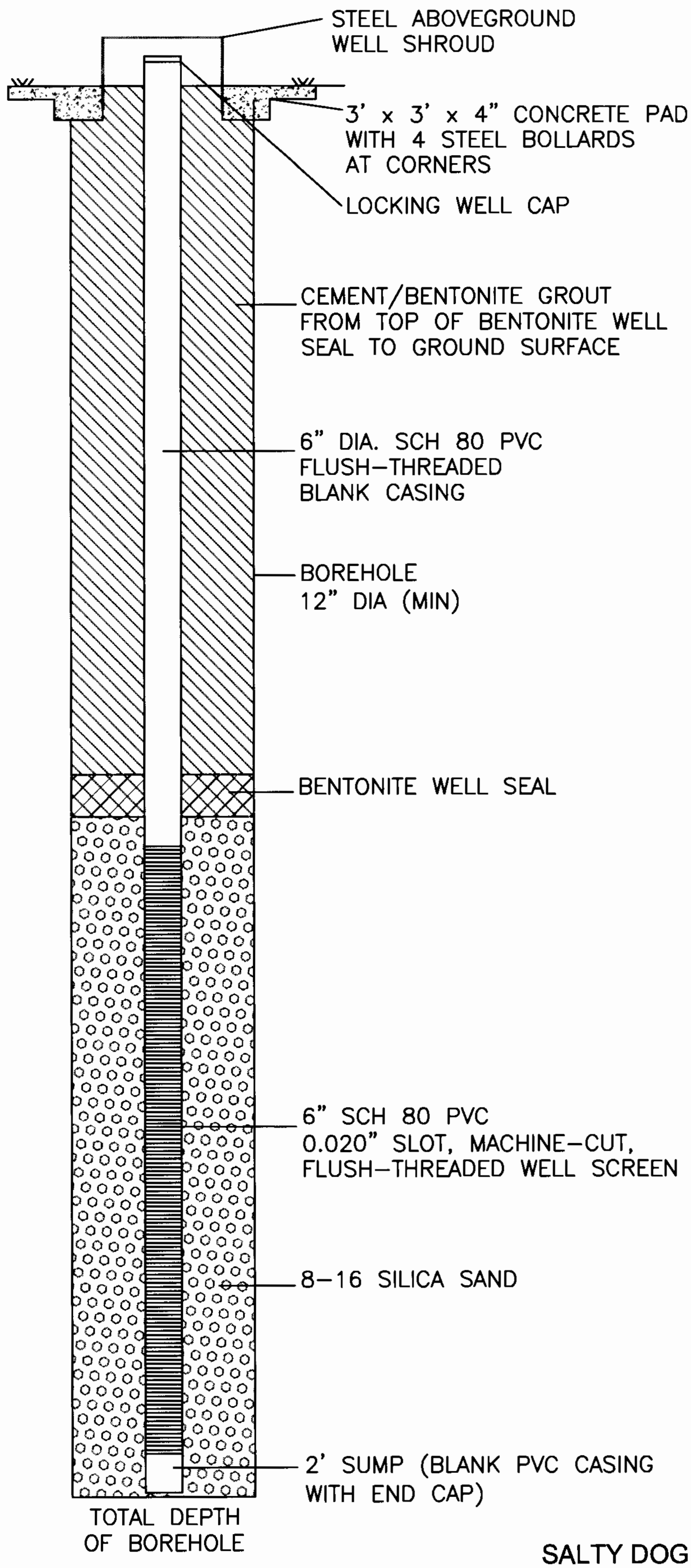
3.1.1.3 Recovery Well

One 6-inch-diameter recovery well (DBS RW-1) will be installed in the brine pond area for groundwater remediation. Although the Order requests that the recovery well be installed at the same time as the monitoring wells, DBS&A proposes that the recovery well be installed after the monitor well and nested well installations and baseline groundwater sampling are completed.

Analysis of samples collected from the shallow, middle, and deep monitor wells of the nested well will allow a determination of the chloride concentration density gradient with depth in the saturated zone, which in turn will allow an initial determination of the lateral extent of the chloride plume in groundwater. Analysis of these data will result in the optimization of the screen interval and location for the recovery well. For the purpose of this Plan, a proposed location of the recovery well is shown on Figure 3; however, the actual location may change based on results of the baseline groundwater sampling.

The soil boring for the recovery well will be advanced to the redbeds (base of the Ogallala Formation) with soil samples collected at 10-foot intervals above the water table. The boring will be terminated once the redbeds are encountered. Soil samples will be submitted to HEAL for chloride analysis using EPA method 300.0 to quantify the chloride concentration profile with depth in the unsaturated zone. The boring will then be completed as a 6-inch-diameter recovery well. A schematic of the proposed recovery well construction is shown in Figure 6.

The well will consist of 6-inch-diameter 0.020-inch slot, flush-threaded, machine-cut, SCH 80 PVC well screen with a 2-foot sump. Blank 6-inch SCH 80 PVC casing will extend to approximately 2.5 feet above the ground surface. The optimal screened interval for the recovery well will be determined based on the chloride concentration density gradient determined form the nested well groundwater analytical results. The filter pack will consist of 8-16 silica sand placed by a tremie pipe and will extend from the bottom of the boring to 3 feet above the well screen. The well will be surged or bailed to settle the sand pack, and additional sand will be added if necessary prior to placing the bentonite seal. A minimum 5-foot bentonite pellet seal (hydrated) will then be placed above the sand pack, and the annular space above the bentonite seal will be filled with a cement/bentonite grout to the surface. The surface completions for the recovery well will consist of a locking, stickup steel well shroud with a 3-foot by 3-foot by 4-inch concrete pad and bollards at the corners.



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SALTY DOG BRINE STATION

Typical Recovery Well Construction Detail

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Figure 6

3.1.2 Shed and Brine Well Area

3.1.2.1 Monitor Wells

Three groundwater monitor wells (DBS-6 through DBS-8) will be installed southeast of the shed and brine well area (Figure 7) to better delineate the cross-gradient extent of the dissolved-phase chloride contaminant plume:

- DBS-6: approximately 300 feet north of existing monitor well MW-4
- DBS-7: approximately 200 feet south of existing monitor well MW-4
- DBS-8: approximately 300 feet southwest of existing monitor well MW-4

The soil borings for the monitor wells will be advanced to the water table. Soil samples will be collected at 10-foot intervals during drilling and submitted to HEAL for chloride analysis using EPA method 300.0 to quantify the chloride concentration profile with depth in the unsaturated zone. Each boring will then be advanced approximately 20 feet below the water table and completed as a 2-inch-diameter groundwater monitor well as discussed in Section 3.1.1.1.

3.1.2.2 Nested well

One nested well (DBS NW-2) will be installed approximately 50 feet northwest of existing monitor well MW-4 (Figure 7) to determine the chloride density gradient with depth in the saturated zone. This proposed location is in the area of the dissolved-phase chloride groundwater plume that contains the highest chloride concentrations based on groundwater sampling performed by DBS&A in June 2008.

The soil boring for the nested well will be advanced to the water table, and soil samples will be collected at 10-foot intervals during drilling for chloride analysis using EPA method 300.0 to quantify the chloride concentration profile with depth in the unsaturated zone. The boring will then be advanced to the redbeds (base of the Ogallala Formation) and completed as a nested well as discussed in Section 3.1.1.2.

Explanation

Source: RGIS aerial photograph dated July 2005

- Existing monitor well
- Water supply well
- Proposed monitor well
- Proposed nested well
- Proposed recovery well
- Proposed soil boring

SALTY DOG BRINE STATION

Proposed Soil Boring and Well Locations
Playa Lake, Shed and Brine Well Area

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Figure 7

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3.1.2.3 Recovery Well

One 6-inch-diameter recovery well (DBS RW-2) will be installed approximately 10 feet southeast of existing monitor well MW-4 for groundwater remediation. As discussed in Section 3.1.1.3, DBS&A proposes to install the recovery well after the monitor well and nested well installations and baseline groundwater sampling are completed. For the purpose of this Plan, the proposed location of the recovery well is shown on Figure 7; however, the actual location may change based on results of the baseline groundwater sampling.

The soil boring for the recovery well will be advanced to the water table, and soil samples will be collected at 10-foot intervals during drilling for chloride analysis using EPA method 300.0 to quantify the chloride concentration profile with depth in the unsaturated zone. The boring will then be advanced to the redbeds (base of the Ogallala Formation) and completed as a 6-inch-diameter recovery well as discussed in Section 3.1.1.3.

3.2 Soil Boring

As specified in the Order, DBS&A will advance one soil boring (SB-1) in the playa lake located north of the shed and brine well area (Figure 7). The purpose of the boring is to quantify the concentrations of any contaminants remaining from the February 2005 brine supply pipeline rupture that resulted in the release of approximately 425 barrels of brine and flooding of the playa lake.

The soil boring will be advanced to the water table with soil samples collected at 10-foot intervals in the unsaturated zone. The soil samples will be submitted to HEAL for chloride and total petroleum hydrocarbons (TPH) analysis using EPA methods 300.0 and 418.1, respectively, to quantify the chloride and TPH concentration profiles with depth in the unsaturated zone. The boring will then be completed as a temporary monitor well for the collection of a groundwater sample. The temporary well completion will consist of 10 feet of 2-inch-diameter, 0.020-inch slot, flush-threaded, machine-cut, SCH 40 PVC well screen. Blank 2-inch-diameter, SCH 40 PVC casing will extend to approximately 2.5 feet above the ground surface. The screen will extend from 3 feet above to 7 feet below the water table. A filter pack consisting of 8-16 silica sand will be placed in the annulus from the bottom of the boring to 2 feet above the top of the screen.

The temporary well will be developed by pumping or bailing until temperature, pH, and electrical conductivity (EC) have stabilized and turbidity has been reduced to the extent practicable. After development, a sample of the groundwater will be collected using a disposable polyethylene bailer. The sample will be transferred into laboratory-provided sample containers and preserved on ice at 4 degrees Celsius until delivered to HEAL for analysis. After a groundwater sample has been collected, the boring will be plugged and abandoned in accordance with the NMED Ground Water Quality Bureau Guidelines for Monitor Well Abandonment, Revision 0.0, dated January 2007.

3.3 Survey

After installation of the monitor wells and nested wells, DBS&A will subcontract with a licensed New Mexico land surveyor to complete a survey all of the existing and newly installed wells. The survey for the two recovery wells will be completed after the wells are installed. Both surveys will consist of surveying the top of casing elevations of each of the wells to a North American Vertical Datum, 1988 (NAVD88) and surveying x-y coordinates of the each well to a North American Datum, 1983 (NAD83) in a state plane coordinate system.

3.4 Aquifer Pump Tests

Following installation and development of the recovery wells (DBS RW-1 and DBS RW-2), aquifer pump tests will be conducted on each well to determine well efficiencies and aquifer parameters. Two types of tests, step-drawdown and constant-rate, will be performed at each well with recovery monitored following each test. Water levels will measured in nearby monitor wells, and field parameters will be collected from the pumping well throughout all of the pump tests. Water will be discharged to aboveground storage tanks.

As described in Section 3.1.1.3, the recovery wells will be installed with 6-inch, SCH-80 PVC casing and screen with a nominal inside diameter of 5.7 inches that will easily house a 4-inch submersible pump and motor. Assuming a total dynamic head (TDH) of approximately 100 feet for the pumping wells based on information gained at other sites, the pump yields could be as high as 90 gallons per minute (gpm), depending on well efficiencies. A lower pumping rate may be used during recovery pumping.

3.4.1 Test Design

Three steps will be performed for 200 minutes each for a total pumping duration of 600 minutes (10 hours) followed by recovery monitoring. The pumping rates for each step will be based upon the maximum yield determined during installation and development of the wells, but steps will likely be 50, 70, and 90 gpm. The step-drawdown test will allow for the calculation of pumping levels, specific capacity, and well efficiencies for these different pumping rates.

After the step-test, water levels must recover to greater than 90 percent of the static water level and be maintained for at least 4 hours before beginning the constant-rate test. The constant-rate test will be run for 24 hours near the maximum pumping rate determined for the recovery well during the step tests (i.e., 80 to 90 gpm), followed by recovery monitoring. The constant-rate test will enable the calculation of aquifer parameters including transmissivity and storativity.

3.4.2 Field Measurements

Water levels will be measured in the aquifer during all pump tests. A transducer will be placed in the pumping well within a sounding tube to monitor changes in head. The surrounding monitor wells will also be used to evaluate drawdown of the water table with transducers or electric water level meters. All depth-to-water measurements will be recorded to one-hundredth of a foot.

Flow rates will be monitored throughout the tests and adjusted to maintain the appropriate rates. Flow rates will be controlled by a gate or ball valve set in the discharge line upstream of a totalizing flow meter.

The field parameters pH, EC, temperature, and chloride concentration will be monitored regularly during the tests. Chloride concentrations will be measured with an ion-selective electrode. All of the meters will be placed in a flow-through cell during the pump tests and data will be recorded at regular intervals.

3.4.3 Capture Zone Analysis and Optimization of Groundwater Remediation

Following the pump tests, the data will be used to calculate capture zones for the recovery wells and travel times for water to reach the recovery wells. Data analysis will use computer software such as AQTESOLV and standard graphical methods. The data will be tabulated in the final report. Pumping rates that will allow for efficient capture and pumping of the chloride plume will be determined based on the site-specific aquifer parameters. The Ogallala Formation has the potential to be a very productive aquifer with yields of several hundred gpm. During recovery operations, a pumping rate will be selected to maximize capture of the chloride plume while minimizing dilution by fresher groundwater.

If the nested wells indicate stratification of the chloride plume by depth, the recovery wells may be preferentially pumped by placing inflatable packers within the screened section of the well to achieve the greatest chloride removal. As the recovery operation continues and quarterly groundwater data are collected, the approach to selective pumping will be evaluated and adjusted to maintain the most efficient chloride recovery.

3.5 Baseline Groundwater Sampling and Reporting

3.5.1 Sampling Activities

Upon completion of the groundwater monitor wells (DBS-1 through DBS-8) and nested wells (DBS NW-1 and DBS NW-2) installed in the brine pond and brine well areas, the newly installed and existing (MW-1, MW-2, MW-3, MW-4, MW-5 and MW-6) monitor wells (Figures 3 and 7) will be sampled for laboratory analysis. The two recovery wells (DBS-RW-1 and DBS-RW-2) will be installed and sampled for baseline water quality after receipt and analysis of laboratory results.

Prior to sampling, fluid levels will be gauged in the eight newly installed monitor wells, two newly installed nested wells (six wells in two completions), and six existing site monitor wells using an electric water level meter. The water level meter will be decontaminated before each measurement using a solution of deionized water and Liquinox (or equivalent) soap.

The wells will be purged by pumping a minimum of three casing volumes using a 12-volt stainless steel, monsoon pump. Both prior to and immediately after purging, groundwater field parameters (EC, pH, and temperature) will be measured in situ in each of the wells to be sampled , using a YSI water quality meter or equivalent device.

3.5.2 Analytical Program

After purging, the eight new monitor wells, two newly installed nested wells (six wells in two completions), and six existing wells (20 total) will be sampled for laboratory analysis pursuant to New Mexico Water Quality Control Commission (NMWQCC) and OCD requirements. The groundwater samples will be analyzed for volatile organic compounds (VOCs) including benzene, toluene, ethylbenzene, and total xylenes (BTEX) using EPA method 8021B; gasoline, diesel and motor oil range organics using EPA method 8015B; and general chemistry (cation/anion balance) using EPA method 300.0.

The bottled groundwater samples will be labeled and preserved on ice in an insulated cooler for delivery to HEAL in Albuquerque, New Mexico, for analysis. Groundwater samples will be accompanied by full chain-of-custody documentation at all times.

The Order requires that groundwater samples also be collected for metals analysis. PAB has requested that the OCD reconsider this requirement, as metals are not a contaminant of concern at the Site and are costly to analyze for.

3.5.3 Reporting

Upon receipt of laboratory analytical reports, DBS&A will prepare a baseline groundwater sampling report conforming to NMWQCC reporting requirements (NMAC 20.6.2.3107). The report will provide results of the groundwater monitoring and will include, but not be limited to, the following:

- Area/vicinity map
- Site map showing underground utilities and other subsurface structures on or adjacent to the Site, buildings, monitor, nested, and recovery wells, and all other pertinent structures

- Potentiometric surface maps with groundwater gradient and flow direction for both the brine pond and shed and brine well areas
- Maps showing groundwater contaminant distribution for both the brine pond and shed and brine well areas
- Data collection and monitor/nested/recovery well development methods
- Laboratory and field analytical results with tables
- Conclusions providing a discussion of groundwater impact and plume stability
- Recommendations
- A familiarity statement signed by the project scientist

Following the baseline groundwater monitoring event, the site will be sampled quarterly for a 1-year period. The subsequent analytical methods may be adjusted, based on the results of the baseline monitoring and discussion with the OCD project manager. For the baseline groundwater monitoring event, DBS&A will perform all sampling and prepare the monitoring report. For the second, third, and fourth quarterly monitoring events, PAB will perform all sampling and forward the data to DBS&A, who will prepare the monitoring reports.

3.6 Design of New Brine Tank Battery and Loading Pad

Upon approval of the Plan, DBS&A will begin design of a new tank battery and loading pad to be constructed at the Site. The tank battery is proposed to be installed prior to removal of the brine pond so that operations at the facility may continue uninterrupted. The precise location of the future tank battery has yet to be determined and will be based on operational efficiency and vehicle traffic patterns. The loading pad will replace the existing brine loading area located adjacent to the pond on the east side of the fence. The new tank battery and loading pad will be designed with input from PAB to meet their needs. Plans and specifications for the tank battery and loading pad will be prepared under the supervision of a DBS&A professional engineer and submitted to the OCD for review and approval prior to construction. The final plans and specifications will be stamped by the professional engineer.

3.6.1 Tank Battery

The tank battery will be designed to initially hold up to 4,000 barrels of brine (eight 500-barrel aboveground tanks) with the ability to be expanded to hold an additional 2,000 barrels of brine (four 500-barrel aboveground tanks). The tank battery will be underlain by a 60-mil high-density polyethylene (HDPE) liner and bermed for secondary containment. The draft design will contain all of the appropriate plans and specifications for construction of the tank battery.

3.6.2 Loading Pad

The loading pad will be designed with two brine filling risers to accommodate up to four trucks filling simultaneously. The loading pad will be appropriately sloped to the middle, where a sump will collect any overfill or spillage from the filling operations. The sump will be connected to a pump so that the accumulated overfill and spillage can be transferred from the sump back to the tanks. The draft design will contain all of the appropriate plans and specifications for construction of the loading pad.

3.7 Removal of Existing Concrete Loading Pad

Section 15.b of the Order requires that the existing loading pad at the southeast corner of the brine pond be sealed to mitigate potential seepage. Rather than seal the existing pad, it will be removed and a new loading pad will be constructed. The existing loading pad consists of a concrete pad measuring approximately 14 feet wide by 40 feet long with metal railing on both sides; a concrete sump covered by a metal grate is located in the center of the pad (Figure 8). The concrete will be broken up with a backhoe or excavator, and the debris will be hauled to a disposal facility. The metal railing and grate will be taken to a local metal recycler.

Source: RGIS aerial photograph dated July 2005

Explanation

- Gridded sampling area
- Proposed soil sample
- Fence

SALTY DOG BRINE STATION

Brine Pond and Loading Area
Proposed Soil Sampling Grid

Daniel B. Stephens & Associates, Inc.
08/25/2008 JN ES08.0118.01

Figure 8

S:/PROJECTS/ES08.0118.01_SALTY_DOG_INC/GIS/MXDS/COMPREHENSIVE_SITE_PLAN/FIG08-BRINE_POND_SAMPLING_GRID.MXD 809280

3.8 Removal of Existing Brine Pond and Brine Loading Area

3.8.1 Brine Pond and Loading Area

The brine pond will be removed in accordance with the Order. The removal will include the contents of the pond (brine water and accumulated salt), pond liner, and berms surrounding the pond. After removal of the pond contents and liner, soil samples will be collected from beneath the liner and from the loading area located adjacent to the pond on the east side. The sample results will provide both verification as to whether the pond liner has leaked and if so, concentrations of chloride in soils beneath the pond and at the loading area.

A grid will be established over the extent of the former pond and loading area (approximately 210 feet long by 155 feet wide). A backhoe will be used to collect soil samples on 30-foot centers from the gridded area and selectively from areas showing visual impact (Figure 8). The samples will be submitted to a local analytical laboratory for 24-hour turnaround chloride analysis using EPA method 300.0.

If sample results show elevated chloride concentrations above an agreed-upon level, PAB proposes two options:

- 1. Install a concrete truck turnaround and loading pad over the extent of the chloride-impacted soils. The concrete will limit infiltration of precipitation and/or surface water into subsurface soils, thereby limiting the potential for chloride migration to the groundwater from contaminated soils left in place.

- 2. Place a 60-mil HDPE liner and 1 foot of topsoil over the impacted area. This would also limit the potential for chloride migration to the groundwater from contaminated soils left in place.

One or both of these options may provide a more cost-effective approach than excavation.

3.8.2 Brine Pond Removal Plan

DBS&A will prepare a plan for removal of the brine pond and contents. The removal plan will be submitted to the OCD for review and approval prior to implementing the field activities.

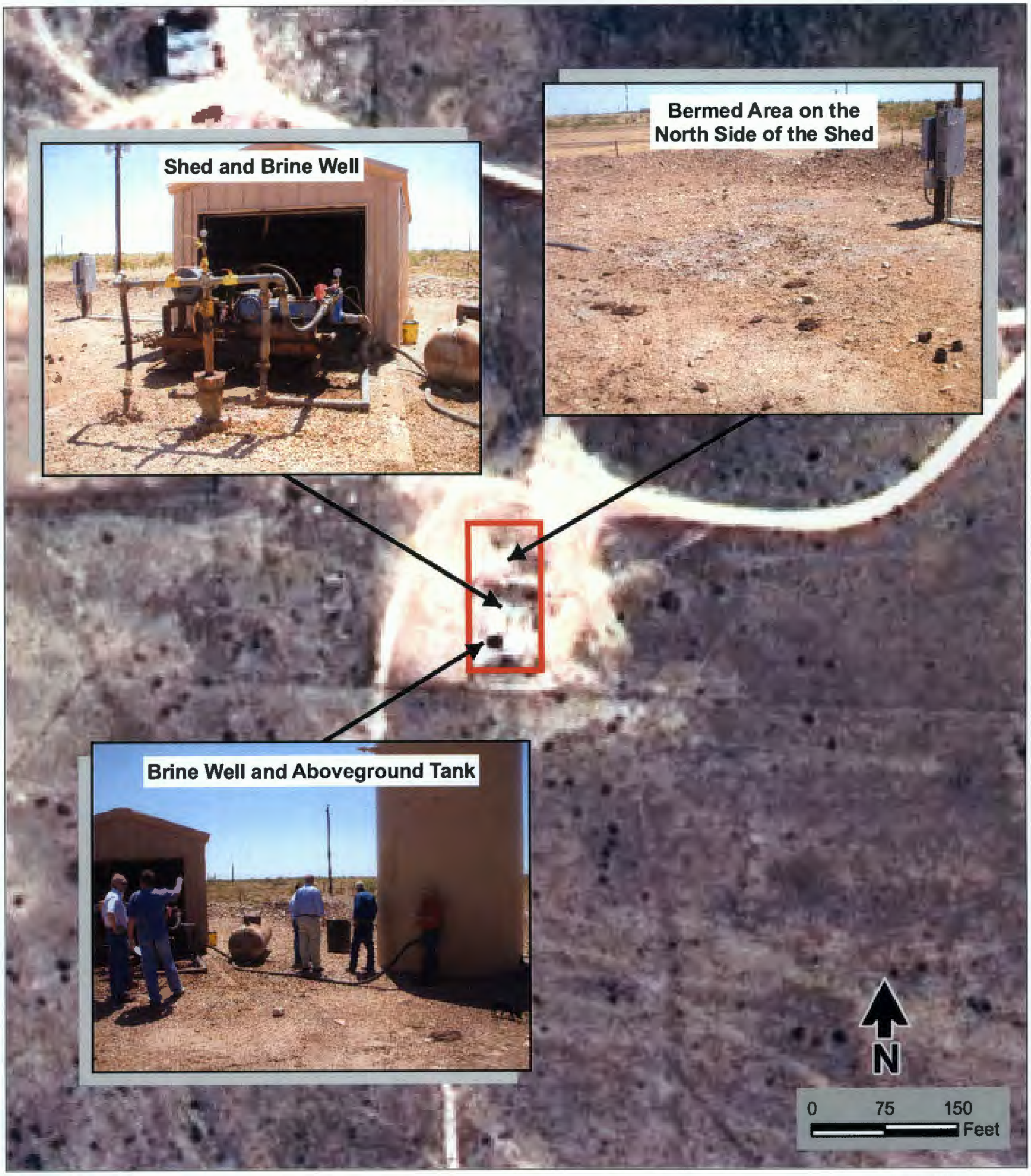
3.8.3 Closure Report

A final closure report will be submitted to the OCD Project Manager after completion of the pond removal. The report will contain daily field logs, laboratory analytical results from soil sampling beneath the liner and at the loading area, details of pond content disposal and copies of the waste manifests, and recommendations for further action (i.e., concrete truck turnaround and loading pad, HDPE liner, or a combination of the two).

3.9 Excavation of Contaminated Soil at the Shed and Brine Well Area and Closure Report

DBS&A will prepare an excavation plan to remove petroleum hydrocarbon- and chloride-contaminated soil in the shed and brine well area. For the purpose of this Comprehensive Site Plan, the proposed extent of excavation is estimated to be an area approximately 150 feet long by 75 feet wide by 5 feet deep (approximately 2,100 cubic yards) (Figure 9). No prior subsurface investigation has been conducted to determine the actual vertical and horizontal extent of hydrocarbon- and chloride-contaminated soil within the bermed area containing the shed and brine well, and as a result, the proposed extent of excavation is an estimate only based on visible soil staining, extent of chloride-encrusted surface soils, and aerial photography of the Site. The extent of excavation may change based on input from the OCD and results of confirmatory soil samples collected during excavation.

The confirmatory soil samples collected during excavation will be used to determine the lateral and vertical extent of hydrocarbon- and chloride-contaminated soils and the actual soil volumes to be removed for off-site disposal based on action levels agreed upon by OCD and PAB. If the vertical extent of chloride contamination exceeding the agreed-upon regulatory standards cannot be defined during excavation, an alternative abatement plan for the Site will be proposed. This plan will be developed in consultation with OCD prior to implementing field activities so that costly standby for the excavation equipment and operators will not be incurred.



Explanation

Proposed extent of excavation

Source: RGIS aerial photograph dated July 2005

SALTY DOG BRINE STATION

Shed and Brine Well Area

Proposed Extent of Excavation

Daniel B. Stephens & Associates, Inc.

08/25/2008

JN ES08.0118.01

Figure 9

S:/PROJECTS/ES08.0118.01 SALTY DOG INC/GIS/MXDS/COMPREHENSIVE SITE PLAN/FIG09-BRINE WELL EXCAVATION AREA.MXD 809280

The excavation plan will be submitted to OCD for approval prior to implementation of field activities. A closure report will be submitted to the OCD Project Manager after completion of excavation and backfilling.

3.10 Groundwater Remediation and Operation and Maintenance

Groundwater remediation will be performed at the Site in accordance with the Order. The two new recovery wells (DBS RW-1 and DBS RW-2), located at the brine pond and the shed and brine well areas, will be screened optimally so that groundwater from the portion of the saturated zone containing the highest concentrations of chloride is selectively pumped. The screened intervals of the recovery wells will be determined based on any observed chloride concentration density gradient as determined from sampling of the nested wells (Section 3.1.1.3).

The optimal pumping rates for plume capture will be determined based on the aquifer pump tests conducted on the two recovery wells and the capture zone analysis performed by DBS&A (Section 3.4.3). PAB will determine the appropriate course of action for handling the water that is extracted from the recovery wells during remediation, which will likely consist of a combination of storage and reinjection into the brine well and off-site disposal.

A potentiometric surface map will be submitted to the OCD at the onset of installation, activation, and upon achieving a steady-state pumping rate condition so that the adequateness of the capture zones for each recovery well can be assessed. PAB will be responsible for operating and maintaining the groundwater extraction equipment and maintaining daily, monthly, and average recovery well flow rates. PAB will forward the daily, monthly, and average recovery well flow rates to DBS&A for inclusion in the quarterly groundwater monitoring reports. As discussed in Section 3.5.3, DBS&A will be responsible for preparing and submitting the first year of quarterly monitoring reports to the OCD.

3.11 Standard Operating Procedures

SOPs describe in detail the routine procedures to be followed for a specific operation, analysis, or action. Consistent use of an approved SOP ensures conformance with organizational practices, reduced work effort, reduction in error occurrences, and improved data comparability, credibility, and defensibility. SOPs also serve as resources for training and for ready reference and documentation of proper procedures.

Table 5 presents an index of the project-specific SOPs that will be used during field activities conducted at the Site. These SOPs are reviewed periodically, and revisions and additions are made as needed to assure consistency with industry standards and the collection of high quality data in the field. Copies of the SOPs are included in Appendix A.

Table 5. Standard Operating Procedures

SOP Number	Title
1.1	Equipment
1.3	Field Log Book
3.1	Drilling Operations
3.2	Soils Logging, Sampling, Handling, and Shipping for Geotechnical and Chemical Analyses
4.1	Monitor Well Design and Installation
4.2	Well Development
4.3	Well and Boring Abandonment
5.1	Preparation for Water Sampling
5.2	Decontamination of Field Equipment
5.3	Measurement of Field Parameters
5.4	Collection of Groundwater Samples
5.6	Sample Preservation
5.7	Sample Filtration
5.8	Quality Assurance/Quality Control (QA/QC) Samples
6.3	Aquifer Pumping Test

Appendix A

Standard Operating Procedures

Appendix A. Standard Operating Procedures

The Standard Operating Procedures (SOPs) included in this appendix (listed below) will be used by all field personnel working at the Site. All SOPs included in this appendix are proprietary in nature and shall not be copied or reproduced, or distributed to any person or organization not employed by DBS&A, without the expressed written approval of the President or his/her designee for quality assurance.

SOP Number	Title
1.1	Equipment
1.3	Field Log Book
3.1	Drilling Operations
3.2	Soils Logging, Sampling, Handling, and Shipping for Geotechnical and Chemical Analyses
4.1	Monitor Well Design and Installation
4.2	Well Development
4.3	Well and Boring Abandonment
5.1	Preparation for Water Sampling
5.2	Decontamination of Field Equipment
5.3	Measurement of Field Parameters
5.4	Collection of Groundwater Samples
5.6	Sample Preservation
5.7	Sample Filtration
5.8	Quality Assurance/Quality Control (QA/QC) Samples
6.3	Aquifer Pumping Test

1.1 Equipment

This SOP provides standard procedures for maintaining equipment and for obtaining equipment from the DBS&A warehouse for conducting technical activities in the field.

The SOPs and SOGs included in this section are applicable to all DBS&A employees for the conduct of all activities listed in this section. **All SOPs and SOGs described in this section are proprietary in nature and shall not be copied or reproduced, or distributed to any person or organization not employed by DBS&A, without the expressed written approval of the President or his/her designee for quality assurance.** All or parts of the SOPs and SOGs described in this section may be reproduced and used in DBS&A reports, proposals, and work plans with the verbal consent of the President, his/her quality assurance designee, or a DBS&A Division Director.

These SOPs and SOGs shall be reviewed periodically, and revisions and additions to these SOPs and SOGs shall be made as needed to assure consistency with industry standards and the collection of high quality data in the field. Requests for revisions shall be made in writing to the President or his/her quality assurance designee.

1.1.1 Equipment and Vehicle Planning and Ordering

All supplies and equipment required for field projects shall be requested through the Environmental Equipment Coordinator (EEC) on a Field Equipment and Materials Load-Up Sheet (DBS&A Form No. 078), Attachment 1.1-1 to this SOP. Use of vehicles and meters can be reserved using this form. The Load-Up Sheet should be submitted to the EEC with enough notice to allow coordination and, if necessary, requisition of equipment and supplies.

DBS&A or rental vehicles shall be loaded one workday prior to field activity with equipment and supplies, as requested. Vehicle fuel tanks shall be filled and fluid levels checked. It is the vehicle operator's responsibility to conduct a visual check of vehicle and safety equipment.

Rental vehicles can be obtained by filling out a Purchase Order (DBS&A Form No. 111), Attachment 1.1-2 to this SOP with the appropriate signature and Purchase Order number. The EEC will make the vehicle reservations at the rental agency and pick up the vehicle at the appropriate time.

The vehicle and all meters and equipment shall be field cleaned per Section 5.2 of the DBS&A Field Technical SOPs prior to returning to the warehouse to avoid contamination of other equipment. Equipment and supplies shall be thoroughly cleaned once returned to the warehouse.

Any defects in equipment, meters or vehicles shall be brought to the attention of the EEC. This notice shall be in writing to ensure repair or replacement.

Upon return of a vehicle from a technical activity in the field, the EEC will thoroughly inventory all supplies, equipment and meters to ensure proper billing.

Vehicles shall depart from the main office on the first day of a field activity and be returned to the main office on the last day of the activity. Company vehicles and rental vehicles must be returned to ensure proper billing. Upon return, notify the EEC. The vehicle may need to be unloaded, cleaned, and reloaded for another field activity.

Company vehicles shall be used, if available, prior to arranging for a rental or for the use of a personal vehicle.

If supplies and equipment are needed because of unforeseen difficulties, a Field Equipment and Materials Load-Up Sheet shall be left for the EEC. This must be done to ensure that DBS&A can properly bill for supplies and equipment.

1.1.2 Equipment Cleaning, Maintenance, and Calibration

The following procedures should be followed to maintain proper operation of all equipment:

- Equipment returned from a field activity shall be thoroughly inspected for wear, breakage, and proper operation by the EEC.

- Equipment shall be cleaned with a tap water and Liquinox solution and then rinsed with distilled water. If the equipment is used for soil or water sampling, it will then receive a second rinse with distilled water.

- *Batteries and power supply units* shall be checked for proper power and replaced or repaired as needed.

- Any worn or broken parts that were noted during the inspection shall be either repaired or replaced by the EEC in accordance with manufacturer's recommendations.

- *Solinst Water Level meters* shall be inspected by the EEC for short circuiting in the electronic board, low battery charge, and worn, torn, or damaged shrink tubing on the probe. Repair shall be completed as needed.

- *Orion pH meters* shall be run through the self-test by the EEC as described in the Operations Manual. The probes shall be inspected to ensure good electrical connections. Following the instructions in the Operators Manual supplied by the manufacturer, probes shall be refilled periodically using the recommended electrode filling solution. Calibration of the instrument is described in the Operators Manual. Use buffer solution close to the parameters to be found in the water to be tested, usually pH 4.0 and pH 7.0.

- *YSI Salinity-Conductivity-Temperature meters* shall be inspected by the EEC for damage and water entry. The probe shall be soaked in a solution of one (1) part HCl, ten (10) parts distilled water, and ten (10) parts isopropyl alcohol for one hour. The probe shall then be washed in a Liquinox solution and rinsed in distilled water. Batteries shall be tested for proper voltage with a voltage tester and replaced as necessary. The instrument shall be calibrated in accordance with manufacturer's recommendations as supplied in the appropriate Operators Manual. The calibration solution shall be as close as possible to parameters expected in the field.

- The *YSI Model 57 Dissolved Oxygen meter* shall be inspected by the EEC for damage and water entry. The probe membrane shall be inspected and changed if needed in accordance with the manufacturer's recommendation in the Operators Manual. The batteries shall be tested and replaced if needed. The meter shall be calibrated as described in the Operators Manual.

- The *Hydrolab Water Quality Meter* shall be inspected thoroughly by the EEC for damage and wear. A close inspection of the probes, cords, and electrical connectors is essential. The batteries shall be tested and replaced as needed. The probes shall be cleaned and calibrated as described in the Operators Manual supplied with the equipment.

- The *Combustible Gas Indicator (MSA #30)* shall be visually inspected by the EEC for worn or damaged parts. The batteries for this unit shall be tested using a voltage tester and replaced as necessary. The instructions provided by manufacturer on the lid of the instrument shall be followed.

- The *LEL/02 Monitor (MX 251) and sampling pump* shall be closely inspected by the EEC for damage and wear. Upper and Lower Explosive set pints and Oxygen Alarm settings shall be checked. Calibration in accordance with manufacturers specifications, outlined in the users handbook, shall be performed using 100 ppm pentane. The batteries shall be tested and replaced as needed.

- The *photoionization detector (PID)* shall be thoroughly checked by the EEC prior to cleaning and maintenance. The meter shall be calibrated using 100 ppm isobutylene following procedures in the Operators Manual and cleaned as needed. The meter shall be fully discharged prior to recharging to avoid memory etching.

Attachments

1.1-1. Field Equipment and Materials Load-Up Sheet (DBS&A Form No. 078)

1.1-2. Purchase Order (DBS&A Form No. 111)

Field Equipment and Materials Load-Up

Daniel B. Stephens & Associates, Inc.

Project No. & Task No.	
Site	
Team	
Due Date & Time	
Request Date	
Vehicle	
Start Mileage	
End Mileage	
Field Activities	
Start Date	

Required	Packed	Used	**Water Sampling**
			Disposable Teflon Bailers (Size ____)
			Teflon Bailer Bottom Empty Device
			Disposable Poly Bailers
			Poly Bailer Bottom Empty Device
			PVC Bailers, Size __________
			Bailer Twine (200-ft rolls)
			Stainless Steel Bailer
			0.45µ Disposable In-Line Filter
			HCL Preservative (Dropper Bottle)
			HNO_2 Preservative (Ampule)
			H_2SO_4 Preservative (Ampule)
			HCL Preservative (Ampule)

Required	Packed	Used	**Soil Sampling**
			Soil Sampling Tool Kit
			Brass Rings, Size __________
			Stainless Rings, Size __________
			End Caps (Reg), Size __________
			Teflon Liners
			Solvent-Free Tape

Sample Containers

Required	Packed	Used	**(EPA Level III Preparation)**
			40mL VOA Amber
			40mL VOA Clear
			1 L Amber Glass
			1 L Clear Glass
			1 lt Cubitainers
			1 Gal Cubitainers
			125mL Soil Jar
			250mL Soil Jar
			500mL Soil Jar

Required	Packed	Used	**Supplies**
			Distilled water
			Paper Towels (rolls)
			Buffers pH (4, 7, 10)
			Buffers - Conductivity (_______ µS/cm)
			Liquinox
			Ziploc (Gallon)
			Ziploc (Quart)
			Garbage Bags (Small)
			Garbage Bags (Large)
			Braided Polypropylene Rope 1,000 ft
			Zip Ties
			Batteries (C)
			Batteries (D)
			Batteries (AA)
			Batteries (AAA)
			Batteries (9 Volt)
			Duct Tape
			Packing Tape
			Strapping Tape
			Bubble Wrap
			Plastic Sheeting
			Sharpies
			Magic Markers
			Drum Markers
			Survey Flagging (rolls)
			Pin Flags
			Survey stakes (tall ones)
			Marking Paint (spray)
			Caution Tape
			Traffic cones

Required	Packed	Used	**Other**
			Power converter for car
			Laptop computer

Required	Packed	Used	Health & Safety
			Latex Disposable Gloves Lg___ Sm___
			Heavy Gloves
			Polypropylene Glove Liners
			Tyvek Regular, Size __________
			Tyvek Hooded, Size __________
			Saranax Suits
			Tyvek Booties
			Latex Boot Covers (Pr)
			Respirator Cartridges (Organic Vapor)
			Bug spray
			Sun lotion
			Hard hat, safety glasses
			First Aid Kit
			Fire Extinguisher
			Field MSDS Book

Required	Packed	Used	Miscellaneous
			Coolers
			Project Notebook Lg___ Sm___
			Well Keys (Project Manager)
			Cameras (Group Secretary)
			Radio Phone
			Decon Buckets (5-gal)
			Side-Spout Wash Bottles
			Calibrated Buckets (5-gal)
			Mason 1-Quart Jars
			Spool for Rope
			Small Locks (P225)
			Medium Locks (X2289)
			Large Locks (14T917)
			Long Shank Locks (2440)
			Food/Drink Cooler

Required	Packed	Used	Equipment/Meters
			Standard Tool Kit
			Electric Air Compressor
			Gas Powered 5K Generator
			Gas Powered Compressor
			pH Orion 250A (pH, temp)
			YSI #33 (salinity, conductivity, temp)
			HYDROLAB
			Ion Selective Electrodes
			Hach Kits (____________________)
			YSI #57 (dissolved oxygen)
			Combustible Gas Indicator MSA #30
			PID/OVA
			FID (rental)
			Draegger Tubes ________________
			MX251 LEL02 Monitor
			GA50 Methane/CO_2/LEL/O_2 Monitor
			Calibration gas ________________
			Peristaltic Pump
			Tubing for Peristaltic Pump
			Water Level Indicator **200** Feet
			100' Fiberglass Tape
			300' Fiberglass Tape with weight
			QED Pump Controller (Small)
			QED Pump Controller (Large)
			Development Pump
			Grundfos Redi-flo2 pump
			Grundfos pump controller
			Tubing for Redi-flo2 (______ feet)
			Transducers and Datalogger (specify)
			Survey Equipment
			Measure Wheel
			Metal Detector
			Brunton Compass
			Troxler Soil Density Gauge
			Neutron Probe and Accessories
			AMS Hand Auger System
			AMS Soil Gas Vapor System

PURCHASE ORDER

Daniel B. Stephens & Associates, Inc.

Ship To:
- ☐ 6020 Academy Rd. NE Ste 100, Albuquerque, NM 87109 Phone: 505-822-9400 Fax: 505-822-8877
- ☐ 4030 W. Braker Ste 325, Austin, TX 78759 Phone: 512-821-2765 Fax: 512-821-2724
- ☐ 4611 50th St., Lubbock, TX 79414 Phone: 806-785-7280 Fax: 792-9346

Issued To:

P.O. #:		Date:		Project/Task #:	
Ship Via:		Terms:		Ship by Date:	

Quantity	Stock No./Description	Unit Price	Total	Rec'd
			-	
			-	
			-	
			-	
			-	
			-	
			-	
			-	
			-	
			-	
			-	
			-	
			-	
			-	
			-	
			-	
			-	
		Sub-Total	$ -	
		Shipping		
		Tax		
		Total	$ -	

See Reverse for Terms and Conditions

Purchase order number must appear on all invoices and correspondence.

Requested by

Authorized by

1.3 Field Log Book

The following SOG describes the appropriate guidelines for note taking during field activities.

The SOPs and SOGs included in this section are applicable to all DBS&A employees for the conduct of all activities listed in this section. **All SOPs and SOGs described in this section are proprietary in nature and shall not be copied or reproduced, or distributed to any person or organization not employed by DBS&A, without the expressed written approval of the President or his/her designee for quality assurance.** All or parts of the SOPs and SOGs described in this section may be reproduced and used in DBS&A reports, proposals, and work plans with the verbal consent of the President, his/her quality assurance designee, or a DBS&A Division Director.

These SOPs and SOGs shall be reviewed periodically, and revisions and additions to these SOPs and SOGs shall be made as needed to assure consistency with industry standards and the collection of high quality data in the field. Requests for revisions shall be made in writing to the President or his/her quality assurance designee.

The field log book is an integral part of the sampling program and forms the basis of the sampling record. A complete field log book is required on most projects. Items documented in the log book are highly relevant to interpreting the subsequent collected data. The objective of taking field notes is to make an accurate written record of the field activities. The field log book serves as a method to record additional site information and observations not easily included on field forms. Field notes often serve as the basis for writing a report after the work is complete. Field notes should be sufficiently accurate and complete that the events that took place can be recreated by someone who was not involved in the activities.

1.3.1 Equipment

- Field log book: water-resistant paper, permanently bound, with sequentially-numbered pages
- Waterproof pens (blue is sometimes preferred to differentiate originals from copies)

1.3.2 General Guidelines

- Make all entries using waterproof pen
- **Write legibly**. If you abbreviate, be sure to define your abbreviation somewhere in the notes.
- Be as brief as clarity will allow. However, it is better to record too much data than to try and recreate activities from memory.
- Be accurate. If you have to guess, identify your entry as a guess.
- Be detailed and quantify your data as much as possible. When in doubt measure.
- Sketches and drawings add depth and detail to your notes.
- Do not scribble through entries you want to change. To make a correction, draw a single line through the entry and date the correction.

- Do not remove pages from the log book. Remember that the field log book can become a legal document.

1.3.3 Requirements

- Each day's log should begin at the top of a page
- At the top of each page, include:
  - A header that identifies the project name and location
  - The date
  - The name and initials of the person taking notes
- The first entry of the day should identify the location, names of DBS&A personnel, visitors, contractors, etc., and the purpose of the activities (e.g., well installation, development, sampling, etc.).
- Each important observation should start with the time (i.e., when)
- The person taking notes should sign and date each page.
- A diagonal line should be drawn across the bottom of each day's entry, then signed and dated.
- For litigation projects, each person should have their own field log book and keep notes as necessary. If only one log book is used, try to have one person do all the note-taking. If the log book is used by more than one person, each person taking notes should sign at the end of their entry before transferring the log book to another person.
- The log book should stay in the custody of the note taker.
- Do not recopy your field notes. Field notes are notes taken in the field. Remember, a few days (or weeks) later, what you think you saw may not actually be what you did see. Field notes can become a legal document so think of them that way from the start.
- Review your notes at least daily for cryptic entries that need additional explanation.

Examples of Noteworthy Items

- Time of arrival and departure
- Attendees at tailgate safety meetings
- Arrival and departure of visitors
- Contents and conclusions of key phone calls and meetings
- Important instructions to staff and contractors (especially if it leads to standby time charges)

- Weather and changes in weather
- Name, type, and condition of equipment being used
- Procedures and results of instrument calibrations
- Changes in activities (e.g., move to decon pad to clean drill rig)
- Down time and cause (e.g., repair drive line on rig)
- Document and explain field decisions (e.g., why you decide not to tremie grout)
- Important results
  - Field parameters collected during well development or sampling
  - Sample IDs and time of collection
  - Sample containers, volumes, and preservation
- Observations
  - General soil type
  - Hard drilling conditions
  - Soil staining or odor
  - Condition of tanks and associated piping
- Health and Safety
  - Document tailgate meetings
  - Document results of utility clearances
  - Site inspections (e.g., condition of excavation)
  - Health and/or safety violations and warnings
  - Results of air or other monitoring (e.g., PID readings)

3.1 Drilling Operations

This section provides standard operating guidelines (SOGs) for drilling programs.

The SOGs included in this section are applicable to all DBS&A employees for the conduct of all activities listed in this section. **All SOPs and SOGs described in this section are proprietary in nature and shall not be copied or reproduced, or distributed to any person or organization not employed by DBS&A, without the expressed written approval of the President or his/her designee for quality assurance.** All or parts of the SOPs and SOGs described in this section may be reproduced and used in DBS&A reports, proposals, and work plans with the verbal consent of the President, his/her quality assurance designee, or a DBS&A Division Director.

The scope of the guidelines described in this section includes the following:

- Drilling Methods
- Drilling Fluids
- Drilling Equipment
- Guidelines to Follow During Drilling Activities

Standards for drilling methods and fluids are described in ASTM D 5092-90 ("Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers"). Refer to Driscoll (1986), U.S. EPA (1986) or Aller et al. (1989) for more detailed information about the above subjects as they relate to the drilling of monitor and extraction wells and borings. Site-specific work plans or sampling plans should identify any special needs or circumstances beyond those described in this SOG.

These SOPs and SOGs shall be reviewed periodically, and revisions and additions to these SOPs and SOGs shall be made as needed to assure consistency with industry standards and the collection of high quality data in the field. Requests for revisions shall be made in writing to the President or his/her quality assurance designee.

3.1.1 Drilling Methods (ASTM D 5092-90)

The drilling method required to create a stable, open, vertical borehole for drilling a borehole or installation of a monitor or extraction well shall be selected according to the site geology, the site hydrology, and the intended use of the data. Tables 3.1-1 and 3.1-2 list common drilling methods and will aid in the selection of an appropriate drilling method. Table 3.1-1 lists the advantages and disadvantages of the different types of drilling methods. Table 3.1-2 assesses the performance of different drilling methods in various types of geologic formations.

3.1.2 Drilling Fluids (ASTM D 5092-90)

Whenever feasible, drilling procedures should be used that do not require the introduction of water or drilling fluids into the borehole and that optimize cuttings control at ground surface. Where the use of drilling fluids is unavoidable, the selected fluid should have as little impact as possible on the water samples for the constituents of interest. In addition, care should be taken to remove as much drilling fluid as possible from the well and the aquifer during the well development process (Section 4.2). If an air compressor is used to inject water or blow cuttings from the borehole, it should be equipped with an oil-air filter or oil trap to keep from introducing oil into the borehole. If water is added to the borehole or well during drilling and/or development, the volume added shall be recorded in the logbook. Depending on the geologic conditions, it may be appropriate or required to remove that volume of water prior to sampling.

Oil-based drilling fluids should **not** be used. Air- or water-based drilling fluids shall be used if drilling fluids are needed for the drilling of monitor and extraction wells and borings. Water-based drilling fluids have the least influence on the groundwater quality in the area of drilling. However, potential problems created by the use of water-based drilling fluids need to be kept in mind. These problems include: (1) fluid infiltration/flushing of the intended monitoring zone, (2) well development difficulties (particularly where an artificial filter pack has been installed), (3) chemical, biological and physical reactivity of the drilling fluid with indigenous fluids in the ground, and (4) introduction of halomethanes into the groundwater.

3.1.2.1 Drilling Fluid Properties

The drilling subcontractor is responsible for checking and adjusting the properties (weight and viscosity) of the drilling fluid. The proper weight of the drilling fluid (1 liter) is needed to maintain stability of the borehole, and the proper viscosity controls the ability of the drilling fluid to remove cuttings from the borehole. However, the DBS&A Project Manager/Site Supervisor or designee should always make sure that the drilling contractor periodically checks the properties of the drilling fluid.

One simple and common way to measure the viscosity of the drilling fluid is a Marsh Funnel. With the use of a Marsh Funnel, a known volume of drilling fluid is allowed to drain from a special funnel into a cup; the flow time is recorded and calibrated against the time required for an equal volume of water to drain from the funnel [approx. 26 seconds @ 70°F (21.1°C)]. The mud weight can be measured with a balance.

Table 3.1-3 describes typical additive concentrations, resulting viscosities, and required uphole velocities for major types of drilling fluids used in various aquifer materials. Table 3.1-4 charts drilling fluid weight adjustments with barite or water.

3.1.2.2 Guidelines for Solving Specific Drilling Fluid Problems (from Driscoll, 1986, Chapter 11)

The drilling subcontractor is responsible for any drilling fluid problems. However, the DBS&A Project Manager/Site Supervisor or designee and field personnel should be aware of and recognize the problems that may arise. Below are some guidelines for solving specific drilling fluid problems which may be helpful to the DBS&A Project Manager/Site Supervisor or designee:

Problem: Inadequate cuttings have been removed from the borehole.

Recommended Action:

1. Clays and polymeric solids in potable water
   a. Increase uphole velocity of the drilling fluid.
   b. Increase viscosity of the drilling fluid by adding more colloidal material.
   c. Increase density of the drilling fluid by adding weighting material (Tables 3.1-3 and 3.1-4).
   d. Reduce penetration rate to limit cuttings load.

2. Air
   a. Increase uphole velocity of fluid system by adding air or water.
   b. Add surfactant to produce foam or to increase concentration of surfactant.
   c. Decrease air injection rate if air is breaking through the foam mix and preventing formation of stable foam.
   d. Decrease water content of the foam system.

Problem: The rate at which cuttings will drop out is too low because the inadvertent addition of native clays during drilling has produced excessive viscosity in the drilling fluid.

Recommended Action:

1. Add potable water to dilute the drilling fluid (Table 3.1-4).
2. Add commercial thinner to reduce the attractive forces between clay colloids.
3. If using clay additives, convert to a polymeric system.
4. Separate the solids from a clay-additive system with a shale shaker or shale shakers and desanders connected in series. A shale shaker or desander may be unnecessary when a polymeric system is being used.
5. Redesign or clean the pit system to increase rate of cuttings settlement.

Problem: Gel strength becomes too great because of strong flocculation, high concentration of solids, or contamination from evaporite deposits or cement. (Excessive gel-strength problems do not occur with polymeric colloids.)

Recommended Action:

1. Add potable water to dilute the drilling fluid.
2. Add polyphosphate or commercial thinner to reduce electrical charges between clay colloids.
3. Use desander or shale shaker to remove solids from a clay-additive system.
4. Lower the pH.

Problem: Excessive fluid loss into the formation causes thick filter cakes that can produce tight places in the hole, development problems, formation (clay) sloughing, and misinterpretation of electric or gamma-ray logs.

Recommended Action:

1. Increase viscosity by adding bentonite or polymeric colloids to any water-based system.

2. Add commercial viscosifiers such as CMC (cellulose gum) or HEC (hydroxyethyl cellulose).

3. Reduce density of the drilling fluid.

4. Prevent drastic changes in downhole pressures and maintain downhole pressures at a minimum. Suggestions include (from Baroid):
   a. Raise and lower the drill string slowly.
   b. Drill through any tight section; do not spud.
   c. Begin rotation of the drill pipe, and then start the pump at a low rate and gradually increase the rate.
   d. Operate the pump at the lowest rate that will assure adequate cooling of the bit and removal of cuttings from the bit face.
   e. Prevent balling at the bit; do not drill soft formations so fast that the annulus becomes overloaded and pressure builds up.

Problem: Lost circulation in permeable formations, faulted and jointed rock, solution cavities in dolomite and limestone, or fractures created by excessive borehole pressures in semiconsolidated or well consolidated rock can all create problems.

Recommended Action:

1. Reduce the density of the drilling fluid system.
2. Switch from a clay-additive drilling fluid system to an air-foam fluid, or add surfactant to a dry-air system.
3. Gel natural polymeric fluids at the point of fluid loss.
4. Use commercial sealing materials.
5. Drill remainder of the hole with a cable tool rig.
6. Case off, then resume rotary drilling.
7. Fill the borehole with clean sand to the point above lost circulation. Let the material stand in borehole overnight. Resume drilling, using low pump pressure.

Problem: Confined pressures in the formation can contribute to a problem.

Recommended Action:

1. Increase density by adding heavy mineral additives such as barite to drilling fluid systems made with clay additives (Table 3.1-4). To suspend barite, the minimum Marsh funnel viscosity must equal four times the final (desired) drilling fluid weight (in lb/gal).
2. Increase density by adding a salt solution to polymeric drilling fluid systems.

Problem: Hydration (swelling and dispersion), pore pressures, and overburden pressure can cause shale sloughing.

Recommended Action:

1. Use polymeric additive to isolate water from shale.
2. Maintain constant fluid pressures in the borehole.
3. Minimize uphole velocities.
4. Avoid pressure surges caused by raising or lowering drill rods rapidly.
5. Add 3 to 4 percent potassium chloride (KCl) to water-based systems.
6. Raise the pH of the drilling fluid to stiffen the clay.

Problem: Contaminants are present. Contaminants usually consist of cement, soluble salts, and gases (hydrogen sulfide and carbon dioxide). Cement in the hole can cause polymeric drilling fluids to break down, thereby increasing fluid losses. Salts may cause drilling fluids with clay additives to separate into liquid and solid fractions. Gases in water may affect the physical condition of the drilling fluid.

Recommended Action:

1. For cement problems:
   a. Maintain the pH for natural polymeric drilling fluids at 7 or lower.
   b. Add commercial chemicals such as sodium acid pyrophosphate to drilling fluids with clay additives to restore original viscosity.

2. For salt problems:
   a. Change the clay additive from montmorillonite to attapulgite.
   b. Change to a natural polymeric drilling fluid additive.

3. For gas problems, add a corrosion inhibitor.

Problem: Drilling at air temperatures significantly below freezing, causing freeze-up of the recirculation system.

Recommended Action:

Add sodium chloride (NaCl) or calcium chloride ($CaCl_2$) to a natural polymeric drilling fluid. Salt must not be added to a drilling fluid made with bentonite.

3.1.3 Drilling Equipment

The DBS&A Drilling Information Checklist (Table 3.1-5) attached to this SOG should be used for the preparation of drilling programs. The checklist should be used as a communication guide between DBS&A and the drilling subcontractor. The checklist should be completed and checked prior to the field stage of the drilling program by both DBS&A and the drilling subcontractor. The Drilling Information Checklist summarizes important phone contacts, length of job, type of rig, underground utility survey, geologic material, sampling, disposal of cuttings, number of wells and soil borings, grouting, and health and safety issues. The Daily Equipment Checklist (Table 3.1-6) should be used by the DBS&A Project Manager/Site Supervisor or designee as a check of equipment needed and daily duties to be performed.

3.1.4 Guidelines to Follow During Drilling Activities

1. A drilling method should be selected that will cause minimal disturbance to the subsurface materials and will not contaminate the subsurface and groundwater (40 CFR 265.91(c)).

2. The drilling contractor is responsible for decontaminating the drilling equipment before it is transported onto the project site (ASTM D 5088-90). DBS&A's Project Manager/Site Supervisor or designee will check the equipment when it arrives on-site, prior to starting each borehole, and before leaving the site.

3. A decontamination procedure should be followed before use and between borehole locations to prevent cross contamination of wells where contamination has been detected or is suspected from the site characterization work that precedes the drilling activities (ASTM D 5088-90).

4. The drilling contractor shall be responsible for securing any and all boring or well drilling permits required by state or local authorities and for complying with any and all state or local regulations with regard to the submission of well logs, samples, etc. DBS&A's Project Manager/Site Supervisor or designee should check that necessary permits have been obtained and are available.

5. The drilling contractor shall comply with any and all (to include placement) regulations with regard to drilling safety and underground utility detection. DBS&A's Project Manager/Site Supervisor or designee shall document that necessary utility clearances have been obtained. The drilling contractor shall have a material safety data sheet (MSDS) for each hazardous chemical that he

brings on-site or intends to use during the job. MSDSs will be available for inspection by all site workers.

6. Air systems shall not be used for drilling, well installation, well development, or sampling without prior approval by the Project Manager. When used, air systems shall include an air line oil filter, frequently replaced, to remove essentially all oil residue from the air compressor. The use of any air system shall be fully described in the DBS&A field logbook to include equipment description, manufacturer(s), model(s), air pressures used, frequency of oil filter change and evaluation of air line filtering.

7. When air is used as the drilling fluid, shrouds, canopies, blooey lines, or directional pipes should be used to contain and direct the drill cuttings away from the drill crew.

8. Any water that is used during the drilling and installation of a well should be of a known chemical source and verified not to alter or impact the chemistry of the groundwater or the operation of the well.

9. When using commercially available mud or additives for the drilling fluid, DBS&A Project Manager/Site Supervisor or designee and field personnel should make sure that the mud or additives do not alter or affect the chemistry of the groundwater or the operation of the well.

10. During rotary drilling, the use of portable recirculation tanks is required. No sumps (lined or unlined) shall be dug without prior approval by the Project Manager and the client.

11. No dyes, tracers, or other substances shall be used or otherwise introduced into borings, wells, lysimeters, grout, backfill, groundwater, or surface water unless specifically approved by the Technical Project Manager.

12. For water supply wells over 100 feet deep, plumbness and alignment should be checked at preselected intervals during the drilling of the boreholes. The readings should be taken by the driller using a single-shot or multi-shot deviation surveying device and should be verified by the DBS&A field personnel.

13. Any contaminated materials (soil and/or water) should be collected and disposed of in an approved waste disposal container or facility.

14. Soil descriptions, collection of samples, field monitoring, and other pertinent information shall be recorded on the Boring Log Form during drilling operations. The Boring Log Form, soil logging procedures, and instructions for completing the Boring Log Form are included in Section 3.2.

Attachments

Table 3.1-1. Drilling Methods for Monitor Wells

Table 3.1-2. Relative Performance of Different Drilling Methods in Various Types of Geologic Formations

Table 3.1-3. Typical Additive Concentrations, Resulting Viscosities, and Required Uphole Velocities for Major Types of Drilling Fluids Used in Various Aquifer Materials

References

Aller, L., T.W. Bennett, G. Hackett, R.J. Petty, J.H. Lehr, H. Sedoris, D.M. Nielson, and J.E. Denne. 1989. *Handbook of suggested practices for the design and installation of ground-water monitoring well design and installation*. National Well Water Association. Dublin, Ohio. 398 p.

Driscoll, F.G. 1986. *Groundwater and wells*. Johnson Division. St. Paul, MN. 1089 p.

U.S. Environmental Protection Agency (EPA). 1986. *RCRA ground-water monitoring technical enforcement guidance document*. Washington, D.C. September 1986. 208 p. and 3 Appendices.

Table 3.1-1. Drilling Methods for Monitor Wells
Page 1 of 4

Type	Advantages	Disadvantages
Hollow-stem auger	• No drilling fluid is used, eliminating contamination by drilling fluid additives • Formation waters can be sampled during drilling by using a screened auger or advancing a well point ahead of the augers • Formation samples taken by split-spoon or core-barrel methods are highly accurate • Natural gamma-ray logging can be done inside the augers • Augers can seal slow-producing formations, making it possible to identify multiple producing zones	• Can be used only in unconsolidated materials • Limited to depths of 100 to 150 ft (30.5 to 45.7 m) • Possible problems in controlling heaving sands • May not be able to run a complete suite of geophysical logs • Delays in sample returns on the augers can affect logging accuracy and detail.
Mud rotary	• Can be used in both unconsolidated and consolidated formations • Capable of drilling to any depth • Core samples can be collected • A complete suite of geophysical logs can be obtained in the open hole • Casing is generally not required during drilling • Many options for well construction • Fast • Smaller rigs can reach most drilling sites • Relatively inexpensive	• Water-based drilling fluid is required and contaminants are circulated with the fluid • Drilling fluid mixes with the formation water and invades the formation and is sometimes difficult to remove • Bentonitic fluids may absorb metals and may interfere with other parameters • Organic fluids may interfere with bacterial analyses and/or organic-related parameters • During drilling, only limited information can be obtained on the location of the water table and the extent of water-producing zones; direct measurements are not possible • Cuttings samples may not be accurate

Table 3.1-1. Drilling Methods for Monitor Wells
Page 2 of 4

Type	Advantages	Disadvantages
Air rotary	• No water-based drilling fluid is used, eliminating contamination by additives • Can be used in both unconsolidated and consolidated formations • A limited suite of geophysical logs can be run in the open borehole • A casing hammer can be used to simultaneously drive casing • Capable of drilling to any depth • Formation sampling is excellent in hard, dry formations • Formation water blown out of the hole makes it possible to determine when the first water-bearing zone is encountered • Field analysis of water blown from the hole can provide information regarding changes for some basic water-quality parameters such as chlorides • Fast	• Casing is required to keep the hole open when drilling in soft, caving formations below the water table • When more than one water-bearing zone is encountered and hydrostatic pressures are different, flow between zones occurs during the time drilling is being completed and before the borehole can be cased and grouted properly • Relatively more expensive than other methods • May not be economical for small jobs
Cable tool	• Only small amounts of drilling fluid are required (generally water with no additives) • Can be used in both unconsolidated and consolidated formations; well suited for extremely permeable formations • Can drill to depths required for most monitoring wells • Highly representative formation samples can be obtained by an experienced driller • Changes in water level can be observed • Relative permeabilities for different zones can be determined by skilled drillers • A good seal between casing and formation is virtually assured if flush-jointed casing is used • Rigs can reach most drilling sites • Relatively inexpensive	• Minimum casing size is 4 in (102 mm) • Steel casing must be used • Cannot run a complete suite of geophysical logs • Usually a screen must be set before a water sample can be taken • Slow • A skilled operator is required to maximize the information obtained from this method

Table 3.1-1. Drilling Methods for Monitor Wells
Page 3 of 4

Type	Advantages	Disadvantages
Dual-tube pneumatic hammer	• Excellent stratigraphic control. Outer tube eliminates slough so cuttings produced are from interval penetrated; core barrel can be used to collect in-situ samples • Outer tube effectively seals borehole allowing individual water-bearing zones to be identified and preventing cross contamination • Capable of drilling to depths required for most monitor wells • Fast	• Limited use in hard, consolidated formations • Because casing is evacuated during drilling, may produce large amounts of formation water and exacerbate flowing sands • Can be very noisy in hard formations • Relatively more expensive than other methods
Casing hammer	• Wells can be drilled in unconsolidated geologic materials that may be difficult to drill with other methods. • The borehole is fully stabilized during the entire drilling operation. • Penetration rates are rapid, even under difficult drilling conditions. • Lost-circulation problems are eliminated. • Accurate formation and water samples can be obtained. • Can be used in all weather conditions. • No water-based drilling fluid is required in unconsolidated materials.	• Method is more expensive. • Operation is noisy.
Rotosonic	• Collects continuous cores and generates very little waste • Very rapid penetration rates are possible (8 to 10 times faster than hollow-stem auger, but slower than mud rotary) • Dual string assembly allows advancement of outer casing with the inner casing used to collect samples • Capable of drilling to depths required for most monitor wells	• Vibrating drill bit or core barrel can raise the temperature of samples and volatilize more sensitive compounds • Driving of material into the borehole wall when using a drill bit may create problems for logging, aquifer testing, and may affect monitor well filter pack • More expensive than other methods

Table 3.1-1. Drilling Methods for Monitor Wells
Page 4 of 4

Type	Advantages	Disadvantages
Reverse rotary	• Porosity and permeability of the formation near the borehole is relatively undisturbed compared to other methods. • Large-diameter holes can be drilled quickly and economically. • No casing is required during the drilling operation. • Well screens can be set easily as part of the casing installation. • Most geologic formations, except igneous and metamorphic rocks, can be drilled. • Washouts in the borehole less likely (due to the low velocity of the drilling fluid).	• Large water supply is generally needed. • Rigs and components are usually larger and thus more expensive. • Large mud pits are required. • Some drill sites are inaccessible because of the rig size. • More personnel are generally required for efficient operation than for other drilling methods.

Table 3.1-2. Relative Performance of Different Drilling Methods in Various Types of Geologic Formations
Page 1 of 2

Type of Formation	Cable Tool	Direct Rotary				Reverse Rotary		Hydraulic Percussion	Jetting	Driven	Auger
		With Fluids	With Air	Down-the-Hole Air Hammer	Drill-Through Casing Hammer	With Fluids	Dual Wall				
Dune sand	2	5	NR	NR	6	5*	6	5	5	3	1
Loose sand and gravel	2	5	NR	NR	6	5*	6	5	5	3	1
Quicksand	2	5	NR	NR	6	5*	6	5	5	NR	1
Loose boulders in alluvial fans or glacial drift	3-2	2-1	NR	NR	5	2-1	4	1	1	NR	1
Clay and silt	3	5	NR	NR	5	5	5	3	3	NR	3
Firm shale	5	5	NR	NR	5	5	5	3	NR	NR	2
Sticky shale	3	5	NR	NR	5	3	5	3	NR	NR	2
Brittle shale	5	5	NR	NR	5	5	5	3	NR	NR	NA
Sandstone-poorly cemented	3	4	NR	NR	NA	4	5	4	NR	NR	NA
Sandstone-well cemented	3	3	5	NR	NA	3	5	3	NR	NR	NA
Chert nodules	5	3	3	NR	NA	3	3	5	NR	NR	NA
Limestone	5	5	5	6	NA	5	5	5	NR	NR	NA
Limestone with chert nodules	5	3	5	6	NA	3	3	5	NR	NR	NA
Limestone with small cracks or fractures	5	3	5	6	NA	2	5	5	NR	NR	NA

*Assuming sufficient hydrostatic pressure is available to contain active sand (under high confining pressures)

NR = Not recommended
NA = Not applicable

Rate of Penetration:

1	Impossible	4	Medium
2	Difficult	5	Rapid
3	Slow	6	Very rapid

(After Driscoll, 1986)

Table 3.1-2. Relative Performance of Different Drilling Methods in Various Types of Geologic Formations

Type of Formation	Cable Tool	Direct Rotary: With Fluids	Direct Rotary: With Air	Direct Rotary: Down-the-Hole Air Hammer	Direct Rotary: Drill-Through Casing Hammer	Reverse Rotary: With Fluids	Reverse Rotary: Dual Wall	Hydraulic Percussion	Jetting	Driven	Auger
Limestone, cavernous	5	3-1	2	5	NA	1	5	1	NR	NR	NA
Dolomite	5	5	5	6	NA	5	5	5	NR	NR	NA
Basalts, thin layers in sedimentary rocks	5	3	5	6	NA	3	5	5	NR	NR	NA
Basalts-thick layers	3	3	4	5	NA	3	4	3	NR	NR	NA
Basalts-highly fractured (lost circulation zones)	3	1	3	3	NA	1	4	1	NR	NR	NA
Metamorphic rocks	3	3	4	5	NA	3	4	3	NR	NR	NA
Granite	3	3	5	5	NA	3	4	3	NR	NR	NA

*Assuming sufficient hydrostatic pressure is available to contain active sand (under high confining pressures)

NR = Not recommended
NA = Not applicable

Rate of Penetration:

1	Impossible	4	Medium
2	Difficult	5	Rapid
3	Slow	6	Very rapid

(After Driscoll, 1986)

Table 3.1-3. Typical Additive Concentrations, Resulting Viscosities, and Required Uphole Velocities for Major Types of Drilling Fluids Used in Various Aquifer Materials
Page 1 of 2

Base Fluid	Additive/Concentration	Marsh Funnel Viscosity (seconds)	Annular Uphole Velocity (ft/min)	Observations
Water	None	26 ± 0.5	100-120	For normal drilling (sand, silt, and clay)
	Clay (High-Grade Bentonite)			Increases viscosity (lifting capacity) of water significantly
	15-25 lb/100 gal	35-55	80-120	For normal drilling conditions (sand, silt, and clay)
	25-40 lb/100 gal	55-70	80-120	For gravel and other coarse-grained, poorly consolidated formations
	35-45 lb/100 gal	65-75	80-120	For excessive fluid losses
	Polymer (Natural)			Increases viscosity (lifting capacity) of water significantly
	4.0 lb/100 gal	35-55	80-120	For normal drilling conditions (sand, silt, and clay)
	6.1 lb/100 gal	65 - 75	80-120	For gravel and other coarse-grained, poorly consolidated formations
	6.5 lb/100 gal	75-85	80-120	For excessive fluid losses
				Cuttings should be removed from the annulus before the pump is shut down, because polymeric drilling fluids have very little gel strength
Air	None	N/A	3,000-5,000	Fast drilling and adequate cleaning of medium to fine cuttings, but may be dust problems at the surface
			4,500-6,000	This range of annular uphole velocities is required for the dual-wall method of drilling
	Water (Air Mist) 0.25-2 gpm	N/A	3,000-5,000	Controls dust at the surface and is suitable for formations that have limited entry of water

Table 3.1-3. Typical Additive Concentrations, Resulting Viscosities, and Required Uphole Velocities for Major Types of Drilling Fluids Used in Various Aquifer Materials
Page 2 of 2

Base Fluid	Additive/ Concentration	Marsh Funnel Viscosity (seconds)	Annular Uphole Velocity (ft/min)	Observations
Air	Surfactant/Water (Air-Foam)	N/A	50-1,000	Extends the lifting capacity of the compressor
	1-2 qt/100 gal (0.25-0.5% surfactant)			For light drilling; small water inflow; also for sticky clay, wet sand, fine gravel, hard rock; few drilling problems
	2-3 qt/100 gal (0.5-0.75% surfactant)			For average drilling conditions; larger diameter, deeper holes; large cuttings; increasing volumes of water inflow; excellent hole cleaning
	3-4 qt/100 gal (0.75-1% surfactant)			For difficult drilling; deep, large-diameter holes; large, heavy cuttings; sticky and incompetent formations; large water inflows
				Injection rates of surfactant/water mixture: Unconsolidated formations 3-10 gpm Fractured rock 3-7 gpm Solid rock 3-5 gpm
Air	Surfactant/Colloids/Water (Stiff Foam)	N/A	50-100	Greatly extends lifting capacity of the compressor
	3-5 qt/100 gal (0.75-1% surfactant) plus 3-6 lb polymer/100 gal or 30-50 lb bentonite/100 gal			For difficult drilling; deep, large-diameter holes; large, heavy cuttings; sticky and incompetent formations; large water inflows
	4-8 qt/100 gal (1-2% surfactant) plus 3-6 lb polymer/100 gal or 30-50 lb bentonite/100 gal			For extremely difficult drilling; large, deep holes; lost circulation; incompetent formations; excessive water inflows

Table 3.1-4. Drilling Fluid Weight Adjustment with Barite or Water

Initial drilling fluid weight, lb/gal	Desired drilling fluid weight, lb/gal											
	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	1.0	14.5	15.0
9.0	69	140	214	293	371	457	545	638	733	833	940	1050
9.5		69	143	219	298	381	467	557	650	750	855	964
10.0	43		71	145	221	305	390	479	569	667	769	876
10.5	85	30		74	148	229	312	398	488	583	683	788
11.0	128	60	23		74	152	233	319	407	500	598	700
11.5	171	90	46	19		76	157	240	326	417	512	614
12.0	214	120	69	37	16		79	160	245	333	426	526
12.5	256	150	92	56	32	14		81	162	250	343	438
13.0	299	180	115	75	48	27	12		81	167	257	350
13.5	342	210	138	94	63	41	24	11		83	171	264
14.0	385	240	161	112	78	54	36	21	10		86	176
14.5	427	270	185	131	95	68	48	32	19	9		88
15.0	470	300	208	150	110	82	60	43	29	18	8	

The lower left half of this table shows the number of gallons of water which must be added to 100 gal of drilling fluid to produce desired weight reductions. To use this portion of the table, locate the initial drilling fluid weight in the vertical column at the left, then locate the desired drilling fluid weight in the upper horizontal row. The number of gal of water to be added per 100 gal of drilling fluid is read directly across from the initial weight and directly below the desired weight. For example, to reduce an 11 lb/gal drilling fluid to a 9.5 lb/gal drilling fluid, 128 gal of water must be added for every 100 gal of drilling fluid in the system.

The upper right half of this table shows the number of pounds of barite which must be added to 100 gal of drilling fluid to produce desired weight increases. To use this portion of the table, locate the initial drilling fluid weight in the vertical column to the left, then locate the desired drilling fluid weight in the upper horizontal row. The number of pounds of barite to be added per 100 gal of drilling fluid is read directly across from the initial weight and directly below the desired weight. For example, to raise a 9 lb/gal drilling fluid to 10 lb/gal, 140 lb of barite must be added per 100 gal of drilling fluid in the system.

(After Petroleum Extension Service, 1969)

Table 3.1-5. Drilling Information Checklist
Page 1 of 2

Project No____________________________DBS&A Project Manager ____________________________

DBS&A field personnel _______________________

Drilling Company _________________________

Drilling Company Contact___________________Phone No. ________________________

Date work to begin_______________Estimated workdays to complete job ____________

Written access agreements in place with property owners _________

Written access agreements in place with owners of property to be crossed to reach drilling site ______

Well permits and/or drilling permits filed with appropriate agency _________

Notify client and/or Agency in timely manner _________

Utility clearance; One-Call contacted ________

Local municipality contacted (water & sewer) _________

Underdetection service contacted (private co.) _________

Utility clearance required time allotted _________

Health and Safety Plan (site specific with emergency medical info) with daily tailgate meeting forms _______

MSDS book for field activities_________

First aid kit, eye wash bottle, and material safety data sheets requested (rental vehicle) _________

Water: Is water available on site or nearby? _________

Can the drilling subcontractor haul adequate amounts of water? _______

Is the water source and equipment used to transport water free of contaminants? _______

Decontamination equipment (steam cleaner, etc.) supplied by drilling contractor_______

Decon pad available if required______Containment of decon water if needed _______

Sample kit for decon water______Arrange for disposal of decon water _______

Drilling fluids containment_______Sample kit for drilling fluids _______

Table 3.1-5. Drilling Information Checklist
Page 2 of 2

Arrange for disposal of drilling fluids _______

Drill cuttings containment_______Sample kit for drill cuttings _______

Arrange for disposal of drill cuttings _______

Drilling method (selected for appropriate geologic conditions to be encountered) _______

Wooden knockout plugs (hollow stem augers in flowing sands) ________

Sampling device______Size of sampling device ______

Sample containers ordered to fit the sampling device _______

Sampling containers (appropriate for the chemical and/or physical parameters to be tested) ______

Sand or core catchers supplied by drillers for unconsolidated soils _______

For brass or stainless steel rings, are end caps, Teflon liners, and the appropriate sealing material available _________

What is sampling interval______ Has an adequate number of sample containers been ordered ______

Well screen and filter pack (well screen and filter pack been sized to match completion formation) _______

Tagline (length, type, and free of contaminants) ______

Tremie pipe (if needed) supplied by drilling contractor _______

Annular seal: selected to prevent grout intrusion and blistering of casing (bentonite vs. cement) _______

Surface well completions; flush mounted well vaults or steel risers with protective posts _______

Table 3.1-6. Daily Equipment Checklist
Page 1 of 2

Item	Specific Procedures and Equipment
Health and Safety ______________	Conduct tailgate health and safety meeting before starting work and as activities or conditions change. Discuss appropriate safety issues. Ensure work crew is wearing the required personal protective equipment. Always adhere to the site-specific health and safety plan. Ensure that MSDS book is on-site.
Meters (at start of work day) _______	Calibrate all meters to be used and record calibration results in the field book.
	Remove all meters from their storage cases and place storage cases in a dry safe place for the day.
	Place all meter probes in the appropriate temporary storage solution (usually distilled or tap water) to prevent drying out of probe membranes (critical for DO probes).
	Use appropriate in-line dust and moisture filters (critical for photoionization detector and GA90 methane meter).
Meters (at end of work day) ________	Turn off power to all meters to conserve batteries.
	Place all probes in their respective storage solutions.
	Clean (decontaminate as necessary) and dry off all meters and return to their storage cases for transport.
	If back up batteries were used, purchase replacement batteries as necessary.
	Recharge all rechargeable batteries over night. Most nickel/cadmium batteries prefer to be fully discharged and fully recharged to prevent memory imprints (e.g., GA-90 methane meter). Read meter manual for proper recharging instructions. If freezing temperatures are possible, make sure all meters are stored in a secure heated area.
Meters (during the work day) _______	Decon all downhole meters between use to prevent cross contamination.
	If a meter reads over its operating range, recalibrate meter before using again (PID).
	Broken or malfunctioning meters should be replaced as soon as possible. Contact the DBS&A Equipment Coordinator.
Decontamination supplies _________	Purchase distilled water, paper towels, garbage bags, and plastic sheeting as necessary.
Sample containers _________	If containers are broken or become contaminated in any way or the scope of work expands, request the appropriate number and type of sample containers and preservatives immediately. Sample containers are usually provided by the laboratory performing the analysis or the DBS&A Equipment Coordinator.

Table 3.1-6. Daily Equipment Checklist
Page 2 of 2

Coolers ________	Purchase adequate ice to keep samples at 4°C at all times. Ice should be placed in double zip-lock baggies and kept from coming in contact with samples. Coolers should be kept as free of melt water as possible to prevent samples from coming in contact with melt water.
Field Book ________	In field book, use indelible ink and record the start and end times of various drilling activities, particularly down-time and standby. Meter readings H&S discussions (i.e., tailgate H&S meeting, 8-8:15) Client contacts or visitors Deviations from the work plan or scope of work

3.2 Soils Logging, Sampling, Handling, and Shipping for Geotechnical and Chemical Analyses

The following SOP describes the appropriate procedures for the logging, sampling, handling, and shipping of soil during soil boring investigations. Sampling methodologies and shipping requirements are provided for collection of geotechnical, physical, and chemical soil samples.

The SOPs and SOGs included in this section are applicable to all DBS&A employees for the conduct of all activities listed in this section. **All SOPs and SOGs described in this section are proprietary in nature and shall not be copied or reproduced, or distributed to any person or organization not employed by DBS&A, without the expressed written approval of the President or his/her designee for quality assurance.** All or parts of the SOPs and SOGs described in this section may be reproduced and used in DBS&A reports, proposals, and work plans with the verbal consent of the President, his/her quality assurance designee, or a DBS&A Division Director.

This procedure provides the minimum logging requirements, sampling protocols, and shipping requirements for soil boring investigations. The appropriate form for logging soil is included in this SOP as Attachment 3.2-1, Soil Boring Log (DBS&A Form No. 080). A soils classification chart is included as Attachment 3.2-2. Tables 3.2-1 and 3.2-2 provide handling and transport, and volume requirements for soil physical analysis samples, respectively.

These SOPs and SOGs shall be reviewed periodically, and revisions and additions to these SOPs and SOGs shall be made as needed to assure consistency with industry standards and the collection of high quality data in the field. Requests for revisions shall be made in writing to the President or his/her quality assurance designee.

3.2.1 Soils Logging

Soil descriptions and other pertinent information will be recorded on the Soil Boring Log form during boring operations. The Soil Boring Form contains a header for recording the boring specifics and a log for describing and classifying soil and tracking soil sampling. Soils will be identified and described in accordance with ASTM D 2488, Standard Practice for Description and Identification of Soil (Visual-Manual Practice). Table 3.2-3 provides a list of equipment that may be required for soils logging, sampling, handling, and shipping.

3.2.1.1 Completing the Header

Most of the header is self-explanatory. On the first page of the log, it is important to complete the entire header. If subsequent forms are necessary, complete the page number, the site, the client, the person logging the soil, the boring number, and the date. On the first page, sketch a location map for the boring, referencing it to known features or landmarks. When specifying the drilling method and drill rig, note the diameter of the drill bit or augers.

3.2.1.2 Completing the Boring Log

PID/FID: Record headspace measurements made with the PID/FID in this column in the appropriate depth interval from which the sample was collected.

Blow Counts: If driving a split-barrel sampling device with a hammer, record the number of hammer "blows" per 6 inches of penetration. Ensure that the driller marks the 6 inch intervals on the drill stem prior to hammering the split-barrel.

Sampling Device: Specify the sampling device (i.e., split-barrel, split-barrel with brass or stainless steel rings, Shelby tube); specify the inside diameter of the sampling device.

Sample Interval: Specify the sampling interval (starting and finishing) by placing an "X" across the appropriate depth interval in this column.

Sample Recovery: State, in tenths of feet, the amount of sample that is recovered.

Sample Number: Record the designated sample number in this column.

Depth (Feet): Complete this column in 5-foot intervals to keep a running tally of the depth of the borehole.

USCS Symbol: Provide the USCS symbol for the soil described; draw a solid contact line at the appropriate depth to signify changes in soil type.

Soil Description: Describe the soil in the format listed on the boring log; a soil classification and geotechnical gauge and a color chart should be used to aid in describing soil. For non-cohesive soils, estimate the grain size distribution, gradation, and grain shape. For cohesive soils, note the plasticity and clay consistency.

3.2.2 Soil Sampling

Soil samples may be collected for geotechnical, physical, or chemical analysis. Geotechnical samples will be collected with a split-barrel sampler lined with brass rings or in the case of cohesive soils to be analyzed for compressive strength, a thin-walled tube sampler. Chemical samples will be collected with an unlined split-barrel sampler or a ring-lined split-barrel sampler. Regardless of which sampling device is employed, care should be taken to minimize slough in the borehole. Slow withdrawal of the drill bit prior to sampling will minimize slough. When drilling below the water table, ensure that the water level in the borehole (or within driven casing) is maintained at or above the water table elevation. For added accuracy, the depth of the borehole can be measured before the sample is collected.

3.2.2.1 Geotechnical/Physical Properties Samples

Geotechnical and/or physical properties samples will be collected with either a ring-lined split-barrel sampler or a thin-walled Shelby tube. If possible, use a ring-lined sampler for physical properties analysis. For triaxial and unconfined compression tests, either a ring-lined sampler or a thin-walled tube sampler may be employed. For cohesive soils, the thin-walled tube sampler should be used for obtaining the least disturbed samples. In non-cohesive soils, a ring-lined sampler is required because of poor sample recovery experienced with a thin-walled sampler.

Ring-Lined Split-Barrel Sampler (ASTM D 3350)

1. Assemble the sampler with the specified rings. For physical properties analysis, the typical ring is 6 inches in length and constructed of brass. Ring requirements will be specified in the Field Sampling Plan (FSP).

2. Attach the sampler to the drill stem and carefully lower it to the bottom of the borehole.

3. Hydraulically push the sampler into the soil in a rapid, continuous manner to a length not to exceed that of the sampler. In dense, non-cohesive soils, the sampler may have to be driven. If so, record the blow counts.

4. Carefully disassemble the sampler to minimize soil disturbance. If required, PID readings should be taken immediately after the sampler is opened. Trim the individual rings flush with a clean knife, and place plastic caps over the ring ends. Use the soil in one of the rings for field classification. If required, cover the ring ends with Teflon sheets before capping. Secure the caps with tape and label the ring, including the vertical orientation.

5. Log the sample information in the field logbook and on the chain of custody form (DBS&A Form No. 194), which is included as Attachment 3.2-3.

6. The samples can be shipped in a dry cooler. If the possibility exists the samples will be handled roughly, pack them with shipping material in the cooler.

Thin-Walled Tube Sampler (ASTM D 1587)

1. Attach the sampling tube to the drill stem and carefully lower to the bottom of the borehole.

2. Rapidly and continuously hydraulically push the Shelby tube a distance of 5 to 10 times the tube diameter in non-cohesive soils and 10 to 15 times the diameter in cohesive soils. In dense, non-cohesive soils it is permissible to drive the sampler. Record the blow counts. It is permissible to "twist" the drill stem to shear the sample bottom prior to retrieval.

3. Carefully withdraw the sampler from the formation to minimize disturbance.

4. The sample can be shipped either unextruded or after extrusion at the site.

   Unextruded: Measure the length of the sample in the tube. Remove any slough from the top of the tube. Remove at least 1 inch of soil from the bottom of the tube for field classification. Seal the top and bottom of the tube with plastic caps and secure with tape. If required, cover the ring ends with Teflon sheets before capping.

   Extruded: Following extrusion, select a 12- to 15-inch segment of the sample that appears least disturbed. Carefully cut the ends with a clean knife, and immediately wrap the sample in cellophane wrap, then aluminum foil. Place the sample in a plastic tube, and cap the ends. Describe the soil with the remainder of the sample. Describe the prepared interval to the extent practicable. DO NOT cut or disturb the interval to be submitted to the laboratory.

5. Log the sample information in the field logbook and on the chain of custody form (DBS&A Form No. 194), which is included as Attachment 3.2-3.

6. Shipped in a similar manner as described above.

3.2.2.2 Soil Chemistry Samples

Soil chemistry samples can be collected with either the split-barrel sampler or with the ring-lined split-barrel sampler. The primary difference in the two methods is the preparation of the samples. In the case of samples obtained from the split-barrel, the soil must be transferred to soil containers (typically glass jars and/or methanol extraction kits). In the case of the ring-lined sampler, the rings will be either stainless steel or brass which are capped with Teflon-lined caps. The rings are labeled, secured with toluene-free tape, and submitted directly for analysis. Exact sample methods, volumes, containers, preservation, and chain of custody procedures will be outlined in the FSP. In general, for soil matrix samples, EPA SW-846 (U.S. EPA, 1986) methods will be specified. Both the split barrel sampler and the ring-lined sampler are hydraulically pushed or driven as described above.

An En Core sampler may also be used to collect soil samples, particularly when volatile contaminants may be present.

Split-Barrel Samples (ASTM D 1586)

1. Upon retrieval of the sample, carefully open the split-barrel. Trim the sample with a decontaminated, sharp stainless-steel knife. Note the general soil type.

2. As quickly as possible, collect samples for volatile organic and semi-volatile organic analysis. Be sure that headspace is minimized in the volatile organic analysis samples. Collect field duplicates and specify that the laboratory perform matrix spike/matrix spike duplicates from the same interval as the sample. Place the samples in certified-clean glass jars with Teflon-lined caps.

3. Collect samples for other required analyses. If the FSP specifies mixing the split barrel sample prior to filling additional sample containers, do so in a clean stainless-steel mixing bowl. Sample volumes and containers will be specified in the FSP.

4. Label the samples in accordance with the FSP. At a minimum, this will include: (1) a unique sample number, (2) boring number and interval (if different from the sample number), (3) time and date, and (4) required analysis. If custody seals are required, secure them across the container lid.

5. Place the sample containers in "ziplock" bags and place on ice. Prior to shipment, the sample containers must be wrapped in bubble-pack, or other suitable packing material.

6. Fully describe the soil sample.

7. Log the sample information in the field logbook and on the chain of custody form (usually supplied by the laboratory or DBS&A Form No. 194).

8. If the rings are not full, refer to FSP for procedure to recollect sample.

Ring-Lined Split-Barrel Samples (ASTM D 3350)

1. Upon retrieval of the sampler, carefully open the split-barrel. Trim the ends of the rings with a clean stainless-steel knife. Cap the rings with Teflon-lined caps and seal with toluene-free tape.

2. Using one or more of the rings (if possible), and soil trimmed from the ring ends, describe and log the soil.

3. Pack and log samples as described above for split-barrel samples. Packing material is optional for the ring samples.

En Core Sampler

The En Core sampler was developed to allow the collection of soil samples with minimal handling and maximum accuracy. This is a self-contained, disposable device designed for one-time-use only and is used to collect, store, and deliver soil samples all within one device. The sampler has an airtight sealing cap, which prevents the transfer of volatiles during handling.

The En Core sampler avoids many of the problems of VOC soil collection techniques, including:

- It eliminates the need for methanol preservation.
- It eliminates the need for preservation with sodium bisulfate.
- It avoids many sources for lab discrepancies, thus assuring more consistent and accurate analyses.

Complete sampling instructions are included in each sampling device packet; a summary of those instructions are included as Attachment 3.2-4. Further information about this device is available on the manufacturer's web site (http://www.ennovativetech.com/encore/encore.htm).

3.2.3 Sample Preservation and Shipment

Proper preservation and shipment of samples is critical for ensuring that reliable analytical results are obtained. In the case of geotechnical or physical properties analysis samples, this involves protecting the samples against excessive impacts that may disturb the samples. For soil chemical analyses, it is important to protect the samples from breakage if they were collected in glass jars. In addition, most chemical methods call for the samples to be maintained at a constant 4°C.

3.2.3.1 Geotechnical and Physical Properties Samples
Shipping requirements for geotechnical and physical properties samples are listed in Table 3.2-1. In general, samples should be shipped in a dry cooler. If the cooler is not being hand-carried to the laboratory (i.e., shipped by overnight carrier) the samples should be protected with packing material to minimize sample disturbance. Plastic bubble-wrap, shredded paper, foam "peanuts," and vermiculite provide adequate sample protection when properly used. It is important to provide packing materials between all samples, such that samples do not come in contact with each other. When shipping samples, it is important to enclose a chain of custody form in the cooler, as specified in the FSP.

3.2.3.2 Soil Chemistry Samples
Soil chemistry samples collected in glass containers must be protected from breakage. Individually wrapping the sample containers in plastic bubble-wrap provides excellent protection. After wrapping the samples in bubble-wrap, they should be placed in sealed "zip-lock" bags. Brass or stainless-steel ring samples need only be placed in sealed "zip-lock" bags. If the FSP calls for chain of custody seals to be placed on individual samples, place them across the jar lid or plastic ring cap. Chain of custody forms should be filled out in accordance with the FSP, placed in a "ziplock" bag, and taped to the inside of the

cooler lid. It is important to use an ample volume of ice in order to maintain the required temperature of 4°C. Custody seals will be placed across the front and back of the cooler lid such that they will be broken in the event of tampering. The cooler lid should be firmly taped shut with several layers of shipping tape encircling the ends of the cooler. Finally, for chemical analyses, always ship the samples by overnight carrier and purchase sufficient insurance for replacement if lost or damaged.

Attachments

3.2-1. Boring Log (DBS&A Form No. 080 4/98)

3.2-2. Unified Soil Classification System Chart (DBS&A Form No. 049)

3.2-3. Chain of Custody Form

3.2-4. En Core Sample Collection Procedures

Table 3.2-1. Soil Physical Analysis Sample Requirements and Transport

Table 3.2-2. Soil Physical Sample Volume Requirements

Table 3.2-3. Soil Sampling Equipment Checklist

References

ASTM D 1586-84. *Standard method for penetration test and split-barrel sampling of soils.*

ASTM D 1587-83. *Standard practice for thin-walled tube sampling of soils.*

ASTM D 2488-90. *Practice for description and identification of soils (visual-manual).*

ASTM D 3350-84. *Standard practice for ring-lined barrel sampling of soils.*

U.S. Environmental Protection Agency (EPA). 1986. *Test methods for evaluation of solid wastes, SW-846,* 3rd Ed.

Daniel B. Stephens & Associates, Inc.

Boring Log

Page___of___

Site		Location Map
Logged by	Client/Project #	
Boring Number	Drilling Co.	
Drilling Method	Drill Rig	
Date Started	Date Completed	

PID/FID Reading	Blow Counts	Sampling Device	Sample Recovery	Sample Interval	Sample Number	USCS Symbol	Depth (feet)	Soil Description/Remarks Soil type, color, texture, grain size, sorting, roundness, plasticity, consistency, moisture content

DBS&A Form No. 080 4/98

P:\SOPs\13-Field\Att_3.2-1_BoringLog.doc

MAJOR DIVISIONS			GRAPH SYMBOL	LETTER SYMBOL	TYPICAL DESCRIPTIONS
Coarse-grained soils More than 50% of material is larger than silt (No. 200 sieve size)	Gravel and gravelly soils More than 50% of coarse fraction retained on No. 4 sieve	Clean gravels (little or no fines <5%)		GW	Well graded gravels, gravel-sand mixtures. Little or no fines
				GP	Poorly graded gravels. Gravel-sand mixtures. Little or no fines.
		Gravels with fines (appreciable amount of fines >15%)		GM	Silty gravels. Gravel-sand-silt mixtures.
				GC	Clayey gravels. Gravel-sand-clay mixtures.
	Sand and sandy soils More than 50% of coarse fraction passing No. 4 sieve	Clean sand (little or no fines <5%)		SW	Well graded sands. Gravelly sands. Little or no fines.
				SP	Poorly graded sands. Gravelly sands. Little or no fines.
		Sands with fines (appreciable amount of fines >15%)		SM	Silty sands. Sand-silt mixtures.
				SC	Clayey sands. Sand-clay mixtures.
Fine-grained soils More than 50% of material is smaller than silt (No. 200 sieve size)	Silts and clays	Liquid limit less than 50		ML	Inorganic silts and very fine sands. Rock flour. Silty or clayey fine sands or clayey silts with slight plasticity.
				CL	Inorganic clays of low to medium plasticity. Gravelly clays. Sandy clays, silty clays, lean clays.
				OL	Organic silts and organic silty clays of low plasticity.
	Silts and clays	Liquid limit greater than 50		MH	Inorganic silts. Micaceous or diatomaceous fine sand or silty soils.
				CH	Inorganic clays of high plasticity. Fat clays.
				OH	Organic clays of medium to high plasticity. Organic silts.
Highly organic				PT	Peat, humus, swamp soils with high organic content.

DBS&A Form No. 049 9/95

Daniel B. Stephens & Associates, Inc.

Chain of Custody

To:

__________ Date __________ Project No. __________

__________ Client __________

__________ Relinquished by __________

Sent by: ☐ Fed Ex ☐ DHL ☐ Other __________

Purpose of shipment __________

Possible contaminants __________

Item No.	Sample No.	Analysis To Be Done	Sample Container	Comments

Date received __________ by __________
Company Representative

Received the above articles in good condition

Except as noted __________

____

____

P:\ADMIN\SECTION 13\Chain Custody_Form.doc

Document5

Daniel B. Stephens & Associates, Inc.

Chain of Custody Form

Attachment 3.2-3

Disposable En Core® Sampler

En Novative Technologies, Inc.
1241 Bellevue Street
Green Bay, WI 54302
Phone: 920-465-3960 • Fax: 920-465-3963
Toll Free: 888-411-0757
www.ennovativetech.com

Sampling Procedures

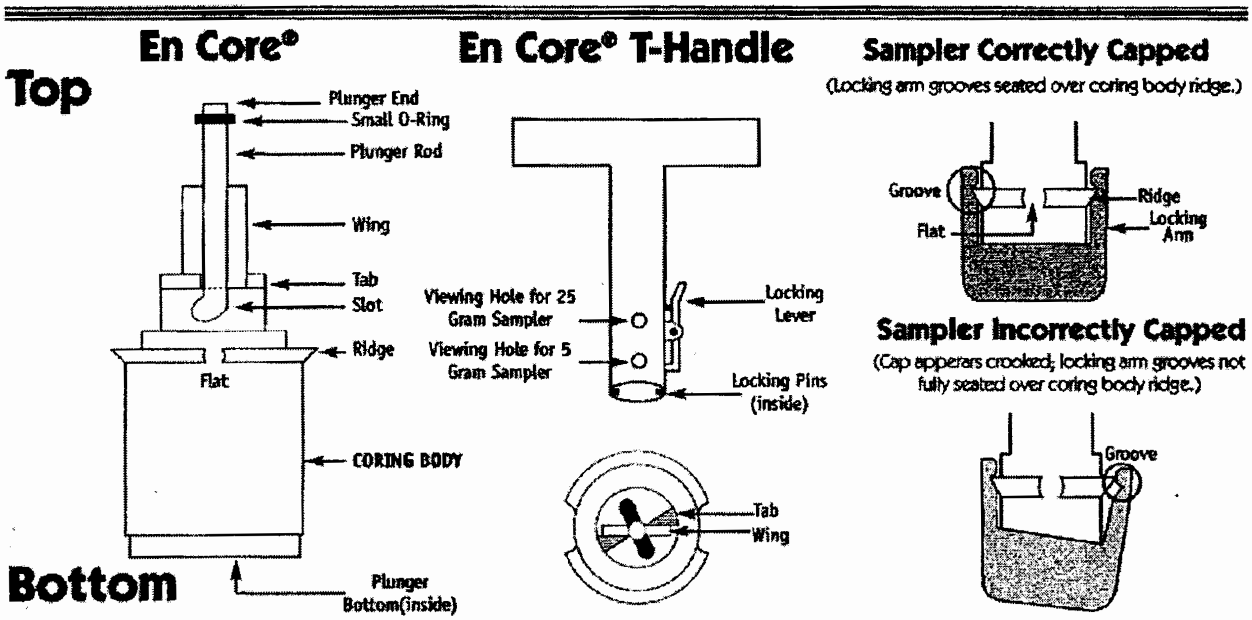
Using The En Core® T-Handle

NOTE:

1. En Core® Sampler is a SINGLE USE device. It cannot be cleaned and/or reused.

2. En Core® Sampler is designed to store soil. Do not use En Core Sampler to store solvent or free product!

3. En Core® Sampler must be used with En Core® T-Handle and/or En Core® Extrusion Tool exclusively. (These items are sold separately.)



BEFORE TAKING SAMPLE:

1. Hold **coring body** and push **plunger rod** down until **small o-ring** rests against **tabs**. This will assure that plunger moves freely.

2. Depress **locking lever** on En Core T-Handle. Place coring body, **plunger end first**, into open end of T-Handle, ***aligning the (2) slots on the coring body with the (2) locking pins in the T-Handle***. Twist coring body clockwise to lock pins in slots. Check to ensure Sampler is locked in place. Sampler is ready for use.

TAKING SAMPLE:

3. Turn T-Handle with T-up and coring body down. This positions plunger bottom flush with bottom of coring body (ensure that plunger bottom is in position). Using T-Handle, push Sampler into soil until coring body is completely full. When full, small o-ring will be centered in T-Handle **viewing hole**. Remove Sampler from soil. Wipe excess soil from coring body exterior.

4. Cap coring body while it is still on T-handle. ***Push*** **cap** over **flat** area of **ridge** ***and twist*** to lock **cap** in place. **CAP MUST BE SEATED TO SEAL SAMPLER (see diagram).**

PREPARING SAMPLER FOR SHIPMENT:

5. Remove the capped Sampler by depressing locking lever on T-Handle while twisting and pulling Sampler from T-Handle.

6. Lock plunger by rotating extended plunger rod fully counter-clockwise until **wings** rest firmly against tabs (see plunger diagram).

7. Attach completed tear-off label (from En Core Sampler bag) to cap on coring body.

8. Return full En Core Sampler to zipper bag. Seal bag and put on ice.

Source: En Novative Technologies, Inc. Available at http://www.ennovativetech.com/encore/sampling.htm.

En Core Sample Collection Procedures

Disposable En Core® Sampler

EXTRUSION PROCEDURES

USING THE En Core® EXTRUSION TOOL

CAUTION! Always use the Extrusion Tool to extrude soil from the En Core Sampler. If the Extrusion Tool is not used, the Sampler may fragment, causing injury.

1. Use a pliers to break locking arms on cap of En Core Sampler. Do not remove cap at this time. **(CAUTION: Broken edges will be sharp.)**

2. To attach En Core Sampler to En Core Extrusion Tool: Depress locking lever on Extrusion Tool and place Sampler, plunger end first, into open end of Extrusion Tool, aligning slots on coring body with pins in Extrusion Tool. Turn coring body clockwise until it locks into place. Release locking lever.

3. Rotate and gently push Extrusion Tool plunger knob clockwise until plunger slides over wings of coring body. (When properly positioned plunger will not rotate further.)

4. Hold Extrusion Tool with capped Sampler pointed upward so soil does not fall out when cap is removed. To release soil core, remove cap from Sampler and push down on plunger knob of En Core Extrusion Tool. Remove and properly dispose of En Core Sampler.

Warranty and Disclaimers

IMPORTANT: FAILURE TO USE THE EN CORE® SAMPLER IN COMPLIANCE WITH THE WRITTEN INSTRUCTIONS PROVIDED HEREIN VOIDS ALL EXPRESS AND IMPLIED WARRANTIES, INCLUDING WARRANTY OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE.

PRINCIPLE OF USE. The En Core Sampler Cartridge System is a volumetric sampling system designed to collect, store and deliver a soil sample. The En Core Sampler comes in two sizes for sample volumes of approximately 25 or 5 grams. There are four components: the cartridge with a movable plunger; a cap with two locking arms; a T-handle (purchased separately); and an extrusion handle (purchased separately). NOTE: The En Core Sampler is designed to store soil. It is not designed to store solvent or free product.

The soil is stored in a sealed headspace-free state. The seals are achieved by three special Viton® * o-rings, two located on the plunger and one on the cap of the Sampler. At no time and under no condition should these o-rings be removed or disturbed.

QUALITY CONTROL. The cartridge is sealed in an airtight package to prevent contamination prior to use. Due to the stringent quality control requirements associated with the use of this system, the disposable cartridge is designed to be used only once.

WARRANTY. En Novative Technologies, Inc. ("En Novative Technologies") warrants that the En Core Sampler shall perform consistent with the research conducted under En Novative Technologies' approval, within thirty (30) days from the date of delivery, provided that the Customer gives En Novative Technologies prompt notice of any defect or failure to perform and satisfactory proof thereof. THIS WARRANTY DOES NOT APPLY TO THE FOLLOWING, AS SOLELY DETERMINED BY EN NOVATIVE TECHNOLOGIES: (a) Damage caused by accident, abuse, mishandling or dropping; (b)Samplers that have been opened, taken apart or mishandled; (c)Samplers not used in accordance with the directions; and (d)Damages exceeding the cost of the sampler. Seller warrants that all En Core Samplers shall be free from defects in title. THE FOREGOING WARRANTIES ARE IN LIEU OF ALL OTHER WARRANTIES, WHETHER ORAL, WRITTEN, EXPRESSED, IMPLIED OR STATUTORY, INCLUDING ANY INFORMATION PROVIDED BY SALES REPRESENTATIVES OR IN MARKETING LITERATURE. IMPLIED WARRANTIES OF FITNESS AND MERCHANTABILITY SHALL NOT APPLY. En Novative Technologies' warranty obligations and Customer's remedies, except as to title, are solely and exclusively as stated herein.

LIMITATION OF LIABILITY. IN NO EVENT SHALL EN NOVATIVE TECHNOLOGIES BE LIABLE FOR ANTICIPATED PROFITS, INCIDENTAL, SPECIAL OR CONSEQUENTIAL DAMAGES, INCLUDING, BUT NOT LIMITED TO, DAMAGES FOR LOSS OF REVENUE, DOWN TIME, REMEDIATION ACTIVITIES, REMOBILIZATION OR RESAMPLING, COST OF CAPITAL, SERVICE INTERRUPTION OR FAILURE OF SUPPLY, LIABILITY OF CUSTOMER TO A THIRD PARTY, OR FOR LABOR, OVERHEAD, TRANSPORTATION, SUBSTITUTE SUPPLY SOURCES OR ANY OTHER EXPENSE, DAMAGE OR LOSS, INCLUDING PERSONAL INJURY OR PROPERTY DAMAGE. En Novative Technologies' liability on any claim of any kind shall be replacement of the En Core Sampler or refund of the purchase price. En Novative Technologies shall not be liable for penalties of any description whatsoever. In the event the En Core Sampler will be utilized by Customer on behalf of a third party, such third party shall not occupy the position of a third-party beneficiary of the obligation or warranty provided by En Novative Technologies, and no such third party shall have the right to enforce same. All claims must be brought within one (1) year of shipment, regardless of their nature.

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The En Core™ Sampler is covered by One or More of the Following U.S. Patents: 5,343,771; 5,505,098; 5,517,868; 5,522,271. Other U.S. and Foreign Patents Pending.

* Viton® is a registered trademark of DuPont Dow Elastomers.

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Disposable En Core® Sampler Sampling Procedures

NOTE:

1. En Core Sampler is a Single Use device. It cannot be cleaned and/or reused.

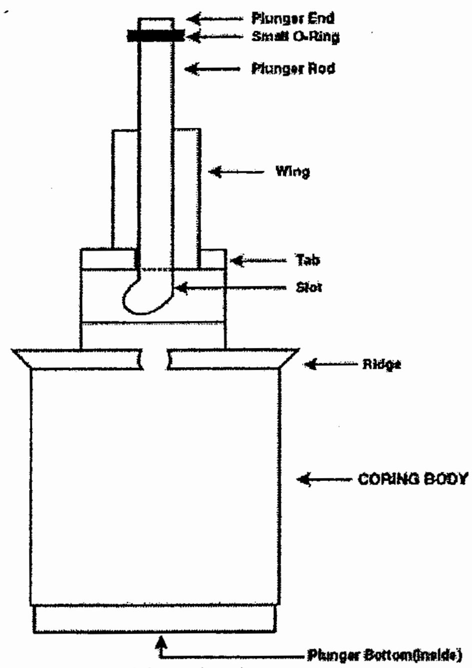
2. En Core Sampler is designed to store soil. Do not use En Core Sampler to store solvent or free product!

3. En Core Sampler must be used with En Core® T-Handle and/or En Core® Extrusion Tool exclusively. (These items are sold separately.)

Using The En Core® T-Handle

Before Taking Sample:

1. Hold coring body and push plunger rod down until small o-ring rests against tabs. This will assure that plunger moves freely.



Click to view larger image.

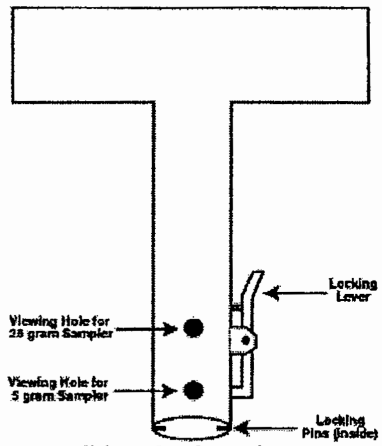
2. Depress locking lever on En Core T-Handle. Place coring body, plunger end first, into open end of T-Handle, *aligning the (2) slots on the coring body with the (2) locking pins in the T-Handle.* Twist coring body clockwise to lock pins in slots. Check to ensure Sampler is locked in place. Sampler is ready for use.

Taking Sample:

3. Turn T-Handle with T-up and coring body down. This positions plunger bottom flush with bottom of coring body (ensure that plunger bottom is in position). Using T-Handle, push Sampler into soil

until coring body is completely full. When full, small o-ring will be centered in T-Handle viewing hole. Remove Sampler from soil. Wipe excess soil from coring body exterior.

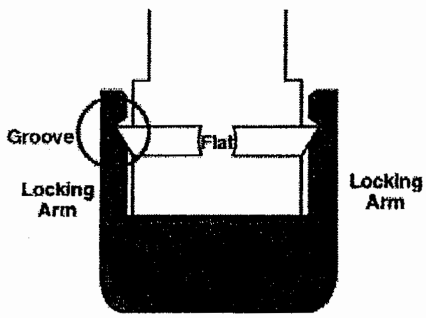
4. Cap coring body while it is still on T-handle. Push cap over flat area of ridge. ***Push and twist cap to lock arm in place. Cap must be seated to seal sampler (see diagram below).***



Click to view larger image

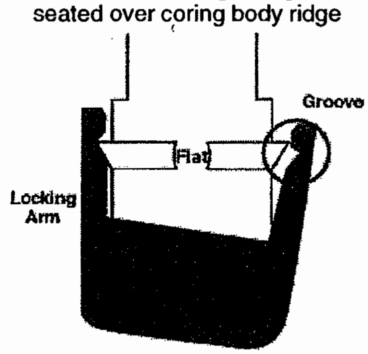
Sampler Correctly Capped

Locking arm grooves seated over coring body ridge.



Sampler Incorrectly Capped

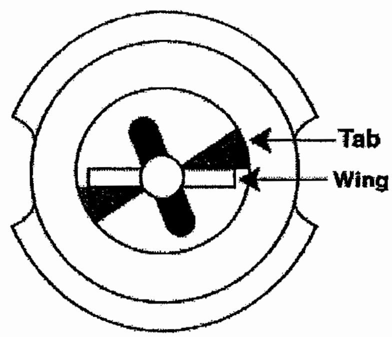
Cap appears crooked; locking arm grooves not fully seated over coring body ridge



Preparing Sampler For Shipment:

5. Remove the capped Sampler by depressing locking lever on T-Handle while twisting and pulling Sampler from T-Handle.

6. Lock plunger by rotating extended plunger rod fully counter-clockwise until wings rest firmly against tabs (see plunger diagram at right).



7. Attach completed label (from En Core Sampler bag) to cap on coring body.

8. Return full En Core Sampler to zipper bag. Seal bag and put on ice.

Download PDF of Directions

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Table 3.2-1. Soil Physical Analysis Sample Requirements and Transport

Physical Property Test	Sample Requirement	Shipping Requirement
Soil Moisture	2.5" O.D. x 3" long ring or in double plastic bag with air removed	Dry cooler
Hydraulic Conductivity	2.5" O.D. x 3" sealed ring	Dry cooler
Moisture Retention (ψ-θ)	2.5" O.D. x 3" sealed ring	Dry cooler with packing material
Air Permeability	2.5" O.D. x 3" sealed ring	Dry cooler with packing material
Bulk Density	2.5" O.D. x 3" sealed or waxed ring	Dry cooler with packing material
Porosity	2.5" O.D. x 3" sealed ring	Dry cooler with packing material
Specific Gravity	2.5" O.D. x 3" sealed ring or plastic bag for bulk sample	Dry cooler
Particle Size	2.5" O.D. x 3" sealed ring; plastic bag for gravelly soil	Dry cooler
Atterberg Limits	2.5" O.D. x 3" sealed ring or plastic bag	Dry cooler preferred
Proctor Tests	5 gallon plastic bucket or large plastic bags	No shipping requirements
Compression Tests	Unextruded in thin-walled tube; extruded wrapped in cellophane wrap and placed in plastic tube; or 2.5" O.D. x 6" sealed ring	Dry cooler with packing material

Table 3.2-2. Soil Physical Sample Volume Requirements

Sample Requirements for Additional Tests	Primary Test Requested: Moisture Content (volumetric)	Hydraulic Conductivity K_{sat}	Hydraulic Conductivity K_{unsat}	Moisture Retention ψ-θ	Air Permeability K_{air}	Bulk Density	Porosity (Calculated)	Porosity (Air Pycnometer)	Particle Density	Particle Size Analysis	Atterberg Limits	Compaction (Proctor) Test
Moisture Content (Volumetric)		Same Sample	(3) Same Sample	Same Sample	Same Sample	Same Sample	Same Sample	Same Sample	(1) Same Sample	(1) Same Sample	Extra Sample	Extra Sample
Hydraulic Conductivity K_{sat}	Same Sample		(3) Same Sample	Same Sample	Same Sample	Same Sample	Same Sample	Same Sample	(1) Same Sample	(1) Same Sample	Extra Sample	Extra Sample
Hydraulic Conductivity K_{unsat}	(3) Same Sample	Same Sample		Same Sample	Same Sample	Same Sample	Same Sample	Same Sample	(1) Same Sample	(1) Same Sample	Extra Sample	Extra Sample
Moisture Retention (ψ - θ) curve	Same Sample	Same Sample	(3) Same Sample		Same Sample	Same Sample	Same Sample	Same Sample	(1) Same Sample	(1) Same Sample	Extra Sample	Extra Sample
Air Permeability K_{air}	Same Sample	Same Sample	(4) Same Sample	Same Sample		Same Sample	Same Sample	Same Sample	(1) Same Sample	(1) Same Sample	Extra Sample	Extra Sample
Bulk Density	Same Sample	Same Sample	(4) Same Sample	Same Sample	Same Sample		(5) Same Sample	Same Sample	(1) Same Sample	(1) Same Sample	Extra Sample	Extra Sample
Porosity (Calculated)	Same Sample	Same Sample	(4) Same Sample	Same Sample	Same Sample	Same Sample		Same Sample	(1) Same Sample	(1) Same Sample	Extra Sample	Extra Sample
Porosity (Air) Pycnometer)	Same Sample	Same Sample	(4) Same Sample	Same Sample	Same Sample	Same Sample	Same Sample		(1) Same Sample	(1) Same Sample	Extra Sample	Extra Sample
Particle Density	Same Sample	Same Sample	Same Sample	Same Sample	Same Sample	Same Sample	(6) Same Sample	Same Sample		Same Sample	Same Sample	Extra Sample
Particle Size Analysis	(2) Extra Sample	(2) Extra Sample	(2) Extra Sample	(2) Extra Sample	(2) Extra Sample	(2) Extra Sample	(2) Extra Sample	(2) Extra Sample	(2) Extra Sample		Extra Sample	Extra Sample
Atterberg Limits	Extra Sample	Extra Sample	Extra Sample	Extra Sample	Extra Sample	Extra Sample	Extra Sample	Extra Sample	Same Sample	Extra Sample		Extra Sample
Compaction (Proctor) Test	Extra Sample	Extra Sample	Extra Sample	Extra Sample	Extra Sample	Extra Sample	Extra Sample	Extra S(1)ample	Extra Sample	Extra Sample	Extra Sample	

(1) Same sample may be run for this additional test provided sample is in a sample ring and meets the sample size requirements for the additional test.
(2) Same sample may be used if sample meets sample size requirements for additional test (is there sufficient sample; usually only fine-grained samples will meet this requirement).
(3) Required for all unsaturated hydraulic conductivity calculations except column imbibition method.
(4) Same sample may be used except for column imbibition test.
(5) Additional test required to perform calculations of primary test.
(6) Additional test preferred for best results of primary test.

Table 3.2-3. Soil Sampling Equipment Checklist

Item	Specific Procedures and Equipment
Soil sampling tool kit______________	Hand lens, grain size chart, USCS soil classification guide, Munsel soil color chart, spatulas, dilute hydrochloric acid, engineer's tape (marked in tenths of feet), geologic hammer, sieves for sizing well screen and filter pack and for washing soil cuttings
Clip board______________________	Boring log forms________________
Field book______________________	Waterproof pens_________ Assortment of sharpies____
Meters_________________________	Photoionization detector, O2/LEL explosivity meter GA90 methane meter, Geiger-Mueller radiation meter Water level meter, sound level meter, dust monitor
Tagline_________________________	Fiberglass tape with weight_________ Steel with stainless steel weight (no tape)________
300-foot tape or measuring wheel_____	
Health and safety kit______________	Hard hat, steel-toed boots, safety glasses, earplugs, respirator with appropriate cartridges and/or filter, Tyvek coveralls
Latex gloves____________________	Glove liners or heavier gloves
Decontamination equipment _________	Minimum of 3 plastic tubs or buckets, plastic bottle brushes Liquinox, distilled or deionized water (minimum of 10 gallons), paper towels, garbage bags, plastic sheeting
Hand auger system________________	
Soil sample containers_____________	Brass rings (physical properties and petroleum hydrocarbons) Stainless steel rings, Teflon liners (organic chemical analyses) Plastic end caps, sealing tape (electrical or solvent free) Cellophane wrap, plastic tubes, purifier wax Aluminum foil, glass headspace jars Glass soil jars, methanol extraction kits, 40 mL VOAs (water) Quart and gallon ziplock bags, strapping and packing tape chain of custody forms, custody seals
Coolers________________________	One for food only, as needed for samples

4.1 Monitor Well Design and Installation

This section provides standard operating guidelines (SOGs) for monitor well design and installation.

The SOPs and SOGs included in this section are applicable to all DBS&A employees for the conduct of all activities listed in this section. All SOPs and SOGs described in this section are proprietary in nature and shall not be copied or reproduced, or distributed to any person or organization not employed by DBS&A, without the expressed written approval of the President or his/her designee for quality assurance. All or parts of the SOPs and SOGs described in this section may be reproduced and used in DBS&A reports, proposals, and work plans with the verbal consent of the President, his/her quality assurance designee, or a DBS&A Division Director.

The scope of the procedures described in this section includes the following:

- Initial Site Characterization
- Monitor Well Materials and Design
- Monitor Well Installation

Standards for monitor well design and installation are described in ASTM D 5092-90 (Reapproved 1995) (Standard Practice for Design and Installation of Groundwater Monitoring Wells in Aquifers). Also, DBS&A technical representatives are required to follow all applicable state regulations pertaining to monitor well design and installation. Refer to Driscoll (1986), EPA (September 1992 and November 1992) or Aller et. al. (1989) for more detailed guidelines about the above subjects as they relate to the design and installation of monitor wells.

These SOPs and SOGs shall be reviewed periodically, and revisions and additions to these SOPs and SOGs shall be made as needed to assure consistency with industry standards and the collection of high quality data in the field. Requests for revisions shall be made in writing to the President or his/her quality assurance designee.

4.1.1 Initial Site Characterization (ASTM D 5092-90)

A conceptual hydrogeologic model that identifies potential flow paths and the target monitoring zone(s) should be developed prior to monitor well design and installation. The following steps for initial site characterization are recommended:

1. Conduct an initial visit to identify and locate aquifers and zones with the greatest potential to contain and transmit groundwater and contaminants from the project area. Study exposed soil and rocks within or near the project area for color and textural changes, landslides, faults, seeps, and springs.

2. Collect and review literature from previous investigations of the project area (i.e., topographic maps, aerial imagery, site ownership and utilization records, geologic and hydrogeologic maps and reports, mineral resource surveys, water well logs, and personal information from local well drillers).

3. Develop a preliminary conceptual model of the project area using the information gathered during the initial site visit and literature search. Target specific aquifers and/or groundwater zones for additional characterization based on the known hydrogeology and potential contaminant characteristics (e.g., screen across water table for light non-aqueous phase liquids [LNAPLs]; include a sump for dense non-aqueous phase liquids [DNAPLs]).

4.1.2 Monitor Well Materials and Design (ASTM D 5092-90)

The following materials and design are for typical shallow zone (single-cased) and deep zone (multi-cased) wells. Figure 4.1-1 is a diagram showing a typical design for a shallow zone (single-cased) well used at DBS&A. Figure 4.1-2 is a diagram showing a typical design for a deep zone (multi-cased) well used at DBS&A. Attachment 4.1-1 to this SOG is a material supply list (Form No. 118) for monitor well installation and should be completed and checked prior to the field stage of the drilling program by both DBS&A and the drilling subcontractor. Attachment 4.1-1 should be used in conjunction with the Drilling Information Checklist (Table 3.1-5) and Section 3.1.

4.1.2.1 Water

Water used in the drilling process, to prepare grout mixtures and to decontaminate the well screen, riser, and annular sealant injection equipment, should be obtained from a source of known chemistry or should be characterized. The chemical analysis should confirm that the added water does not contain constituents that could compromise the integrity of the well installation or that may be potential contaminants.

4.1.2.2 Filter Pack

1. The grain-size distribution curve for the filter pack is selected by multiplying the 70% retained size of the finest formation sample by 3 or 4. Usually, 10/20 silica sand is appropriate for the filter pack of most monitor wells.

2. Do not select too fine a filter pack because this will reduce the yield of the well, causing longer sampling times.

3. Uniformity coefficients for filter pack materials should range from 1 to 3.

4. All filter pack material should be purchased from reputable suppliers who have properly cleaned and bagged the material.

5. To prevent downward migration of the bentonite or cement into the screen, the filter pack is extended a minimum of 2 feet above the top of the screen.

6. The filter pack should not extend into an overlying water-bearing formation because this could permit downward vertical seepage in the pack and either dilute or add to the contamination of the water being monitored. This could also affect the accuracy of the water level measurements in the well.

4.1.2.3 Well Screen

1. The well screen should be new, machine-slotted or continuous-wrapped wire-wound, and composed of materials that are inert to the subsurface water being tested. Table 4.1-1 lists the advantages and disadvantages of several common screen materials.

2. The well screen material should be plastic-wrapped and certified by the manufacturer as clean.

3. If not certified by the manufacturer as clean, the well screen should be steam cleaned or high-pressure water cleaned (if appropriate for the selected well screen materials) with water from a source of known chemistry immediately prior to installation.

4. The screen should be capped at the bottom with the same material as the well screen.

5. The minimum nominal internal diameter of the well screen should be chosen based on the criteria that it will permit effective development and rapid sample recovery. In most instances, a minimal diameter of 2 inches (50 mm) is needed to allow for the introduction and withdrawal of sampling devices. However, a minimum of 4 inches may be needed if pumping tests are to be performed.

6. The slot size of the well screen should retain filter pack or natural formation along with permitting efficient development of the wells.

4.1.2.4 Riser

A riser is a blank casing extending from the screen interval to the ground surface.

1. The riser should be new and composed of materials that are inert to the subsurface water being tested. Table 4.1-1 lists the advantages and disadvantages of several common riser materials.

2. The riser material should be plastic-wrapped and certified by the manufacturer as clean.

3. If not certified by the manufacturer as clean, each section of the riser should be steam cleaned or high-pressure water cleaned (if appropriate for the selected material) using water from a source of known chemistry immediately prior to installation.

4. The minimal nominal internal diameter of the riser should be chosen based on the criteria that it will permit effective development and rapid sample recovery. In most instances, a minimum of 2 inches (50 mm) is needed to accommodate sampling devices. However, a minimum of 4 inches may be needed if pumping tests are anticipated.

5. Threaded joints are recommended. Alternatively, O-rings composed of materials that would not affect the subsurface water being sampled may be selected for use on flush joint threads.

6. The diameter of the casing for filter packed wells should be selected so that a minimum annular space of 2 inches (50 mm) is maintained between the inside diameter of the casing and the outside diameter of the riser.

4.1.2.5 Casing

1. The casing material should be new and composed of materials that are inert to the subsurface water being tested. Table 4.1-1 lists the advantages and disadvantages of several common casing materials. The exterior casing (temporary or permanent multi-cased wells) is generally constructed of steel although other appropriate materials may be used.

2. Where conditions warrant, the use of permanent casing installed to prevent communication between water-bearing zones is encouraged.

3. The casing material should be certified by the manufacturer as clean.

4. If not certified by the manufacturer as clean, the casing material should be steam cleaned or high-pressure water cleaned (if appropriate for the selected material) using water from a source of known chemistry immediately prior to installation.

5. The material type and minimum wall thickness of the casing should be adequate to withstand forces of installation (e.g., handling during installation and heat produced by curing of cement grout).

6. All casing that is to remain as a permanent part of the installation (that is, multi-cased wells) should be new and cleaned of interior and exterior protective coatings.

7. The diameter of the casing for filter packed wells should be selected so that a minimum annular space of 2 inches (50 mm) is maintained between the inside diameter of the casing and the outside diameter of the riser. In addition, the diameter of the casings in multi-cased wells should be selected so that a minimum annular space of 2 inches is maintained between the casing and the borehole (that is, a 2-inch diameter screen will require first setting a 6-inch (152 mm) diameter casing in a 10-inch (254 mm) diameter boring).

8. The ends of each casing section should be either flush-threaded or bevelled for welding.

4.1.2.6 Annular Sealants

The materials used to seal the annulus may be prepared as a slurry or used unmixed in a dry pellet, granular, or chip form. Sealants should be selected to be compatible with ambient geologic, hydrogeologic, and climatic conditions and any man-induced conditions anticipated to occur during the life of the well. Table 4.1-2 lists some of the advantages and disadvantages of using bentonite or cement as grouting material for monitor wells. The following guidelines for the bentonite seal and grout backfill should be considered:

1. A bentonite seal of at least 2 feet is placed above the filter pack. Bentonite should be powdered, granular, pelletized, or chipped sodium montmorillonite furnished in sacks or buckets from a commercial source and free of impurities which adversely impact the water quality in the well. The diameter of pellets or chips selected for monitoring well construction should be less than one fifth the width of the annular space into which they are placed to reduce the potential for bridging.

2. The grout backfill that is placed above the bentonite seal is ordinarily a liquid slurry consisting of either a bentonite (powder or granules, or both) base and water or a Portland cement base and water. A mixture of bentonite and Portland cement can be used for the grout backfill. Refer to ASTM D 5092-90 for standards in mixing and placing the grout backfill.

4.1.2.7 Annular Seal Equipment

Prior to use, the equipment used to inject the annular seals and filter pack should be steam cleaned or high-pressure water cleaned (if appropriate for the selected material) using water from a known chemical source. This procedure is performed to prevent the introduction of materials that may ultimately alter the water sample quality.

4.1.3 Monitor Well Installation (ASTM D 5092-90)

A well completion diagram (DBS&A Form No. 048, Attachment 4.1-2) should be completed as an on-going process during the installation of the monitor well. General steps for monitor well installation are as follows:

1. A stable borehole must be constructed prior to installing the monitor well casing, screen, and riser (refer to Section 3.1 for drilling guidelines). Working components of the drilling rig (drill pipe, subs, collars, belly, and all parts of the rig chassis near the borehole) should be cleaned as described in step 2.

2. The well casing, screen, riser, and bottom plug materials should either be plastic-wrapped and certified by the manufacturer as clean or cleaned with a steam cleaner or high-pressure water combined with a low-sudsing soap or detergent.

3. All plastic screens and casing should be joined by threads and couplings or flush threads. Solvent glues should not be used because of potential contamination.

4. Prior to installation, the well material should be inspected and measured. Measuring allows more accurate placement of the screen interval.

5. The well screen and riser assembly can be lowered to the predetermined level and suspended and held in position by a ballast or by hydraulic arms on the drilling rig. The assembly must be installed straight to allow for the introduction and withdrawal of sampling devices. Centralizers should be used when the casing is installed in an open borehole.

6. The riser should extend above grade and be capped temporarily to deter entrance of foreign materials during completion operations.

7. The volumes of filter pack (gravel and/or silica sand), bentonite seal, and grout required to fill the annular space between the well screen and borehole should be calculated, measured during installation, and recorded on the well completion diagram during installation.

8. The filter pack is placed in the annulus from the bottom of the borehole up to a minimum of 2 feet above the well screen. Note that during the emplacement of the filter pack, air within the borehole, including organic vapors, will be forced up and out of the borehole, drill pipe, and/or casing string. These vapors can present a significant risk to worker health and thus should be monitored.

9. As the filter pack is put in place, the temporary casing or hollow stem auger (if used) is withdrawn, usually in stipulated increments. Care should be taken to minimize lifting the riser with the withdrawal of the temporary casing/augers. To limit borehole collapse, the temporary casing or hollow stem auger is usually withdrawn until the lowermost point on the temporary casing or hollow stem auger is at least 2 feet, but no more than 5 feet, above the filter pack for unconsolidated materials or at least 5 feet, but no more than 10 feet, for consolidated materials.

   For filter pack placements well below the water table, it is recommended that the filter pack be surged before emplacing the bentonite seal. This will ensure that the filter pack is properly settled and that no voids are present.

A secondary filter pack of finer sand may be emplaced above the primary filter pack to prevent the intrusion of the bentonite grout seal into the primary filter pack. As with the primary filter pack, the secondary filter pack must not extend into an overlying hydrologic unit.

10. A bentonite pellet or chip seal is placed in the annulus between the borehole and the riser pipe on top of the filter pack. To be effective, the bentonite seal should extend above the filter pack a minimum of 2 feet, depending on local conditions.

11. If the water level in the borehole is below the top of the bentonite seal, the bentonite should be hydrated by adding potable water of a known chemical quality. Sufficient time (approximately one-half hour) should be allowed for the bentonite pellet seal to hydrate prior to grouting the remaining annulus. The volume and elevation of the bentonite seal material should be measured and recorded on the well completion diagram.

    If the water level in the borehole is well above the top of the filter pack, there may be concern about bridging of bentonite being poured through the standing water column. In that case, a thick slurry of high-solids bentonite (e.g., Baroid Quik Grout) can be mixed according to the manufacturer's recommendations and pumped through a tremie pipe to fill the space immediately above the filter pack. The slurry should initially be pumped slowly so as to not disturb the filter pack.

12. Grout, typically cement with up to 5 percent powdered bentonite, should be mixed according to industry specifications (typically 6 to 7 gallons of water per 94 pound sack of Type I Portland cement; refer to Driscoll, 1986). The volume and location of grout used to backfill the remaining annular space is recorded on the well completion diagram. An ample volume of grout should be premixed on-site to compensate for unexpected losses.

13. Grout will be pumped into the annulus through a tremie pipe to fill the annulus from bottom to top and should be introduced in one continuous operation until full-strength grout flows out at the ground surface without evidence of drill cuttings or fluid. Grout may be placed in more than one layer if the length of the grout column may be sufficient (greater than 150 feet) to cause collapse (melting) of the casing from the heat liberated as the hydrating grout cures.

14. The riser or casing or both should not be disturbed until the grout sets and cures for the amount of time necessary to prevent a break in the seal between the grout and riser, or grout and casing, or both. The amount of time required for the grout to set and cure will depend on the grout content and climatic conditions. Typically, 24 hours is considered sufficient.

15. Specific grouting procedures for single- and multi-cased wells are included in ASTM D 5092-90.

16. Well protection refers specifically to installations made at the ground surface to deter unauthorized entry to the monitor well and to prevent surface water from entering the annulus. Typically a concrete pad, protective shroud with a lock, and vented cap are placed on monitor wells constructed for DBS&A projects.

17. In areas where there is a high probability of damaging the well (high traffic, heavy equipment, and/or poor visibility), it may be necessary to enhance the normal protection of the monitor well through the use of posts, markers, signs, etc.

18. Once the monitor well installation is complete, the well should be developed according to standards outlined in Section 4.2.

19. The drilling subcontractor is responsible for filing any paperwork (e.g., well record) with the State Engineer or other regulating agency within the specified time period after completion of the well.

Attachments

4.1-1. Material Supply List (DBS&A Form No. 118, 6/93)
4.1-2. Well Completion Record (DBS&A Form No. 048)
Figure 4.1-1. Typical Monitor Well Design, Single-Cased Well
Figure 4.1-2. Typical Monitor Well Design, Multi-Cased Well
Table 4.1-1. Well Casing, Screen, and Riser Materials
Table 4.1-2. Grouting Materials for Monitoring Wells
Table 4.1-3. Monitor Well Installation Checklist

References

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Driscoll, F.G. 1986. *Groundwater and wells.* Johnson Division. St. Paul, MN. 1089 p.

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Monitor Well Installation Supply List

DANIEL B. STEPHENS & ASSOCIATES, INC.

Project No. ______________ DBS&A Project Manager ______________

DBS&A Technical Representative ______________ DBS&A Field Representative(s) ______________

Drilling Company ______________

Drilling Company Contact ______________ Phone No. ______________

Date and Time for Work to Begin ______________

Material	Size	Quantity	Equipment Supplier*
Sand			
Sand			
Pea Gravel			
Bentonite Powder			
Bentonite Pellets			
Bentonite Chips (Ca-montmorill. Slow, NA-montmorill. Fast Hydration)			
PVC (Flush-Threaded Schedule 40)			
PVC (Flush-Threaded Schedule 40)			
PVC (Flush-Threaded Schedule 40)			
PCV Screen Schedule 40 with Slot______			
PCV Screen Schedule 40 with Slot______			
PCV Screen Schedule 40 with Slot______			
Stainless Steel Channel Pack			
Steel Conductor Casing			
Slip Caps			
Slip Caps			
Threaded Endcaps			
Threaded Endcaps			
Locking Caps			
Concrete			
Portland Cement			
Locking Well Vault			

DBS&A Form No. 118 6/93

*DBS&A or Other (specify)

DANIEL B. STEPHENS & ASSOCIATES, INC.
ENVIRONMENTAL SCIENTISTS AND ENGINEERS

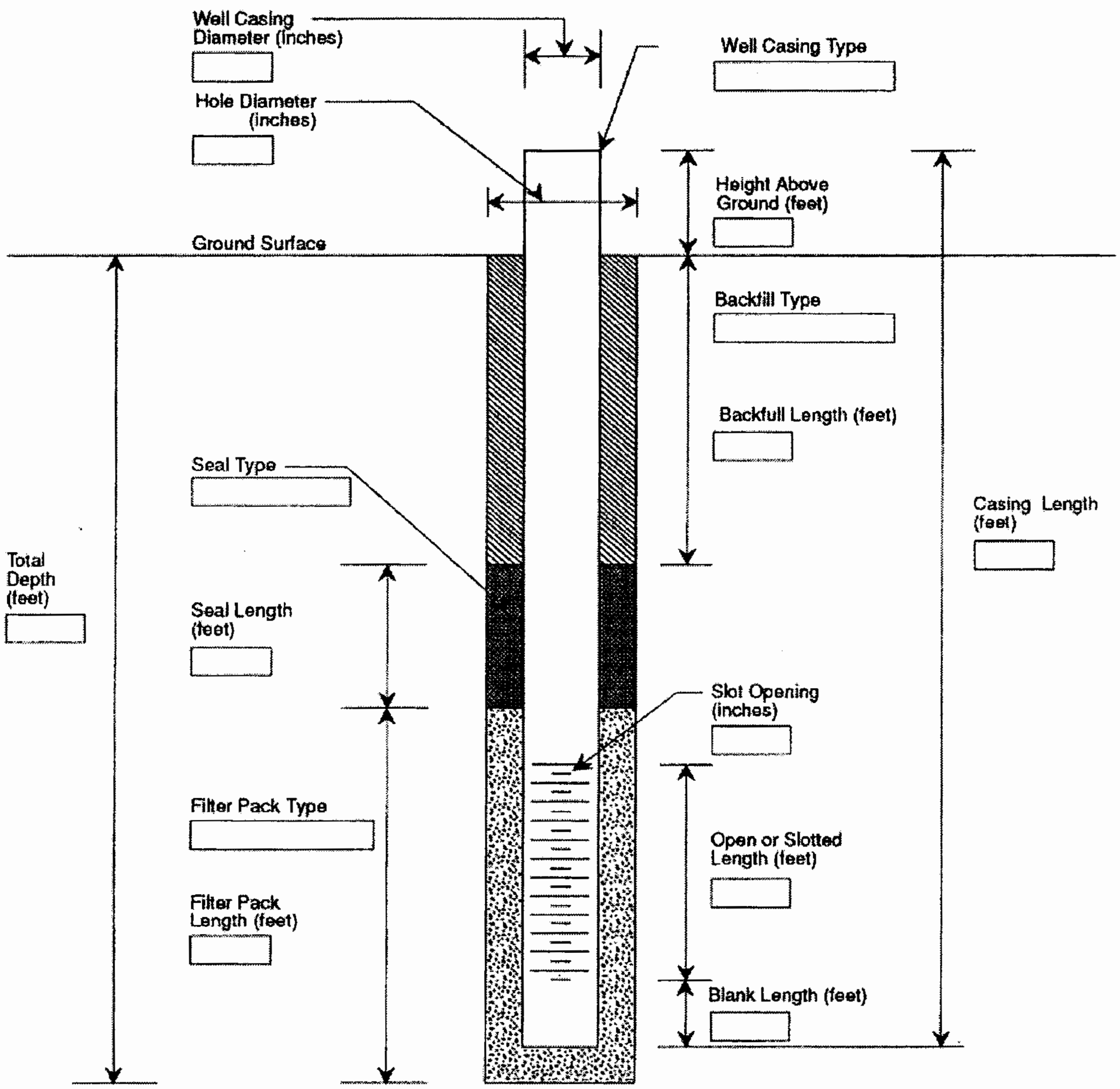
WELL COMPLETION RECORD

Client ______________________ Project No. ______________

Well No. ____________ Site ______________________ Date Installed ______________

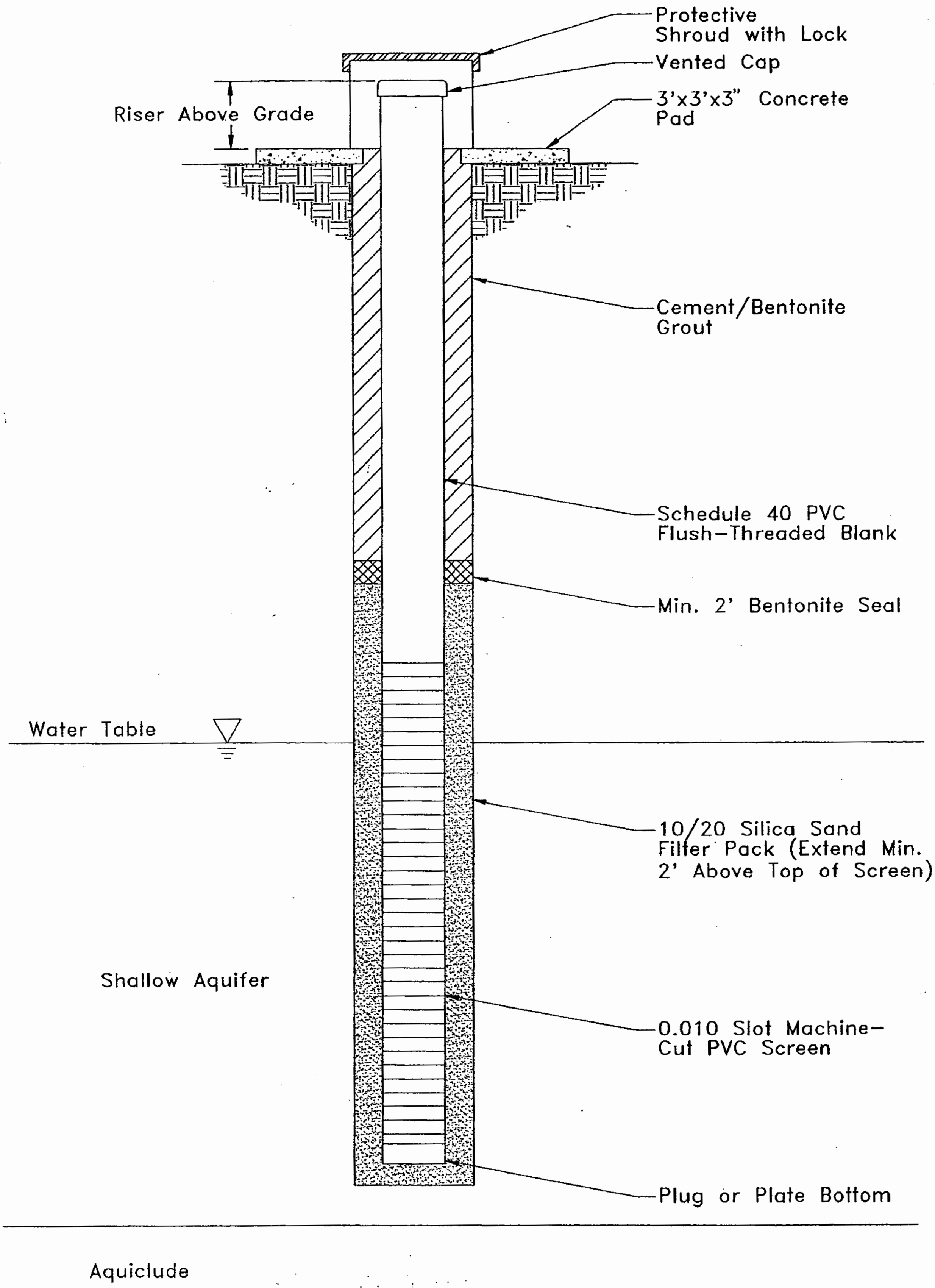
Formation of Completion ______________________________

DBS&A Personnel ______________________ Driller ______________________



Comments ______________________________

DBS&A Form No. 048 4/92



Not to scale

Typical Monitor Well Design
Single-Cased Well

Daniel B. Stephens & Associates, Inc.
11-21-02

Figure 4.1-1

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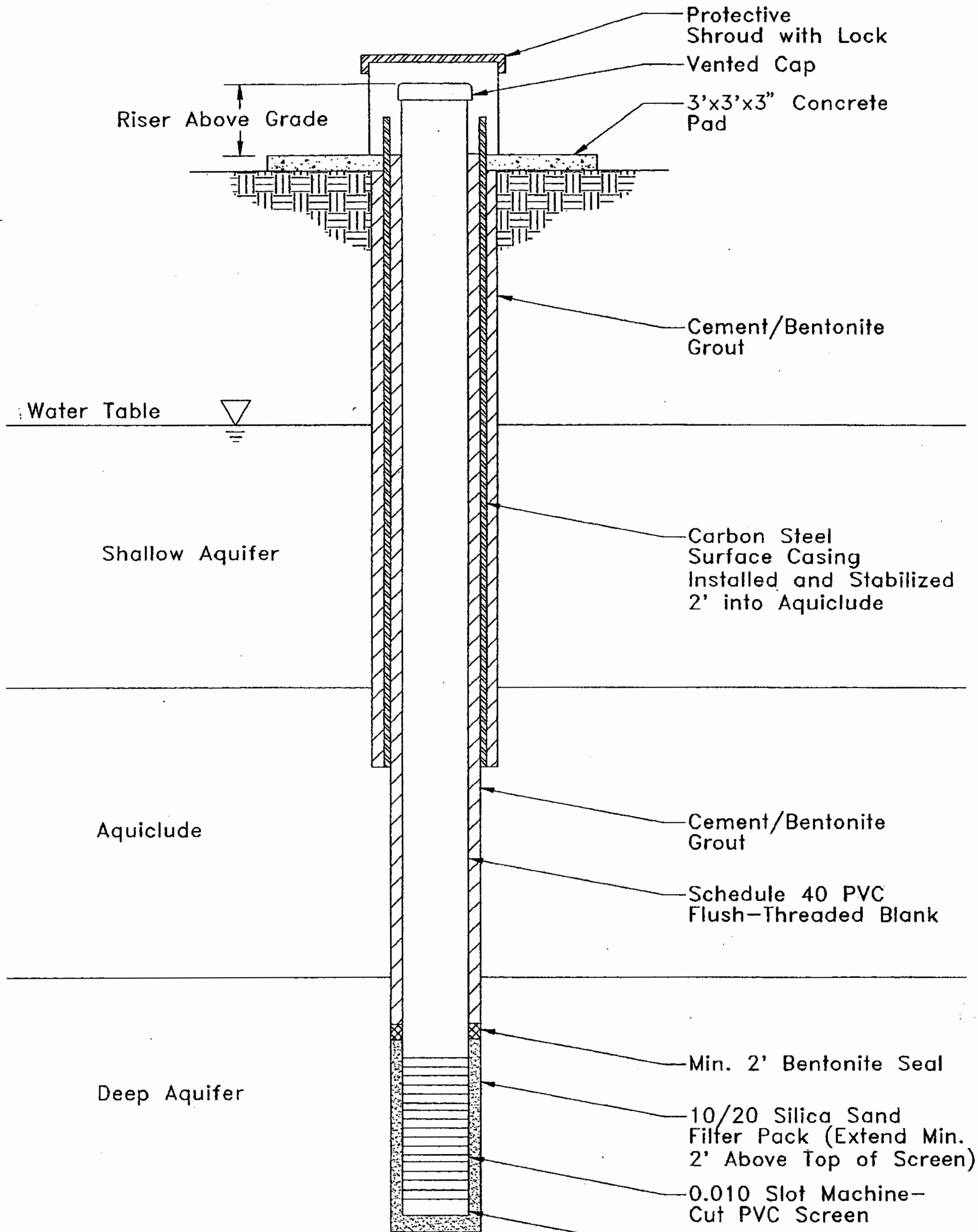

Not to scale

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11-21-02

Typical Monitor Well Design
Multi-Cased Well

Figure 4.1-2

Table 4.1-1. Well Casing, Screen, and Riser Materials
Page 1 of 2

Type	Advantages	Disadvantages
Stainless steel	• Least absorption of halogenated and aromatic hydrocarbons • High strength at a great range of temperatures • Excellent resistance to corrosion and oxidation • Readily available in all diameters and slot sizes	• Heavier than plastics • May corrode and leach some chromium in highly acidic waters • May act as a catalyst in some organic reactions • Screens are higher priced than plastic screens
PVC (Polyvinyl-chloride)	• Lightweight • Excellent chemical resistance to weak alkalis, alcohols, aliphatic hydrocarbons, and oils • Good chemical resistance to strong mineral acids, concentrated oxidizing acids, and strong alkalis • Readily available • Low priced compared to a stainless steel and Teflon	• Weaker, less rigid, and more temperature sensitive than metallic materials • May adsorb some constituents from groundwater • May react with and leach some constituents from groundwater • Poor chemical resistance to ketones, esters, and aromatic hydrocarbons
Teflon	• Good resistance to attack by most chemicals • Lightweight • High impact strength	• Screen slot openings may decrease in size over time • Tensile strength and wear resistance low compared to other engineering plastics • Expensive relative to other plastics and stainless steel
Mild steel	• Strong, rigid; temperature sensitivity not a problem • Readily available • Low priced relative to stainless steel and Teflon	• Heavier than plastics • May react with and leach some constituents into groundwater • Not as chemically resistant as stainless steel

**Table 4.1-1. Well Casing, Screen, and Riser Materials
Page 2 of 2**

Type	Advantages	Disadvantages
Polypropylene	• Lightweight • Excellent chemical resistance to mineral acids • Good to excellent chemical resistance to alkalis, alcohols, ketones, and esters • Fair chemical resistance to concentrated oxidizing acids, aliphatic hydrocarbons, and aromatic hydrocarbons • Low priced compared to stainless steel and Teflon	• Weaker, less rigid, and more temperature sensitive than metallic materials • May react with and leach some constituents into groundwater • Poor machinability--it cannot be slotted because it melts rather than cuts
Kynar	• Greater strength and water resistance than Teflon • Resistant to most chemicals and solvents • Lower priced than Teflon	• Not readily available • Poor chemical resistance to ketones, acetone

Source: Driscoll, 1986

Table 4.1-2. Grouting Materials for Monitoring Wells

Type	Advantages	Disadvantages
Bentonite	• Creates a flexible, low permeability seal • No heat of hydration • Readily available • Inexpensive • Coated pellet available for placement below water table (more expensive) • High solids (20%) bentonite grouts available (e.g., Baroid Quick Grout)	• May produce chemical interference with water-quality analysis • May not provide a complete seal because: – During installation, bentonite pellets may hydrate before reaching proper depth, thereby sticking to formation or casing and causing bridging – Cannot determine how effectively material has been placed – Cannot assure complete bond to casing
Cement	• Readily available • Inexpensive • Can use sand/or gravel filter • Possible to determine how well the cement has been placed by temperature logs or acoustic bond logs	• May cause chemical interference with water-quality analysis • Requires mixer, pump, and tremmie line; generally more cleanup than with bentonite • Shrinks when it sets; complete bond to formation and casing not assured (bentonite powder can be added to retard shrinkage and provide plasticity)

Source: Driscoll, 1986

Table 4.1-3. Monitor Well Installation Checklist
Page 1 of 2

Item	Specific Procedures and Equipment
Access__________	Written access agreements in place with property owners and owners of any property to be crossed to reach drill site
Permits__________	Well permits, drilling permits, and/or digging permits filed with appropriate agencies
Utility clearance__________	One call contacted, local municipality contacted (water and sewer), private underdetection service contacted, required allotted time passed since requesting utility clearance
Notification__________	Notify client or agency in advance as required
Health and safety__________	Site specific health and safety plan with emergency medical information and daily tailgate forms, health and safety kit (hard hat, steel-toed boots, safety glasses, earplugs respirator, Tyvek), latex gloves, first aid kit, eye wash bottle, material safety data sheets
Water__________	Is a contaminant-free source of water on-site or nearby? Can drilling subcontractor haul adequate amounts of water?
Decontamination equipment__________	Decontamination equipment (steam cleaner, etc.) supplied by drilling contractor, containment of decon water provided (decon pad available if required), sample kit for decon water, minimum of three plastic tubs or buckets for decontaminating, plastic bottle brushes, Liquinox, D.I. water (minimum of 10 gallons), paper towels, garbage bags, plastic sheeting
Drill cuttings and fluids__________	Containment of drill cuttings and fluids provided. Arrangements for disposal of cuttings and fluids made. Sample kit for cuttings and/or drilling fluids.
Soil sampling tool kit__________	Hand lens, grain size chart, USCS soil classification guide, Munsel soil color chart, spatulas, dilute hydrochloric acid, engineers tape (marked in tenths of feet), geologic hammer
Clip board__________	Boring log forms, well completion forms
Field book__________	Waterproof pens, assortment of waterproof markers

Table 4.1-3. Monitor Well Installation Checklist
Page 2 of 2

Item	Specific Procedures and Equipment
Meters______________	Photoionization detector, O2/LEL explosivity meter, GA90 methane meter, Geiger-Mueller radiation meter, sound level meter, dust monitor, water level meter, pH meter, EC meter, D.O. meter
Hand auger system______________	Available to post-hole upper 5 feet as a utility check
Well construction supplies______________	Screen, end cap, blank riser, filter pack, (all sized for depth of well and matched to the formation of completion), bentonite, grouting material (selected to prevent grout intrusion and melting of casing), tremie pipe, well vaults or steel riser, protective posts, locks.
Tagline______________	Fiberglass with weight taped, steel tape with stainless steel weight (no tape)
Surveying______________	Surveying company subcontracted, 300-ft. tape or measuring wheel, transit or builders level
Sampling containers______________	Brass rings (physical properties and petroleum hydrocarbons), stainless steel rings, Teflon liners, (organic chem. analyses), plastic endcaps, sealing tape (electrical or solvent-free), cellophane wrap, plastic tubes, aluminum foil, glass headspace jars, glass soil jars, Methanol extraction kits, water sampling kit, quart and gallon ziplock baggies, strapping and packing tape, chain of custody forms, custody seals
Coolers______________	One for food only, as needed for samples

4.2 Well Development

This section provides standard operating guidelines (SOGs) for well development.

The SOPs and SOGs included in this section are applicable to all DBS&A employees for the conduct of all activities listed in this section. All SOPs and SOGs described in this section are proprietary in nature and shall not be copied or reproduced, or distributed to any person or organization not employed by DBS&A, without the expressed written approval of the President or his/her designee for quality assurance. All or parts of the SOPs and SOGs described in this section may be reproduced and used in DBS&A reports, proposals, and work plans with the verbal consent of the President, his/her quality assurance designee, or a DBS&A Division Director.

Table 4.2-1 summarizes disadvantages and advantages for different well development methods. Table 4.2-2 identifies critical items for well development and should be used to prepare for well development activities. The scope of the procedures described in this section includes the following:

- Development process
- Development methods
- Timing and duration of well development
- Decontamination of well development equipment
- Well recovery test

Standards for well development are described in ASTM D 5092-90 (Reapproved 1995) (Standard Practice for Design and Installation of Groundwater Monitor wells in Aquifers) and ASTM D 5521-94 (Standard Guide for Development of Groundwater Monitor wells in Granular Aquifers). Also refer to Driscoll (1986), EPA (1992) or Aller et al. (1989) for more detailed guidelines about well development.

These SOPs and SOGs shall be reviewed periodically, and revisions and additions to these SOPs and SOGs shall be made as needed to assure consistency with industry standards and the collection of high quality data in the field. Requests for revisions shall be made in writing to the President or his/her quality assurance designee.

Well development is an important component of monitor well completion. Proper well development serves to (1) remove some finer grained material from the well screen and filter pack that may otherwise interfere with water quality analyses, (2) restore the groundwater properties disturbed during the drilling process, and (3) improve the hydraulic characteristics of the filter pack and hydraulic communication between the well and the hydrologic unit adjacent to the screened interval.

Well development methods vary with the physical characteristics of the geologic formation in which the monitor well is screened, the construction details of the well, the drilling method used during the construction of the borehole in which the well is installed, and the quality of the water. The development method for each individual monitor well should be selected from among the several methods described in this guide and should be employed by the well construction contractor or the person responsible for monitor well completion.

The importance of well development in monitor wells cannot be overestimated; all too often development is not performed or is carried out inadequately. Proper and careful well development will improve the ability of most monitor wells to provide representative, unbiased chemical and hydraulic data. The additional time and money spent performing this important step in monitor well completion will minimize the potential for damaging pumping equipment and in-situ sensors, and increase the probability that groundwater samples are representative of water contained in the monitored formation.

4.2.1 Well Development Process (ASTM D 5092-90 and ASTM D 5521-94)

The well development process consists of three phases: predevelopment, preliminary development, and final development.

4.2.1.1 Predevelopment

Predevelopment refers to techniques used to mitigate formation damage during well construction. This is particularly important when using direct or reverse rotary drilling systems that depend on drilling fluid to carry cuttings to the surface and support an open borehole. Control of drilling fluid properties, during the drilling operation and immediately prior to the installation of screen, casing, and filter pack, is very important.

4.2.1.2 Preliminary Development

Preliminary development takes place after the screen, casing, and filter pack have been installed. Methods used to accomplish this task include surging, bailing, hydraulic jetting, and air lifting. The primary purpose of this operation is to apply sufficient energy in the well to rectify formation damage due to drilling; draw fine-grained materials from the formation, filter pack, and screen into the well where they can be removed; stabilize and consolidate the filter pack; retrieve drilling fluid (if used); and create an effective hydraulic interface between the filter pack and the formation.

4.2.1.3 Final Development

Final development refers to procedures performed with a pump, such as pumping and surging, and backwashing. These techniques are used as the final step in achieving the objectives of well development. If preliminary development methods have been effective, the time required for final development should be relatively short. However, if the preliminary methods have not been successful, or if conditions preclude the use of the preliminary techniques listed, the final development phase should be continued until the development completion criteria (described below) are satisfied.

4.2.2 Well Development Methods (ASTM D 5092-90 and ASTM D 5521-94)

Of the various methods available for developing wells, the most often used, and most appropriate for developing groundwater monitor wells, are mechanical surging and bailing or pumping, over-pumping and backwashing, and high-velocity hydraulic jetting with pumping. For any method, the development work should be started slowly and gently and be increased in vigor as the well is developed. Most methods of well development require the application of sufficient energy to disturb the filter pack, thereby freeing the fine particles and allowing them to be drawn into the well. The coarser fractions then settle around and stabilize the screen. The well development method chosen should be documented in the field notebook. This section summarizes each of the well development methods; more details for each method are located in ASTM D 5521-94 and ASTM D 5092-90.

4.2.2.1 Mechanical Surging
For mechanical surging, a close-fitting surge block is affixed to the end of a length of drill pipe, a solid rod, or a cable, and operated like a piston in the well casing or screen. The up and down plunging action alternately forces water to flow into (on the upstroke) and out of (on the downstroke) the well. The downstroke causes a backwash action to loosen bridges in the formation or filter pack and the upstroke then pulls dislodged fine-grained material into the well. This method is equally applicable to small-diameter and large-diameter wells, but is most effective for small-diameter wells.

Several designs for surge blocks exist, including solid, valved, spring-loaded, and multiple-flange surge blocks. A heavy bailer or a pump fitted with flexible disks similar to those on a surge block may also be used to produce the surging action, but these are not as effective as a close-fitting surge block.

Before surging, the well should be pumped or bailed to make sure that the well will yield water. If the screen is completely plugged and water does not enter the well upon bailing or pumping, the strong negative pressure created on the upstroke of the surge block may cause the screen to collapse. Surging should always begin above the screen and move progressively downward to prevent the surge block from becoming sand locked and prevent damage to the screen. Sediment will accumulate in the bottom of the well and should be bailed or pumped out as often as possible. The rate and volume of sediment accumulation should be recorded to provide data on the progress of development. Surging and cleaning should be continued until little or no sediment is measured after surging. The time required to properly surge a well depends on the character of the aquifer material, and may vary widely from well to well.

4.2.2.2 Over Pumping and Backwashing
The easiest and least expensive technique of well development is some form of pumping. With over pumping, the well is pumped at a rate considerably higher than it would be during normal operation. Theoretically, increasing the drawdown to the lowest possible level will result in increased flow velocities toward the well, thus causing movement of fine-grained materials into the well. However, limitations to over-pumping include the following:

- Over-pumping by itself will not adequately develop a well because water flows only in one direction.
- Over-pumping often requires the use of larger pumping equipment than will fit into the small-diameter casings used in many monitor wells.
- Over-pumping subjects the pump used in the operation to abrasion, excessive wear, and loss of efficiency.
- Over-pumping results in the production of potentially large volumes of water that may require containment or treatment.

Over-pumping is not an adequate development method if used alone and is best used in combination with backwashing. Backwashing is the term applied to the method of well development in which water is added to the well to reverse the flow. A commonly used backwashing procedure is to pump water into the well in a sufficient volume to maintain a head greater than that in the formation. This requires a high-capacity and high-quality water source. The amount of water added should be recorded and recovered during the well development process.

In the case where no backflow prevention valve is installed, the pump can be alternately started and stopped. This method is called "rawhiding." Starting and stopping the pump allows the column of water that is initially picked up by the pump to be alternately dropped and raised up in a surging action. Each time the water column falls back into the well, an outward surge of water flows into the formation. This surge tends to loosen the bridging of the fine particles into and out of the well.

4.2.2.3 High-Velocity Hydraulic Jetting

Another method of development is high-velocity hydraulic jetting. The well screen area is jetted with water to loosen fine-grained material and drilling mud residue from the formation. The loosened material moves inside the well screen and can be removed from the well by concurrent pumping or bailing. Jetting is particularly successful in developing highly stratified unconsolidated formations, consolidated bedrock wells, large-diameter wells, and naturally developed wells. A drawback of hydraulic jetting is that the water added during the development procedure will alter the natural, ambient water quality and may be difficult to remove. Therefore, the water added should be obtained from a source with known chemistry. Water from the monitor well being developed may be used if the suspended sediments are first removed.

4.2.2.4 High-Velocity Hydraulic Jetting with Simultaneous Pumping

Although jetting is effective in dislodging material from the formation, maximum development efficiency is achieved when jetting is combined with simultaneous pumping. This combination of development techniques is particularly successful for wells in unconsolidated sands and gravels. The volume of water pumped from the well should always exceed the volume pumped into the well during jetting, by as much as 1.5 to 2 times, so that a gradient is created toward the well.

4.2.2.5 Developing With Air

Developing with air is not recommended for monitor wells. Air development may force air into contact with the formation, which may alter the oxidation-reduction potential of the formation water and change the chemistry of the water in the vicinity of the well. The effects of this type of chemical disturbance may persist for several weeks or more after well development.

4.2.3 Timing and Duration of Well Development (ASTM D 5092-90 and ASTM D 5521-94)

The timing and duration of well development are planned to match the type of well, formation or completion, and other conditions of the drilling process. The following sections outline these considerations.

4.2.3.1 Timing of Well Development

Well development should always take place prior to water sampling, but other timing factors depend on the design and construction of the well. For example, if the well is installed with the intent of using natural formation material as the filter pack (that is, a "naturally developed" well), development is generally performed after the screen and casing have been installed and the formation material has collapsed against the screen, but before the annular seal is installed. Because well development for this well design will remove a significant fraction of the formation materials adjacent to the well screen, developing the well after installing the annular seal may result in portions of the annular seal collapsing into the vicinity of the well screen. On the other hand, properly designed and constructed filter-packed wells may be developed after the annular seal materials have been installed because the well screen is designed to retain at least 90 percent of filter pack materials, and little or no sloughing should occur.

4.2.3.2 Duration of Well Development

The duration of well development depends on the primary purpose of the development process. For example, if the primary purpose for development is to remove drilling fluid lost to the formation during borehole installation, the time required for completion of development may be based on the time it takes to remove from the well some multiple of the estimated volume lost. If the primary purpose of development is to rectify damage done during drilling to the borehole wall and the adjacent formation, the time for development may be based on the response of the well to pumping. An improvement in the recovery rate of the well indicates that the localized reduction in hydraulic conductivity has been rectified by development. If the primary purpose of development is to remove fine-grained materials, development may continue until visibly clear water is discharged from the well, or until the turbidity of water removed from the well is at some specified level. These criteria may be difficult or impossible to satisfy in formations with a significant fraction of fine-grained material.

Another criterion used for determining when development is complete is stabilization of indicator parameters, such as pH, temperature, and specific conductivity. While this criterion may be an indicator of when native formation water is being produced, it does not necessarily indicate that well development is complete. The minimum duration of well development will vary according to the method used to develop the well. The duration of well development and the pH, temperature, and specific conductivity readings should be recorded in the field notebook.

4.2.4 Decontamination of Well Development Equipment (ASTM D 5088-90)

Any equipment or materials used to develop a monitor well should be thoroughly cleaned in accordance with the procedures outlined in Section 5.2 (ASTM D 5088-90). Cleaning should take place before any equipment is used in any monitor well and between uses in either the same well or other wells.

4.2.5 Well Recovery Test (ASTM D 5092-90)

A well recovery test can be performed immediately after and in conjunction with well development. The well recovery test not only indicates well performance, but also may provide data for determining the transmissivity of the screened hydrologic unit. Estimates of the hydraulic conductivity of the unit can then be determined. Readings should be taken at intervals suggested in Table 4.2-3 until the well has recovered to 90 percent of its static water level, and these readings should be recorded in the field notebook. Section 6 describes specific methods for aquifer hydraulic testing that can be used to establish more detailed aquifer hydraulic parameters.

Attachments

Table 4.2-1. Summary of Advantages and Disadvantages of Well Development Methods

Table 4.2-2. Well Development Checklist

Table 4.2-3. Suggested Recording Intervals for Well Recovery Tests

References

Aller, L., T.W. Bennett, G. Hackett, R.J. Petty, J.H. Lehr, H. Sedoris, D.M. Nielson, and J.E. Denne. 1989. *Handbook of suggested practices for the design and installation of groundwater monitor well design and installation.* National Well Water Association. Dublin, Ohio. 398 p.

American Society for Testing and Materials (ASTM). 1994. *Standard practice for development of groundwater monitor wells in granular aquifers*. Standard D 5521-94. Philadelphia, Pennsylvania.

ASTM. 1995. *Standard practice for design and installation of groundwater monitor wells in aquifers*. Standard D 5092-90 (Reapproved 1995). Philadelphia, Pennsylvania.

Driscoll, F.G. 1986. *Groundwater and wells*. Johnson Division. St. Paul, Minnesota. 1089 p.

U.S. Environmental Protection Agency (EPA). 1992. *RCRA ground-water monitoring: draft technical guidance*. U.S. EPA. Washington, D.C. November. 236 p. and 4 Appendices.

Table 4.2-1. Summary of Advantages and Disadvantages of Well Development Methods
Page 1 of 2

Reference	Over-pumping	Backwashing	Mechanical Surging: Surge Block	Mechanical Surging: Bailer	Well Jetting	Air-lift Pumping
Gass (1986)	Works best in clean coarse formations and some consolidated rock; problems of water disposal and bridging	Breaks up bridging, low cost & simple; preferentially develops	Can be effective; size made for ≥2" well; preferential development where screen >5'; surge inside screen		Consolidated and unconsolidated application; opens fractures, develops discrete zones; disadvantage is external water needed	Replaces air surging; filter air
United States Environmental Protection Agency (1986)	Effective development requires flow reversal or surges to avoid bridges	Indirectly indicates method applicable; formation water should be used	Applicable; formation water should be used; in low-yield formation, outside water source can be used if analyzed to evaluate impact	Applicable		Air should not be used
Barcelona et al.** (1983)	Productive wells; surging by alternating pumping and allowing to equilibrate; hard to create sufficient entrance velocities; often used with airlift		Productive wells; use care to avoid casing and screen damage	Productive wells; more common than surge blocks but not as effective		
Scalf et al. (1981)		Suitable; periodic removal of lines	Suitable; common with cable-tool; not easily used on other rigs	Suitable; use sufficiently heavy bailer; advantage of removing fines; may be custom made for small diameters		Suitable
National Council of the Paper Industry for Air and Stream Improvement (1981)	Applicable; drawback of flow in one direction; smaller wells hard to pump if water level below suction		Applicable; caution against collapse of intake or plugging screen with clay		Methods introducing foreign materials should be avoided (i.e., compressed air or water jets)	

* Schalia and Landick (1986) report on Special 2' valved block
** For low hydraulic conductivity wells, flush water up annulus prior to sealing; afterwards pump
(compiled by Aller et al, 1989)

Table 4.2-1. Summary of Advantages and Disadvantages of Well Development Methods

Reference	Over-pumping	Backwashing	Mechanical Surging		Well Jetting	Air-lift Pumping
			Surge Block	Bailer		
Everett (1980)	Development operation must cause flow reversal to avoid bridging; can alternate pump off and on		Suitable; periodic bailing to remove fines		High velocity jets of water generally most effective; discrete zones of development	
Keely and Boateng (1987 a and b)	Probably most desirable when surged; second series of evacuation/recovery cycles is recommended after resting the well for 24 hours; settlement and loosening of fines occurs after the first development attempt; not as vigorous as backwashing	Vigorous surging action may not be desirable due to disturbance of gravel pack	Method quite effective in loosening fines but may be inadvisable in that filter pack and fluids may be displaced to degree that damages value as a filtering media		Popular but less desirable; method different from water wells; water displaced by short downward bursts of high pressure injection; important not to jet air or water across screen because fines driven into screen cause irreversible blockage; may substantially displace native fluids	Air can become entrained behind screen and reduce permeability

* Schalia and Landick (1986) report on Special 2' valved block
** For low hydraulic conductivity wells, flush water up annulus prior to sealing; afterwards pump
(compiled by Aller et al, 1989)

Table 4.2-2. Well Development Checklist

Item	Specific Equipment and Supplies
Notification____________________	Notify client or agency in advance as required
Health and safety_______________	Site specific health and safety plan with emergency medical information and daily tailgate forms, health and safety kit (hard hat, steel-toed boots, safety glasses, earplugs, respirator, Tyvek coveralls), first aid kit, eye wash bottle, material safety data sheets
Latex gloves__________________	Glove liners or heavier gloves
Water________________________	Is a contaminant free source of water on site or near by. Can drilling subcontractor haul adequate amounts of water
Decontamination equipment_______	Decontamination equipment (steam cleaner, etc.) supplied by drilling contractor, containment of decon water provided (decon pad available if required), sample kit for decon water, minimum of three plastic tubs or buckets for decontaminating, plastic bottle brushes, Liquinox, D.I. water (minimum of 10 gallons), paper towels garbage bags, plastic sheeting
Development water______________	Containment of development water provided, arrangements for disposal of development water made. Sample kit for development water.
Field book____________________	Waterproof pens, assortment of waterproof markers
Meters_______________________	Depending on the scope of work, may include photoionization detector, O2/LEL explosivity meter, sound level meter, water level meter, pH meter, EC meter, DO meter, Eh meter, turbidity meter.
Well development equipment______	Pump pulling or drill rig with hydraulic winch, and drill pipe, solid rod, and/or cable. Close-fitting surge block, bailers, rope or twine, development pump capable of pumping sediment, jetting tool, air lines and fittings, drop pipe, air compressor with in-line oil trap and filter.
Sampling containers_____________	Jars for collecting parameter samples, water sampling kit, quart and gallon ziplock baggies, strapping and packing tape, chain of custody forms, custody seals
Storage coolers_________________	One for food only, as needed for samples

Table 4.2-3. Suggested Recording Intervals for Well Recovery Tests

Time Since Starting Test	Time Interval
0 to 15 min	1 min
15 to 50 min	5 min
50 to 100 min	10 min
100 to 300 min (5 hours)	30 min
300 to 1,440 min (24 hours)	60 min

4.3 Well and Boring Abandonment

This section provides standard operating guidelines (SOGs) for the abandonment of wells, piezometers, boreholes, and vadose zone monitoring devices (e.g., lysimeter).

The SOPs and SOGs included in this section are applicable to all DBS&A employees for the conduct of all activities listed in this section. All SOPs and SOGs described in this section are proprietary in nature and shall not be copied or reproduced, or distributed to any person or organization not employed by DBS&A, without the expressed written approval of the President or his/her designee for quality assurance. All or parts of the SOPs and SOGs described in this section may be reproduced and used in DBS&A reports, proposals, and work plans with the verbal consent of the President, his/her quality assurance designee, or a DBS&A Division Director.

The scope of the guidelines described in this section includes the following topics:

- Objectives of decommissioning wells
- Well abandonment considerations
- Common well abandonment procedures
- Well abandonment notification and documentation

Further guidelines and procedures for decommissioning wells are described in ASTM D 5299-92 (1992), Driscoll (1986), and Aller et al. (1989).

These SOPs and SOGs shall be reviewed periodically, and revisions and additions to these SOPs and SOGs shall be made as needed to assure consistency with industry standards and the collection of high quality data in the field. Requests for revisions shall be made in writing to the President or his/her quality assurance designee.

4.3.1 Objectives of Decommissioning Wells

The primary objective of abandonment activities is to permanently decommission the well or monitoring device so as to prevent any further disturbance to the pre-existing hydrogeological conditions that exist within the subsurface so the natural migration of groundwater and soil vapor is not significantly influenced. Abandoned wells and monitoring devices need to be sealed carefully to prevent pollution of the groundwater source, conserve aquifer yield, maintain confined head conditions, prevent poor-quality water of one aquifer from entering another, eliminate any physical hazards at the ground surface, and eliminate the possibility that the well or monitoring device is used for purposes other than intended.

4.3.2 Well Abandonment Considerations

4.3.2.1 Research

It is important to compile as much information as possible on the well or monitoring device that is to be abandoned. The type of materials used and the way in which a well was constructed in part determine the method of abandonment. Research the drillers' logs, geophysical logs, geologic logs, local stratigraphy and structural geology, well construction information, depth, screened intervals, hydraulic gradients (vertical as well as horizontal), and variations in water levels over time. Also research the chemical data for soil and water during the life of the well. If information on the well is limited it may be necessary to conduct downhole inspections such as video logs to determine casing and screen conditions, caliper logs to measure inside diameters, cement bond logs (sonic) to determine annular seal conditions, and hydraulic integrity tests to determine if the casing is intact.

4.3.2.2 Condition of the Well

The condition of the annular seal and the well casing often determine the method of decommissioning a well. If the condition of the annular seal is suspect or unknown it is advisable to remove the casing and annular seal by overdrilling the well. Cement bond logs (sonic) can be used to evaluate annular seal conditions. Damaged or badly corroded well casing may be impractical to pull or overdrill and may require down-hole ripping or perforating prior to grouting. Caliper logs and video logs can be used to determine down-hole conditions such as casing breaks and the condition of the well casing and screen.

4.3.2.3 Casing and Well Screen Materials

The type of well casing and screen will often determine the technique used to abandon a well. Well casing and screen generally fall into two categories; metallic and non-metallic. Non-metallic casing tends to be low in tensile strength, this limits the pressure that can be applied when pulling the casing or using the casing as a guide for overdrilling. The diameter of the casing may also limit the method selected for abandonment of a well.

4.3.2.4 Depth of the Well

The total depth of a well may determine the type and size of rig needed to abandon a well. The weight and friction associated with a long casing string needs to be considered when selecting a rig to pull casing.

4.3.2.5 Hydrologic Setting

The hydrogeology of the site will influence the method used to abandon a well. Many supply wells are screened over more than one interval. These intervals usually correspond to different water bearing units that were encountered during initial drilling of the well. The abandonment technique selected needs to prevent vertical movement of and mixing of water from the different producing zones. If artesian conditions exist within a well to be abandoned, it may be necessary to stop flow into the well and to lower the water level within the well during seal emplacement. If the rate of flow is high and flow into the well cannot be controlled, sealing the borehole requires that grout pressure be maintained at a pressure greater than the formation pressure until initial grout set occurs.

4.3.2.6 Level of Contamination

The level of contamination and the zone in which the contamination occurs may modify the technique of well or monitoring device abandonment. The method of abandonment needs to prevent movement and cross contamination between the various zones. The containment of and proper disposal of displaced fluids and other materials (such as cuttings, drilled out casing, and grout seals) should be taken into consideration.

4.3.3 Common Well Abandonment Procedures

Because of the wide variety of materials and techniques used in well and monitoring device construction, numerous methods of well abandonment are also employed. The abandonment procedures listed in this guideline are some of the more common ones used. However, DBS&A employees and subcontractors should not limit their abandonment methods to those listed but should evaluate each individual situation separately and apply the appropriate technology that best meets the site conditions. In addition, be aware that some state regulatory agencies have their own requirements for abandonment of wells. Table 4.3-1 identifies critical items and issues related to well abandonment and should be used to prepare for those operations.

4.3.3.1 In-Situ Grouting of the Well Screen

If the annular seal of the well is in good condition, no cross contamination can occur between various zones, and contamination cannot enter from the surface then the most simplistic method of well abandonment is to cut the blank casing at the surface and fill the screened interval with cement-bentonite grout. Verifying the integrity of the annular seal is difficult. In most situations it is desirable to remove any sediment from the casing and fill the entire well from bottom to top with grout to minimize borehole collapse.

4.3.3.2 Pulling the Casing and Grouting the Borehole

If a well has metal casing or was not grouted originally, the casing may be pulled with hydraulic casing jacks or with a rig. Removal of the casing allows the borehole to be sealed completely, thus lessening the concern about the integrity of the annular seal. Other techniques for pulling casing include the use of a pulling pipe or other tools locked inside the casing. If the borehole becomes unstable when the casing is removed, grout must be simultaneously put in place as the casing is removed. Casing cutters can be used to remove the end cap from the bottom of the casing.

4.3.3.3 Overdrilling to Remove Casing and Annular Seals

Overdrilling can be used to remove both the casing and annular seal from a borehole. Overdrilling can be accomplished with hollow-stem augers and rotary techniques. When overdrilling, it is usually necessary to use some type of guide or pilot bit (stinger bit) that will prevent the drill string from deviating from the original borehole. Deviation from the original borehole is common when overdrilling and must be prevented for proper abandonment of a well or monitoring device. After the casing and annular seal are removed from the borehole, grout can be put in place from the bottom to the surface. This technique may not be practical for abandoning large diameter wells.

4.3.3.4 Perforating Casing and Pressure Grouting

When the casing is in poor condition it can be perforated with casing rippers or a gun- or jet-perforating device. After the casing is perforated it is filled and pressure grouted thus allowing plugging material to come in contact with the annular space and the formation. After pressure grouting, the upper portion of the casing can be pulled and the borehole grouted to provide a watertight plug. If the integrity of the annular seal is good this step may be omitted. This method does not work in small diameter wells because it requires the use of downhole tools.

4.3.4 Well Abandonment Notification and Documentation

4.3.4.1 Well Abandonment Notification

A review of all local, state, and federal regulations governing well decommissioning activities at the site should be conducted and all applicable documentation and forms prepared. All required approvals and access agreements shall be obtained from all parties involved with the site, including, but not limited to local, state, and federal regulatory agencies, responsible parties, land owners, tenants, and the well permit holder.

4.3.4.2 Well Abandonment Documentation

Complete, accurate information shall be recorded in the field notebook. This should include the methods, equipment, and materials used to decommission the well or monitoring device. The depth of the well, borehole, or monitoring device should be measured. The volume of plugging material required should be calculated and compared to that placed in the borehole or well to assure that the minimum amount of material was put into place, and any discrepancy should be explained. Loss of plugging material to the formation, voids, fractures and washout zones will make this comparison only an approximation and additional material may be needed.

Attachment

Table 4.3-1. Well Abandonment Checklist

References

Aller, L, T.W. Bennett, G. Hackett, R.J. Lehr, H. Sedoris, D.M. Nielson, and J.E. Denne. *Handbook of suggested practices for the design and installation of groundwater monitoring well design and installation.* National Well Water Association. Dublin, OH. 398 p.

ASTM. 1992. *Standard guide for decommissioning of groundwater wells, vadose zone monitoring devices, boreholes, and other devices for environmental activities.* Standard D 5299-92. Philadelphia, PA.

Driscoll, F.G. 1986. *Groundwater and wells.* Johnson Division. St. Paul, MM. 1089 p.

Table 4.3-1. Well Abandonment Checklist
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Item	Specific Procedures Equipment
Access________	Written access agreements in place with property owners and owners of any property to be crossed to reach well site
Notification________	Notify client or agency in advance as required. The owner or well permit holder should notify the appropriate state or local agency of abandonment.
Health and safety________	Site specific Health and Safety plan with emergency medical information and daily tailgate forms, health and safety kit (hard hat, steel-toed boots, safety glasses, earplugs, respirator, Tyvek coveralls), latex gloves, first aid kit, eye wash bottle, material safety data sheets
Water________	Is a contaminant free source of water on site or near by. Can drilling subcontractor haul adequate amounts of water
Decontamination equipment________	Decontamination equipment (steam cleaner and etc.) supplied by drilling contractor, containment of decon water provided (decon pad available if required), sample kit for decon water, minimum of three plastic tubs or buckets for decontaminating, plastic bottle brushes, Liquinox, D.I. water (minimum of 10 gallons), paper towels garbage bags, plastic sheeting
Drill cuttings and fluids________	Containment of drill cuttings and fluids provided, Arrangements for disposal of cuttings and fluids made. Sample kit for cuttings and/or drilling fluids.
Clip board________	Boring log forms and well completion forms
Field book________	Waterproof pens, assortment of waterproof markers
Meters________	Water level meter
Well abandonment equipment________	Drill rig and drill bit capable of drilling out old casing and screen, (stinger bit or drill bit with pilot bit designed to follow casing), grouting material (bentonite and/or cement), tremie pipe, grout pump
Tagline________	Fiberglass with weight taped, steel tape with stainless steel weight (no adhesive tape)

Table 4.3-1. Well Abandonment Checklist
Page 2 of 2

Item	Specific Procedures Equipment
Coolers____________________	One for food only, as needed for samples
Camera and film____________________	

5.1 Preparation for Water Sampling

The following standard operating procedure (SOP) defines activities to be completed prior to each sampling event.

The SOPs and SOGs included in this section are applicable to all DBS&A employees for the conduct of all activities listed in this section. All SOPs and SOGs described in this section are proprietary in nature and shall not be copied or reproduced, or distributed to any person or organization not employed by DBS&A, without the expressed written approval of the President or his/her designee for quality assurance. All or parts of the SOPs and SOGs described in this section may be reproduced and used in DBS&A reports, proposals, and work plans with the verbal consent of the President, his/her quality assurance designee, or a DBS&A Division Director.

These SOPs and SOGs shall be reviewed periodically, and revisions and additions to these SOPs and SOGs shall be made as needed to assure consistency with industry standards and the collection of high quality data in the field. Requests for revisions shall be made in writing to the President or his/her quality assurance designee.

5.1.1 DBS&A Warehouse

Prior to any water sampling event, the water sampler shall requisition all necessary equipment and supplies by completing a DBS&A Field Equipment and Materials Load-Up Sheet (see Section 1.1) and giving it or e-mailing it to the warehouse manager. The load-up sheet should be provided to the warehouse manager as much in advance as is possible, so that equipment and supply requisitions can be made.

All equipment to be used, with the exception of rental equipment, shall be calibrated and tested in the DBS&A warehouse by the warehouse manager prior to being sent to the field per the guidance prescribed in Section 1.1. Meter calibration shall be conducted in accordance with standard manufacturer recommended procedures using clean, fresh reagents. The warehouse manager shall ensure that all equipment is clean and in working order prior to leaving the DBS&A warehouse.

5.1.2 Analytical Laboratory

Prior to a water sampling event, the number and type of samples to be collected (field and quality assurance samples) shall be determined by the Project Manager (PM) or designated project Technical Representative (TR). The PM or project TR shall order appropriate sample containers (Section 1.1) from the analytical laboratory and shall inform the analytical laboratory of the expected arrival date of the samples, the analytes to be determined for each sample, and the required turnaround time. It is the water sampler's (Field Representative; FR) responsibility to confirm that all sample bottles have been received and are loaded for sampling.

5.1.3 Site-Specific Instructions

Prior to each water sampling event, the PM or TR shall compile a list of samples (including quality assurance samples) to be collected. The order in which the samples should be collected shall also be listed. In general, locations with the lowest concentrations of select analytes shall be sampled before wells with higher concentrations, so the potential for cross-contamination can be minimized. The PM or TR will also list any special procedures that are unique to the site or to the sampling event.

Before each sampling round, the PM or TR shall make all access arrangements with the client and/or property owners. The FR(s) will confirm that access arrangements have been made and should determine if additional on-site access procedures are required.

Prior to leaving for the field, FR(s) shall assemble and be familiar with materials that describe the general conditions of the site, the hydrogeology, well completion information, and objectives of the sampling program. The project health and safety plan shall also be consulted before initiation of the field program.

5.2 Decontamination of Field Equipment

The following standard operating procedure (SOP) defines activities required to decontaminate field equipment used in the sampling of soils, sludges, surface water, and groundwater in order to prevent cross-contamination of samples from different sampling locations.

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5.2.1 Procedures

These SOPs and SOGs shall be reviewed periodically, and revisions and additions to these SOPs and SOGs shall be made as needed to assure consistency with industry standards and the collection of high quality data in the field. Requests for revisions shall be made in writing to the President or his/her quality assurance designee.

All non-disposable field equipment that may potentially come in contact with any soil, sludge, or water sample shall be decontaminated in order to minimize the potential for cross-contamination between sampling locations. Thorough decontamination of all sampling equipment shall be conducted in the warehouse before each sampling event. In addition, the field representative shall decontaminate all equipment in the field as required to prevent cross-contamination of samples collected in the field (see Section 1.1). The procedures described in this section are specifically for field decontamination of sampling equipment.

A decontamination station should be established using plastic sheeting to contain splashes. At a minimum, field sampling equipment should be decontaminated following the procedures listed below:

1. Wash the equipment in a solution of non-phosphate detergent (e.g., Liquinox™) and potable or distilled/deionized water. All surfaces that may come in direct contact with the samples shall be washed. Use a clean Nalgene and/or plastic tub to contain the wash solution and a scrub brush to mechanically remove loose particles. Wear clean latex or plastic gloves during all washing and rinsing operations.

2. Rinse twice, once with potable water and a second time with distilled/deionized water. Use clean Nalgene and/or plastic tubs or buckets to contain the rinse solutions.

3. Dry the equipment before use, to the extent practicable, and take measures to keep the equipment clean before use.

For specific projects requiring more rigorous decontamination of field sampling equipment, the following procedures may be used:

1. Wash the equipment in a solution of non-phosphate detergent (e.g., Liquinox™) and potable or distilled/deionized water. All surfaces that may come in direct contact with the samples shall be

washed. Use a clean Nalgene and/or plastic tub to contain the wash solution and a scrub brush to mechanically remove loose particles. Wear clean latex or plastic gloves during all decontamination procedures.

2. For field equipment used in the collection of samples for inorganic analyses, an acid rinse may be employed, using either a 10% reagent-grade nitric or a hydrochloric acid solution in deionized water. A 1% acid solution may be used on low-carbon steel equipment in order to avoid damaging such equipment. The Project Manager will determine if an acid rinse is required for specific equipment and projects.

3. Rinse equipment with potable or distilled/deionized water.

4. If field equipment is to be used in the collection of samples for organic analyses, a solvent rinse may be used. Organic solvents may include reagent grade isopropanol, acetone, or methanol. Project Managers will determine if a solvent rinse is required for specific equipment used on their projects.

5. Rinse equipment with reagent grade organic-free distilled/deionized water.

6. Allow equipment to air dry before use, to the extent practicable.

7. Wrap equipment for transport with inert material (aluminum foil or plastic wrap) to prevent direct contact with potentially contaminated material.

All liquid and solid material generated from the decontamination process should be contained and disposed of in accordance with project-specific disposal guidelines.

5.3 Measurement of Field Parameters

This section outlines standard operating procedures (SOPs) for field measurement of electrical conductivity, temperature, pH, alkalinity, oxidation/reduction potential (Eh), and dissolved oxygen (DO).

The SOPs and SOGs included in this section are applicable to all DBS&A employees for the conduct of all activities listed in this section. All SOPs and SOGs described in this section are proprietary in nature and shall not be copied or reproduced, or distributed to any person or organization not employed by DBS&A, without the expressed written approval of the President or his/her designee for quality assurance. All or parts of the SOPs and SOGs described in this section may be reproduced and used in DBS&A reports, proposals, and work plans with the verbal consent of the President, his/her quality assurance designee, or a DBS&A Division Director.

These SOPs and SOGs shall be reviewed periodically, and revisions and additions to these SOPs and SOGs shall be made as needed to assure consistency with industry standards and the collection of high quality data in the field. Requests for revisions shall be made in writing to the President or his/her quality assurance designee.

These parameters should be measured during monitor well purging prior to sampling. Surface water samples should also be characterized when they are collected.

5.3.1 Electrical Conductivity and Temperature

This SOP describes the procedure for determining the electrical conductivity (EC) and temperature of a water sample. Electrical conductivity is a measure of the ease of flow of electric current, and is the inverse (reciprocal) of resistivity. The term electrical conductivity, sometimes referred to simply as "conductivity," is defined as the electrical conductance that would occur through the water between the faces of a 1-cm cube of the water. EC is usually reported in units of micromhos per centimeter (μmhos/cm), which has recently been renamed microsiemens per centimeter (μS/cm). By measuring the EC of a water sample in the field, one can estimate the total dissolved solids (TDS) concentration of the water using the approximate conversion TDS = 0.6 x EC. Because the EC of a water allows rapid determination of TDS (salinity), EC is probably the single most useful water quality parameter.

The EC of water containing dissolved ions increases with increasing temperature of the water. The temperature dependence varies for different waters and is dependent on the type and concentrations of dissolved ions, but an approximate rule of thumb is that EC increases 2% per °C temperature increase. For quantitative comparison of EC values measured on different water samples at different field temperatures, it is necessary to correct all values to the EC at 25°C. For most qualitative work, however, this is unnecessary. Whether or not temperature corrections are to be applied, the EC value as measured at field temperature should always be recorded in the field logbook, along with the temperature of the water sample at the time the measurement was made.

EC can be measured either at the wellhead using the Hydrolab or other EC meter, or by downhole profiling using the Hydrolab. General procedures for these two methods are provided in Sections 5.3.1.1 and 5.3.1.2. Specific procedures for measuring EC using the YSI Model 33 EC meter and probe and the Hydrolab Minisonde are provided in Sections 5.3.1.3 and 5.3.1.4, respectively.

Most pH and EC meters also include a water temperature sensor with a precision of ±0.1°C. Groundwater temperature may be determined either using a downhole probe (Section 5.3.1.1), or above ground at the wellhead during purging (Sections 5.3.1.2 and 5.3.1.3) using a standard pH or EC meter equipped with a temperature sensor. Determine and record the groundwater temperature at the same time and using the same technique as for determining groundwater pH and EC, as described below.

Temperature sensors generally do not require calibration. However, to ensure that the temperature sensor is functioning properly, check it against a high-quality mercury thermometer at least once a year. If not in agreement within ±0.2°C, have the temperature probe serviced by the manufacturer.

5.3.1.1 Determination of Groundwater EC During Well Purging

If downhole profiling is not required, use the Hydrolab or a standard EC meter to measure the EC of the groundwater at the wellhead periodically during well purging (see Section 5.3.1.4 for Hydrolab setup and calibration procedures). Check that the EC meter is functioning properly at the start of each day using a standard potassium chloride (KCl) solution (e.g., 1000 μS/cm KCl solution). Record the EC value and temperature of the standard solution in the field logbook, and note whether or not the EC values are temperature compensated to 25°C. Ensure that the observed value is within ±2 percent of the nominal value for the standard solution at that temperature. If not, follow the manufacturer's instructions for cleaning the electrodes.

Place the EC probe in a bucket or other suitable container into which the groundwater can be directed during purging. Measure and record the groundwater EC at the start of purging, then several more times during purging until the EC and other field parameters have stabilized. Record the final EC value in the field logbook. The Hydrolab is equipped with a flow-through cell which should be used whenever possible. The flow-though cell allows collection of continuous data and protects the fragile probes.

5.3.1.2 Downhole EC Profiling

Downhole profiling is most important at sites with potential groundwater contaminants that can cause water to become chemically stratified, such as where floating or sinking nonaqueous-phase liquids (NAPLs) are present.

Downhole EC profiling may be performed using the Hydrolab Minisonde (Section 5.3.1.4). Check that the Hydrolab is functioning properly at the beginning of each day by immersing the probe in an appropriate standard KCl solution (e.g., 1000 μS/cm KCl solution). Record the EC value and temperature of the standard solution in the field logbook, and note whether or not the EC values are temperature compensated to 25°C. Ensure that the observed value is within ±2 percent of the nominal value for the standard solution at that temperature. If not, follow the manufacturer's instructions for cleaning the electrodes.

Perform downhole EC profiling concurrently with pH profiling (Section 5.3.2.1). First determine the depth to water (Section 6.1), then begin lowering the EC probe just below the water surface. Record the EC value just beneath the surface, then slowly lower the EC probe down the well, being cautious to minimize agitation of the water column. Watch the EC meter for any change when lowering the probe. If the EC value changes more than 10 μS/cm, note the EC value and depth at several levels spanning the interval of changing EC. Continue to the bottom of the well, paying particular attention to the EC values near the bottom. Record all values in the field logbook. (See Section 5.3.1.4.9 for additional information on downhole profiling using the Hydrolab Minisonde.)

5.3.1.3 Use of YSI Model 33 EC Meter and Probe

The following equipment is needed to measure EC in the field:

- YSI Model 33 EC meter and probe
- Spare D-cell batteries
- Beaker for water sample
- Deionized water in squirt bottle
- KCl conductivity standard solution.

The following procedure shall be used to measure EC in the field:

1. Verify that the meter needle rests on zero prior to turning on the meter. If not, adjust it to zero using the set screw on the face of the meter movement.
2. Calibrate the meter by turning the MODE switch to REDLINE and adjusting the REDLINE control knob until the needle lines up with the small red line on the meter scale. (If unable to calibrate meter, replace the batteries.)
3. Plug in probe cable, and insert gray plastic probe into water sample. Allow at least one minute for temperature equilibration of probe.
4. Set MODE control to TEMPERATURE and record the temperature of the water sample in the field logbook. (Note that the temperature scale is at the bottom of the meter face and that the values decrease to the right.)
5. Switch the MODE control to the conductivity setting that gives the maximum needle deflection without going off-scale (X100, X10, or X1). Do not allow the probe to touch the sides or bottom of the beaker when making a measurement because this can result in a low reading.
6. Record the EC value, remembering to multiply the meter reading by the appropriate factor if using the X10 or X100 settings.
7. Rinse the probe with deionized water prior to making another measurement or putting the instrument away.

Other information about the YSI Model 33 SCT Meter may be needed occasionally:

- The probe preferably should be stored in deionized water between uses during each day of field work. If the probe has been stored dry, it is recommended that it be soaked in deionized water at the start of the day prior to making any measurements. This is not absolutely essential, however.
- The SALINITY mode will not ordinarily be used unless dealing with brines or other samples with salinity of seawater or above. The TEMPERATURE potentiometer only functions in SALINITY mode; it does nothing when operating in EC mode and cannot be used to correct EC values to 25°C.

- To test probe operation, press the CELL TEST button while measuring the EC of a water sample on the X10 or X100 scales. If the probe is functioning properly, the meter reading should not fall more than 2% when depressed. If the meter reading falls more than 2%, notify the equipment technician that the probe needs attention.

- The meter and probe should be periodically checked against a standard KCl solution to verify proper internal calibration. To do so, immerse the (clean) probe in the KCl standard, and record the temperature and EC values as described above. Check that the EC value is within ±5% of the nominal EC value for that particular KCl solution at that temperature. Record the observed value and the nominal value (from label on bottle) in the field logbook.

5.3.1.4 Use of the Hydrolab Minisonde
The Hydrolab Surveyor unit is configured to display the following field parameters:

- Electrical conductance (EC)
- pH
- Dissolved oxygen (DO)
- Oxidation-reduction potential (ORP)
- Water depth (Dep; ft of water above probe)
- Water temperature (Tem)
- Barometric pressure (BP)

5.3.1.4.1 Hydrolab Setup. Connect the Minisonde probe to the Surveyor display using the 100-ft long black cable. Where the cable connects to the downhole probe, line up the raised dot on the rubber connector with the large brass pin on the probe bulkhead fitting. Next screw the black cablehead fitting securely onto the stainless steel bulkhead fitting on the top of the Minisonde to ensure that the probe does not become disconnected downhole (very bad).

Next turn on the Surveyor display by pressing the O/I key at the lower right of the display. After a few seconds, the screen should begin to display values for the seven water quality parameters listed above. Note that the instrument updates the display every second, so you may notice the values changing slowly as the sensors reach equilibrium.

The next step is to calibrate the Minisonde probe. Each individual sensor is calibrated separately, except for temperature and barometric pressure, which do not require calibration. For best results, it is recommended that you sequentially calibrate the sensors in the order listed below. You will need the following items to perform all calibrations:

- Deionized water
- Kimwipes
- pH buffer solutions (4, 7, 10)

- EC calibration solution (e.g., YSI 3167: 1000 µS @ 25°C)
- ORP calibration solution (e.g., YSI 3682 Zobell solution)

5.3.1.4.2 EC Sensor Calibration. Note that all field EC values are to be recorded at field water temperature (not temperature compensated). You should see a small letter "N" just to the right of the EC value shown on the Surveyor display, indicating that no temperature compensation.

Hold the Minisonde with sensors up, and remove the white plastic cap from the top of the clear storage cup. Rinse the sensors with several small volumes of the EC calibration solution. With the Minisonde mounted with sensors up, fill the clear cup to the top of the sensors with the EC calibration solution.

Record the probe temperature shown on the Surveyor display. Using Table 5.3-1 below, determine the EC value for the EC calibration solution at the probe temperature recorded previously. Interpolate to the nearest 0.1°C if necessary.

Table 5.3-1. EC Values of YSI 3167 Conductivity Calibration Solution (1000 µS/cm @ 25°C)

Temp (°C)	EC (µS/cm @ 25°C)	Temp (°C)	EC (µS/cm @ 25°C)	Temp (°C)	EC (µS/cm @ 25°C)	Temp (°C)	EC (µS/cm @ 25°C)
1	539	11	731	21	923	31	1115
2	558	12	750	22	942	32	1134
3	578	13	770	23	962	33	1154
4	597	14	789	24	981	34	1173
5	616	15	808	25	1000	35	1192
6	635	16	827	26	1019	36	1211
7	654	17	846	27	1038	37	1230
8	674	18	866	28	1058	38	1249
9	693	19	885	29	1077	39	1268
10	712	20	904	30	1096	40	1287

Press the Setup/Cal key, then the Calibrate key, then press Sonde and wait a few seconds. Using the arrow keys, scroll down and select ECond:µS/cm. Enter the new EC calibration standard value from Table 5.3-1, then press Done. Press Go Back until you see the real-time parameters displayed. The EC value for the EC calibration solution should now be the same as the value you entered, and calibration of the EC sensor is complete.

5.3.1.4.3 pH Sensor Calibration. Choose the two pH buffer solutions that you expect will straddle the pH values you plan to measure, either pH4 and pH7 or pH7 and pH10.

Hold the Minisonde with sensors up, and remove the white plastic cap from the top of the clear storage cup. Rinse the sensors with several small volumes of the first pH buffer solution (e.g., pH7). With the Minisonde mounted with sensors up, fill the clear cup to the top of the sensors with the pH buffer solution.

Press the Setup/Cal key, then the Calibrate key, then press Sonde and wait a few seconds. Using the arrow keys, scroll down and select pH:Units. Enter the new pH value (e.g., 7.0), then press Done. Press

Go Back until you see the real-time parameters displayed. The pH value for the pH buffer solution should now be the same as the value you entered (e.g., 7.00).

Repeat the above procedure for the other pH buffer solution (e.g., pH 4.0). Calibration of the pH sensor is complete.

5.3.1.4.4 DO Sensor Calibration (Water-Saturated Air). Remove the white plastic cap from the probe, and rinse the sensors with DI water. Secure the probe with sensors facing up, and fill the clear cup with DI water to the level of the black O-ring on the DO membrane, making sure not to cover the DO sensor membrane. Remove any water droplets from the membrane by blotting with a Kimwipe. Place the white plastic cap loosely on top of the clear plastic cup to create a 100% humidity atmosphere inside the cup. Do not screw on the white cap. Allow about a minute for equilibration.

While you are waiting, record the barometric pressure (BP) in millimeters of mercury (mm Hg) shown on the Surveyor display. Press the Setup/Cal key, then the Calibrate key, then press Sonde and wait a few seconds. Using the arrow keys, scroll down and select DO%:Sat. Press Select, then enter the new barometric pressure recorded previously. Press Done, the Go Back until you see the real-time parameters displayed. The DO% value should now read 100%, and calibration of the DO sensor is complete.

5.3.1.4.5 ORP Sensor Calibration. Hold the Minisonde with sensors up, and remove the white plastic cap from the top of the clear storage cup. Rinse the sensors with several small volumes of the YSI 3682 Zobell solution. Note the preparation date on the Zobell solution to ensure that it is no more than 6 months old.

With the Minisonde mounted with sensors up, fill the clear cup to the top of the DO sensor with the YSI Zobell solution. Record the solution temperature shown on the display.

Allow at least one minute for the ORP sensor to equilibrate. Determine correct Eh value for temperature recorded above from Table 5.3-2. Press the Setup/Cal key, then the Calibrate key, then press Sonde and wait a few seconds. Using the arrow keys, scroll down and select ORP:mV. Press Select, enter the new Eh value from Table 5.3-2, then press Done.

Table 5.3-2. Eh Values of YSI 3682 Zobell Solution (using Ag/AgCl Reference Electrode)

Temp (°C)	Eh (mV)	Temp (°C)	Eh (mV)	Temp (°C)	Eh (mV)	Temp (°C)	Eh (mV)
1	262.2	11	249.2	21	236.2	31	223.2
2	260.9	12	247.9	22	234.9	32	221.9
3	259.6	13	246.6	23	233.6	33	220.6
4	258.3	14	245.3	24	232.3	34	219.3
5	257	15	244	25	231	35	218
6	255.7	16	242.7	26	229.7	36	216.7
7	254.4	17	241.4	27	228.4	37	215.4
8	253.1	18	240.1	28	227.1	38	214.1
9	251.8	19	238.8	29	225.8	39	212.8
10	250.5	20	237.5	30	224.5	40	211.5

Press Go Back until you see the real-time parameters displayed. The ORP value for the Zobell solution should now be the same as the value you entered, and calibration of the ORP sensor is complete.

5.3.1.4.6 Water Depth Sensor Calibration. Note: This sensor measures feet of water above the probe, not depth to water in a well.

If the Minisonde is to be put down a well, the Depth sensor must be zeroed immediately prior to insertion in the well. First empty any solution out of the clear plastic cup.

Press the Setup/Cal key, then the Calibrate key, then press Sonde and wait a few seconds. Using the arrow keys, scroll down and select Dep25:feet and press Select. With the new value set to 0.00, press Done to zero the sensor. Calibration of the Minisonde is now complete. Press Go Back to return to real-time parameter monitoring

5.3.1.4.7 Measurement of Field Parameters at Wellhead Using the Hydrolab. Set up the Hydrolab as described in Section 5.3.1.4.1, and calibrate the appropriate Hydrolab sensors as described in Sections 5.3.1.4.2 through 5.3.1.4.5, depending on what field parameters are to be measured for the specific project. Screw the probe guard onto the Minisonde probe to protect the sensors. Place the probe in a large bucket or barrel, and secure it in such a manner that it cannot fall. Begin purging the well into the bucket or barrel, and record field parameters periodically during well purging. After all field parameters have stabilized, record the final values in the field logbook.

5.3.1.4.8 Use of Hydrolab Flow-Through Cell. Use of the flow-through cell is desirable to minimize contact with air. This is especially important when measuring DO and ORP. Set up the Hydrolab as described in Section 5.3.1.4.1, and calibrate the appropriate Hydrolab sensors as described in Sections 5.3.1.4.2 through 5.3.1.4.5, depending on what field parameters are to be measured for the specific project.

Screw the flow-through cell onto the Minisonde probe, being careful not to damage the sensors. Secure the probe so that it cannot fall; a C-clamp is provided in the Hydrolab case for this purpose. Attach the discharge hose from the sampling pump (e.g., QED pump) to the inlet on the flow-through cell. Attach a section of plastic tubing to the outlet, and direct the tube into a waste container.

Turn on the sampling pump, causing water to pass through the flow-through cell. It is not necessary to turn on the Hydrolab Circulator when using the flow-through cell. Record field parameters periodically during well purging. After all field parameters have stabilized, record the final values in the field logbook.

5.3.1.4.9 Use of the Hydrolab Minisonde for Downhole Profiling. Set up the Hydrolab as described in Section 5.3.1.4.1, and calibrate the appropriate Hydrolab sensors as described in Sections 5.3.1.4.2 through 5.3.1.4.5, depending on what field parameters are to be measured for the specific project. Screw the probe guard onto the Minisonde probe to protect the sensors.

Zero the water-depth sensor prior to insertion into the well, as described in Section 5.3.1.4.6. Begin slowly lowering the Minisonde hand over hand into the well using the cable. Watch the water depth reading on the Surveyor display unit to determine when the Minisonde has reached the surface of the water in the well.

Turn on the Circulator (stirrer) by pressing the Setup/Cal key, then the Setup key, then press Sonde and wait a few seconds. Use the arrow keys to scroll down to Circltr:Off/On. Press Select, then set the new value to either 0 (off) or 1 (on), and press Done. The Circulator should be turned on when making downhole measurements of field parameters.

Lower the Minisonde slowly through the water column in the well, stopping at appropriate depth intervals to record water quality parameters in the field logbook. Note any abrupt changes in water quality parameters. Turn off the Minisonde circulator following the same procedure as described above.

5.3.2 pH

As with EC, pH can be measured either at the wellhead using a standard pH meter or by downhole profiling. General procedures for these two methods are provided in Sections 5.3.2.1 and 5.3.2.2. Specific procedures for measuring pH using an Orion Model 250A or 290A pH/mV meter are provided in Section 5.3.2.3. Use of the Hydrolab Minisonde is described in Section 5.3.1.4.

5.3.2.1 Determination of Groundwater pH During Well Purging
A standard pH meter can be used to measure the pH of the groundwater at the wellhead periodically during well purging. Calibrate the pH meter at the start of each day following the manufacturer's instructions and using two standard pH buffers that straddle the expected groundwater pH. Check that the meter remains in calibration several times during the day by immersing the probe in the buffer solutions. Recalibrate as necessary.

Groundwater pH should be measured immediately upon withdrawal from the well, as pH can change as a result of temperature change and exposure to air. Place the pH probe in a bucket or other suitable container into which the groundwater can be directed during purging. Measure and record the groundwater pH at the start of purging, then several more times during purging until the pH and other field parameters have stabilized to ±0.1 pH units over one casing volume. Record the final pH in the field logbook.

5.3.2.2 Determination of Groundwater pH Using an Orion Model 250A or 290A pH/mV Meter
This section describes the procedure for determining the pH of a water sample using the Orion Model 250A or 290A pH/mV meter with automatic temperature compensation (ATC). Calibration of the meter is performed at least daily using two buffer solutions that bracket the sample pH. A temperature sensor is included on the pH probe to make the minor correction from the sample temperature to 25°C. For information on manual temperature correction, refer to the meter instruction manual. The Orion 250A and 290A can also be used in millivolt mode with a variety of ion selective electrodes (refer to ISE SOPs).

The following equipment is needed to measure pH in the field:

- Orion Model 250A or 290A pH meter
- Buffer solutions (pH 4.01, 7.00, 10.00)
- Spare 9-volt battery
- Beaker for water sample
- Deionized water in squirt bottle

The following procedure shall be used to measure pH in the field:

1. Plug the pH probe and thermistor (ATC) into the appropriate jacks of the meter.

2. Insert battery (if necessary), and press the power button to turn on the meter.

3. If the meter is not already in pH mode as indicated by the caret at the bottom of the display, press the Mode button to select pH mode.

4. Remove the plastic end cap on the probe, rinse the tip of the probe in deionized water to remove any dried KCl salts, and insert the probe in the pH 7.0 buffer.

5. Press 2nd, then Cal to put the meter in calibration mode. The word "calibrate" should appear on the display, and the designation "P1" indicates that the meter is ready for the first buffer calibration.

6. Stir the probe gently in the pH 7.0 buffer solution. When the reading has stabilized, the meter will beep and the word "ready" will appear. Press Yes to accept the reading and set the pH 7.0 calibration. "P2" will be displayed, indicating that the meter is ready for the second buffer solution.

7. Rinse the probe with deionized water, and insert it in the pH 4.0 buffer. (If the pH of the water sample is anticipated to be greater than 7, then substitute the pH 10.0 buffer.)

8. When the meter indicates "ready," press Measure to accept the pH 4.0 calibration. The Model 290A meter will prompt for a third buffer solution (P3), at which point press Measure once more. The slope of the calibration curve will be displayed briefly. Record the slope in the field logbook. The slope value should be within the range of 90 to 110. If not, repeat the calibration procedure. The meter will automatically exit the calibration mode, and the word "measure" will be displayed.

9. Rinse the probe and insert it into the water sample to be measured. Stir gently while waiting for the word "ready" to appear. Record the pH value in the field logbook.

10. If more measurements are to be made, rinse the probe and store temporarily in a beaker of deionized water. If finished for the day, turn the meter off, rinse the probe, disconnect the plugs, and store the probe with a few milliliters of the KCl electrode storage solution inside the black plastic end cap.

5.3.2.3 Downhole pH Profiling

If a downhole pH probe is available, calibrate the probe and perform pH profiling of each well as follows. At the beginning of each day, calibrate the pH meter following the manufacturer's instructions using two standard pH buffer solutions that straddle the expected groundwater pH. For example, if the groundwater pH is expected to be slightly below neutral, use pH 7.0 and 4.0 buffer solutions for calibration of the pH probe. Ensure that the buffer solutions are obtained from a reputable manufacturer and that the expiration date has not been exceeded. The pH probe should respond rapidly when alternately immersed in the two calibration buffer solutions. If the sensor displays a sluggish or drifting response, the pH reference junction may be clogged. If so, consult the manufacturer's instructions for cleaning of the reference junction. If the pH probe is to be used for more than a few hours, it is good practice to periodically check that the pH probe remains in calibration during the course of the day by immersing the probe in the calibration buffer solutions. This can be done after moving from one well to the next, and prior to profiling the next well. Recalibrate if necessary.

To perform pH profiling, first determine the depth to water (Section 6.1). Begin by lowering the calibrated pH probe just below the water surface. Record the pH at the surface, then slowly lower the pH probe down the well with minimum agitation while watching the pH meter for any change. If the pH value changes more than 0.1 pH unit, note the pH value and depth at several levels spanning the interval of changing pH. Continue to the bottom of the well, paying particular attention to the pH values near the bottom. Record all values in the field logbook. Compare the pH profile with that obtained during the previous monitoring event. If significant changes are apparent, bring this to the attention of the project manager.

5.3.3 Alkalinity

This section describes the procedures for determining the total alkalinity in near-neutral pH, high-alkalinity water samples (most groundwaters) using the Hach Alkalinity Test Kit (i.e., Hach model 24443). For information on the procedure for low-alkalinity samples or high pH samples (pH>8), refer to the Hach instruction sheet.

The following equipment is needed to determine total alkalinity in the field:

- Hach Alkalinity Test Kit

The following procedure shall be used to determine total alkalinity in the field:

1. Fill the small plastic test tube with the water to be tested.

2. Pour the contents of the test tube into the square glass bottle.

3. Add the contents of one foil packet containing the Bromcresol Green/Methyl Red color indicator. The water will turn a dark green.

4. Carefully begin adding the standard sulfuric acid titrant dropwise using the eye dropper, counting the number of drops added and swirling to mix the solution. Keep the eye dropper nearly vertical to maintain a constant drop volume.

5. When the solution begins to change from green to red, slow down. The titration is complete when the solution is a bright pink color.

6. Record the total number of drops added. Multiply the number of drops by 20 to obtain the total alkalinity, reported as mg/L of $CaCO_3$.

5.3.4 Oxidation-Reduction Potential

Oxidation-reduction potential (ORP), also known as redox potential (Eh), is an indicator of the oxidizing or reducing potential of the water. It is generally reported as the voltage difference in millivolts between a platinum electrode immersed in the water sample and the standard hydrogen electrode (SHE). As with EC and pH, Eh can be measured either through downhole profiling or at the wellhead using a standard Eh meter. General procedures for these two methods are provided in Sections 5.3.4.1 and 5.3.4.2. Specific procedures for measuring Eh using an Orion Model 250A or 290A pH/mV meter are provided in Section 5.3.4.3. Use of the Hydrolab Minisonde is described in Section 5.3.1.4.

5.3.4.1 Determination of Groundwater Eh During Well Purging
Eh can also be measured at the wellhead periodically during well purging using a standard Eh meter. Eh should be measured immediately upon withdrawal of groundwater from the well, as it can change as a result of temperature change and exposure to air. Check that the Eh meter is functioning properly at the start of each day using a standard redox solution (e.g., Zobell's solution or Quinhydrone solution). Record the Eh value and temperature of the standard solution in the field logbook. Ensure that the observed value is within ±2 percent of the nominal value for the standard solution at that temperature. If not, follow the manufacturer's instructions for cleaning the platinum electrode.

Place the Eh probe in a bucket or other suitable container into which the groundwater can be directed during purging. Measure and record the groundwater Eh at the start of purging, then several more times during purging until the Eh and other field parameters have stabilized. Record the final Eh in the field logbook.

5.3.4.2 Downhole ORP Profiling
Downhole ORP profiling may be performed using the Hydrolab Minisonde 4a Multiprobe. Check that the platinum electrode is bright and clean. Ensure that it is functioning properly at the beginning of each day by immersing the electrode in an appropriate and freshly prepared standard redox solution (e.g., Zobell's solution or Quinhydrone solution). Record the ORP value and temperature of the standard solution in the field logbook. Ensure that the observed value is within ±2 percent of the nominal value for the standard redox solution at that temperature. If not, follow the manufacturer's instructions for cleaning the electrode.

Perform downhole ORP profiling concurrently with pH and/or EC profiling. First determine the depth to water (Section 6.1), then begin lowering the ORP probe just below the water surface. Record the ORP value just beneath the surface, then slowly lower the ORP probe down the well, being cautious to minimize agitation of the water column. Note any significant changes in ORP when lowering the probe, and record the ORP value at the same depths as for pH and EC. Continue to the bottom of the well, paying particular attention to the values observed near the bottom. Record all values in the field logbook.

5.3.4.3 Determination of Groundwater ORP Using an Orion Model 250A or 290A pH/mV Meter
The following equipment is needed to measure Eh in the field:

- Yellow oxidation-reduction potential (ORP) electrode
- Orion Model 250A pH/mV meter
- Standard Zobell solution.

The following procedure should be used to measure Eh in the field:

1. Plug the BNC connector into an Orion 250A pH/mV meter.
2. Turn on the meter. If using the Orion 250A, use MODE key to set meter to "mV" mode (not rel mV).
3. Check probe operation by immersing it in a disposable beaker with Zobell Solution. The reading should be ± 10 mV of that listed on the table with the Zobell Solution at the temperature of the solution (e.g., 231 mV at 25°C).

4. Rinse the probe and immerse it in the groundwater sample. Following stabilization, record the mV value, along with a ± estimate to indicate the stability of the meter. Also record the sample temperature.

5.3.5 Dissolved Oxygen (DO)

Dissolved oxygen (DO) provides a measure of the concentration of oxygen (O2) dissolved in the water. As with EC, pH, and Eh, DO can be measured either through downhole profiling or at the wellhead using a standard DO meter. General procedures for these two methods are provided in Sections 5.3.5.1 and 5.3.5.2.

5.3.5.1 Determination of DO in Groundwater During Well Purging

The Hydrolab Minisonde can be used to measure the DO concentration periodically at the wellhead during well purging using the flow-through cell. Calibrate the DO meter at the start of each day following the procedures in Section 5.3.1.4.4.

Groundwater DO concentrations should be measured immediately in the field, since subsequent DO changes can occur as a result of exposure to air. Place the DO probe in a bucket or other suitable container into which the groundwater can be directed during purging. Try to minimize aeration of the water due to splashing. Measure and record the groundwater DO concentration at the start of purging, then several more times during purging until the DO and other field parameters have stabilized. Record the final DO value in the field logbook.

5.3.5.2 Downhole DO Profiling

Downhole DO profiling may be performed using the Hydrolab Minisonde instrument. Check that the plastic membrane is clean and tight across the gold internal electrode, and that no bubbles are trapped beneath the membrane. If bubbles are present, replace the membrane following the manufacturer's instructions. Calibrate the DO meter following the procedures in Section 5.3.1.4.4, being certain to account for the site-specific barometric pressure and temperature.

Perform downhole DO profiling concurrently with pH and/or EC profiling. First determine the depth to water (Section 6.1), then begin lowering the DO probe just below the water surface. Record the DO value just beneath the surface, then slowly lower the probe down the well, being cautious to minimize agitation of the water column. Note any significant changes in DO when lowering the probe, and record the DO value at the same depths as for pH and EC. Continue to the bottom of the well, paying particular attention to the values observed near the bottom. Record all values in the field logbook.

5.4 Collection of Groundwater Samples

The following standard operating procedure (SOP) defines activities to be completed for the collection of groundwater samples.

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These SOPs and SOGs shall be reviewed periodically, and revisions and additions to these SOPs and SOGs shall be made as needed to assure consistency with industry standards and the collection of high quality data in the field. Requests for revisions shall be made in writing to the President or his/her quality assurance designee.

5.4.1 Wellhead Preparation

Prior to groundwater sample collection, the following wellhead protection activities shall be conducted:

1. Inspect the area around the well for wellhead integrity, cleanliness, and signs of possible tampering or contamination.

2. Spread a clean plastic sheet over the ground around the wellhead, where required.

3. Remove the cap on the wellhead. Note any obvious odors within the wellbore in the field logbook.

4. If possible, measure the static water level (see Section 6.1) prior to initiation of water sampling. Clean the electrical sounder or steel tape used for water level measurement after each use, as described in Section 5.2, to avoid cross contamination.

5. If floating product (e.g., gasoline) is suspected at the site, conduct the following procedures:

    - Use a bailer to extract a sample from the surface of the water within the well, if possible.

    - After an initial visual inspection, slowly pour the fluid from the bailer into a small tub or container in order to check for a sheen or any other sign of free product. Note any obvious odors in the field logbook.

    - If free product is detected, use the bailer to remove as much free product as is possible from the wellbore. Lower the bailer into the water slowly in order to prevent mixing and volatilization. Contain all recovered product for proper disposal and note the quantity of product removed in the field logbook.

    - If the site has not been previously sampled, a sample of the free product may be desired. Consequently, place some of the product in an unpreserved 40-mL glass VOA vial, and store it away from the other samples. Confirm sample analysis with the project manager.

- After any free product has been removed from the wellbore, spread a fresh plastic sheet around the wellhead, and clean all contaminated equipment, or segregate it from the other equipment.

5.4.2 Well Purging

The purpose of purging the well prior to sampling is to remove stagnant water from the well bore so that a representative groundwater sample can be collected. The method of purging can have a pronounced effect on the quality of the groundwater sample. For example, rapid purging may increase sample turbidity and is, therefore, not recommended.

In general, positive displacement (bladder) pumps are preferred for most sampling situations. However, depending on the hydraulic conductivity of the aquifer to be sampled and the project objectives, wells may either be equipped with dedicated pumps or may need to be purged with bailers. Consequently, purging techniques may vary depending on the aquifer conditions, the presence or absence of a dedicated pump, and the proposed sample analytes.

The optimum amount of water to be purged from each well also varies between sites. According to Barcelona et al., 1985, pg. 47, "The number of well volumes to be pumped from a monitoring well prior to the collection of a water sample must be tailored to the hydraulic properties of the geologic materials being monitored, the well construction parameters, the desired pumping rate, and the sampling methodology to be employed."

Site-specific purging procedures shall be prepared for each site. The following purging procedure can be used as a general guideline:

1. Calculate the volume of water standing in the casing (cubic feet) by using the formula:

   $V = \pi r^2 L$

   where:

   r = the radius of the casing (remember to convert inches to feet)

   L = the length of the water column (total depth of well minus the static water level) (feet)

   Note: 1 cubic foot holds 7.48 gallons of water

2. Purge the well at a rate equal to or greater than the sampling rate.

3. Measure applicable field parameters (see Section 5.3) at the pump outlet at a minimum after each 0.5 casing volume is pumped. Purging is generally considered complete when the above parameters are approximately stable over at least one casing volume. Wherever possible, purge a minimum of three (3) casing volumes from each well.

4. In low permeability formations, it may not be possible to purge three casing volumes before the well goes dry. When the formation permeability is too low to allow for continuous purging, remove all of the standing water in the well by pumping or bailing. As soon as the well has recharged sufficiently, collect a sample so as to minimize volatilization in the wellbore.

5. Contain all fluid from obviously contaminated or potentially contaminated wells for later disposal. Anomalous values for the above field parameters, odor, visible sheen, or the presence of free

product may be taken as signs of contamination. Results of previous water sampling events will be consulted when available.

6. Take careful notes in order to document all purging procedures. The notes shall include: date, time, name(s) of sampler(s), weather, purge rate, purge method, field parameters (at each time measured, with corresponding purge volume), visual observations, odor, and any other relevant information.

The following guidelines as outlined in pertinent references on water sampling can be used when developing site-specific purging procedures:

- The EPA RCRA Technical Enforcement Guidance Document (TEGD) states, "in low yield formations, water should be purged so that it is removed from the bottom of the well." (EPA, 1992).

- The TEGD also states "Whenever a well is purged to dryness, a sample for field parameters should be collected as soon as the well has recovered sufficiently. A second measurement of field parameters should be made immediately after sampling. Do not pump a well to dryness if it causes formation water to cascade down the well." (Ibid).

- The inlet line of the sampling pump or the submersible pump should be placed near the bottom of the screen section, and pump approximately one well volume of water at the well's recovery rate, and then collect the sample from the discharge line (EPA 1977, pg. 211).

- According to Wehrmann (1984), "For high yielding monitoring wells which cannot be pumped to dryness, bailing without pre-pumping the well is not recommended; there is no absolute safeguard against contaminating the sample with stagnant water." The following procedures should be used:

Place the inlet line of the sampling pump just below the surface of the well water, and pump three to five volumes of water at a rate equal to the well's recovery rate. This provides reasonable assurance that all stagnant water has been evacuated and that the sample will be representative of the groundwater body at that time.

- Wehrmann (1984) further states, "The rate at which wells are purged should be kept to a minimum. Purging rates should be lower than development rates so that well damage does not occur. Pumping at very low rates in effect, isolates the column of stagnant water in the well bore and negates the need for its removal, if the pump intake is placed at the top of, or in, the well screen. This approach can be very useful when disposal of purge water is a problem."

- If a well completed in a highly permeable formation is being purged, it may be useful to periodically move the intake of the purge pump during purging so that stagnant water does not remain in the well bore while fresh water comes in at only one level (Scalf et al., 1981, pg. 44).

5.4.3 Groundwater Sample Collection

The following procedure shall be used to collect groundwater samples:

1. If the well is not equipped with a sampling pump, use only Teflon, stainless steel, or disposable polyethylene bailers for sampling.

2. Whenever possible, collect groundwater samples first from wells that have the lowest potential concentrations of analytes of interest, and last from the wells with the highest suspected concentrations (i.e., clean → dirty). The specific sampling order should be detailed in the site-specific sampling plan.

3. Pumps equipped with Teflon tubing or disposable Teflon or polyethylene bailers are generally recommended for collection of samples to be analyzed for volatile organics.

4. Select the appropriate sample container and preservative as described in Section 5.6.

5. After the well has been purged, collect water samples as soon as possible in order to reduce the possibility of volatilization within the wellbore. If a pump has been used for purging, lower the pump rate so that the sampling rate is lower than the purge rate. If volatile organic samples are to be collected, set the pump at the lowest possible setting. If possible, the sampling rate should be less than 100 ml per minute, or the minimum setting on the pump.

6. Collect samples in decreasing order of volatility, i.e., collect samples to be analyzed for volatile organic compounds (VOCs) first, followed by semi-volatile organic compounds, PCBs and pesticides, and inorganics. The preferred order of sampling according to the TEGD is VOCs, SVOCs, total organic carbon (TOC), extractable organics, total metals, dissolved metals, phenols, cyanide, sulfate and chloride, turbidity, nitrate and ammonia, and radionucleides.

7. Do not allow the outlet of the sampling pump discharge tubing to come into direct contact with the sample vial or the water within the vial.

8. Make sure that no air is entrapped in the sample vials to be analyzed for volatile organics. Take the sample by holding the vial at an angle so that aeration is minimized. Avoid touching the lip of the vial or the Teflon liner. If the sample cannot be transferred directly to the vial, (i.e. high production well) use a clean stainless steel cup to pour the water into the vial. Direct the water stream against the inside surface of the vial. Allow a convex meniscus to form across the mouth of the filled vial. Carefully cap the vial, then invert and tap the vial to insure that no entrapped air is present. If entrapped air is present, recollect the sample.

9. If filtering of any samples is required by the site specific sampling plan, use the filtering procedure described in Section 5.7.

10. Preserve the sample as indicated in Section 5.6. Whenever possible, use pre-preserved containers supplied by the analytical laboratory rather than adding preservatives in the field.

11. Measure field parameters as described in Section 5.3. Temperature, electrical conductivity, and pH generally will be measured at all locations. Alkalinity, dissolved oxygen, and ORP will be measured only as required by the site specific sampling plan.

12. If the sample is to be collected from a domestic well or location other than a monitoring well, it may be necessary to clean the sampling port prior to sample collection (e.g., an outside hose bib or an inside water faucet). Flush the faucet/line by allowing it to run for a minimum of five minutes.

13. Collect samples from domestic wells downstream of water softeners or chlorinators or in-home filters that modify water quality. However, if the objective of the domestic sampling is to evaluate the groundwater prior to treatment, the samples may be taken upstream of such devices.

14. Record all pertinent information in the field notebook. Data to be recorded include the date and time of sample collection, climatic conditions at the time of sampling, well sampling sequence, types of sample containers used, sample identification numbers, field parameter data, name(s) of collector(s), deviations from established sampling protocol (e.g., equipment malfunctions), purpose of sampling (e.g., surveillance, compliance), and collection of quality control samples.

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5.7 Sample Filtration

The following standard operating procedure (SOP) defines activities to be completed to properly filter water samples in preparation for analysis by an analytical laboratory.

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These SOPs and SOGs shall be reviewed periodically, and revisions and additions to these SOPs and SOGs shall be made as needed to assure consistency with industry standards and the collection of high quality data in the field. Requests for revisions shall be made in writing to the President or his/her quality assurance designee.

5.7.1 Procedures

Research indicates that if samples are obtained correctly, field filtration for metals may not be necessary (Puls and Powell, 1992). However, filtration of samples to be analyzed for dissolved metals may be required in some cases. If filtration is required, it shall be outlined in the site specific sampling plan.

If filtration is required, filter the samples in the field if possible. If field filtering is not possible, preserve the sample by chilling to 4°C (i.e., do not add acid), and immediately ship the sample via overnight delivery to the laboratory. Indicate on the chain of custody that laboratory filtration and preservation are required.

Vacuum filtration of groundwater samples is not recommended (Barcelona et al., 1985, pg. 65). Samples to be analyzed for TOC, VOCs or other organic compounds should not be filtered. Filtration may be performed on samples collected for analysis of dissolved metals, however.

The following procedure shall be followed to filter samples in the field with a peristaltic pump (e.g., GeoPump):

1. Connect the GeoPump to an automobile cigarette lighter or outlet if electricity is available.

2. Replace the tubing for the GeoPump at the beginning of each sampling round. If the samples are collected in any order other than most contaminated to least contaminated, or if very high levels of contamination are suspected or observed, then replace the tubing between each sample or as necessary.

3. If the tubing is not replaced between each sample, flush the lines with Liquinox followed by at least three flushes with distilled water.

4. Collect an unfiltered water sample as discussed in Sections 5.4 and 5.5.

5. Place the intake line in the unfiltered sample.

6. Pump at least a few hundred milliliters of the sample through the GeoPump prior to sample collection in order to flush the line. Set the GeoPump at the lowest rate possible in order to minimize aeration. Dispose of this water appropriately.

7. Place a new disposable 0.45-micron filter on the output line. Direct the output stream from the filter into the pre-acidified sample container, as outlined in Section 5.6.

References

Barcelona, M.J., J.P. Gibb, J.A. Helfrich, and E.E. Garske. 1985. *Practical guide for ground-water sampling*. Prepared in cooperation with RSKERL, Ada, Oklahoma. SWS Contract Report 374. DBS&A #560/BAR/1985.

Puls, R.W. and R.M. Powell. 1992. *Acquisition of representative ground water quality samples for metals*. R.S. Kerr Environmental Research Laboratory (RSKERL). Ground Water Monitoring Review, Summer 1992.

5.8 Quality Assurance/Quality Control (QA/QC) Samples

The following standard operating procedure (SOP) defines activities to be completed to assure quality assurance (QA) and quality control (QC) for water samples collected in the field.

The SOPs and SOGs included in this section are applicable to all DBS&A employees for the conduct of all activities listed in this section. All SOPs and SOGs described in this section are proprietary in nature and shall not be copied or reproduced, or distributed to any person or organization not employed by DBS&A, without the expressed written approval of the President or his/her designee for quality assurance. All or parts of the SOPs and SOGs described in this section may be reproduced and used in DBS&A reports, proposals, and work plans with the verbal consent of the President, his/her quality assurance designee, or a DBS&A Division Director.

These SOPs and SOGs shall be reviewed periodically, and revisions and additions to these SOPs and SOGs shall be made as needed to assure consistency with industry standards and the collection of high quality data in the field. Requests for revisions shall be made in writing to the President or his/her quality assurance designee.

QA/QC samples include split samples, duplicates, blind duplicates, blind check standards, trip blanks, and equipment blanks. The specific QA/QC samples that will be collected during each sampling event shall be designated in the site sampling plan.

5.8.1 General QA/QC Guidelines

The following general guidelines shall be followed for collection of QA/QC samples:

1. A trip blank is a sample of analyte-free water that is transported with the sample containers from the laboratory to the field site and back again. A trip blank is useful in assessing contamination of volatile organics samples attributable to shipping and field handling procedures. Include a trip blank with each cooler that contains samples to be analyzed for volatile organic compounds (VOCs). Ideally, trip blanks will be prepared at the lab in advance and will be shipped with the sample bottles received from the lab. If trip blanks are prepared in the DBS&A warehouse or in the field, prepare them well away from any areas of known or suspected contamination. Prepare the trip blanks by filling a pre-acidified 40-mL VOA vials with organic-free water.

2. An equipment (rinsate) blank is a sample of analyte-free water which has been used to rinse any non-disposable equipment that comes in contact with the water to be sampled, such as non-dedicated pumps or bailers or field filtration devices. The rinsate blank is useful in documenting adequate decontamination of equipment. Collect the equipment blank by running or pouring deionized water through any portion of the device that normally comes in contact with the water sample or presents a potential for cross-contamination, including hoses, valves, etc. Equipment blanks generally are not required for disposable equipment which is certified clean by the manufacturer (e.g., disposable teflon bailers). The exact number and type of equipment blanks to be collected will be determined on a site-specific basis. Describe the process used to collect the equipment blank in the field log book.

3. A duplicate consists of two separate samples from the same source which are collected as close as possible to the same point in space and time, analyzed independently. Duplicates are used to

evaluate laboratory precision, heterogeneity of the material, and precision of field sampling techniques.

4. Split samples are replicate samples collected in the same manner in alternating fashion which are analyzed independently for the same parameters. Split samples are used to evaluate inter- or intralaboratory precision.

5. In some cases, blind check standards may be submitted to the analytical laboratory. These may be obtained commercially or prepared in advance in the DBS&A laboratory. Alternatively, a duplicate sample may be spiked in the field with a known quantity of the analyte(s) of concern.

5.8.2 Well Security

All monitor wells shall be securely locked following the completion of sampling.

5.8.3 Chain-of-Custody Procedures

Chain-of-custody (COC) documents shall be kept for all samples collected by DBS&A. The COC program includes proper labeling of the samples to prevent misidentification. The following general guidelines for sample handling and custody procedures will be followed:

1. As few people as possible should handle the samples.

2. Samples must be within a locked/secure area at all times when not within view of DBS&A personnel.

3. Use the COC form provided by the analytical laboratory that will be performing the analyses. A representative form is included as Attachment 5.8-1 (DBS&A Form No. 095).

4. The Field Representative is responsible for the custody of the samples until they are transferred to the analytical laboratory or until custody is transferred to another designated individual. If the sample is transferred to another DBS&A employee, both people should sign and date the "relinquished" and "received" sections of the form, respectively.

5. Include the following information on the COC form:

   - The date and time of sample collection
   - The exact identification of the sample
   - The type of sample (e.g., water, soil, fuel)
   - Any preservatives used
   - The number of containers for each sample
   - The job number and name

- Whether or not the sample was filtered
- The analytical methods to be used (e.g., EPA 8240)

6. Have a second member of the water sampling team check the COC document to ensure that all data is correct and exactly matches the information on the sample bottle labels. Place the appropriate copies of the COC form(s) in a sealed plastic bag taped to the inside lid of the cooler containing the samples. If more than one cooler is being shipped, each cooler should have a separate COC form listing all samples in that cooler.

7. Whenever the sample leaves control of the sampling team (e.g., when shipped by common carrier) place a COC seal on the shipping container or individual sample bottles. Sign and date the COC seal. The purpose to the seal is to ensure that the samples have not been tampered with prior to receipt at the lab.

8. If samples are shipped to arrive on Friday afternoon, weekends, or holidays, special arrangements need to be made with the analytical laboratory to ensure that someone will be available for sample receipt, and that the holding times will be met.

Attachment

5.8-1. Chain-of-Custody Form (DBS&A Form No. 095)

Daniel B. Stephens & Associates, Inc.

Chain of Custody

To:

______________________ Date __________ Project No. __________

______________________ Client ______________________

______________________ Relinquished by ______________________

Sent by: ☐ Fed Ex ☐ DHL ☐ Other ______________________

Purpose of shipment ______________________

Possible contaminants ______________________

Item No.	Sample No.	Analysis To Be Done	Sample Container	Comments

Date received __________ by ______________________
Company Representative

Received the above articles in good condition

Except as noted ______________________

____

____

P:\OM\SECTION.13\Chain-Custody_Form.doc

P:\SOPs\13-Field\Att_3.2-3_Custody.doc

6.3 Aquifer Pumping Test

This section provides standard operating guidelines (SOGs) for conducting aquifer pumping tests in the field using groundwater wells. The characterization of a groundwater system is a critically important first step in solving aquifer problems (Batu, 1998). A pumping test is performed by pumping groundwater from a well and measuring resultant water level changes to determine the hydraulic characteristics of an aquifer and/or lower-permeability aquitards (if present or desired). A pumping test is the most reliable type of aquifer test that is commonly conducted during groundwater investigations (EPA, 1993).

Although the primary purpose of this SOG is to describe the tasks needed to successfully perform constant-rate pumping tests, a brief description of two other commonly-used testing procedures (specific capacity tests and step-drawdown tests) is also presented.

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These SOPs and SOGs shall be reviewed periodically, and revisions and additions to these SOPs and SOGs shall be made as needed to assure consistency with industry standards and the collection of high quality data in the field. Requests for revisions shall be made in writing to the President or his/her quality assurance designee.

6.3.1 Procedures

An aquifer pumping test is a controlled field test conducted by imposing a stress (pumping from a well) on an aquifer and determining the aquifer's response to that stress by measuring the changes in the potentiometric (unconfined) or piezometric (confined) surface. The recovery of the water level surface once the stress on the aquifer is relieved will also be measured during a pumping test. Aquifer pumping tests are conducted to determine aquifer hydraulic characteristics, such as aquifer transmissivity, hydraulic conductivity, storage, well yield, and specific capacity. Depending on the test configuration and the reliability of the collected data, aquifer pumping tests may also be used to determine the location of hydrologic boundaries or to determine the impact of pumping on surface waters.

Several types of tests are commonly performed depending on the objectives of the investigation; these include specific capacity tests, step-drawdown tests, and constant-rate pumping tests.

6.3.1.1 Specific Capacity Test

The specific capacity of a well is defined as the ratio of its discharge to its total drawdown (typical units are gallons per minute per foot of drawdown); this value typically decreases with the length of time a well is pumped. A specific capacity test is a single-well test that is typically performed at water supply wells in order to estimate the yield of a well. The specific capacity of a well is its yield per unit of drawdown, after a given time has elapsed. During this test, the flow from the well may vary by as much as 50 percent as drawdown in the well progressively increases.

6.3.1.2 Step-Drawdown Test

A step-drawdown test is also a single-well test performed at a pumping well. The test was developed to examine the performance of wells having turbulent flow (Driscoll, 1986), as it allows the efficiency and yield of a well to be evaluated. When performing a step-drawdown test, it is good practice to use a pump that has sufficient capacity to remove all of the water from a well. The test consists of pumping a well at a constant rate for specified time period (a "step", whose duration typically ranges from 60 to 120 minutes) and to measure the resultant drawdown in the well until the drawdown in the well stabilizes. Typically, three to four steps are performed at increasing higher pumping rates. The test data is used to obtain information on the well and aquifer's ability to produce water, and/or the degree of hydraulic interconnection between the open portion of the well and the surrounding saturated material.

A step-drawdown test should typically be performed at a well that is going to be used as the pumping well in a constant-rate pumping test. This is especially true when testing formations that produce little water, since it will be important to produce the maximum stress (the greatest amount of drawdown) without permitting the well to go dry prior to the end of the proposed pumping period. Data generated during a step-drawdown test can potentially be used to:

- Estimate the overall transmissivity of an aquifer
- Evaluate whether nearby observation wells will adequately characterize the cone of depression caused by a proposed constant-rate test
- Identify the depth(s) of significant water-producing zones intersected by the well open interval, although this applies primarily to fractured bedrock aquifers
- Confirm that a newly installed well has been properly developed, or determine whether an existing well may need to be redeveloped

6.3.1.3 Constant-Rate Pumping Test

A constant-rate pumping test is performed by withdrawing water at a constant rate from (or applying a known stress to) an aquifer of known or assumed dimensions, and observing the temporal changes in water levels in the pumping and observation wells. Depending on the type and quality of the test data, and the method used to analyze the resulting data, the primary hydraulic characteristics that may be estimated include:

- Transmissivity (T)
- Coefficient of storage (S)
- Specific yield (S_y)
- Horizontal and vertical hydraulic conductivity (K_h and K_v, respectively)
- Leakage from or through adjacent confining layer(s)

In addition, it may be possible to determine the location and type of aquifer boundaries (e.g., barrier or constant-head boundaries) if appropriate monitoring points are used and sufficient data are collected.

The main advantages of performing a constant-rate pumping test (versus a slug test or a single-well test) are that:

- The test monitors the hydraulic response over a larger portion of an aquifer and therefore can generate data that may provide better estimates of aquifer hydraulic characteristics.
- The storativity and/or specific storage of an aquifer may be determined.
- The hydraulic interconnection between different water-producing zones (separated by lower-permeability zones) may be evaluated.
- Leakage from or through confining layer(s) below or above an aquifer may be assessed.

The disadvantages of the technique are that:

- The tests are costly to design and perform.
- New wells may need to be installed to properly monitor the response to pumping.
- If elevated pumping rates need to be used at contaminated sites, disposal of contaminated groundwater may be expensive.

The procedures described are in accordance with the ASTM document Standard Guide for Selection of Aquifer Test Method in Determining Hydraulic properties by Well Techniques (ASTM D 4043-96) and Standard Test Method (Field Procedure) for Withdrawal and Injection Well Tests for Determining Hydraulic Properties of Aquifer Systems (ASTM D 4050-96). Additional references which may be helpful in planning and performing aquifer tests are Suggested Operating Procedures for Pumping Tests (EPA, 1993), Groundwater and Wells (Driscoll, 1986), and Applied Hydrogeology (Fetter, 1994).

The main tasks required to successfully perform a constant-rate pumping test are described below; these include the following:

- Review hydrogeologic information (Section 6.3.1.4)
- Pumping well design (Section 6.3.1.5)
- Pumping test design (Section 6.3.1.6)
- Antecedent data collection (Section 6.3.1.7)
- Pumping period (Section 6.3.1.8)
- Recovery period (Section 6.3.1.9)
- Precautions (Section 6.3.1.10)
- Data analysis (Section 6.3.1.11)

This SOG does not describe how data generated during an aquifer pumping test may be analyzed.

6.3.1.4 Review Hydrogeologic Information

The first task of any aquifer test is to determine which type of aquifer will be tested and which data analysis method will be used. The reliability of any determination of hydraulic properties depends on the conformance of the hydrogeologic site characteristics to the assumptions of the test method (EPA, 1993). Available information on the aquifer and the site should therefore be collected and reviewed; this information will provide the basis for the development of a conceptual model of the site and test design. Existing data on the aquifer and related geologic and hydrologic units should be collected and analyzed to assess the following:

- Geologic characteristics of the subsurface (i.e., lithologic, stratigraphic and structural features that may influence the flow of groundwater)
- Aquifer type (confined versus unconfined)
- Location and type of aquifer boundaries
- Confining bed thicknesses and lateral extent (if present)
- Surface water features
- Information on wells located near the test area (e.g., water supply, observation or monitoring wells)
- Data on the groundwater flow system (e.g., estimates of the aquifer transmissivity, thickness, and horizontal and vertical hydraulic gradients; the presence and effect of lower-permeability zones)
- And other pertinent data

Based on known site conditions and the nature of the problem being addressed, pumping and observation wells that are best suited for testing will be selected. Trial calculations of well drawdown using estimated values of aquifer transmissivity should be performed. The results of these calculations may be used to confirm that sufficient observation wells are located at appropriate distances from the pumping well so that water level fluctuations measured during the test will generate good quality data that defines a strong signal (water-level response curve) with little associated noise.

6.3.1.5 Pumping Well Design

There are six principal elements that need to be evaluated during the design of the pumping facility (EPA, 1993):

1. Well construction and setup
2. Water-level measurement access
3. Reliable power source
4. Pump selection
5. Discharge control and measurement equipment
6. Water disposal

Each of these elements is briefly described below.

6.3.1.5.1 Well Construction and Setup. The construction details of the pumping well should be reviewed to determine its diameter, depth, and all intervals that are open to the aquifer. Information on how the well was installed and developed should be reviewed. Available data that demonstrates that the well was properly developed should be collected and reviewed, since data collected from a poorly-developed well may not be representative of the aquifer.

For example, head losses at a pumping well that are associated with the entry of water from the aquifer may be significant if the well is poorly constructed or if the well is in poor hydraulic connection with the aquifer (e.g., the well screen is plugged). If this is suspected, a step-drawdown test should be performed at the well to obtain an estimate of well entry losses and determine whether the well should be redeveloped (EPA, 1993). If a well is redeveloped, a second step-drawdown test should be performed to confirm the well redevelopment has been effective.

6.3.1.5.2 Water-Level Measurement Access. One must be able to measure the water level in the pumping well before, during and after pumping. Typically, water levels will be measured using electric sounders and data loggers equipped with pressure transducers.

The installation of a "stilling tube" is often warranted at a pumping well since the presence of the pump, electric wires, and the discharge line often causes water-level-measuring devices to become tangled in the well. A stilling tube consists of an open small-diameter PVC pipe that is lowered into the well to a depth that extends past the pump, and is securely attached to the well. A measuring point is then established and its height above the existing measuring point determined. Once installed, water levels at the well can be measured (using pressure transducers and electric sounders) inside the stilling tube. Two added benefits of using a stilling tube are that it eliminates potential effects that may be caused by turbulence in the well due to pumping, as well as those potentially caused by cascading water.

In cases where a pump is isolated by a packer to limit production to a certain portion of an open hole, a transducer system should be used to monitor pumping hydraulic heads.

6.3.1.5.3 Reliable Power Source and Pump Selection. Having continuous power for the pump for the duration of the test is crucial for the success of the test. If interruptions occur, it may be necessary to stop the test and allow the aquifer to recover prior to restarting the test. Depending on the proposed location and duration of a test, it may be warranted to consider having the local power company provide a power drop to supply a reliable source of power for the pump. This is especially true if the test is long (for example, a 30- to 60-day aquifer stress test performed in a residential neighborhood where the use of a generator might cause undue disruption). When using a gasoline or diesel powered generator, it is prudent to have a backup generator.

The pump should be sized to ensure that the desired pumping rate can be maintained throughout the duration of the pumping period. To obtain good data during the recovery period, a check valve should be installed at the base of the pump column pipe in the pumping well. This will prevent the backflow of water from the discharge line into the well when pumping ceases and the recovery period begins.

6.3.1.5.4 Discharge Control and Measurement Equipment. Control of the pumping rate requires an accurate means of measuring the pumping rate, and a convenient means of adjusting the rate to keep it as constant as possible. It is critical that the pump discharge be closely monitored throughout the test. An instantaneous flow meter should be used to monitor the pumping rate, and a second measurement method should be used to confirm the accuracy of the primary measurement device as well as providing a backup means of monitoring the discharge from the well (such as the use of a calibrated bucket and stopwatch or the use of orifice plates equipped with a manometer). The discharge should be measured frequently at the beginning of the test (every few minutes), and the discharge rate should be adjusted as needed to maintain as constant a pumping rate as possible. When the discharge becomes more stable, reduce the frequency of adjustments and check the discharge less frequently (hourly checks should be sufficient). The method used to monitor the flow should have an accuracy of at least plus or minus 2 percent. The accuracy and precision of the method(s) used to monitor the flow rate are important since the flow rate during the test should not be allowed to vary by more than 5 to 10 percent.

If the proposed pumping rate is less than 10 gallons per minute (gpm), the flow rate can typically beadjusted using a rheostatic control on the electric pump or a valve installed in the discharge line to create back pressure and control the discharge rate. The use of both of these controls will greatly facilitate making minor adjustments to the pumping rate. Most higher-yield pumps used to pump groundwater at rates of approximately 20 gpm and greater will most likely be controlled solely using valves installed on the discharge line. At elevated pumping rates (50 to over 500 gpm), the use of a gate valve as the primary means of rate adjustment is recommended since ball valves often tend to open as the test proceeds. The installation of a second “fine adjustment” valve is recommended at higher pumping rates, where a smaller diameter bypass pipe valve can facilitate small adjustments to the pumping rate.

If groundwater samples are to be collected during the pumping period of the test, a separate valve should be installed on the discharge line as close to the well casing as practicable.

6.3.1.5.5 Water Disposal. Water generated during the test should either be temporarily stored during the testing period, or may be discharged if the discharge point is located far enough away to ensure that water discharged will not be able to recharge the portion of the aquifer that is being tested. This may require that piping be installed to transport the pumped water a considerable distance from the test site. If the water being pumped is contaminated, the water may need to be stored in temporary on-site storage containers (i.e., steel storage tank). It may be necessary to obtain permits for the on-site storage and final disposal of contaminated fluids.

6.3.1.6 Pumping Test Design

The conceptual understanding of the site hydrogeology forms the basis for the design of the aquifer testing method(s). It is important that the geometry of the aquifer, location and depth of pumping and observation wells, and the pumping period correspond to the mathematical model which will be used to analyze the data (EPA, 1993). The hydraulic properties that can be determined from a test depend on the instrumentation of the field test, knowledge of the aquifer system being investigated, and the conformance of the site's hydrogeology to the assumptions of the test method. Most test methods allow the hydraulic conductivity and storage coefficient of an aquifer to be determined. However, some test methods may allow other hydraulic parameters to be estimated, such as vertical and horizontal anisotropy, aquifer discontinuities, vertical hydraulic conductivity of confining beds, specific storage, etc.

Information on existing wells should be reviewed to identify suitable candidates for monitoring the aquifer response to pumping. If a well has not been recently used, it should be field tested to confirm it will be suitable for monitoring the aquifer response. Such a test may be performed by injecting or withdrawing water from a well and measuring the subsequent water level changes to identify wells that should be redeveloped, replaced, or dropped from consideration in favor of another available well. The type and number of observation wells needed to monitor the aquifer response to pumping depends on the information that needs to be determined from the test data. Depending on the type of information which is wanted, additional observation wells may need to be installed. The diameter of the observation wells only needs to be large enough to permit accurate and rapid measurements of water levels. A 2-inch diameter well is usually fine, although these small diameter wells are often difficult to develop properly.

Each site needs to be evaluated independently to determine appropriate distances for the placement of observation wells, since certain hydraulic conditions may warrant the use of closer or more distant wells. If aquifer boundaries are suspected, observation wells should be located in a manner which will identify the location and effect of the boundaries. Furthermore, if aquifer anisotropy is suspected, wells may be located in a pattern based on the suspected or known anisotropic conditions at the site.

Prior to beginning data collection, a schedule should be created for each well that contains a timetable for required water level measurements. Field data sheets should be used to record critical data (e.g., depth-to-water measurements) for the pumping well and the observation wells being monitored during the test (Attachments 6.3-1 and 6.3-2).

6.3.1.7 Antecedent Data Collection

Collecting data to characterize the pre-test water levels is essential if the analysis of the test data is to be completed successfully (EPA, 1993). The antecedent water level data provide the basis for correcting test data to account for on-going regional water level changes or fluctuations caused by short-term changes in atmospheric pressure. If possible, water levels in key off-site wells near the site should also be measured to identify off-site pumping which may affect the test results. As a general rule, water levels in the pumping and key observation wells may be collected every 15 minutes for 3 to 7 days prior to the start of pumping to establish a baseline for the test. These data are generally collected using data loggers equipped with pressure transducers; manual measurements of the depth to water should be performed to confirm the loggers are functioning properly. Well caps should be vented or removed during the entire testing period to ensure that water levels in the well are in equilibrium with atmospheric pressure.

In addition to collecting water level data (at wells and nearby surface water bodies), precipitation and barometric pressure should be monitored and data collected. Atmospheric pressure data, when analyzed with the water level data collected during the antecedent period, may be used to correct water levels for the effect of short-term atmospheric pressure changes. The atmospheric pressure data should be collected at the same times as the water level data (as this greatly facilitates the subsequent analysis of an aquifer's barometric efficiency).

Nearby pumping activities that may occur near the site should be identified and characterized, if possible; pump on-off times should be recorded, and their discharge rates determined. Significant effects caused by off-site pumping can often be removed from the test data if the on-off times of these wells are monitored during the test.

6.3.1.8 Pumping Period

Prior to the start of pumping, all watches and data logger clocks used by the field personnel to record the time of depth-to-water measurements shall be synchronized. Immediately before pumping is to begin, static water levels in all wells being monitored during the test shall be recorded. If possible, dedicated water-level-measuring devices should be used at each well being monitored during the test, and these should be lowered into each well 30 to 60 minutes prior to the start of the test. Data loggers being used to collect on-site data should be programmed to collect data on a logarithmic schedule. Water levels in wells where levels are being monitored using data loggers should also be measured manually in case of data logger failure and to provide proper quality assurance/quality control (QA/QC) of the test data. If drawdown is expected in an observation well soon after pumping begins, and the well is not equipped with a data logger, an observer should be stationed at each well to record water levels for the first two or three hours of the test (EPA, 1993). If numerous observation wells are being used to monitor a test, using data loggers will reduce manpower needs.

There are no firm rules regarding the time frame for measuring water levels at wells used during a pumping test. However, measurements are performed much more frequently at the start of a test. Measurements in observation wells should occur often enough, and soon enough, after pumping begins to avoid missing the initial drawdown in each well. The actual timing of the start of drawdown at a well will vary depending on the aquifer, the distance from the pumping well, and the pumping rate used during the test. Estimates for the timing of drawdown at observation wells should be made during the planning stages (Section 6.3.4) using estimated aquifer parameters and the proposed pumping rate.

Frequent measurements during early times are needed to define the drawdown curve; this is especially important to accurately determine the storativity of an aquifer. As time since pumping started increases, the logarithmic time scale used to analyze the data dictates that less frequent measurements are needed to adequately define the curve, since most data analysis techniques involve plotting the drawdown versus the log of the time passed since pumping began. A minimum of ten measurements should be collected during each log interval.

When data loggers are used to monitor water levels at a site, the maximum logging interval is typically set to 15 minutes. The EPA maximum recommended time intervals for water-level measurements are listed below (Table 6.3-1, 1993):

Table 6.3-1. EPA Maximum Recommended Time Intervals for Water-Level Measurements

Elapsed Time	Measurement Frequency
0 to 3 minutes	every 30 seconds
3 to 15 minutes	every minute
15 to 60 minutes	every 5 minutes
60 to 120 minutes	every 10 minutes
2 to 10 hours	every 30 minutes
10 to 48 hours	every 4 hours
48 hours to shut down	every 24 hours

It is important when starting the test to bring the pumping rate to the chosen rate as quickly as possible. At the immediate start of the test, attaining and maintaining the desired pumping rate will require diligence from the field crew as they monitor and adjust the discharge rate. If using valves to control the discharge rate, it is advantageous to have these at a pre-set position known to create the desired rate; the valves should be set well in advance of the start of the test to ensure the disturbance caused by pumping at the well will not impact the test data. This setting of the valve position can be done during the antecedent period, preferable 24 to 48 hours prior to the start of the pumping period.

How frequently the discharge needs to be monitored and adjusted during a test depends on the pump, well, aquifer, and power characteristics (EPA, 1993). During the initial hour of the test, well discharge at the pumping well should be monitored and recorded as often as practical. The date and time of adjustments made to the discharge rate should be noted, and the pre-adjustment and post-adjustment pumping rates recorded. The EPA (1993) recommends that the discharge should never be allowed to vary more that plus or minus 5 percent, since the variation of the discharge rate has a large effect on permeability estimates calculated using data collected during the test. However, it is important to note that some random short-term variations in the discharge rate may be acceptable if the average discharge does not vary by more than plus or minus 5 percent.

The length of the pumping period depends on the following:

- Objectives of the test
- Type of aquifer
- Location of suspected boundaries
- Degree of accuracy need to establish the storage coefficient and transmissivity
- Rate of pumping

The pumping period should continue until the data are adequate to define the shape of the drawdown curve and permit the desired hydraulic parameters to be calculated. This may require that pumping continue for a significant period after the rate of water level change becomes small, especially when the location of boundaries or the effects of delayed yield are of interest. Typically, the pumping period of a test performed on a confined aquifer may be 24 to 48 hours long, whereas a test performed on an unconfined aquifer may be 48 to 96 hours long. The anticipated length of the pumping period should be estimated based on the data needs and using the estimated site hydraulic parameters and conceptual model.

Plotting the drawdown data on semi-log paper during the test is essential for monitoring the status and effectiveness of the test. Plotting the data may also allow the field staff to identify erroneous data, which is especially important if data loggers are being used to collect data. Finally, the plots of drawdown will indicate when enough data for a solution has been collected.

6.3.1.9 Recovery Period

Recovery measurements should be made in the same manner and frequency as drawdown measurements made during the pumping period. These measurements should be collected until water levels have recovered to 95 percent of their pretest levels. If possible, water levels at selected wells and the barometric pressure should be monitored for three to seven days after pumping stops; these data will bolster the use of any corrections which may be identified using the antecedent data.

6.3.1.10 Precautions

- All depth-to-water measurements need to be performed using the same measuring points. If the location of a measuring point needs to be changed during a test, the time of the change shall be recorded and any change in the elevation of the point determined.

- The exact time of each depth-to-water measurement will be recorded regardless of the prescribed time interval.

- Comments describing all actions performed as testing is performed may be valuable when analyzing the data. It is very important to note any problems or events that may affect the quality of test data.

- If several water-level measurement devices are used during the test, they should be calibrated to each other by simultaneously measuring the water level in single well during the antecedent or late in the recovery period.

- If water levels are changing very rapidly (typically only in the pumping well when pumping first starts or ceases), it is easier to set the water-level measuring device immediately above or below the level of the water in the well and then record the exact time at which that the level occurs.

6.3.1.11 Data Analysis

This document is not intended to be an overview of aquifer test analytical methods. Numerous solutions are available to determine aquifer hydrogeologic parameters; the method selected depends on the type of aquifer and the type of test. Aquifer Hydraulics: A Comprehensive Guide to Hydrogeologic Data Analysis (Batu, 1998) describes many analytical methods which can be used to analyze aquifer testing data for various hydrogeologic settings. The computer program AQTESOLV for Windows (HydroSolve, Inc.) is a powerful program that greatly facilitates the analysis of data using some of the more commonly used solutions. Other useful references include Kruseman and de Ritter (1994), Dawson and Istok (1991), Driscoll (1986), and Domenico and Schwartz (1990).

Attachments

6.3-1. Pumping Test Data Sheet, Pumping Well

6.3-2. Pumping Test Data Sheet, Observation Well

References

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Pumping Test Data Sheet

Daniel B. Stephens & Associates, Inc.

Sheet ___ of ___

Project Name: ______________________________ Pumping Well: ____________________

Date	Time	Rate (gpm)	Depth to Water (ft)	Elapsed Time (min)	Drawdown (feet)	Comments

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Pumping Test Data Sheet

Daniel B. Stephens & Associates, Inc.

Sheet ___ of ___

Project Name: ____________________ Observation Well: ____________________

Date	Time	Depth to Water (ft)	Elapsed Time (min)	Drawdown (feet)	Comments

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