WELL CONSTRUCTION DETAILS
40 CFR 146.82(a)(9), (11), (12), and 40 CFR 146.86

FRONT RANGE STORAGE COMPLEX

Facility Information

Facility name: Carbon Storage Solutions
Front Range 1-1

Facility contact: Dan Sanders, President
Carbon Storage Solutions, LLC
31375 Great Western Drive
Windsor, CO 80550
Phone: (970) 674-2910
Email: drsanders@frontrangeenergy.com

Well surface location: 31375 Great Wester Drive, Windsor, CO 80550
Lat: 40.454962 Long: -104.859761 NAD 83 (2011)

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List of Acronyms and Abbreviations

°F = degrees Fahrenheit	Lbs = pounds (force)
AoR = Area of Review	lb/ft = pounds per foot
API = American Petroleum Institute	lb/ft^3 = pounds per cubic feet
CO_2 = carbon dioxide	MMA = maximum monitoring area
CR = Chrome	NA = not applicable
CSS = Carbon Storage Solutions, LLC	P&ID = piping and instrumentation diagram
ECMC = Energy and Carbon Management Commission	PISC = Post-Injection Site Care
EOR = Enhanced Oil Recovery	ppg = pounds per gallon
ft = feet	psi = pound-force per square inch
ft bgs = feet below ground surface	psig = pound-force per square inch, gauge
ft^3/sx = cubic feet per sack	UIC = Underground Injection Control
GS = geologic sequestration	US EPA = United States Environmental Protection Agency
IPCC = Intergovernmental Panel on Climate Change	USDW = Underground Source of Drinking Water
lbs = pounds (weight)	

A.II.1. Summary

[redacted]

A.II.2. Construction of Front Range 1-1

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

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A.II.4. Construction of Above Confining Zone Groundwater Monitoring Wells

CSS has installed a network of six monitoring stations (MS-1 through MS-6) for monitoring groundwater in the water table and Upper Pierre aquifer (commonly used USDW) within and in the vicinity of the AoR and maximum monitoring area (MMA) as illustrated in Figure A.II.4-1 below. Each monitoring station contains a shallow groundwater monitoring well (SMW-1 through SMW-6) for monitoring groundwater within the surficial groundwater zone (water table). Three monitoring stations, MS-1 through MS-3, include a deeper monitoring well (DMW-1 through DMW-3) screened in the Upper Pierre aquifer. Figure A.II.4-2 illustrates the depths and corresponding geologic cross-section of each well. See Appendix A.II.2 Groundwater Monitoring Logs for the detailed logs. All groundwater wells were constructed as per Colorado Division of Water Resources 2 CCR 402-2 (Sept 2016) and permitted with the Division of Natural Resources.

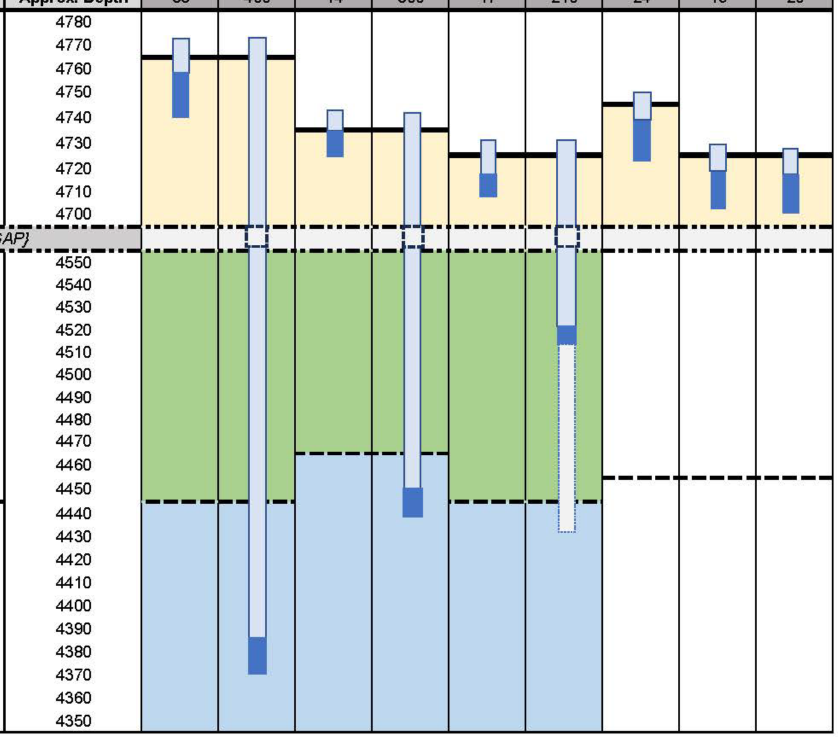
[redacted]

Figure A.II.4-2. Groundwater Monitoring Wells Depths and Geologic Cross-Sections

Summary of Groundwater Monitoring System - CSS-FRE Project Site - Windsor, CO

	MS-1		MS-2		MS-3		MS-4	MS-5	MS-6
Well ID	SMW-1	DMW-1	SMW-2	DMW-2	SMW-3	DMW-3	SMW-4	SMW-5	SMW-6
Ground Elev.	4775	4775	4743	4743	4729	4729	4753	4736	4735
TOS Elev.	4762	4395	4739	4463	4722	4539	4744	4732	4730
BOS Elev.	4742	4375	4729	4443	4712	4519	4729	4717	4715
Approx. Depth	33	400	14	300	17	210	24	19	20

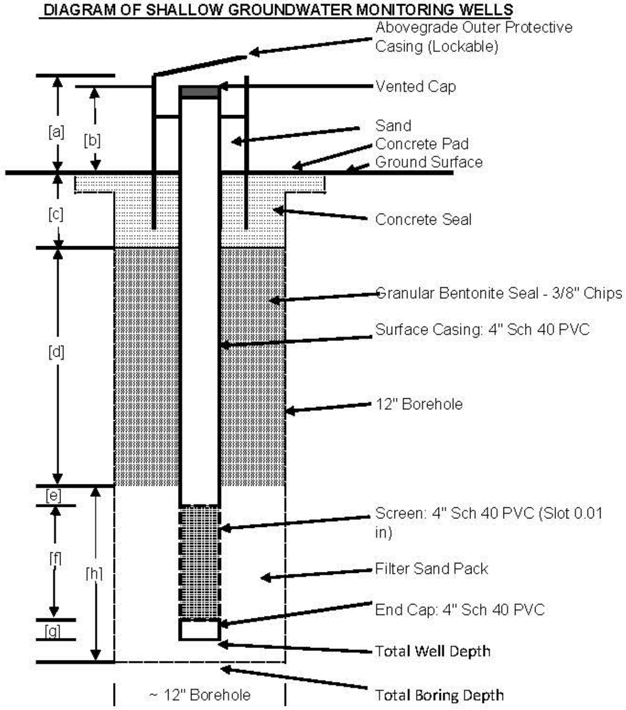
System	Series	Formation	Lithologic Unit/member		Aquifer Systems	Approx. Top Elevation (ft NAVD88)	Approx. Thickness (ft)
Quaternary	Holocene - Pleistocene	Unconsolidated alluvium, sands, & gravels	sands, gravels, & some eolian deposits	Qa Qg Qe	South Platte Alluvial Aquifer	4725-4775	30 - 70
{~150 ft GAP}							
Cretaceous	Upper Cretaceous	Pierre Shale	upper transitional interval / upper shale member	Kpu	Confining Unit {aquitard}	4695-4705	180 - 300
			Upper Pierre sands	Kpm Kph	Upper Pierre Aquifer {aka Pawnee Aquifer}	4445-4475	~800 -- 1,000



Notes:
- TOS: Top of Screen
- BOS: Bottom of Screen
- NAVD88: North America Vertical Datum (1988)
- MS: Monitoring Station
- SMW: Shallow Monitoring Well
- DMW: Deep Monitoring Well

Figure A.II.4-3. Groundwater Monitoring Well Diagram and Construction Details – Shallow

DIAGRAM OF SHALLOW GROUNDWATER MONITORING WELLS



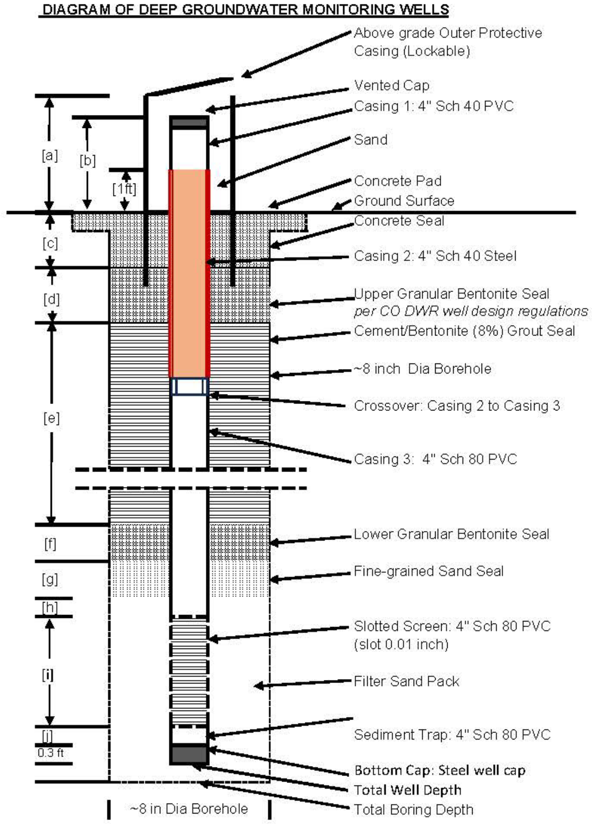
- ags: Above Ground Surface
- bgs: Below Ground Surface
- Sch 40: Schedule 40
- NAVD88: North America Vertical Datum (1988)
- PVC: Poly Vinyl Chloride
- TOC: Top of Casing
- SMW: Shallow Monitoring Well

Source: Trihydro (2023)

CONSTRUCTION DETAILS	SMW-1	SMW-2	SMW-3	SMW-4	SMW-5	SMW-6
Colorado DWR Permit Number	4000181-MH	4000167-MH	4000182-MH	4000155-MH	4000179	4000178-MH
Completion Date	8/2/2023	8/9/2023	8/5/2023	8/4/2023	8/8/2023	8/10/2023
Above Grade Prot. Casing						
Material	Metal	Metal	Metal	Metal	Metal	Metal
Approximate Height (ft ags) - [a]	3.2	3.2	3.3	3.1	3.1	3.2
Concrete Surface Pad						
Approximate Dimensions (ft)	2 x 2	2 x 2	2 x 2	2 x 2	2 x 2	2 x 2
Ground Surface Elevation (NAVD88) (ft)	4,774.5	4,743.1	4,729.2	4,755.0	4,735.9	4,735.1
Concrete Pad Thickness (ft)	0.5	0.5	0.5	0.5	0.5	0.5
Well Casing						
TOC Height (ft ags) - [b]	2.7	2.7	2.8	2.6	2.6	2.7
PVC Casing Material	Sch 40 PVC	Sch 40 PVC	Sch 40 PVC	Sch 40 PVC	Sch 40 PVC	Sch 40 PVC
PVC Casing Length, including stickup (ft)	15.9	7.1	9.8	13.6	6.9	7.6
Concrete Seal						
Concrete Thickness (ft) - [c]	2.0	1.0	1.5	2.0	1.0	1.0
Concrete Depth (ft bgs)	0-2.0	0-1.0	0-1.5	0-2.0	0-1.0	0-1.0
Bentonite Seal - Granules						
Bentonite Seal Thickness (ft) - [d]	9.0	2.0	2.5	7.0	2.0	2.9
Bentonite Seal Depth (ft bgs)	2.0-11.0	1.0-3.0	1.5-4.0	2.0-9.0	1.0-3.0	1.0-3.9
Sand Filter Pack & Screen (Monitoring Zone)						
Filter Sand Pack: Material	12/20 Silica	10/20 Silica	12/20 Silica	12/20 Silica	10/20 Silica	10/20 Silica
Filter Sand Pack Height above Screen - [e]	1.8	1.4	3.0	2.0	1.3	1.0
Filter Sand Pack: Thickness (ft) - [h]	24.0	12.0	13.3	18.0	17.0	11.2
Filter Sand Pack: Depth (ft bgs)	11.0-35.0	3.0-15.0	4.0-17.3	9.0-27.0	3.0-20.0	3.9-15.1
Screen: Slot Size (inches)	0.01	0.01	0.01	0.01	0.01	0.01
Screen: Length (ft) - [f]	20	10	10	15	15	10
Screen: Depth (ft bgs)	12.8-32.8	4.4-14.4	7.0-17.0	11.0-26.0	4.3-19.3	4.9-14.9
Screen (top): Elevation (NAVD88) (ft)	4,761.7	4,738.7	4,722.2	4,744.0	4,731.6	4,730.2
End Cap (Sch 40 PVC): Length (ft) - [g]	0.2	0.2	0.3	0.2	0.2	0.2
Approximate CTD Sensor Depth (ft bgs)	28.8	11.8	16.4	24.8	17.4	13.8
Approx. GeoTech Pump Inlet Depth (ft bgs)	27.3	10.3	14.9	23.3	15.9	12.3
Total Depth						
Total Well Depth (ft bgs)	33.0	14.6	17.3	26.3	19.5	14.9
Total Boring Depth (ft bgs)	35.0	15.0	17.3	27.0	20.0	15.1

Figure A.II.4-4. Groundwater Monitoring Well Diagram and Construction Details – Deep

DIAGRAM OF DEEP GROUNDWATER MONITORING WELLS



Notes:
- ags: Above Ground Surface
- bgs: Below Ground Surface
- Sch 40: Schedule 40
- Sch 80: Schedule 80
- NAVD88: North America Vertical Datum (1988)
- PVC: Poly Vinyl Chloride
- CTD: Conductivity, Temperature, Depth
- TOC: Top of Casing
- DMW: Deep Monitoring Well
* DMW-2 exhibits low-flow artesian conditions

Source: Trihydro (2023)

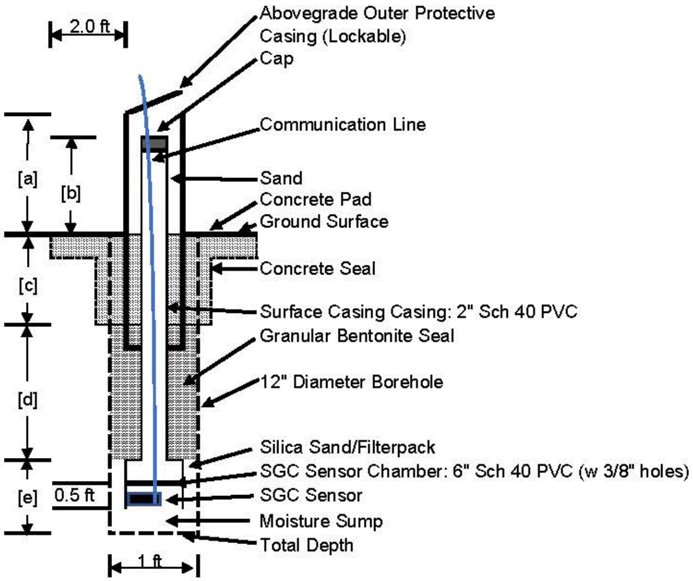
CONSTRUCTION DETAILS	DMW-1	DMW-2*	DMW-3
Colorado DWR Permit Number	331498	331499	331500
Completion Date (End)	9/21/2023	9/22/2023	9/22/2023
Above Grade Protective Casing			
Material	Metal	Metal	Metal
Approximate Height - [a] (ft ags)	3.2	3.1	3.3
Concrete Surface Pad			
Pad Approximate Dimensions (ft)	5 x 5	5 x 5	5 x 5
Ground Surface Elevation (ft NAVD88)	4,775.0	4,743.1	4,729.2
Concrete Pad Thickness (ft)	0.5	0.5	0.5
Well Casing			
TOC Height - [b] (ft ags)	2.4	3.0	2.9
Casing 1: Material	Sch 40 PVC	Sch 40 PVC	Sch 40 PVC
Casing 1: Length (ft)	2.2	2.0	1.9
Casing 2: Material	Sch 40 Steel	Sch 40 Steel	Sch 40 Steel
Casing 2: Length (ft)	30.0	20.0	20.0
Crossover (Casing 2 to Casing 3): Material	PVC	PVC	PVC
Crossover (Casing 2 to Casing 3): Length (ft)	1.0	1.0	1.0
Casing 3: Material	Sch 80 PVC	Sch 80 PVC	Sch 80 PVC
Casing 3: Length (ft)	350.0	259.7	170.0
Concrete Seal			
Concrete Thickness (ft) - [c]	2.0	2.0	2.0
Concrete Depth (ft bgs)	0-2.0	0-2.0	0-2.0
Upper Bentonite Seal - Granules			
Bentonite Seal Thickness - [d] (ft)	2.0	2.0	2.0
Bentonite Seal Depth (ft)	2.0-4.0	2.0-4.0	2.0-4.0
Cement / Bentonite Grout Seal			
Grout Material Type	8% Bentonite	8% Bentonite	8% Bentonite
Cement/ Bentonite Grout Seal Thickness - [e] (ft)	364.0	270.0	177.0
Cement/Bentonite Grout Seal Depth (ft bgs)	4.0-368.0	4.0-274.0	4.0-181.0
Lower Bentonite Seal - Granules			
Bentonite Seal Thickness - [f] (ft)	4	2.7	2.7
Bentonite Seal Depth (ft bgs)	368.0-372.0	274-276.7	181-183.7
Fine Grained Sand Seal			
Fine Grained Sand Material	#60 Sand	#60 Sand	#60 Sand
Fine Grained Sand Thickness - [g] (ft)	6.0	1.3	1.3
Fine Grained Sand Pack Depth (ft bgs)	372.0-378.0	276.7-278.0	183.7-185.0
Sand Filter Pack & Screen (Monitoring Zone)			
Filter Sand Pack Material	20/40 Silica	10/20 Silica	10/20 Silica
Filter Sand Pack Height above Screen - [h]	2.0	2.0	5.0
Filter Sand Pack Depth (ft bgs)	378.0-403.0	278.0-300.0	185-210.3
Screen Slot Size (inches)	0.01	0.01	0.01
Screen Length (ft)	20.0	20.0	20.0
Screen Depth - [i] (ft bgs)	380.0-400.0	279.7-299.7	190.0-210.0
Screen (Top): Elevation (ft NAVD88)	4,395	4,463	4,539
Sediment Trap Length - [j] (ft)	2	Not Installed	Not Installed
Approximate Sediment Trap Depth (ft bgs)	400.0-402.0	Not Installed	Not Installed
Approximate CTD Sensor Depth (ft bgs)	390.8	Not Installed	205.0
Approximate GeoTech Pump Depth (ft bgs)	386.8	Not Installed	201.1
Total Depth			
Total Well Depth (ft bgs)	402.3	300.0	210.3
Total Boring Depth (ft bgs)	403.0	301.0 (post-backfill)	210.3 (post backfill)

A.II.5. Construction of Soil Gas Monitoring Wells

CSS has installed a network of six monitoring stations (MS-1 through MS-6) within and in the vicinity of the AoR and MMA as illustrated in Figure A.II.4-1 (previous section). Each monitoring station contains instruments for measuring CO_2 concentrations in the vadose zone at approximately 4 ft bgs (SGC-1 through SGC-6). In addition, each monitoring station also contains a soil gas well (SVP-1 through SVP-6). These monitoring locations were constructed in general accordance with the appropriate state, ASTM International, and US EPA standard operating procedures for Design and Installation of Monitoring Wells (Appendix A.II.1) and the construction schematics are summarized in Figures A.II.5-1 through A.II.5-2. Well logs are represented in the first 5 ft of the shallow groundwater monitoring wells as shown in Appendix A.II.2.

Figure A.II.5-1. CO_2 Soil Gas Chamber Diagram and Construction Details

DIAMGRAM OF SOIL (VADOSE ZONE) GAS CHAMBER SENSOR WELL



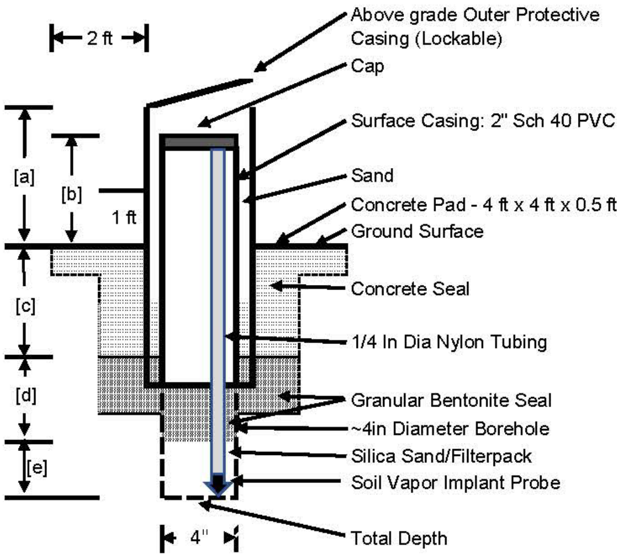
Notes:
- ags: Above Ground Surface
- bgs: Below Ground Surface
- Sch 40: Schedule 40
- Sch 80: Schedule 80
- NAVD88: North America Vertical Datum (1988)
- PVC: Poly Vinyl Chloride
- SGC: Soil Gas Chamber Sensor Well

Source: Trihydro (2023)

CONSTRUCTION DETAILS	SGC 1	SGC 2	SGC 3	SGC 4	SGC 5	SGC 6
Completion Date	8/2/2023	8/9/2023	8/5/2023	8/4/2023	8/8/2023	8/10/2023
Above Grade Protective Casing						
Material	Metal	Metal	Metal	Metal	Metal	Metal
Height (ft ags) - [a]	3.1	3.0	3.2	3.1	3.1	3.0
Concrete Surface Pad						
Approximate Dimensions (ft)	2 x 2	2 x 2	2 x 2	2 x 2	2 x 2	2 x 2
Ground Surface Elevation (NAVD88) (ft)	4774.1	4743.4	4729.3	4755.1	4735.7	4735.2
Concrete Pad Thickness (ft)	0.5	0.5	0.5	0.5	0.5	0.5
Well Casing Material						
Surface Casing: Material	Sch 40 PVC	Sch 40 PVC	Sch 40 PVC	Sch 40 PVC	Sch 40 PVC	Sch 40 PVC
Surface Casing: Height (ft ags) - [b]	2.8	2.7	2.9	2.8	2.8	2.7
Surface Casing: Depth (ft bgs)	0-4.0	0-3.5	0-3.5	0-4.0	0-3.7	0-4.0
Concrete Seal						
Concrete Thickness (ft) - [c]	1.0	1.0	1.0	1.0	1.0	1.0
Concrete Depth (ft bgs)	0-1.0	0-1.0	0-1.0	0-1.0	0-1.0	0-1.0
Bentonite Seal - Granules						
Granule Type and Size	3/8" chips	3/8" chips	3/8" chips	3/8" chips	3/8" chips	3/8" chips
Bentonite Seal Thickness (ft) - [d]	2.8	2.0	2.0	2.5	2.0	2.6
Bentonite Seal Depth (ft bgs)	1.0-3.8	1.0-3.0	1.0-3.0	1.0-3.5	1.0-3.0	1-3.6
Soil Gas Monitoring Zone						
Sand Pack Material	12/20 Silica	10/20 Silica	12/20 Silica	12/20 Silica	10/20 Silica	10/20 Silica
Sand Pack Thickness (ft) - [e]	1.2	2.0	1.5	1.1	2.0	1.4
Sand Pack Depth (ft bgs)	3.8-5.0	3.0-5.0	3.0-4.5	3.5 - 4.6	3.0-5.0	3.6-5.0
SGC Chamber: Material	Sch 40 PVC	Sch 40 PVC	Sch 40 PVC	Sch 40 PVC	Sch 40 PVC	Sch 40 PVC
SGC Chamber: Hole Size/Spacing	0.375"/1"	0.375"/1"	0.375"/1"	0.375"/1"	0.375"/1"	0.375"/1"
SGC Chamber: Length (ft)	0.5	0.5	0.5	0.5	0.5	0.5
SGC Chamber: Depth (ft bgs)	4.0-4.5	3.5-4.0	3.5-4.0	4.0-4.5	3.7-4.2	4.0-4.5
SGC Sensor Depth (ft bgs)	~4.3	~3.8	~3.8	~4.3	~3.9	~4.3
Total Depth						
Total Depth (ft bgs)	5.0	5.0	4.5	4.6	5.0	5.0

Figure A.II.5-2. CO_2 Soil Gas Sample Probe Diagram and Construction Details

DIAGRAM OF SOIL GAS SAMPLE PROBE



Notes:
- ags: Above Ground Surface
- bgs: Below Ground Surface
- Sch 40: Schedule 40
- NAVD88: North America Vertical Datum (1988)
- PVC: Poly Vinyl Chloride
- TOC: Top of Casing
- TOC: Top of Casing
- SVP: Soil Vapor Point

Source: Trihydro (2023)

CONSTRUCTION DETAILS	SVP 1	SVP 2	SVP 3	SVP 4	SVP 5	SVP 6
Date Installed	8/2/2023	8/7/2023	8/5/2023	8/4/2023	8/7/2023	8/7/2023
Above Grade Protective Casing						
Material	Metal	Metal	Metal	Metal	Metal	Metal
Approximate Height (ft ags) - [a]	3.3	3.4	3.3	3.0	3.3	3.2
Concrete Surface Pad						
Approximate Dimensions (inches)	4 x 4	4 x 4	4 x 4	4 x 4	4 x 4	4 x 4
Ground Surface Elevation (NAVD88) (ft)	4773.6	4743.5	4729.3	4755.0	4735.6	4735.3
Concrete Pad Thickness (ft)	0.5	0.5	0.5	0.5	0.5	0.5
Surface Casing						
Surface Casing Material	Sch 40 PVC	Sch 40 PVC	Sch 40 PVC	Sch 40 PVC	Sch 40 PVC	Sch 40 PVC
Surface Casing Height (ft ags) - [b]	3.0	3.1	3.0	2.7	3.0	2.9
Surface Casing Depth (ft bgs)	2.7	1.9	1.8	2.0	1.9	2.1
Concrete Seal						
Concrete Seal Thickness (ft) - [c]	1.0	1.0	1.0	1.0	1.0	1.0
Concrete Seal Depth (ft bgs)	0-1.0	0-1.0	0-1.0	0-1.0	0-1.0	0-1.0
Bentonite Seal - Granules						
Bentonite Seal Thickness (ft) - [d]	2.9	2.0	2.0	2.0	1.8	2.0
Bentonite Seal Depth (ft bgs)	1.0-3.9	1.0-3.0	1.0-3.0	1.0-3.0	1.0-2.8	1.0-3.0
Soil Vapor Monitoring Zone						
Sand Pack Material	12/20 sand	12/20 sand	12/20 sand	12/20 sand	12/20 sand	12/20 sand
Sand Pack Thickness (ft) - [e]	0.6	1.0	1.0	1.8	1.2	1.3
Sand Pack Depth (ft bgs)	3.9-4.5	3.0-4.0	3.0-4.0	3.0-4.8	2.8-4.0	3.0-4.3
Vapor Probe Depth (ft bgs)	4.2	3.7	3.7	4.4	3.7	4.0
Total Depth						
Total Depth (ft bgs)	4.5	4.0	4.0	4.8	4.0	4.3

A.II.6. References

API 2007. Background Report: Summary of Carbon Dioxide Enhanced Oil Recovery (CO2 EOR) Injection Well Technology. American Petroleum Institute. Available at: https://www.api.org/~/media/files/ehs/climate-change/summary-carbon-dioxide-enhanced-oil-recovery-well-tech.pdf.

EPA 2012, Geologic Sequestration of Carbon Dioxide: Underground Injection Control (UIC) Program Class VI Well Construction Guidance, EPA 816-R-11-020, May 2012. Available at: https://www.epa.gov/sites/default/files/2015-07/documents/epa816r11020.pdf.

Colorado Division of Water Resources, Rules and Regulations for Water Well Construction, Pump Installation, Cistern Installation, and Monitoring and Observation Hole/Well Construction, 2 CCR 402-2, Sept 2016
Available at:
https://dnrweblink.state.co.us/dwr/ElectronicFile.aspx?docid=3121539&dbid=0.

IPCC 2005, IPCC Special Report on Carbon Dioxide Capture and Storage, Intergovernmental Panel on Climate Change, Cambridge University Press, New York. Available at: https://www.ipcc.ch/site/assets/uploads/2018/03/srccs_wholereport-1.pdf.

Appendix A.II.1. U.S. EPA Standards for Design and Installation of Monitoring Wells

Region 4 U.S. Environmental Protection Agency Science and Ecosystem Support Division Athens, Georgia	
GUIDANCE	
Title: **Design and Installation of Monitoring Wells**	
Effective Date: January 16, 2018	**Number:** SESDGUID-101-R2
Authors	
Name: Brian Striggow Title: Environmental Engineer Signature:	Date: 1-9-18
Approvals	
Name: John Deatrick Title: Chief, Field Services Branch Signature: John Deatrick	Date: 1/10/18
Name: Hunter Johnson Title: Field Quality Manager, Science and Ecosystem Support Division Signature:	Date: 1/10/18

Revision History

This table shows changes to this controlled document over time. The most recent version is presented in the top row of the table. Previous versions of the document are maintained by the SESD Document Control Coordinator.

History	Effective Date
SESDGUID-101-R2, *Design and Installation of Monitoring Wells*, replaces SESDPROC-101-R1 **General:** Corrected any typographical, grammatical and/or editorial errors. **Cover Page:** Cover page was updated to reflect reorganization and new personnel. **Section 2.2.5:** Added Direct Push Technology as drilling method. **Section 2.7:** Added additional cautions regarding early sampling of permanent wells **Section 2.8:** Added greater detail to decommissioning procedures **Section 4:** Generalized description of screen point installation. Added section on direct push technology well installation.	January 16, 2018
SESDGUID-101-R1, *Design and Installation of Monitoring Wells*, replaces SESDPROC-101-R0.	January 29, 2013
SESDGUID-101-R0, *Design and Installation of Monitoring Wells*, Original Issue	February 18, 2008

TABLE OF CONTENTS

1 General Information

1.1 Purpose

This document describes general and specific procedures, methods and considerations to be used and observed when designing and installing permanent and temporary groundwater monitoring wells to be used for collection of groundwater samples.

1.2 Scope/Application

The procedures contained in this document are to be used by field personnel when designing, constructing and installing groundwater monitoring wells. On the occasion that SESD field personnel determine that any of the procedures described in this section are either inappropriate, inadequate or impractical and that another procedure must be used for any aspect of the design, construction and/or installation of a groundwater monitoring well, the variant procedure will be documented in the field log book, along with a description of the circumstances requiring its use. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

1.3 Documentation/Verification

This procedure was prepared by persons deemed technically competent by SESD management, based on their knowledge, skills and abilities and has been tested in practice and reviewed in print by a subject matter expert. The official copy of this procedure resides on the SESD local area network (LAN). The Document Control Coordinator is responsible for ensuring the most recent version of the procedure is placed on the LAN and for maintaining records of review conducted prior to its issuance.

1.4 References

USEPA Region 4 Environmental Investigations Standard Operating Procedures and Quality Assurance Manual (EISOPQAM), November 2001

USEPA. Safety, Health and Environmental Management Program Procedures and Policy Manual. Science and Ecosystem Support Division, Region 4, Athens, GA, Most Recent Version

SESD Operating Procedure for Field Sampling Quality Control, SESDPROC-011, Most Recent Version

SESD Operating Procedure for Field Equipment Cleaning and Decontamination, SESDPROC-205, Most Recent Version

SESD Operating Procedure for Logbooks, SESDPROC-010, Most Recent Version

SESD Operating Procedure for Groundwater Sampling, SESDPROC-301, Most Recent Version

SESD Operating Procedure for Management of Investigation Derived Waste, SESDPROC-202, Most Recent Version

EPA/540/S-95/503, *Nonaqueous Phase Liquids Compatibility with Materials Used in Well Construction, Sampling, and Remediation*

ASTM standard D5092, *Design and Installation of Ground Water Monitoring Wells in Aquifers*

1.5 General Precautions

1.5.1 Safety

Proper safety precautions must be observed when constructing and installing groundwater monitoring wells. Refer to the SESD Safety, Health and Environmental Management Program Procedures and Policy (SHEMP) Manual (Most Recent Version) and any pertinent site-specific Health and Safety Plans (HASPs) for guidelines on safety precautions. These guidelines should be used to complement the judgment of an experienced professional. When using this procedure, minimize exposure to potential health hazards through the use of protective clothing, eye wear and gloves. Address chemicals that pose specific toxicity or safety concerns and follow any other relevant requirements, as appropriate. Section 2.6, Safety Procedures for Drilling Activities, contains detailed and specific safety guidelines that must be followed by Branch personnel when conducting activities related to monitoring well construction and installation.

1.5.2 Procedural Precautions

The following precautions should be considered when constructing and installing groundwater monitoring wells.

- Special care must be taken to minimize or prevent inadvertent cross-contamination between borehole locations. Equipment, tools and well materials must be cleaned and/or decontaminated according to procedures found in SESD Operating Procedure for Field Equipment Cleaning and Decontamination (SESDPROC-205).
- All field activities are documented in a bound logbook according to the procedures found in SESD Operating Procedure for Logbooks (SESDPROC-010).

2 Permanent Monitoring Well Design Considerations

2.1 General

The design and installation of permanent monitoring wells involves drilling into various types of geologic formations that exhibit varying subsurface conditions. Designing and installing permanent monitoring wells in these geologic environments may require several different drilling methods and installation procedures. The selection of drilling methods and installation procedures should be based on field data collected during a hydrogeologic site investigation and/or a search of existing data. Each permanent monitoring well should be designed and installed to function properly throughout the duration of the monitoring program. When designing monitoring wells, the following should be considered:

- Short-and long-term objectives;
- Purpose of the well(s);
- Probable duration of the monitoring program;
- Contaminants likely to be monitored;
- Surface and subsurface geologic conditions;
- Properties of the aquifer(s) to be monitored;
- Well screen placement;
- General site conditions; and
- Potential site health and safety hazards.

In designing permanent monitoring wells, the most reliable, obtainable data should be utilized. Once the data have been assembled and the well design(s) completed, a drilling method(s) must be selected. The preferred drilling methods for installing monitoring wells are those that temporarily case the borehole during drilling and the construction of the well, e.g. hollow-stem augers and sonic methods. However, site conditions or project criteria may not allow using these methods. When this occurs, alternate methods should be selected that will achieve the project objectives. The following discussion of methods and procedures for designing and installing monitoring wells will cover the different aspects of selecting materials and methods, drilling boreholes, and installing monitoring devices.

2.2 Drilling Methods

The following drilling methods may be used to install environmental monitoring wells or collect samples under various subsurface conditions. In all cases the preferred methods are those that case the hole during drilling, i.e. Hollow Stem Augers (HSA) and sonic methods using an override system. Other methods may be used where specific subsurface or project criteria dictate.

2.2.1 Hollow Stem Auger (HSA)

This type of auger consists of a hollow, steel stem or shaft with a continuous, spiraled steel flight, welded onto the exterior. A hollow auger bit, generally with carbide teeth, disturbs soil material when rotated, whereupon the spiral flights transport the cuttings to the surface. This method is best suited in soils that have a tendency to collapse when disturbed. A monitoring well can be installed inside of hollow-stem augers with little or no concern for the caving potential of the soils. If caving sands exist during monitoring well installations, a drilling rig must be used that has enough power to extract the augers from the borehole without having to rotate them. A bottom plug, trap door, or pilot bit assembly can be used at the bottom of the augers to keep out most of the soils and/or water that have a tendency to enter the bottom of the augers during drilling. Potable water (analyzed for contaminants of concern) may be poured into the augers during drilling to equalize pressure so that the inflow of formation materials will be held to a minimum. Water-tight center bits are not acceptable because they create suction when extracted from the augers. This suction forces or pulls cuttings and formation materials into the augers, defeating the purpose of the center plug. Augering without a center plug or pilot bit assembly is permitted, provided that the soil plug, formed in the bottom of the augers, is removed before sampling or installing well casings. Removing the soil plug from the augers can be accomplished by drilling and washing out the plug using a rotary bit, or augering out the plug with a solid-stem auger bit sized to fit inside the hollow-stem auger. Bottom plugs can be used where no soil sampling is conducted during the drilling process. The bottom plug is wedged into the bottom of the auger bit and is knocked out at depth with drill pipe or the weight of the casing and screen assembly. The plug material should be compatible with the screen and casing materials. The use of wood bottom plugs is not acceptable. The type of bottom plug, trap door, or pilot bit assembly proposed for the drilling activity should be approved by a senior field geologist prior to drilling operations. Boreholes can be augered to depths of 150 feet or more (depending on the auger size), but generally boreholes are augered to depths less than 100 feet.

2.2.2 Solid Stem Auger

This type of auger consists of a sealed hollow or solid stem or shaft with a continuous spiraled steel flight welded on the outside of the stem. An auger bit connected to the bottom disturbs soil material when rotated and the helical flights transport cuttings to the surface. At the desired depth the entire auger string is removed to gain access to the bottom of the borehole. This auger method is used in cohesive and semi-cohesive soils that do not have a tendency to collapse when disturbed. Boreholes can be augered to depths of 200 feet or more (depending on the auger size), but generally boreholes are augered to depths less than 100 feet.

Both of the previously discussed auger methods can be used in unconsolidated soils and semi-consolidated (weathered rock) soils, but not in competent rock. Each method can be employed without introducing foreign materials into the borehole such as water and drilling fluids, minimizing the potential for cross contamination. Minimizing the risk of cross contamination is one of the most important factors to consider when selecting the appropriate drilling method(s) for a project.

2.2.3 Sonic Methods

These methods generally alternately advance concentric hollow drill stems using rotation in conjunction with axial vibration of the drill stem. After each stage of drill stem advancement, the inner string is removed with a core of drill cuttings while the outer 'override' string remains to hold the borehole open. The cuttings can be removed nearly intact from the inner casing for examination of the stratigraphy prior to sampling or disposal. Because there are no auger flights to increase the borehole diameter, the quantity of cuttings removed from the hole is minimized as compared to hollow stem augering. With moderate rotation, smearing of the formation materials on the borehole walls is reduced as well. This drilling method is useful in a variety of materials, from flowing sands to heavily consolidated or indurated formations.

In flowing sands, the drill casings can be filled and/or pressurized with potable water to prevent excess entry of formation materials into the drill string. The same QA/QC requirements for sampling of material introduced to the borehole apply as in other drilling methods. Because the amount of water introduced into the borehole can be significant, an approximation of the water used in the drilling process should be logged for use in estimating appropriate well development withdrawal.

Sonic drilling allows a larger diameter temporary casing to be set into a confining layer while drilling proceeds into deeper aquifers. This temporary casing is then removed during the grouting operation. In many cases this will be acceptable technique. However, the level of contamination in the upper aquifer, the importance of the lower aquifers for drinking water uses, the permeability and continuity of the confining layer, and state regulations should be taken into account when specifying this practice as opposed to permanent outer casing placed into the confining unit. Note that when using the temporary casing practice, it is critical that grout be mixed and placed properly as specified elsewhere in this section.

Because the total borehole diameter in sonic drilling is only incrementally larger than the inner casing diameter, particular care should be taken that the well casing is placed in the center of the drill stem while placing the filter pack. Centralizers should be used in most cases to facilitate centering, particularly in the case of deep wells with PVC casing.

2.2.4 Rotary Methods

These methods consist of a drill pipe or drill stem coupled to a drilling bit that rotates and cuts through the soils. The cuttings produced from the rotation of the drilling bit are transported to the surface by drilling fluids which generally consist of water, drilling mud, or air. The water, drilling mud, or air are forced down through the drill pipe, and out through the bottom of the drilling bit. The cuttings are then lifted to the surface between the borehole wall and the drill pipe, (or within a concentric drill stem in reverse rotary). Except in the case of air rotary, the drilling fluid provides a hydrostatic pressure that reduces or prevents borehole collapse. When considering this method, it is important to evaluate the potential for contamination when fluids and/or air are introduced into the borehole.

Due to the introduction of the various circulating fluids, the use of rotary methods requires that the potential for contamination by these fluids be evaluated. Water and mud rotary methods present the possibility of trace contamination of halogenated compounds when municipal water supplies are used as a potable water source. Air rotary drilling can introduce contamination through the use of lubricants or entrained material in the air stream. Unless contaminated formations are cased off, the circulation of drilling fluids presents a danger of cross contamination between formations. In any of the rotary (or sonic) methods, care must be exercised in the selection and use of compounds to prevent galling of drill stem threads.

2.2.4.1 Water Rotary

When using water rotary, potable water (that has been analyzed for contaminants of concern) should be used. If potable water (or a higher-quality water) is not available on-site, then potable water will have to be transported to the site or an alternative drilling method will have to be selected. Water does not clog the formation materials, but the suspended drilling fines can be carried into the formation, resulting in a very difficult to develop well. This method is most appropriate for setting isolation casing.

2.2.4.2 Air Rotary

Air rotary drilling uses air as a drilling fluid to entrain cuttings and carry them to the surface. High air velocities, and consequently large air volumes and compressor horsepower are required. “Down-the-hole” (DTH) percussion hammers driven by the air stream can be used with this method to rapidly penetrate bedrock materials. Where a casing through unconsolidated material is required to prevent borehole collapse, it can be driven in conjunction with advancement of the drill stem.

When using air rotary drilling in any zone of potential contamination, the cuttings exiting the borehole must be controlled. This can be done using the dual-tube reverse circulation method where cuttings are carried to the surface inside dual-wall drill pipe and separated with a cyclone separator. An air diverter with hose or pipe carrying cuttings to a waste container is also an acceptable alternative. Allowing cuttings to blow uncontrolled from the borehole is not acceptable.

When using air rotary, the issue of contaminants being introduced into the borehole by the air stream must be addressed. Screw compressor systems should have a coalescing filter system in good working order to capture excess entrained compressor oils. The lubricant to be used with DTH hammers as well as thread lubricants to be used on drill stem should be evaluated for their potential impact on analytical samples.

2.2.4.3 Mud Rotary

Mud rotary is an undesirable drilling method because contamination can be introduced into the borehole from the constituents in the drilling mud, cross contamination can occur along the borehole column, and it is difficult to remove the drilling mud from the borehole after drilling and during well development. The drilling mud can also carry contaminates from a contaminated zone to an uncontaminated zone thereby cross-contaminating the borehole. If mud rotary is selected, only potable water and pure (no additives) bentonite drilling muds should be used. All materials used should have adequate documentation as to manufacturer's recommendations and product constituents. QA/QC samples of drilling muds and potable water should be sampled at a point of discharge from the circulation system to assure that pumps and piping systems are not contributing cross-contamination from previous use.

2.2.5 Direct Push Technology

Direct Push Technology (DPT) uses hollow drive rods either driven percussively or by large forces from a rig weighted or anchored to the ground. Percussive rigs are used for general soil and groundwater investigations and the push only rigs are generally used for cone penetrometer testing (CPT). DPT does not bring cuttings to the surface but instead compresses them into the borehole walls. A variety of tool systems are available to perform soil sampling, groundwater sampling, well installation, and to profile contamination with in situ systems. The light tooling, small crews required, and reduced IDW can make DPT operations an economical investigation tool. Although significant depths have been explored with DPT, investigations are generally limited to 100 ft (and more practically 50 ft.) in unconsolidated materials.

2.2.6 Other Methods

Other methods such as the cable-tool method, jetting method, and boring (bucket auger) method are available. If these and/or other methods are selected for monitoring well installations, they should be approved by a senior field geologist before field work is initiated.

2.3 Borehole Construction

2.3.1 Annular Space

The borehole or hollow stem auger should be of sufficient diameter so that well construction can proceed without major difficulties. For open boreholes, the annular space should be approximately 2" to allow the uniform deposition of well materials around the screen and riser, and to allow the passage of tremie pipes and well materials without unduly disturbing the borehole wall. For example, a 2" nominal diameter (nom.) casing would require a 6" inside diameter (ID) borehole.

In hollow stem augers and sonic method drill casing, the ID should be of sufficient size to allow the passage of the tremie pipe to be used for well grout placement, as well as free passage of filter sands or bentonite pellets dropped through the auger or casing. In general, 4-1/4" ID should be the minimum size used for placement of 2" nom. casing and 8-1/4" ID for 4" nom. casing. Larger augers should be used where installation difficulties due to geologic conditions or greater depths are anticipated, e.g. larger augers might be required to place a bentonite pellet seal through a long water column.

2.3.2 Over-drilling the Borehole

Sometimes it is necessary to over-drill the borehole in anticipation of material entering the augers during center bit removal or knocking out of the bottom plug. Normally, 3 to 5 feet is sufficient for over-drilling. The borehole can also be over-drilled to allow for an extra space or a "sump" area below the well screen. This "sump" area provides a space to attach a 5 or 10 foot section of well casing to the bottom of the well screen. The extra space or "sump" below the well screen serves as a catch basin or storage area for sediment that flows into the well and drops out of suspension. These "sumps" are added to the well screens when the wells are screened in aquifers that are naturally turbid and will not yield clear formation water (free of visible sediment) even after extensive development. The sediment can then be periodically pumped out of the "sump" preventing the well screen from clogging or "silting up". If the borehole is inadvertently drilled deeper than desired, it can be backfilled to the design depth with bentonite pellets, chips, or the filter sand that is to be used for the filter pack.

2.3.3 Filter Pack Placement

When placing the filter pack into the borehole, a minimum of 6-inches of the filter pack material should be placed under the bottom of the well screen to provide a firm base. Also, the filter pack should extend a minimum of 2-feet above the top of the well screen to allow for settling and to isolate the screened interval from the grouting material. In open boreholes, the filter pack should be placed by the tremie or positive displacement method. Placing the filter pack by pouring the sand into an open drill stem is acceptable with the use hollow stem augers, and other methods where the borehole is temporarily cased down to the filter pack.

2.3.4 Filter Pack Seal – Bentonite Pellet Seal (Plug)

Bentonite pellets consist of ground, dried bentonite compacted into pellets available in several sizes. Bentonite pellets are compressed to a bulk density of 70-80 lbs/ft^3 and hydrate to a 30% min. solids material. Where neat cement grouts are to be used, the placement of a bentonite pellet seal above the filter pack is mandatory to prevent the possibility of grout infiltration into the screened interval prior to setting. Bentonite chips or other sealing products should not be substituted in this application. Where bentonite grouts are to be used, the placement of a bentonite pellet seal is optional, but desirable.

Since bentonite pellets begin hydrating rapidly, they can be very difficult to place properly. They are generally placed by pouring slowly into open boreholes, hollow stem augers or sonic drill pipe. In some cases, pellets are placed by tremie pipe and flushed into place with potable water. A tamper can be used to ensure that the material is being placed properly and to rapidly break up any pellet bridging that occurs.

Pellet seals should be designed for a two-foot thickness of dry pellets above the filter pack. Hydration may extend the height of the seal. Where neat cement grouts are to be used, the pellets should be hydrated for eight hours, or the manufacturer's recommended hydration time, whichever is greater. Where the water table is temporarily below the pellet seal, potable (or higher quality) water should be added repeatedly to hydrate the pellets prior to grouting.

2.3.5 Grouting the Annular Space

The annular space between the casing and the borehole wall should be filled with either a 30% solids bentonite grout, a neat cement grout, or a cement/bentonite grout. Each type of grout selected should be evaluated as to its intended use and integrity. Bentonite grouts are preferred unless the application dictates the use of another material.

Bentonite grout shall be a 30% solids pure bentonite grout. Drilling muds are not acceptable for grouting. The grout should be placed into the borehole, by the tremie method, from the top of the bentonite seal to within 2-feet of the ground surface or below the frost line, whichever is the greater depth. The bentonite pellet seal or filter pack should not be disturbed during grout placement, either by the use of a side discharge port on the tremie tube, or by maintaining clearance between the bottom of the tremie tube and the bentonite seal or filter pack. The grout should be allowed to cure for a minimum of 24 hours before the concrete surface pad is installed. The preferred method of achieving proper solids content is by measurement of ingredients per the manufacturer's specifications during mixing with a final check by grout balance after mixing. Bentonite grouts should have a minimum density of 10 lbs/gal to ensure proper gelling and low permeability. The density of the first batch of grout should be measured while mixing to verify proper measurement of ingredients. In addition, the grouting operation should not cease until the bentonite grout flowing out of the borehole has a minimum density of 10 lbs/gal. Estimating the grout density is not acceptable.

Cement grouts are generally dictated where a high level of dissolved solids or a particular dissolved constituent would prevent proper gelling of a bentonite grout. Neat cement grouts (cement without additives) should be mixed using 6 gallons of water per 94-lb bag of Type 1 Portland cement to a density of 15lbs/gal. The addition of bentonite (5 to 10 percent) to the cement grout can be used to delay the "setting" time and may not be needed in all applications. The specific mixtures and other types of cement and/or grout proposed should be evaluated on a case by case basis by a senior field geologist.

2.3.6 Above Ground Riser Pipe and Outer Casing

The well casing, when installed and grouted, should extend above the ground surface a minimum of 2.5 feet. A vent hole should be drilled into the top of the well casing cap to permit pressure equalization, if applicable. An outer protective casing should be installed into the borehole after the annular grout has cured for at least 24 hours. The outer protective casing should be of steel construction with a hinged, locking cap. Generally, outer protective casings used over 2-inch well casings are 4 inches square by 5 feet long. Similarly, protective casings used over 4-inch well casings are 6 inches square and 5 feet long. Other types of protective casing including those constructed of pipe are also acceptable. All protective casings should have sufficient clearance around the inner well casings, so that the outer protective casings will not come into contact with the inner well casings after installation. The protective casings should have a weep hole to allow drainage of accumulated rain or spilled purge water. The weep hole should be approximately 1/4-inch in diameter and drilled into the protective casings just above the top of the concrete surface pad to prevent water from standing inside of the protective casings. Protective casings made of aluminum or other soft metals are normally not acceptable because they are not strong enough to resist tampering. Aluminum protective casing may be used in very corrosive environments such as coastal areas.

Prior to installing the protective casing, the bentonite grout in the borehole annulus is excavated to a depth of approximately two feet. The protective casing is installed by pouring concrete into the borehole on top of the grout. The protective casing is then pushed into the wet concrete and borehole a minimum of 2 feet. Extra concrete may be needed to fill the inside of the protective casing so that the level of the concrete inside of the protective casing is at or above the level of the surface pad. In areas where frost heave of the surface pad is possible, the protective casing should first be pressed into the top surface of the bentonite grout seal and concrete poured around the protective casing. A granular material such as sand or gravel can then be used to fill the space between the riser and protective casing. The use of granular material instead of concrete between the protective casing and riser will also facilitate the future conversion of the well to a flush-mount finish, if required.

The protective casing should extend above the ground surface to a height so that the top of the inner well casing is exposed when the protective casing is opened. At each site, all locks on the outer protective casings should be keyed alike.

2.3.7 Concrete Surface Pad

A concrete surface pad should be installed around each well at the same time as the outer protective casing is being installed. The surface pad should be formed around the well casing. Concrete should be placed into the pad forms and into the borehole (on top of the grout) in one operation making a contiguous unit. The size of the concrete surface pad is dependent on the well casing size. If the well casing is 2 inches in diameter, the pad should be 3 feet x 3 feet x 4 inches. If the well casing is 4 inches in diameter, the pad should be 4 feet x 4 feet x 6 inches. Round concrete surface pads are also acceptable. The finished pad should be slightly sloped so that drainage will flow away from the protective casing and off of the pad. A minimum of one inch of the finished pad should be below grade to prevent washing and undermining by soil erosion.

2.3.8 Surface Protection – Bumper Guards

If the monitoring wells are located in a high traffic area, a minimum of three bumper guards consisting of steel pipes 3 to 4 inches in diameter and a minimum 5-foot length should be installed. These bumper guards should be installed to a minimum depth of 2 feet below the ground surface in a concrete footing and extend a minimum of 3 feet above ground surface. Concrete should also be placed into the steel pipe to provide additional strength. Substantial steel rails and/or other steel materials can be used in place of steel pipe. Welding bars between the bumper posts can provide additional strength and protection in high traffic areas, but the protective bumpers should not be connected to the protective casing.

2.4 Construction Techniques

2.4.1 Well Installation

The borehole should be bored, drilled, or augered as close to vertical as possible, and checked with a plumb bob or level. Deviation from plumb should be within 1° per 50ft of depth. Slanted boreholes are undesirable and should be noted in the boring logs and final construction logs. The depth and volume of the borehole, including the over-drilling if applicable, should have been calculated and the appropriate materials procured prior to drilling activities.

The well casings should be secured to the well screen by flush-jointed threads and placed into the borehole and plumbed by the use of centralizers and/or a plumb bob and level. Another method of placing the well screen and casings into the borehole and plumbing them at the same time is to suspend the string of well screen and casings in the borehole by means of a hoist on the drill rig. This wireline method is especially useful if the borehole is deep and a long string of well screen and casings have to be set and plumbed.

No lubricating oils or grease should be used on casing threads. No glue of any type should be used to secure casing joints. Viton® O-rings can be used where the joints are designed for same.

Before the well screen and casings are placed on the bottom of the borehole, at least 6 inches of filter material should be placed at the bottom of the borehole to serve as a firm footing. The string of well screen and casings should then be placed into the borehole and plumbed. Centralizers can be used to plumb a well, but centralizers should be placed so that the placement of the filter pack, bentonite pellet seal, and annular grout will not be hindered. Centralizers placed in the wrong locations can cause bridging during material placement. Monitoring wells less than 50 feet deep generally do not need centralizers. If centralizers are used they should be placed below the well screen and above the bentonite pellet seal. The specific placement intervals should be decided based on site conditions.

When installing the well screen and casings through hollow-stem augers, the augers should be slowly extracted as the filter pack, bentonite pellet seal, and grout are tremied and/or poured into place. The gradual extraction of the augers will allow the materials being placed in the augers to flow out of the bottom of the augers into the borehole. If the augers are not gradually extracted, the materials (sand, pellets, etc.) will accumulate at the bottom of the augers causing potential bridging problems.

After the string of well screen and casing is plumb, the filter pack material should then be placed around the well screen to the designated depth. With cased drilling methods, the sand should be poured into the casing or augers until the lower portion is filled. The casing or augers are then withdrawn, allowing the sand to flow into the evacuated space. With hollow stem augers, sand should always fill the augers 6-12 inches, maintained by pouring the sand while checking the level with a weighted tag line. The filter pack sand in open boreholes should be installed by tremie methods, using water to wash the sand through the pipe to the point of placement.

After the filter pack has been installed, the bentonite pellet seal (if used) should be placed directly on top of the filter pack to an unhydrated thickness of two feet. When installing the seal for use with cement grouts, the bentonite pellet seal should be allowed to hydrate a minimum of eight hours or the manufacturer's recommended hydration time, whichever is longer.

After the pellet seal has hydrated for the specified time, the grout should then be pumped by the tremie method into the annular space around the casings. The grout should be allowed to set for a minimum of 24 hours before the surface pad and protective casing are installed.

After the surface pad and protective casing are installed, bumper guards should be installed (if needed). The bumper guards should be placed around the concrete surface pad in a configuration that provides maximum protection to the well. Each piece of steel pipe or approved material should be installed into an 8-to 10-inch diameter hole, to a minimum depth of 2 feet below ground surface, and filled with concrete. As previously stated, the bumper guard should extend above the ground surface a minimum of 3 feet. The total length of each bumper guard should be a minimum of 5 feet.

After the wells have been installed, the outer protective casing should be painted with a highly visible paint. The wells should be permanently marked with the well number, date installed, site name, elevation, etc., either on the cover or an appropriate place that will not be easily damaged and/or vandalized.

If the monitoring wells are installed in a high traffic area such as a parking lot, in a residential yard, or along the side of a road it may be desirable to finish the wells to the ground surface and install water-tight flush mounted traffic and/or man-hole covers. Flush mounted traffic and man-hole covers are designed to extend from the ground surface down into the concrete plug around the well casing. Although flush mounted covers may vary in design, they should have seals that make the unit water-tight when closed and secured. The flush mounted covers should be installed slightly above grade to minimize standing water and promote runoff. Permanent identification markings should be placed on the covers or in the concrete plug around the cover. Expansive sealing plugs should be used to cap the well riser to prevent infiltration of any water that might enter the flush cover.

2.4.2 Double-Cased Wells

Double-cased wells should be constructed when there is reason to believe that interconnection of two aquifers by well construction may cause cross-contamination or when flowing sands make it impossible to install a monitoring well using conventional methods. A highly contaminated surface soil zone may also be cased off so that drilling may continue below the casing with reduced danger of cross contamination. A pilot borehole should be bored through the overburden and/or the contaminated zone into the clay confining layer or bedrock. An outer casing (sometimes called surface or pilot casings) should then be placed into the borehole and sealed with grout. The borehole and outer casing should extend into tight clay a minimum of two feet and into competent bedrock a minimum of 1 foot. The total depths into the clay or bedrock will vary, depending on the plasticity of the clay and the extent of weathering and\or fracturing of the bedrock. The final depths should be approved by a senior field geologist. The size of the outer casing should be of sufficient inside diameter to contain the inner casing, and the 2-inch minimum annular space. In addition, the borehole should be of sufficient size to contain the outer casing and the 2-inch minimum outer annular space, if applicable.

The outer casing should be grouted by the tremie, displacement, grout shoe, or Halliburton method from the bottom to the ground surface. The grout should be pumped into the annular space between the outer casing and the borehole wall. A minimum of 24 hours should be allowed for the grout plug (seal) to cure before attempting to drill through it. The grout mixture used to seal the outer annular space should be either a neat cement, cement/bentonite, cement/sand, or a 30% solids bentonite grout. However, the seal or plug at the bottom of the borehole and outer casing should consist of a Type I portland cement/bentonite or cement/sand mixture. The use of a pure bentonite grout for a bottom plug or seal is not acceptable, because the bentonite grout cures to a gel-like material, and is not rigid enough to withstand the stresses of drilling. When drilling through the seal, care should be taken to avoid cracking, shattering, or washing out the seal. If caving conditions exist so that the outer casing cannot be sufficiently sealed by grouting, the outer casing should be driven into place and a grout seal placed in the bottom of the casing.

2.4.2.1 Bedrock Wells

The installation of monitoring wells into bedrock can be accomplished in two ways:

1. The first method is to drill or bore a pilot borehole through the soil overburden into the bedrock. An outer casing is then installed into the borehole by setting it into the bedrock, and grouting it into place as described in the previous section. After the grout has set, the borehole can then be advanced through the grout seal into the bedrock. The preferred method of advancing the borehole into the bedrock is rock coring. Rock coring makes a smooth, round hole through the seal and into the bedrock without cracking and/or shattering the seal. Roller cone bits are used in soft bedrock, but extreme caution should be taken when using a roller cone bit to advance through the grout seal in the bottom of the borehole because excessive water and "down" pressure can cause cracking, eroding (washing), and/or shattering of the seal. Low volume air hammers may be used to advance the borehole, but they have a tendency to shatter the seal because of the hammering action. If the structural integrity of the grout seal is in question, a pressure test can be utilized to check for leaks. A visual test can also be made by examining the cement/concrete core that is collected when the seal is cored with a diamond coring bit. If the seal leaks (detected by pressure testing) and/ or the core is cracked or shattered, or if no core is recovered because of washing, excessive down pressure, etc., the seal is not acceptable. The concern over the structural integrity of the grout seal applies to all double cased wells. Any proposed method of double casing and/or seal testing will be evaluated on its own merits, and will have to be approved by a senior field geologist before and during drilling activities, if applicable. When the drilling is complete, the finished well will consist of an open borehole from the ground surface to the bottom of the well. There is no inner casing, and the outer surface casing, installed down into bedrock, extends above the ground surface, and also serves as the outer protective casing. If the protective casing becomes cracked or is sheared off at the ground surface, the well is open to direct contamination from the ground surface and will have to be repaired

immediately or abandoned. Another limitation to the open rock well is that the entire bedrock interval serves as the monitoring zone. In this situation, it is very difficult or even impossible to monitor a specific zone, because the contaminants being monitored could be diluted to the extent of being non-detectable. The installation of open bedrock wells is generally not acceptable in the Superfund and RCRA programs, because of the uncontrolled monitoring intervals. However, some site conditions might exist, especially in cavernous limestone areas (karst topography) or in areas of highly fractured bedrock, where the installation of the filter pack and its structural integrity are questionable. Under these conditions the design of an open bedrock well may be warranted.

2. The second method of installing a monitoring well into bedrock is to install the outer surface casing and drill the borehole (by an approved method) into bedrock, and then install an inner casing and well screen with the filter pack, bentonite seal, and annular grout. The well is completed with a surface protective casing and concrete pad. This well installation method gives the flexibility of isolating the monitoring zone(s) and minimizing inter-aquifer flow. In addition, it gives structural integrity to the well, especially in unstable areas (steeply dipping shales, etc.) where the bedrock has a tendency to shift or move when disturbed. Omitting the filter pack around the well screen is a general practice in some open rock borehole installations, especially in drinking water and irrigation wells. However, without the filter pack to protect the screened interval, sediment particles from the well installation and/or from the monitoring zone could clog the well screen and/or fill the screened portion of the well rendering it inoperable. Also, the filter pack serves as a barrier between the bentonite seal and the screened interval. Rubber inflatable packers have been used to place the bentonite seal when the filter pack is omitted, but the packers have to remain in the well permanently and, over a period of time, will decompose and possibly contribute contaminants to the monitoring zone.

2.5 Well Construction Materials

2.5.1 Introduction

Well construction materials are chosen based on the goals and objectives of the proposed monitoring program and the geologic conditions at the site(s). In this section, the different types of available materials will be discussed.

2.5.2 *Well Screen and Casing Materials*

When selecting the materials for well construction, the prime concern should be to select materials that will not contribute foreign constituents, or remove contaminants of concern from the ground water. If the monitoring program is designed to analyze for organic compounds, stainless steel materials are the preferred choice. If the monitoring program calls for the analyses of only inorganic compounds or the contaminants or formation are highly corrosive, then rigid PVC materials meeting National Sanitary Foundation (NSF) Standard 14 type WC (Well Casing) are acceptable. PVC materials may be acceptable for monitoring identified organic compounds in a soluble aqueous phase where incompatibilities are known to not exist. EPA document EPA/540/S-95/503, *Nonaqueous Phase Liquids Compatibility with Materials Used in Well Construction, Sampling, and Remediation* should be used for guidance in this area and in the use of PVC with non-aqueous phase liquids (NAPLs). Another concern is to select materials that will be rugged enough to endure the entire monitoring period. Site conditions will generally dictate the type of materials that can be used. A preliminary field investigation should be conducted to determine the geologic conditions, so that the most suitable materials can be selected. The best grade or highest quality material for that particular application should be selected. Each manufacturer can supply the qualitative data for each grade of material that is being considered. All materials selected for monitoring well installation should be evaluated and approved by a senior field geologist prior to field activities.

Well screen and casing materials generally used in monitoring well construction on RCRA and Superfund sites are listed in order of preference:

1. Stainless Steel (304 or 316)
2. Rigid PVC meeting NSF Standard 14 (type WC)
3. Other (where applicable)

There are other materials used for well screens and casings such as black iron, carbon steel, galvanized steel, and fiberglass, but these materials are not recommended for use in long term monitoring programs at hazardous waste sites, because of their low resistance to chemical attack and potential constituent contribution to the ground water. In cases where a driven casing is used, or a high strength outer casing is needed, carbon steel may be acceptable in non-corrosive aquifers. This outer casing should have threaded connections. Welding casing is not an acceptable practice unless all relevant safety issues have been adequately addressed.

The minimum nominal casing size for most permanent monitoring wells will be 2". Where a complete program of installation, monitoring, and abandonment is being designed, smaller wells may be installed if suitable purging and sampling equipment for the smaller diameter wells can be specified and obtained. The length of well screens in permanent monitoring wells should be long enough to effectively monitor the interval or zone of interest. However, well screens designed for long term monitoring purposes should normally not be less than 5 feet in length. Well screens less than 5 feet long are generally only used in temporary monitoring wells where ground water samples are collected for screening purposes.

2.5.3 Filter Pack Materials

The filter pack materials should consist of clean, rounded to well-rounded, hard, insoluble particles of siliceous composition. The required grain-size distribution or particle sizes of the filter pack materials should be selected based upon a sieve analysis conducted on the soil samples collected from the aquifer materials and/or the formation(s) to be monitored. Filter pack materials should not be accepted unless proper documentation can be furnished as to the composition, grain-size distribution, cleaning procedure, and chemical analysis. If a data search reveals that there is enough existing data to adequately design the well screen and filter pack, then it may not be necessary to conduct a sieve analysis on the formation materials to be monitored. However, all data and design proposals will be evaluated and approved by a senior staff geologist before field activities begin.

2.5.4 Filter Pack and Well Screen Design

The majority of monitoring wells are installed in shallow ground water aquifers that consist of silts, clays, and sands in various combinations. These shallow aquifers are not generally characteristic of aquifers used for drinking water. Therefore, modifications to the procedures used for the design of water well filter packs may be required. In cases where insufficient experience exists with local or similar materials, the filter pack and well screen design should be based on the results of a sieve analysis conducted on soil samples collected from the aquifer or the formation(s) that will be monitored.

In formations consisting primarily of fines (silts and clays), the procedures for water well screen design may result in requirements for filter packs and screen slot sizes that are not available. In those cases the selection of 0.010" screen slots with a 20-40 sand filter pack, or 0.005" screen slots with 100 sand filter pack for very fine formations, will be acceptable practice. Table 6.6.1 provides size specifications for the selection of sand packs for fine formation materials. ASTM standard D5092, *Design and Installation of Ground Water Monitoring Wells in Aquifers*, may be consulted for further guidance on specifications for sand appropriate for these applications.

Table 6.6.1
Sand Pack Specifications

Screen Opening (in)	Sand Pack Mesh Name	1% Passing Size (d-1) (in)	10% Passing Size (d-10) (in)	30% Passing Size (d-30) (in)	Derived 60% Passing Size (d-60) (in)	Range for Uniformity Coefficient
0.005-0.006	100	.0035 - .0047	.0055 - .0067	.0067 - .0083	.0085 - .0134	1.3 - 2.0
0.010"	20-40	.0098 - .0138	.0157 - .0197	.0197 -.0236	.020 - .0315	1.1 - 1.6

The following procedure should be used in coarser grained formations:

The data from the sieve analysis are plotted on a grain-size distribution graph, and a grain-size distribution curve is generated. From this grain-size distribution curve, the uniformity coefficient (Cu) of the aquifer material is determined. The Cu is the ratio of the 60 percent finer material (d60) to the 10 percent finer material (d10)

$$Cu = (d60/d10)$$

The Cu ratio is a way of grading or rating the uniformity of grain size. For example, a Cu of unity means that the individual grain sizes of the material are nearly all the same, while a Cu with a large number indicates a large range of particle sizes. As a general rule, a Cu of 2.5 or less should be used in designing the filter pack and well screen.

Before designing the filter pack and well screen, the following factors should be considered:

1. Select the well screen slot openings that will retain 90 percent of the filter pack material.

2. The filter pack material should be of the size that minimizes head losses through the pack and also prevents excessive sediment (sand, silt, clay) movement into the well.

3. A filter material of varying grain sizes is not acceptable because the smaller particles fill the spaces between the larger particles thereby reducing the void spaces and increasing resistance to flow. Therefore, filter material of the same grain size and well-rounded is preferred.

4. The filter pack design is based on the gradation of the finest aquifer materials being analyzed.

Steps to design a filter pack in aquifers:

1. Construct a grain-size distribution curve, on a grain-size distribution graph, from the sieve analysis of the aquifer materials. The filter pack design (as stated above) is based on the gradation of the finest aquifer materials.

2. Multiply the d30 size from the grain-size distribution graph by a factor of four to nine (Pack-Aquifer ratio). A factor of four is used if the formation is fine-grained and uniform (Cu is less than 3), six if it is coarse-grained and non-uniform, and up to nine if it is highly non-uniform and contains silt. Head losses through filter packs increase as the Pack-Aquifer (P-A) ratios decrease. In order to design a fairly stable filter pack with a minimum head loss, the d30 size should be multiplied by a factor of four.

3. Plot the point from step 2 on the d30 abscissa of a grain-size distribution graph and draw a smooth curve with a uniformity coefficient of approximately 2.5.

4. A curve for the permissible limits of the filter pack is drawn plus or minus 8 per cent of the desired curve with the Cu of 2.5.

5. Select the slot openings for the well screen that will retain 90 per cent or more of the filter pack material.

The specific steps and procedures for sieve analysis and filter pack design can be found in soil mechanics, ground water, and water well design books. The staff geologists and/or engineers should be responsible for the correct design of the monitoring wells and should be able to perform the design procedures.

2.6 Safety Procedures for Drilling Activities

A site health and safety plan should be developed and approved by the Branch Safety Officer or designee prior to any drilling activities, and should be followed during all drilling activities. The driller or designated safety person should be responsible for the safety of the drilling team performing the drilling activities. All personnel conducting drilling activities should be qualified in proper drilling and safety procedures. Before any drilling activity is initiated, utilities should be marked or cleared by the appropriate state or municipal utility protection organization. In developed areas, additional measures should be taken to locate utilities not covered by the utility protection program. Before operating the drill rig, a pilot hole should be dug (with hand equipment) to a depth of three feet to check for undetected utilities or buried objects. Proceed with caution until a safe depth is reached where utilities normally would not be buried. The following safety requirements should be adhered to while performing drilling activities:

1. All drilling personnel should wear safety hats, safety glasses, and steel toed boots. Ear plugs are required and will be provided by the safety officer or driller.

2. Work gloves (cotton, leather, etc.) should be worn when working around or while handling drilling equipment.

3. All personnel directly involved with the drilling rig(s) should know where the kill switch(s) is located in case of emergencies.

4. All personnel should stay clear of the drill rods or augers while in motion, and should not grab or attempt to attach a tool to the drill rods or augers until they have completely stopped rotating. Rod wipers, rather than gloves or bare hands should be used to remove mud, or other material, from drill stem as it is withdrawn from the borehole.

5. Do not hold drill rods or any part of the safety hammer assembly while taking standard penetration tests or while the hammer is being operated.

6. Do not lean against the drill rig or place hands on or near moving parts at the rear of the rig while it is operating.

7. Keep the drilling area clear of any excess debris, tools, or drilling equipment.

8. The driller will direct all drilling activities. No work on the rig or work on the drill site will be conducted outside of the driller's direction. Overall drill site activities will be in consultation with the site geologist or engineer, if present.

9. Each drill rig will have a first-aid kit and a fire extinguisher located on the rig in a location quickly accessible for emergencies. All drilling personnel will be familiarized with their location.

10. Work clothes will be firm fitting, but comfortable and free of straps, loose ends, strings etc., that might catch on some moving part of the drill rig.

11. Rings, watches, or other jewelry will not be worn while working around the drill rig.

12. The drill rig should not be operated within a minimum distance of 20 feet of overhead electrical power lines and/or buried utilities that might cause a safety hazard. In addition, the drill rig should not be operated while there is lightening in the area of the drilling site. If an electrical storm moves in during drilling activities, the area will be vacated until it is safe to return.

2.7 Well Development

A newly completed monitoring well should not be developed for at least 24 hours after the surface pad and outer protective casing are installed. This will allow sufficient time for the well materials to cure before development procedures are initiated. The main purpose of developing new monitoring wells is to remove the residual materials remaining in the wells after installation has been completed, and to try to re-establish the natural hydraulic flow conditions of the formations which may have been disturbed by well construction, around the immediate vicinity of each well. A new monitoring well should be developed until the column of water in the well is free of visible sediment, and the pH, temperature, turbidity, and specific conductivity have stabilized. In most cases the above requirements can be satisfied; however, in some cases the pH, temperature, and specific conductivity may stabilize but the water remains turbid. In this case the well may still contain well construction materials, such as drilling mud in the form of a mud cake and/or formation soils that have not been washed out of the borehole. Excessive or thick drilling mud cannot be flushed out of a borehole with one or two well volumes of flushing. Continuous flushing over a period of several days may be necessary to complete the well development. If the well is pumped to dryness or near dryness, the water table should be allowed to sufficiently recover (to the static water level) before the next development period is initiated. Caution should be taken when using high rate pumps and/or large volume air compressors during well development because excessive high rate pumping and high air pressures can damage or destroy the well screen and filter pack. The onsite geologist should make the decision as to the development completion of each well. All field decisions should be documented in the field log book.

The following development procedures, listed in approximate increasing order of the energy applied to the formation materials, are generally used to develop wells:

1. Bailing
2. Pumping/overpumping
3. Surging
4. Backwashing ("rawhiding")
5. Jetting
6. Compressed air (with appropriate filtering): airlift pumping and air surging

These development procedures can be used, individually or in combination, in order to achieve the most effective well development. In most cases, over-pumping and surging will adequately develop the well without imparting undue forces on the formation or well materials. Because of the danger of introducing contaminants with the airstream, the possibility of entraining air in the aquifer, and the violent forces imparted to the formation, air surging is the least desired method of development and should only be used where there is a specific need for the procedure. Air-lift pumping is permissible where an eductor pipe is used and several well volumes of water are removed from the well by other pumping means after air-lift pumping. Additional time before the first sampling event should be allowed when using air development methods, particularly airlift. The selected development method(s) should be approved by a senior field geologist before any well installation activities are initiated.

Wells can require a considerable length of time to equilibrate with the aquifer after construction and development. The length of time between development and the first sampling event should be as long as possible with times from 1 to 14 days recommended. The possibility of the first sampling event’s results being non-representative should always be considered.

2.8 Well Decommissioning (Abandonment)

When a decision is made to decommission (abandon) a monitoring well, the borehole should be sealed in such a manner that the well cannot act as a conduit for migration of contaminants from the ground surface to the water table or between aquifers. To properly decommission a well, the preferred method is to completely remove the well casing and screen from the borehole, clean out the borehole, and backfill with a cement or bentonite grout, neat cement, or concrete. In order to comply with state well decommissioning requirements, the appropriate state agency should be notified (if applicable) of monitoring well decommissioning. However, some state requirements are not explicit, so a technically sound well abandonment method should be designed based on the site geology, well casing materials, and general condition of the well(s).

2.8.1 Decommissioning Procedures

As previously stated, the preferred method should be to completely remove the well casing and screen from the borehole. This may be accomplished by augering with a hollow-stem auger over the well casing down to the bottom of the borehole, thereby removing the grout and filter pack materials from the hole. The well casing should then be removed from the hole with the drill rig. The clean borehole can then be backfilled with the appropriate grout material. The backfill material should be placed into the borehole from the bottom to the top by pressure grouting with the positive displacement method (tremie method). This abandonment method can be accomplished on small diameter (1-inch to 4-inch) wells without too much difficulty. With wells having 6-inch or larger diameters, the use of hollow-stem augers for casing removal is very difficult or almost impossible. Instead of trying to ream the borehole with a hollow-stem auger, it is more practical to force a drill stem with a tapered wedge assembly or a solid-stem auger into the well casing and extract it out of the borehole. Wells with little or no grouted annular space and/or sound well casings can be removed in this manner. However, old wells with badly corroded casings and/or thickly grouted annular space have a tendency to twist and/or break-off in the borehole. When this occurs, the well will have to be grouted with the remaining casing left in the borehole. The preferred method in this case should be to pressure grout the borehole by placing the tremie tube to the bottom of the well casing, which will be the well screen or the bottom sump area below the well screen. The pressurized grout will be forced out through the well screen into the filter material and up the inside of the well casing sealing holes and breaks that are present.

A PVC well casing may be more difficult to remove from the borehole than a metal casing, because of its brittleness. If the PVC well casing breaks during removal, the borehole should be cleaned out by using a drag bit or roller cone bit with the wet rotary method to grind the casing into small cuttings that will be flushed out of the borehole by water or drilling mud. Another method is to use a solid-stem auger with a carbide tooth pilot bit to grind the PVC casing into small cuttings that will be brought to the surface on the rotating flights. After the casing materials have been removed from the borehole, the borehole should be cleaned out and pressure grouted with the approved grouting materials.

Where state regulations and conditions permit, it may be permissible to grout the casing in place. This decision should be based on confidence in the original well construction practice, protection of drinking water aquifers, and anticipated future property uses. The pad should be demolished and the area around the casing excavated. The casing should be sawn off at a depth of three feet below ground surface. The screen and riser should be tremie grouted with a 30% solids bentonite grout. Pouring bentonite chips into the well will be acceptable with wells large enough for the chips to fall to the bottom (generally 4” or larger).

3 Temporary Monitoring Well Installation

3.1 Introduction

Five types of temporary monitoring well installation techniques have been demonstrated as acceptable. The type selected for a particular site is dependent upon site conditions. The project leader and site geologist should be prepared to test temporary well installations on site and select the best solution. Temporary wells are cost effective, may be installed quickly, and can provide a rapid assessment of ground water quality.

Temporary monitoring well locations are not permanently marked, nor are their elevations normally determined. Sand pack materials may or may not be used, but typically there is no bentonite seal, grout, surface completion, or extensive development (as it normally applies to permanent monitoring wells). Temporary wells are generally installed, purged, sampled, removed, and backfilled in a matter of hours.

Due to the nature of construction, turbidity levels may initially be high. However, these levels may be reduced by low flow purging and sampling techniques as described in SESD Operating Procedure for Groundwater Sampling, SESDPROC-301.

Temporary wells may be left overnight, for sampling the following day, but the well must be secured, both against tampering and against the fall hazard of the open annulus. If the well is not sampled immediately after construction, the well should be purged prior to sampling as specified in SESD Operating Procedure for Groundwater Sampling, SESDPROC-301.

3.2 Data Limitation

Temporary wells described in this section are best used for delineation of contaminant plumes at a point in time, for some site screening purposes, or for determination of groundwater elevations and gradients. They are not intended to replace permanent monitoring wells. Temporary wells can be used in conjunction with a mobile laboratory, where quick-turnaround analytical results can be used to rapidly delineate contaminant plumes.

3.3 Temporary Well Materials

Materials used in construction of temporary monitoring wells are the same standard materials used in the construction of permanent monitoring wells. Sand used for the filter pack (if any) should be as specified in Section 2.5.3, Filter Pack Materials. The well screen and casing should be stainless steel for ruggedness and suitability for steam cleaning and solvent rinsing. Other materials may be acceptable, on a case by case basis. Some commercially available temporary well materials, pre-packed riser, screen and filter pack assemblies are available commercially; however, these pre-assembled materials cannot be cleaned. Appropriate QA/QC must be performed to assure there will be no introduction of contamination.

3.4 Temporary Monitoring Well Borehole Construction

Borehole construction for temporary wells is as specified in Section 2.3, using a drill rig. Alternatively, boreholes may be constructed using hand augers or portable powered augers (generally limited to depths of ten feet or less). If a drill rig is used to advance the borehole, the augers must be pulled back the length of the well screen (or removed completely) prior to sampling. When hand augers are used, the borehole is advanced to the desired depth (or to the point where borehole collapse occurs). In situations where borehole collapse occurs, the auger bucket is typically left in the hole at the point of collapse while the temporary well is assembled. When the well is completely assembled, a final auger bucket of material is quickly removed and the well is immediately inserted into the borehole, pushing, as needed, to achieve maximum penetration into the saturated materials.

3.5 Temporary Monitoring Well Types

Five types of monitoring wells which have been shown to be acceptable are presented in the order of increasing difficulty to install and increasing cost:

3.5.1 No Filter Pack

This is the most common temporary well and is effective in many situations. After the borehole is completed, the casing and screen are simply inserted. This is the least expensive and fastest well to install. This type of well is extremely sensitive to turbidity fluctuations because there is no filter pack. Care should be taken to not disturb the casing during purging and sampling.

3.5.2 Inner Filter Pack

This type differs from the "No Filter Pack" well in that a filter pack is placed inside the screen to a level approximately 6 inches above the well screen. This ensures that all water within the casing has passed through the filter pack. For this type well to function properly, the static water level must be at least 6-12 inches above the filter pack. The screen slots may plug with this construction method.

3.5.3 Traditional Filter Pack

For this type of well, the screen and casing are inserted into the borehole, and the sand is poured into the annular space surrounding the screen and casing. It may be difficult to effectively place a filter pack in open boreholes, due to collapse.

3.5.4 Double Filter Pack

The borehole is advanced to the desired depth. As with the "inner filter pack" the well screen is filled with filter pack material and the well screen and casing inserted until the top of the filter pack is at least 6 inches below the water table. Filter pack material is poured into the annular space around the well screen. This type temporary well construction can be effective in aquifers where fine silts or clays predominate.

3.5.5 Well-in-a-Well

The borehole is advanced to the desired depth. At this point, a 1-inch well screen and sufficient riser is inserted into a 2-inch well screen with sufficient riser, and centered. Filter pack material is then placed into the annular space surrounding the 1-inch well screen, to approximately 6 inches above the screen. The well is then inserted into the borehole.

This system requires twice as much well screen and riser, with attendant increases in assembly and installation time. The increased amount of well construction materials results in a corresponding increase in decontamination time and costs. The use of pre-packed well screens in this application will require rinse blanks of each batch of screens. Pre-pack Screen assemblies cannot be decontaminated for reuse.

3.6 Decommissioning

Temporary well boreholes must be decommissioned after sampling and removal of the screen and riser. Use of cuttings for backfilling holes will not be acceptable practice.

4 Direct-Push Technology in Groundwater Investigations

4.1 Screen Point Samplers

Screen Point samplers allow temporary wells to be established quickly and can return high quality samples. The sampler consists of a stainless steel or PVC screen housed in a hollow steel sheath and topped with a drive cap to adapt to the drive rods in use. A disposable point is inserted in the bottom of the sheath and serves to prevent soil from entering the sheath and damaging the screen during driving.

After driving the sampler to the target depth, an inner rod is inserted to hold the screen down at the bottom of the borehole while the sheath and rods are withdrawn to expose the screen. The disposable point stays at the bottom of the borehole. The inner rod system is withdrawn and sampling can commence immediately.

O-rings are commonly used on the disposable point. The additional friction from the O-ring can prevent the point from being driven off of the sampler in loose material or when encountering a hollow space such as during redriving.

Screen point samplers are deployed to a specified interval. If a greater sampling depth is desired after deployment, the sampler must be withdrawn, reassembled with a new point, and redriven to the greater depth. The standard screens can be withdrawn to a shallower interval if needed, but the sampler would still be accessing the deeper aquifer to some extent.

4.1.1 Special Considerations for Screen Point Samplers

<u>Decommissioning (Abandonment)</u>

Like other wells, temporary screen points should be properly decommissioned. The most common means of decommissioning at SESD is to withdraw the screen point sampler, remove the screen, install a new disposable point, and redrive the sheath to the previously screened interval. A grouting head is attached to the probe rods, and grout pressure applied while withdrawing the rods to pull the disposable point free. The grout volume pumped is carefully managed to match the volume grouted during rod withdrawal.

Where preventing cross-connection of aquifers is critical or potential caving would prevent re-entry, a disposable screen can be used with some systems. The disposable screen is not linked to the sheath and will pull out and be left in the borehole. After sampling, the grouting head is attached to the rods, the rods pumped full of grout, and the sampler sheath is pulled off of the screen. Grouting proceeds as with re-entry grouting.

Geoprobe® Screen Points samplers have a feature available to knock a plug out of the bottom of the screen and thread a small diameter high-pressure grouting tube to the bottom of the borehole. Grout is pumped through the tubing while rods are withdrawn and left threaded over the tubing aboveground. As this system is unwieldy and cannot reliably pump grout over 20% solids, it is not used at SESD.

SESD pressure-grouts soil sampling boreholes by reentry grouting or tremie grouting when depths exceed 10 ft, or groundwater is encountered. Shallower boreholes can be decommissioned by pouring pellets in short lifts and hydrating each lift with water, or by pouring a pourable grout.

Screen Material Selection

The screen point screens are available in stainless steel and PVC. Because of stainless steel's durability, ability to be cleaned and re-used, and overall inertness and compatibility with most contaminants, it is the material most used for SESD investigations. When stainless steel screens are stowed wet, they should be segregated from carbon steel components. Contact of the stainless screens with carbon steel when wet will cause galvanic corrosion that will shed chrome-bearing material when first flushed.

4.2 Groundwater Profiling

Rapid investigations can be facilitated by the use of groundwater profiling systems. A groundwater profiler allows a sampler to be advanced from one area of interest to the next with a discrete groundwater sample collected at each. The system may allow soil samples to be collected during advancement. As some sampler components are common for all samples, the groundwater profiler does not offer the same protection from cross-contamination that separate screen point samples would.

4.3 Small-Diameter Well Installation

With some limitations, direct push technology can be used to install permanent monitoring wells of quality commensurate with other drilling systems. The use of small diameter wells limits the possibilities for the pumps to be used in sampling. For shallow groundwater with water levels higher than 25 ft below ground surface, peristaltic pumps can be used with no limitation on minimum well diameter. For water levels deeper than 25 feet below ground surface, bladder pumps may be the only pumping option and well diameters should be 1" nominal diameter with an absolute minimum of ¾" nominal diameter.

Well materials are difficult to place with DPT systems and best results will be achieved with total depths less than 50 ft. It is also difficult or impossible to place bentonite seals, and caution should be used when aquifer isolation is particularly important. Grout should be placed in the annular space by tremie pipe, as with conventional drilling installation. Grout placement by tremie will likely rule out the use of the smaller diameter tool strings such as 2.125” and 2.25” outside diameter (od). A 3.5” tool string with 2.75” inside diameter (id) will allow room for a 1” nom. diam. casing with grout pumped through ½” nom. dia. tremie. Pre-pack screens are available to install 2” nom. dia. wells in 3.5” od tool string, but grout cannot be placed by tremie with these systems and they should not be used.

Pre-packed screens are typically used, consisting of a slotted well screen surrounded by a sand filter pack wrapped in stainless steel screen wire. Sand packs wrapped by textile materials capable of or intended to filter fines or lower turbidity are unacceptable. Above the pre-packed screen standard well casing matching the slotted screen diameter is used.

Installation involves driving a tool string with disposable point to depth, placing the screen and casing inside, and withdrawing the tool string to dislodge the disposable point. The drive casing is withdrawn to fully expose the screen. Filter pack sand is then added during drive casing withdrawal until sand is placed to 2 ft above the screen. There is a narrow annular space between the pre-pack screen and borehole walls that the added sand may not fully fill. The placement of 2 ft of sand above the screen allows for settling.

Bentonite grout mixed to 30% solids content is then installed by tremie pipe while withdrawing the remaining drive casing. Care must be taken to not jet out the placed filter sand by resting the tremie on the bottom.

Alternate systems are available that use a polyethylene and foam skirt to isolate a bentonite seal wrapped in kraft paper from the screened interval. These systems result in natural development of the entire annular space around the pre-pack screen and introduce several materials that may have compatibility, contaminant leaching, or long-term stability issues. Although the placement of a bentonite seal is desirable, SESD does not use these systems due to concern over the other issues.

Appendix A.II.2. Groundwater Monitoring Well Logs

BOREHOLE LOG

BOREHOLE NO: MS-1-DMW

TOTAL DEPTH: 403 ft

PROJECT INFORMATION	DRILLING INFORMATION
PROJECT: 23-26 CSS-FRE Baseline Monitoring	DRILLING CO: Authentic Drilling, Cascade Drilling
SITE LOCATION: FRE Windsor, CO	DRILLERS: Quicksilver Simon (Authentic Drilling); Kevin Rogers (Cascade)
JOB NUMBER: CARB0-023-0001	METHOD OF DRILLING: Rotosonic /8-inch diameter boring
LOGGED BY: Marc Morton	SAMPLING METHOD: continuous sonic core bagged samples
PROJECT MANAGER: Brad Pekas	Started: 8/16/2023; Installed:8/29/2023; Developed: 9/21/2023

NOTES:		
	Static water level : 30.11 ft BTOC 9-29-2023	Total Depth of Boring: 403 ft
	Screened Interval: 380-400 ft bgs	Borehole diamter: 8 in
	DWR Permit # 331498	

DEPTH (FT)	Sample Depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
Ground Surface						PVC Above grade completion (2.4 ft)
0.5	0-2.5	100	ML	SILT, sandy, brown, dry (topsoil)		
2.5	2.5-5	100	ML	SILT, sandy, loose, brown, dry (alluvium)		
5.0	5-7.5	100				
7.5	7.5-10	100				
10.0	10-12.5	100		As above (SILT) with cccasional white mottling, consolidated		
12.5	12.5-15	100	SP	SAND, fine to medium, loose, dry (alluvium)		
15.0	15-17.5	100	GP	GRAVEL, sandy, multi-colored, fine-medium, well rounded, loose, moist (alluvium)		
17.5	19.5-20	100				
20.0						

DEPTH (FT)	Sample Depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
22.5	20-22.5	100	SP	SAND, occasional gravel, fine-medium, well rounded, loose, (alluvium) saturated at 25.5		
25.0	22.5.25	100				
27.5	25-27.5	100	GP	GRAVEL, sandy, fine to coarse, well rounded, wet (alluvium)		saturated at 25.5 ft during drilling
30.0	27.5-30	100				
32.5	30-32.5	50	GC	GRAVEL, clayey, well-rounded, wet (alluvium)		
35.0	32.5-35	50				
37.5	35-37.5	100	CL	SHALE, blue-gray, indurated, slightly moist, occasional sandy lenses		
40.0	37.5-40	100				
42.5	40-42.5	100				
45.0	42.5-45	100				
47.5	45-47.5	100				

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DEPTH (FT)	Sample Depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
	47.5-50	100				
50.0	50-52.5	100				
52.5	52.5-55	100				
55.0	55-57.5	100				
57.5	57.5-60	100				
60.0	60-62.5	100	CL	SHALE, gray, blocky, crumbly, slightly moist		
62.5	62.5-65	100				
65.0	65-67.5	100				
67.5	67.5-70	100				
70.0	70-72.5	100				
72.5	72.5-75	100				
75.0						

DEPTH (FT)	Sample Depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
77.5	75-77.5	100	CL	SHALE, gray, blocky, crumbly, slightly moist		
80.0	77.5-80	100				
82.5	80-82.5	100				
85.0	82.5-85	100				
87.5	85-87.5	100				
90.0	87.5-90	100				
92.5	90-92.5	100	CL	SHALE, gray to light gray, blocky, crumbly, very wet to saturated (90-98)		very wet to saturated during drilling - 90-98
95.0	92.5-95	100				
97.5	95-97.5	100				
100.0	97.5-100	100	CL	SHALE, gray, hard, indurated, dry		
102.5	100-102.5	100				

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DEPTH (FT)	Sample Depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
105.0	102.5-105	100				
107.5	105-107.5	100				
110.0	107.5-110	100				
112.5	110-112.5	100				
115.0	112.5-115	100				
117.5	115-117.5	100	CL	SHALE, some sand, gray, hard, indurated, dry to slightly moist, occasional white mottling		
120.0	117.5-20	100				
122.5	120-122.5	0				
125.0	122.5-125	100				
127.5	125-127.5	100				
130.0	127.5-130	100				

DEPTH (FT)	Sample Depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
132.5	130-132.5	100				
135.0	132.5-135	100				
137.5	135-137.5	100				
140.0	137.5-140	100				
142.5	140-142.5	100				
145.0	142.5-145	100	CL	SHALE, some sand, gray, crumbly, dry to slightly moist, occasional white mottling		
147.5	145-147.5	100				
150.0	147.5-150	100				
152.5	150-152.5	100				
155.0	152.5-155	100				
157.5	155-157.5	100				

DEPTH (FT)	Sample Depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
160.0	157.5-160	100	CL/ML	SHALE, silty, sandy, gray, very hard, dense, slightly moist		
162.5	160-162.5	100				
165.0	162.5-165	100				
167.5	165-167.5	100	CL	SHALE, gray, very sandy, slightly moist		
170.0	167.5-170	100				
172.5	170-172.5	100				
175.0	172.5-175	100				
177.5	175-177.5	100				
180.0	177.5-180	100	SC/SM	SANDSTONE/SILTSTONE, gray, very fine-grained, slightly moist		
182.5	180-182.5	100				
185.0	182.5-185	100				

DEPTH (FT)	Sample Depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
	185-187.5	0	NR	No recovery (185-190) slough 185-191 on second attempt		
187.5	187.5-190	0				
190.0	190-192.5	100	ML	SILTSTONE, gray to light gray, sandy, uneven bedding, dry to slightly moist.		
192.5	192.5-195	100				
195.0	195-917.5	100				
197.5	197.5-200	100				
200.0	200-202.5	100				
202.5	202.5-205	100				
205.0	205-207.5	100				
207.5	207.5-210	100				
210.0	210-212.5	100				
212.5						

DEPTH (FT)	Sample Depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
215.0	212.5-215	100				
217.5	215-217.5	0	NR	No recovery (215-220), slough on second attempt		
220.0	217.5-220	0				
222.5	220-222.5	100	ML	SILTSTONE, gray to light gray, sandy, wavy bedding, dense, occ. thin sandy lenses interpsersed, dry to slightly moist		
225.0	222.5-225	100				
227.5	225-227.5	100				
230.0	227.5-230	100				
232.5	230-232.5	100				
235.0	232.5-235	100				
237.5	325-237.5	100				
240.0	237.5-240	100				

DEPTH (FT)	Sample Depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
242.5	240-242.5	100				
245.0	242.5-245	100				
247.5	245-247.5	100	CL	SHALE, gray to light gray, sandy, stiff, dry		
250.0	247.5-250	100				
252.5	250-252.5	100				
255.0	252.5-255	100				
257.5	255-257.5	100				
260.0	157.5-260	100	ML	SILTSTONE, gray, sandy, wavy bedding, with occ. white minerlized partings, dry		
262.5	260-262.5	100				
265.0	262.5-265	100				
267.5	265-267.5	100				

DEPTH (FT)	Sample Depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
270.0	267.5-270	100				
272.5	270-272.5	100				
275.0	272.5-275	100				
277.5	175-177.5	100				
280.0	277.5-280	100				
282.5	280-282.5	100				
285.0	282.5-285	100				
287.5	285-287.5	100	CL	SHALE, gray to dark gray, dry to slightly moist		
290.0	287.5-290	100				
292.5	290-292.5	100				
295.0	292.5-295	100				

DEPTH (FT)	Sample Depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
297.5	295-297.5	100				
300.0	297.5-300	100				
302.5	300-302.5	100				
305.0	302.5-305	100				
307.5	305-307.5	100				
310.0	307.5-310	100	ML/SC	SILTSTONE, gray to dark gray, v sandy, moist.		
312.5	310-312.5	100				
315.0	312.5-315	100				
317.5	315-317.5	100				
320.0	317.5-320	100				
322.5	320-322.5	100				

DEPTH (FT)	Sample Depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
325.0	322.5-325	100				
327.5	325-327.5	100				
330.0	327.5-330	100	SC	SANDSTONE, very clayey, well-cemented, moist		
332.5	330-332.5	100				
335.0	332.5-335	100				
337.5	335-337.5	100				
340.0	337.5-340	100				
342.5	340-342.5	100				
345.0	342.5-345	100				
347.5	345-347.5	100				
350.0	347.5-350	100				

DEPTH (FT)	Sample Depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
352.5	350-352.5	100	ML	SILTSTONE, very sandy & clayey, gray to light gray, with occ. marine fossil, well cemented, dry		
355.0	352.5-355	100				
357.5	355-357.5	100				
360.0	357.5-360	100	SC	SANSDSTONE, gray to lt gray, very clayey, fine-grained, loose, v. moist to wet, interspersed clay seams		
362.5	360-362.5	100				
365.0	362.5-365	100				
367.5	365-367.5	0	NR	No recovery		
370.0	267.5-270	100	SC	SANSDSTONE, gray, very clayey, fine-grained, loose, v. moist to wet, interspersed clay seams		
372.5	370-372.5	100				
375.0	372.5-375	100				
377.5	375-377.5	100	CL	SHALE, gray, very sandy, very moist		

DEPTH (FT)	Sample Depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
380.0	377.5-380	100				
182.5	380-382.5	100	CL/SC	INTERBEDDED SANDSTONE/SHALE, gray to dark gray, wet to saturated, faint petroleum odor noted by driller, Saturated at 388.5.		
385.0	382.5-385	100				
387.5	385-387.5	100				Saturated during drilling at 388 ft
390.0	387.5-390	100				well screen
392.5	390-392.5	100				
395.0	392.5-395	100				
397.5	395-397.5	100	CL	SHALE, gray to dk gray, very sandy, no odor, moist to very moist		
400.0	397.5-400	100				
402.5 403.0 (TD)				Not sampled		Sediment Trap Well cap

Boring completed to 403.0 ft on 8-29-2023.
Well screened from 380 to 400 ft.

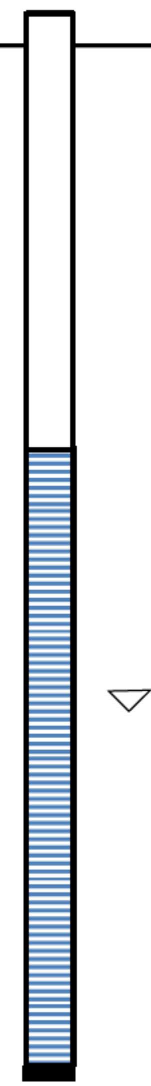
FIELD BOREHOLE LOG

BOREHOLE MS-1-SMW

TOTAL BORING DEPTH: 35.0 ft

	DRILLING INFORMATION
PROJECT: 23-26 CSS-FRE Baseline Monitoring	DRILLING CO: Cascade LLC
SITE LOCATION: FRE Windsor, CO	DRILLER: Ryan Olive
PROJECT NUMBER: CARBO-023-0001	METHOD OF DRILLING: Geoprobe DH101 with 12-in (OD) hollow stem auguers
LOGGED BY: Ryan Athey	SAMPLING METHOD: 5-foot continuous 2-inch acetate liners
PROJECT MANAGER: Brad Pekas	Started:8/1/2023; Well Installed: 8/2/2023;

NOTES:	Static water level : 23.91 ft BTOC 9-29-2023	Total Depth of Boring: 35 ft BGS
	Screened Interval: 12.8-32.8 ft bgs	BOREHOLE DIAMETER: 12 in
	DWR Permit #: 4000181-MH	

DEPTH (FT)	Inches Driven	Recovered (in)	USCS	LITHOLOGICAL DESCRIPTION	Well Construction	Notes
Ground Surface						PVC Above grade completion (3.1 ft)
1	60	48	ML	Topsoil (SILT), light brown, unconsolidated, frequent roots, dry		
5			ML	SILT, brown, sandy, unconsolidated, with vf-fn sand, dry		
	60	48	ML	SILT, reddish brown, sandy, unconsolidated, with vf-fn sand, dry		
10				SILT, tan to light brn, trace sand, poorly cemented, dry, w purple clay & white anyhydrite lenses from 10-12 ft, dry		
	60	60	SC	SAND, silty, fg, lt brn-orange, unconsol. dry		
15			GP	SAND with gravel, silt, & clay, multi-colored, poorly sorted, unconsolidated, dry (alluvium); saturated at 22 ft		well screen
	60	60				
20	60	60				saturated at 22 ft during drilling
25			CL	CLAY, silty, brown, plastic, saturated		
	24	24	SP	SAND, gravelly, multi-colored, cobbles to 1 "in diameter, tr silt, poorly sorted, unconsolidated, satuarated		
30	0	0	SP	DPT refusal at 28 ft 28-35 ft - Same as above (SP) based on cuttings; hole TD'd at 35 ft with 12-inch hollow stem augers		Well cap
35.0						

Notes:

Boring completed to 35.0 ft on 8-2-2023.

Well screened from 12.8-32.8 ft bgs

BOREHOLE LOG

BOREHOLE NO: MS-2-DMW

TOTAL BORING DEPTH: 400 ft

PROJECT INFORMATION	DRILLING INFORMATION
PROJECT: 23-26 CSS-FRE Baseline Monitoring	DRILLING CO: Authentic Drilling, Cascade Drilling
SITE LOCATION: FRE Windsor, CO	DRILLERS: Quicksilver Simon (Authentic Drilling); Kevin Rogers (Cascade)
JOB NUMBER: CARB0-023-0001	METHOD OF DRILLING: Rotosonic / 8-inch diameter boring
LOGGED BY: Ryan Athey / Marc Morton	SAMPLING METHOD: continuous sonic core, bagged samples
PROJECT MANAGER: Brad Pekas	Started: 8/30/2023; Well Installed: 9/11/2023; Developed: 9/21/2023

NOTES:		
	Static water level : 0.1 ft ATOC 9-29-2023	Total Depth of Boring: 400 ft
	Screened Interval: 279.7 - 299.7 ft bgs	Backfilled: 373-400 (slough) 305-373 (bentonite holeplug)
	DWR Permit # 331499	Backfilled: 301-305 ft by caving and/or bentonite expansion.

DEPTH (FT)	Sample depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
Ground Surface						PVC above grade completion (3.0 ft)
0.5 – 2.5	0-2.5	100	ML	SILT, brown, sandy, loose (topsoil); saturated at 3.5 ft.		
2.5 – 5.0	2.5-5	100			▽	saturated conditions observed durng drilling
5.0 – 7.5	5-7.5	100	SC	SAND, medium-grained, brown, clayey, orange and gray mottling, wet (alluvium)		
7.5 – 10.0	7.5-10	100	GM	GRAVEL, silty, brown, v loose, wet (alluvium)		
10.0 – 12.5	10-12.5	50				
12.5 – 15.0	12.5-15	50	CL	SHALE, gray, soft, wet		
			NR	slough		
15.0 – 17.5	15-17.5	100.0	CL	SHALE, sandy,gray, soft, moist		
17.5 –	19.5-20	100				

DEPTH (FT)	Sample depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
20.0						
22.5	20-22.5	100	CL	SHALE, gray, some sand, crumbly, moist, grades stiff with depth		
25.0	22.5.25	100				
27.5	25-27.5	100				
30.0	27.5-30	100				
32.5	30-32.5	50				
35.0	32.5-35	50				
37.5	35-37.5	100				
40.0	37.5-40	100				
42.5	40-42.5	100				
45.0	42.5-45	100				
	45-47.5	100				

DEPTH (FT)	Sample depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
47.5						
	47.5-50	100				
50.0						
	50-52.5	100				
52.5						
	52.5-55	100				
55.0						
	55-57.5	100				
57.5						
	57.5-60	100				
60.0						
	60-62.5	100	CL	SHALEgray to dark gray, some sand - moist to slightly wet at 62-63 ft.		
62.5						
	62.5-65	100				
65.0						
	65-67.5	100				
67.5						
	67.5-70	100				
70.0						
	70-72.5	100				
72.5						
	72.5-75	100				

DEPTH (FT)	Sample depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
75.0						
	75-77.5	100	CL	SLILTSTONE, gray to dark gray, stiff, indurated, laminated, slightly moist		
77.5						
	77.5-80	100				
80.0						
	80-82.5	100				
82.5						
	82.5-85	100				
85.0						
	85-87.5	100				
87.5						
	87.5-90	100				
90.0						
	90-92.5	100	CL	SHALE, gray to light gray, indurated, whitish laminations interspersed, dry		
92.5						
	92.5-95	100				
95.0			ML	SILTSTONE, clayey, sandy, indurated, dry to v slightly moist		
	95-97.5	100				
97.5						
	97.5-100	100				
100.0						
	100-102.5	100				

DEPTH (FT)	Sample depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
102.5						
105.0	102.5-105	100	ML	SILTSTONE, very clayey, sandy, indurated, dry to v slightly moist		
107.5	105-107.5	100				
110.0	107.5-110	100	SC	SANDSTONE, clayey, silty, gray to dark gray, wet		
112.5	110-112.5	100				
115.0	112.5-115	100	ML	SILTSTONE, very clayey, sandy, indurated, slightly moist		
117.5	115-117.5	100				
120.0	117.5-20	100	SC	SANDSTONE, v find-grained, w clay lenses, silty, crumbly, gray to dark gray, moist.		
122.5	120-122.5	0				
125.0	122.5-125	100				
127.5	125-127.5	100				
	127.5-130	100				

DEPTH (FT)	Sample depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
130.0						
132.5	130-132.5	100	SC	SANDSTONE, very find-grained, with clay lenses, silty, crumbly, gray to dark gray, moist.		
135.0	132.5-135	100				
137.5	135-137.5	100				
140.0	137.5-140	100				
142.5	140-142.5	100				
145.0	142.5-145	100				
147.5	145-147.5	100	ML/CL	SILTSTONE/SHALE, gray to light gray, wavy bedding, v. moist		
150.0	147.5-150	100				
152.5	150-152.5	100				
155.0	152.5-155	100				
	155-157.5	100				

DEPTH (FT)	Sample depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
157.5						
	157.5-160	100	ML/CL	SILTSTONE/SHALE, gray to light gray, wavy bedding, v. moist		
160.0	160-162.5	100	CL	SHALE, gray to light gray, indurated, wavy bedding, moist		
162.5	162.5-165	100				
165.0	165-167.5	100				
167.5	167.5-170	100	CL/SC	SHALE/SANDSTONE INTERBEDDED, gray to dark gray, wavy bedding, moist		
170.0	170-172.5	100				
172.5	172.5-175	100				
175.0	175-177.5	100				
177.5	177.5-180	100	ML	SILTSTONE, mottled gray & light gray, soft, crumbly, wavy bedding, dry to slightly moist		
180.0	180-182.5	100				
182.5	182.5-185	100				

DEPTH (FT)	Sample depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
185.0						
187.5	185-187.5	0				
190.0	187.5-190	0	SC	SANDSTONE, V. clayey, fine-grained, friable, moist		
192.5	190-192.5	100				
195.0	192.5-195	100				
197.5	195-197.5	100				
200.0	197.5-200	100	SC/CL	SHALE/SANDSTONE, gray to dark gray, friable, wavy bedding, slightly moist		
202.5	200-202.5	100				
205.0	202.5-205	100				
207.5	205-207.5	100				
210.0	207.5-210	100				
	210-212.5	100				

DEPTH (FT)	Sample depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
212.5						
wet to sat	212.5-215	100	CL/SC	SHALE and CLAYEY SANDSTONE interbedded, gray to dark gray, wavy bedding, wet to saturated 215 to 222.	▽	Wet to saturated conditions observed during drilling (215-222 ft)
215.0	215-217.5	0				
217.5	217.5-220	0				
220.0	220-222.5	100				
222.5	222.5-225	100				
225.0	225-227.5	100	SC/CL	SHALE AND CLAYEY SANDSTONE, gray to dark gray, wavy bedding, dry		
227.5	227.5-230	100				
230.0	230-232.5	100				
232.5	232.5-235	100				
235.0	325-237.5	100	SC	SANDSTONE, clayey, gray, v. fine grained, poorly to mod indurated, poorly bedded, dry		
237.5						

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DEPTH (FT)	Sample depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
240.0	237.5-240	100	SC	SANDSTONE, gray, v. fine grained, poorly to mod indurated, poorly bedded, dry		
242.5	240-242.5	100				
245.0	242.5-245	100				
247.5	245-247.5	100	SC/CL	SHALE, soft, poorly indurated, interbedded with SANDSTONE, very fg, clayey, poorly to mod cemented, uneven bedding, dry		
250.0	247.5-250	100				
252.5	250-252.5	100				
255.0	252.5-255	100				
257.5	255-257.5	100				
260.0	157.5-260	100				
262.5	260-262.5	100				
265.0	262.5-265	100	SC/CL	INTERBEDDED SANDSTONE, vfg, clayey, silty, mod cemented, hard, dry and SHALE, sandy, poorly to mod indurated, soft to mod hard, dry, uneven bedding		

DEPTH (FT)	Sample depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
267.5	265-267.5	100				
270.0	267.5-270	100	SC/CL	INTERBEDDED SANDSTONE, vfg, clayey, silty, mod cemented, hard, dry and SHALE, sandy, poorly to mod indurated, soft to mod hard, dry, uneven bedding		
272.5	270-272.5	100				
275.0	272.5-275	100	SC/SM	SANDSTONE, clayey, silty, fg, poorly-mod cemented, massive, moist to dry		
277.5	175-177.5	100				
280.0	277.5-280	100				
282.5	280-282.5	100				well screen
285.0	282.5-285	100				
287.5	285-287.5	100	SC/SM	SANDSTONE, clayey, silty, fg, poorly-mod cemented, massive, moist to wet.		
290.0	287.5-290	100				
292.5	290-292.5	100				

DEPTH (FT)	Sample depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
295.0	292.5-295	100				
297.5	295-297.5	100	SM	SANDSTONE, silty, fine-grained, dry to slightly moist		well screen
300.0	297.5-300	0		SLOUGH (WET, soft)		END Cap Backfilled 301-305 from slouging or bentonite expansion.
302.5	300-302.5	0				Backfilled with Bentonite holeplug 305-373 ft bgs
305.0	302.5-305	100	SM	SANDSTONE, gray, silty, v. fine grained, dense, massive, well cemented, dry		
307.5	305-307.5	100	SC/CL	INTERBEDDED SANDSTONE, vfg, silty, hard, moist to wet and SHALE, sandy,		
310.0	307.5-310	100				
312.5	310-312.5	100				
315.0	312.5-315	100				
317.5	315-317.5	0	NR	No recovery		
320.0	317.5-320	100	SC	SANDSTONE, gray to dark gray, with interbedded clay seams, very moist		

DEPTH (FT)	Sample depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
322.5	320-322.5	100				
325.0	322.5-325	0	NR	No Revovery		
327.5	325-327.5	100	SC/CL	SANDSTONE, medium-grained, gray to dark gray, with interbedded clay seams, indurated, massive, very hard, dry to slightly moist.		
330.0	327.5-330	100				
332.5	330-332.5	100				
335.0	332.5-335	100				
337.5	335-337.5	100	NR	no recovery - slough		
340.0	337.5-340	100				
342.5	340-342.5	100				
345.0	342.5-345	100	SC/CL	SANDSTONE, medium-grained, gray to light gray, with interbedded clay seams and lenses, slightly moist		
347.5	345-347.5	100				

DEPTH (FT)	Sample depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
	347.5-350	100				
350.0						
	350-352.5	100	SC/CL	SANDSTONE, medium-grained, gray to light gray, with interbedded sandy clay seams and lenses, slightly moist		
352.5	352.5-355	100				
355.0	355-357.5	100				
357.5	357.5-360	100				
360.0	360-362.5	0	NR	No Recovery		
362.5	362.5-365	0	SC/SM	SANDSTONE, silty, friable, crumbly, slightly wet with clay lenses - seams interbedded, saturated at 372.5.		
365.0	365-367.5	0				
367.5	367.5-370	100				
370.0	370-372.5	100				
372.5	372.5-375	100			▽	saturated coinditions observed during drilling (372.5 ft)
375						

DEPTH (FT)	Sample depth Interval (ft)	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
377.5	375-377.5		NR	No Recovery		
380	377.5-380	100	CL/SC	SHALE, sandy, with interbedded sandy lenses, varved, gray to light gray, wavy bedding, dry to slightly moist		
382.5	380-382.5	100				
385	382.5-385	100				
387.5	385-387-5	100				
390	387.5-390	100				
392.5	390-392.5	100				
395	392.5-395	100				
397.5	395-397.5	0.0	NR	No Recovery		
400	397.5-400	0	NR	No Recovery		

Notes:

Boring completed to 400.0 ft on 9-10-2023.
Boring backfilled 373-305 (bentonite hole plug) on 9/11/2023; hole open to 373 on 9-11 (due to cave in)
Backfilled 305 to 301 from caving and/or bentonite expansion
Well screened from 279.7 - 299.7 ft.

FIELD BOREHOLE LOG

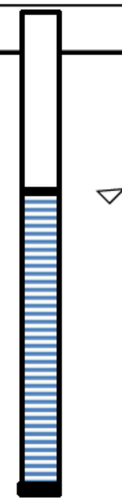
BOREHOLE MS-2-SMW

TOTAL BORING DEPTH: 15.0 ft

	DRILLING INFORMATION
PROJECT: 23-26 CSS-FRE Baseline Monitoring	DRILLING CO: Cascade LLC
SITE LOCATION: FRE Windsor, CO	DRILLER: Ryan Olive
PROJECT NUMBER: CARBO-023-0001	METHOD OF DRILLING: Geoprobe DH101 with 12-in (OD) hollow stem auguers
LOGGED BY: Ryan Athey / M. Morton	SAMPLING METHOD: 5-foot continuous with 2-inch acetate liners
PROJECT MANAGER: Brad Pekas	Started:8/8/2023; Well Installed: 8/9/2023

NOTES:		
	Static water level : 7.84 ft BTOC on 9-29-2023	Total Depth of Boring: 15 ft BGS
	Screened Interval: 4.4-14.4 ft bgs	BOREHOLE DIAMETER: 12 in
	DWR Permit #: 4000167-MH	

DEPTH (FT)	Inches Driven	Recovered (in)	USCS	LITHOLOGICAL DESCRIPTION	Well Construction	Notes
Ground Surface						PVC Above grade completion (3.0 ft)
1–5	60	24	ML	(Topsoil to 0.5 ft) SILT, brown with trace sand, trace clay; v stiff, occ. Light brown mottling, dry, Grades sandier & softer with depth; saturated at 5 ft.		Saturated at 5 ft during drilling
5–10	60	60	SM	SAND, silty ,med to fg, brown, very loose, occ. pyrite flakes, grades to med-grnd (alluvium), saturated		well screen
10–15	60	48		slough 10-11		
			SP	SAND, med to coarse grained, loose, occ. Fine gravel, well-rounded to subangular, trace clay, saturated (alluvium)		
15			CL	SHALE, gray, silty, indurated at base, moist		well cap



Notes:

Boring completed to 15.0 ft on 8-9-2023.

Well screened from 4.4 -14.4 ft bgs

	BOREHOLE LOG **BOREHOLE NO: MS-3-DMW** **TOTAL BORING DEPTH: 318.0 ft**
PROJECT INFORMATION	**DRILLING INFORMATION**
PROJECT: 23-26 CSS-FRE Baseline Monitoring	DRILLING CO: Authentic Drilling, Cascade Drilling
SITE LOCATION: FRE Windsor, CO	DRILLERS: Quicksilver Simon (Authentic Drilling); Kevin Rogers (Cascade)
JOB NUMBER: CARB0-023-0001	METHOD OF DRILLING: Rotosonic /8-inch diameter boring
LOGGED BY: Marc Morton	SAMPLING METHOD: continuous sonic core; bagged samples
PROJECT MANAGER: Brad Pekas	Started: 9/13/2023; Well Installed: 9/18/2023; Developed: 9/22/2023

NOTES:		
	Static water level : 178.19 ft BTOC 9-29-2023	Total Depth of Boring: 318.0 ft
	Screened Interval: 190.0-210.0 ft bgs	Backfilled: 210.3 - 298 ft with bentonite-holeplug
	DWR Permit # 331500	Backfilled: 298 - 318 ft with well cuttings / slough

DEPTH (FT)	Sample depth Interval	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
Ground Surface						PVC Above grade completion (2.9 ft)
0.5 – 2.5	0-2.5	100	CL	CLAY, Light Brown, silty, loose (topsoil)		
2.5 – 5.0	2.5-5	100	SM	SAND, silty, light brown, saturated at 4.5 ft bgs (alluvium)		saturated conditions observed at 4.5 ft during drilling
5.0 – 7.5	5-7.5	100	SP	SAND, coarse, with frequent gravel, well rounded, wet (alluvium)		
7.5 – 10.0	7.5-10	100				
10.0 – 12.5	10-12.5	100	ML	SILT, light brown, dense		
12.5 – 15.0	12.5-15	50	CL	SHALE, gray to light gray with interbedded fine-med sand, wavy bedding, slightly moist		
15.0 – 17.5	15-17.5	100.0				
17.5 –	19.5-20	100				

DEPTH (FT)	Sample depth Interval	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
20.0						
22.5	20-22.5	100	CL	SHALE, gray to light gray with interbedded fine-med sand, wavy bedding, slightly moist		
25.0	22.5.25	100				
27.5	25-27.5	100				
30.0	27.5-30	100	CL	SHALE, gray to light gray with some fine sand, crumbly, friable, grades morecompetent, massive		
32.5	30-32.5	50				
35.0	32.5-35	50				
37.5	35-37.5	100				
40.0	37.5-40	100	CL	SHALE, Gray to light gray with fine sand and clay interspersed, wavy bedding, friable, moist		
42.5	40-42.5	100				
45.0	42.5-45	100				
	45-47.5	100				

DEPTH (FT)	Sample depth Interval	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
47.5			CL	SHALE, gray, silty, dense, very hard homogenous, dry		
	47.5-50	100				
50.0						
	50-52.5	100				
52.5						
	52.5-55	100				
55.0			CL	SHALE, Gray to light gray with fine sand and clay lenses interspersed, wavy bedding, friable, moist		
	55-57.5	100				
57.5						
	57.5-60	100				
60.0						
	60-62.5	100				
62.5						
	62.5-65	100	ML	SILTSTONE, gray to dark gray, abundant fine sand and clay, occ. mineralized thin lenses, dry		
65.0						
	65-67.5	100				
67.5						
	67.5-70	100				
70.0						
	70-72.5	100				
72.5						
	72.5-75	100				

DEPTH (FT)	Sample depth Interval	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
75.0						
77.5	75-77.5	100	CL	SHALE, gray to dark gray, hard, thinly laminated 1/8 in to 1 in, , trace sand, dry		
80.0	77.5-80	100				
82.5	80-82.5	100				
85.0	82.5-85	100				
87.5	85-87.5	100				
90.0	87.5-90	0	NR	No Recovery		
92.5	90-92.5	100	CL	SHALE, gray to light gray with interspersed sandy laminations / lenses, indurated, wavy bedding (very difficult/slow drilling)		
95.0	92.5-95	100				
97.5	95-97.5	100				
100.0	97.5-100	100				
	100-102.5	100				

DEPTH (FT)	Sample depth Interval	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
102.5						
105.0	102.5-105	100	CL	SHALE, gray to light gray with interspersed sandy laminations / lenses, indurated, wavy bedding (very difficult/slow drilling)		
107.5	105-107.5	100	NR	No recovery		
110.0	107.5-110	100				
112.5	110-112.5	100				
115.0	112.5-115	100				
117.5	115-117.5	100				
120.0	117.5-20	100	CL	SHALE, gray to dark gray, with intermittant thin, disconinuous sandy lenses, very thinly bedded, somewhat firable, slightly moist		
122.5	120-122.5	100				
125.0	122.5-125	100				
127.5	125-127.5	100				
	127.5-130	100				

DEPTH (FT)	Sample depth Interval	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
130.0						
132.5	130-132.5	100	CL	SHALE, gray, sandy, thinly bedded, wavy bedding, dry (Very slow drilling)		
135.0	132.5-135	100				
137.5	135-137.5	20		Slough		
140.0	137.5-140	100	SC/CL	SANDSTONE, mottled gray and light gray and interbedded SHALE, sandy, dry		
142.5	140-142.5	100	SC	SANDSTONE, fine grained, silty, massive, homogenous, dense, dry		
145.0	142.5-145	100				
147.5	145-147.5	100	CL/SC	SHALE, gray to light gray, silty, with interbedded thin sandy, lenses, wavy bedding, dry.		
150.0	147.5-150	100				
152.5	150-152.5	100				
155.0	152.5-155	100				
	155-157.5	100	ML/SC			

DEPTH (FT)	Sample depth Interval	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
157.5						
	157.5-160	100	ML/SC	Interbedded SHALE and SILTSTONE, mottled gray and light gray, very thinly beeded 1/10 in. to 1/4 in.		
160.0	160-162.5	100				
162.5	162.5-165	100				
165.0	165-167.5	100				
167.5	167.5-170	100				
170.0	170-172.5	100				
172.5	172.5-175	100	SM	SANDSTONE, silty, fine-grained, moderately loose, friable, with infrequent clayey lenses, moist		
175.0	175-177.5	100				
177.5	177.5-180	100				
180.0	180-182.5	100				
182.5	182.5-185	100				

DEPTH (FT)	Sample depth Interval	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
185.0						
187.5	185-187.5	0		No recovery on Ist attempt - second attempt slough very wet		
				Becomes wet		
190.0	187.5-190	20	SC	SANDSTONE, silty, clayey, very moist to wet		
192.5	190-192.5	20				well screen
195.0	192.5-195	100				
197.5	195-197.5	100	SC/CL	SANDSTONE, gray, with interbedded lenses of gray clay, moist		
200.0	197.5-200	100				
202.5	200-202.5	100	SM	SANDSTONE, gray, v. fine-grained, dense, massive, some silt & clay, dry		
205.0	202.5-205	100				
207.5	205-207.5	0		slough		well screen
210.0	207.5-210	0				
	210-212.5	100	ML	SILTSTONE, gray to light gray, wavy bedding, dry		well cap Boring backfilled 210.3 - 298 with bentonite holeplug

DEPTH (FT)	Sample depth Interval	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
212.5						
215.0	212.5-215	100	ML	SILTSTONE, gray to light gray, wavy bedding, dry		backfilled 298-318 with with well cuttings
217.5	215-217.5	0	CL/ML	SHALE/SILTSTONE, gray to dark gray, dense, platy, well cemented, (very slow drilling), dry		
220.0	217.5-220	0				
222.5	220-222.5	100				
225.0	222.5-225	100				
227.5	225-227.5	100				
230.0	227.5-230	100				
232.5	230-232.5	100				
235.0	232.5-235	100	ML	SILTSTONE, gray, sandy, dense, hard, well cemented, dry		
237.5	325-237.5	100				
	237.5-240	100				

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DEPTH (FT)	Sample depth Interval	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
240.0						
	240-242.5	100	SM	SANDSTONE, vfg, stilty, clayey, dense, hard, massive, well cemented, dry		
242.5	242.5-245	100				
245.0	245-247.5	100	ML	SLILTSTONE, well cemented, gray to dark gray, occ. fossil, & whitish mineralized lenses,wavy bedding planes, dense, strong, dry		
247.5	247.5-250	100				
250.0	250-252.5	100				
252.5	252.5-255	100				
255.0	255-257.5	100				
257.5	157.5-260	100				
260.0	260-262.5	100				
262.5	262.5-265	100				
265.0	265-267.5	100				

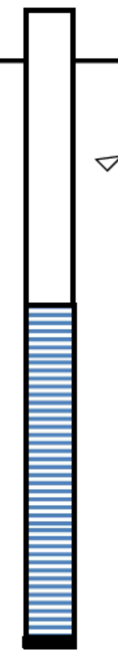
DEPTH (FT)	Sample depth Interval	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
267.5						
270.0	267.5-270	100	ML	SLILTSTONE, well cemented, gray to dark gray, occ. fossil, & whitish mineralized lenses, v dense, wavy bedding planes strong, dry		
272.5	270-272.5	100				
275.0	272.5-275	100				
277.5	275-177.5	100	CL/ML	SHALE, gray to dark gray, silty, with interbedded sandy SLTSTONE lenses, dense, moderately strong, uneven bedding, dry		
280.0	277.5-280	100				
282.5	280-282.5	100				
285.0	282.5-285	100				
287.5	285-287.5	100	CL	SHALE, gray, silty with some sand, very dense, well cemented, homgenous, strong, dry		
290.0	287.5-290	100				
292.5	290-292.5	100				
	292.5-295	100				

DEPTH (FT)	Sample depth Interval	Recovery (%)	USCS	LITHOLOGIC DESCRIPTION	Well Construction	Notes
295.0						
	295-297.5	100	CL	SHALE, gray, silty with some sand, very dense, well cemented, strong, dry		
297.5	297.5-300	0				
300.0	300-302.5	0				
302.5	302.5-305	100				
305.0	305-307.5	100	SM	SANDSTONE, V. fine grained, well-cemented, massive, homogenous - (refusal at 318 on 9-17-2023)		
307.5	307.5-310	100				
310.0	310-312.5	100				
312.5	312.5-315	100				
315.0	315-317.5	100				
317.5						
318.0						

Notes:
Boring completed to 318.0 ft on 9-17-2023.
Boring backfilled from 210.3 to 298 with bentonite holeplug and 298-318 with with well cuttings / slough
Well screened (shaded gray) from 190.0 -210.0 ft bgs. Installed on 9-18-2023.

	FIELD BOREHOLE LOG BOREHOLE MS-3-SMW TOTAL BORING DEPTH: 17.3 ft
	DRILLING INFORMATION
PROJECT: 23-26 CSS-FRE Baseline Monitoring	DRILLING CO: Cascade LLC
SITE LOCATION: FRE Windsor, CO	DRILLER: Ryan Olive
PROJECT NUMBER: CARBO-023-0001	METHOD OF DRILLING: Geoprobe DH101 with 12-in (OD) hollow stem auguers
LOGGED BY: Ryan Athey	SAMPLING METHOD: 5-foot continuous 2-inch acetate liners
PROJECT MANAGER: Brad Pekas	Started:8/4/2023; Well Installed: 8/5/2023;

NOTES:		
	Static water level : 11.84 ft BTOC 9-29-2023	Total Depth of Boring: 17.3 ft BGS
	Screened Interval: 7.0-17.0 ft bgs	BOREHOLE DIAMETER: 12 in
	DWR Permit #: 4000182-MH	

DEPTH (FT)	Inches Driven	Recovered (in)	USCS	LITHOLOGICAL DESCRIPTION	Well Construction	Notes
Ground Surface						PVC Above grade completion (3.2 ft)
1	60	40	ML	SILT, sandy with clayand sand, lt brn, moderately consolidated, dry		Saturated at 3 ft during drilling
5			ML	SILT, clayey, lt brn-gray, trace sand, soft, non-plastic, moist to wet		
10	60	36	SM/SP	SAND, silty, dark brown, fine- med grained, moist to wet Grades with gravel and coarse sand, multi color (alluvium)		
13	36	36	GP	SAND & GRAVEL, with silt, multi-color, cobbles to 2 in diameter, unconsolidatred, saturated (alluvium)		well screen
15	60	0		No sample due to flowing sands SHALE based on HSA at end end of center bit		
17.3			CL	REFUSAL at 18 with DPT due to flowing sand in barrel		well cap

Notes:
Boring completed to 17.3 ft on 8-5-2023.
Well screened from 7.0-17.0 ft bgs

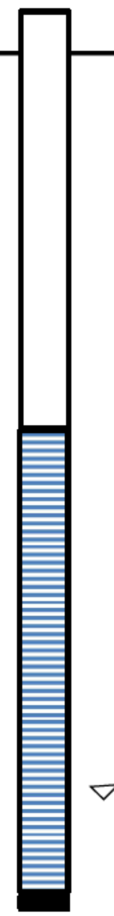
FIELD BOREHOLE LOG

BOREHOLE MS-4-SMW

TOTAL BORING DEPTH: 27.0 ft

	DRILLING INFORMATION
PROJECT: 23-26 CSS-FRE Baseline Monitoring	DRILLING CO: Cascade LLC
SITE LOCATION: FRE Windsor, CO	DRILLER: Ryan Olive
PROJECT NUMBER: CARBO-023-0001	METHOD OF DRILLING: Geoprobe DH101 with 12-in (OD) hollow stem auguers
LOGGED BY: Ryan Athey	SAMPLING METHOD: 5-foot continuous 2-inch acetate liners
PROJECT MANAGER: Brad Pekas	Started:8/3/2023; Well Installed: 8/3/2023;

NOTES:		
	Static water level : 19.30 ft BTOC 9-29-2023	Total Depth of Boring: 27.0 ft BGS
	Screened Interval: 7.0-17.0 ft bgs	BOREHOLE DIAMETER: 12 in
	DWR Permit #: 4000155-MH	

DEPTH (FT)	Inches Driven	Recovered (in)	USCS	LITHOLOGICAL DESCRIPTION	Well Construction	Notes
Ground Surface						PVC Above grade completion (3.1 ft)
1				Topsoil (no sample due to hand augering)		
5	60	38	CL	CLAY, silty, brn-gray, trace vf sanmd, anhydrite streaks.stiff non-plastic, moist		
10	60	48	CL	CLAY, Sitly, gray, tr vf sand, still moderatley plastic, moist (alluvium)		
			CL	CL, siltty, lt brn, orange streaks (Fe staining), stiff, plastic, moist (alluvium)		
15	60	48	SM	SAND, silty, lt brown, coarse-fine granined, unconsolidated, poorly soorted, dry (alluvium)		
			SP	SAND, gravelly, silty, fine-coarse, multi-color, poorly sorted, unconsolidated, wet at 16.5 (alluvium)		wet at 16.5 ft during drilling
20	60	48	GP	GRAVEL, (2-3 in diameter), sandy, silty, fine-coarse, multi-color, poorly sorted, unconsolidated, saturated (alluvium)		well screen Saturated at 23 during drilling
25	0	0				
27			ML	SHALE, blue-gray, slightly weathered, sandy		well cap

Notes:
Refusal @ 27 ft with HSA
Boring completed to 27.0 ft on 8-5-2023.
Well screened from 11.0-26.0 ft bgs

FIELD BOREHOLE LOG

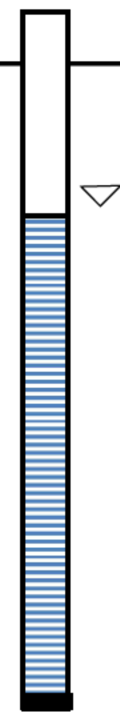
BOREHOLE MS-5-SMW

TOTAL BORING DEPTH: 20.0 ft

	DRILLING INFORMATION
PROJECT: 23-26 CSS-FRE Baseline Monitoring	DRILLING CO: Cascade LLC
SITE LOCATION: FRE Windsor, CO	DRILLER: Ryan Olive
PROJECT NUMBER: CARBO-023-0001	METHOD OF DRILLING: Geoprobe DH101 with 12-in (OD) hollow stem auguers
LOGGED BY: Ryan Athey/ Chad Linzman	SAMPLING METHOD: 5-foot continuous 2-inch acetate liners
PROJECT MANAGER: Brad Pekas	Started:8/7/2023; Well Installed: 8/8/2023;

NOTES:		
	Static water level : 11.2 ft BTOC 9-29-2023	Total Depth of Boring: 20.0 ft BGS
	Screened Interval: 4.3-19.3 ft bgs	BOREHOLE DIAMETER: 12 in
	DWR Permit #: 4000179-MH	

DEPTH (FT)	Inches Driven	Recovered (in)	USCS	LITHOLOGICAL DESCRIPTION	Well Construction	Notes
Ground Surface						PVC Above grade completion (3.2 ft)
1–5	0	0	ML	SILT, clayey, sandy, lt brown, anhydrite streaks. Moist		saturated at 5 ft during drilling
			SM	(Hand-augured 0 to 6 ft) SAND, gravelly, with silt, & clay, light brown, saturated at 5 ft		
10	48	24	GP	GRAVEL, sandy (rig hydraulic failure, no DPT beyond 10 ft)		
15	0	0	GP	GRAVEL, sandy (based on HAS cuttings)		Well screen
20			CL	SHALE, blue gray, stiff (based on HSA cuttings)		Well cap



Notes:
Boring completed to 20.0 ft on 8-8-2023.
Well screened from 4.3-19.3 ft bgs

FIELD BOREHOLE LOG

BOREHOLE MS-6-SMW

TOTAL BORING DEPTH: 20.0 ft

	DRILLING INFORMATION
PROJECT: 23-26 CSS-FRE Baseline Monitoring	DRILLING CO: Cascade LLC
SITE LOCATION: FRE Windsor, CO	DRILLER: Ryan Olive
PROJECT NUMBER: CARBO-023-0001	METHOD OF DRILLING: Geoprobe DH101 with 12-in (OD) hollow stem auguers
LOGGED BY: M. Morton	SAMPLING METHOD: 5-foot continuous 2-inch acetate liners
PROJECT MANAGER: Brad Pekas	Started:8/10/2023; Well Installed: 8/10/2023

NOTES:	Static water level : 9.65 ft BTOC 9-29-2023	Total Depth of Boring: 20.0 ft BGS
	Screened Interval: 4.9-14.9 ft bgs	BOREHOLE DIAMETER: 12 in
	DWR Permit #: 4000178-MH	Backfilled: 15.1- 20.0 (cuttings)

DEPTH (FT)	Inches Driven	Recovered (in)	USCS	LITHOLOGICAL DESCRIPTION	Well Construction	Notes
Ground Surface						PVC Above grade completion (3.2 ft)
1			ML	SILT, brown, clayey, loose, occasional root fragments, dry		
	60	42	CL	CLAY, silty, borwn to light brown, trace sand, occasional white mottlings		
5			ML	SILT, lt brown, sandy, wet		
			SM/ML	SAND, silty, loose, saturated, grades to SILT at 7.5		Saturated at 6.5 during drilling
	60	42				
						well screen
10						
			GP	GRAVEL, sandy, brown, subrounded (alluvium)		
15						well cap
						Backfilled: 15.1-20.0 (cuttings)
			CL	SHALE, blue-gray, poorly cemented, trace silt and sand, moist to dry		
20						

Notes:
Boring completed to 20.0 ft on 8-10-2023.

Well screened from 4.9-14.9 ft bgs