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Errata

To: Craig Stevens, Rio Tinto
Copies: Dave Cline and Tom Zimmer, Rio Tinto
From: Brett Beaulieu, Scott Adamek, and Jessi Massingale, Floyd|Snider
Date: June 4, 2019
Project No: RT-Holden Mine
Re: **Errata for *Holden Mine Planned Spring 2019 Groundwater Monitoring Well Installation* (attached following this page)**

These errata are intended to clarify topics raised by the U.S. Department of Agriculture, Forest Service, the Washington State Department of Ecology, and the U.S. Environmental Protection Agency, collectively referred to as the Agencies, and the Confederated Tribes and Bands of the Yakama Nation, during a conference call with Rio Tinto on May 31, 2019.

1. Replace "the waste management area (WMA)" on page 1 with "Tailings Piles 2 and 3."
2. The phrase "…previously identified as a losing stretch" on page 2 does not indicate Agencies' agreement that this section of Railroad Creek is currently a losing stretch.
3. Add the following to the paragraph describing investigation-derived waste (IDW) management at the bottom of page 4: "In the event that tailings are encountered during drilling, soil cuttings containing tailings will be managed as potentially contaminated and transported to the sludge filter cake management facility on Tailings Pile 1."
4. Add the following to the paragraph describing how the intermediate well screen interval will be placed on the top of page 3: "In the event that pH measurements do not clearly indicate a depth range for monitoring mining-affected water in the intermediate zone, the intermediate well screen will be set approximately at the average elevation rage of intermediate zone wells adjacent to and downgradient of TP-3 (DS-13I, DS-4I, and DS-9I), which is 3,090 to 3,100 feet above mean sea level."
5. In cases where there may be a discrepancy between text and figures, the description in the text will be followed. For example, the total depth of proposed deep zone monitoring well borings, as described in the text, will be into bedrock. The total boring depth for proposed monitoring wells is not shown on Figures 2 and 3.
6. Add the following to the paragraph describing IDW management at the bottom of page 4: "Best management practices (BMPs) for soil erosion control and surface water runoff will be employed to protect Railroad Creek. Soil cuttings and development/purge water will be placed in the inside ditch along the barrier wall platform road and prevented from draining to Railroad Creek using BMPs."

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Memorandum

To: Craig Stevens, Rio Tinto

Copies: Dave Cline and Tom Zimmer, Rio Tinto

From: Brett Beaulieu, Scott Adamek, and Jessi Massingale, Floyd|Snider

Date: May 23, 2019

Project No: RT-Holden Mine

Re: **Holden Mine Planned Spring 2019 Groundwater Monitoring Well Installation**

This memorandum describes the groundwater monitoring well installation activities planned for June 2019, at the Holden Mine Site (Site) located in Chelan County, Washington. Ten new groundwater monitoring wells are planned to be installed at four multi-completion location clusters. These monitoring wells are intended to address data needs raised by the U.S. Department of Agriculture, Forest Service (USFS), the Washington State Department of Ecology (Ecology), and the U.S. Environmental Protection Agency (USEPA), collectively referred to as the Agencies, as part of the review and response to comments process for the Performance Standards Verification Plan (PSVP) that is currently undergoing revision.

Groundwater Monitoring Well Locations and Screened Intervals

The data quality objectives (DQOs) for the new monitoring wells include:

- Updating the groundwater and groundwater-to-surface water conceptual site model (CSM) for post-Phase 1 conditions.
- Assessing current compliance with groundwater cleanup levels including cleanup levels based on surface water criteria.
- Assessing post-Phase 1 trends relative to compliance with groundwater cleanup levels including cleanup levels based on surface water criteria.

Ten new groundwater monitoring wells are planned to be installed at four multi-completion location clusters along the north margin of TP-2 and TP-3 that is not fronted by the Phase 1 barrier wall. The locations of proposed monitoring wells are shown on Figure 1. The rationale for these monitoring wells locations is to verify that the Phase 1 barrier wall and other remedy components have achieved remedial objectives along this section of the waste management area (WMA), by providing data to address the DQOs stated above. The monitoring well clusters are spaced to be representative of the unwalled portion of TP-2 and TP-3 between the barrier wall and DS-13. The monitoring wells will provide for water level measurements and associated gradients that will be used to assess upwelling conditions in a section of Railroad Creek previously identified as a losing stretch. The monitoring wells will provide water quality data for comparison to cleanup levels and for trend analysis.

Table 1 lists the new wells to be installed and includes the proposed target well depths and screened intervals. The proposed wells are illustrated in cross sections on Figures 2 and 3. These cross-sections showing relevant hydrostratigraphic units were developed based on subsurface lithology reported in the Baseline Water Quality Conditions Report (MWH 2013) updated to reflect as-built conditions for ground-surface topography and the barrier wall. The four clusters of wells (DS-15 through DS-18) are planned with 15-foot screened intervals in the shallow zone (approximately 5 to 25 feet below ground surface [bgs] in this vicinity) and 10-foot screened intervals in the intermediate zone (approximately 30 to 70 feet bgs in this vicinity). The screened interval and screen length for shallow zone wells were selected to intercept the water table and to allow seasonal variability in water levels close to Railroad Creek to be measured.

The screened interval target depth and screen length for intermediate zone wells was selected to monitor mining-affected water, consistent with the screened intervals of nearby intermediate zone wells DS-13I, DS-4I, DS-4D, and DS-9I. Well screen intervals for intermediate zone monitoring wells will be determined using the current understanding of the vertical extent of impacted groundwater in the area and on field observations including groundwater pH measured with a sealed-screen sampler (Hydropunch or equivalent) during drilling. The same procedure was successfully applied to detect and intersect mining-affected groundwater during the fall of 2018 for drilling of the intermediate-depth replacement well NRC-3IR (Arcadis 2018a and 2018b).

Two of these clusters, DS-16 and DS-18, along the northern and northeastern edge of TP-3 will also include monitoring wells with 10-foot screened intervals in the deep zone (approximately 65 to 100 feet bgs in this vicinity). A 10-foot screened interval in the deep zone in these locations was selected to provide representative water level and water quality information. The deep well borings at these two locations will be drilled to bedrock, as detected by observation of retrieved core. The screen will be placed in the deep zone above bedrock.

The field geologist will adjust the well screen placement as needed from the planned screened intervals in Table 1 based on field observations. Placement of shallow zone monitoring well screens will be adjusted as needed to ensure the screen intercepts the water table, as measured at the time of drilling using a water-level indicator. Placement of intermediate zone monitoring well screens will be based on multiple field observations. The geologist will direct the collection of water samples at discrete depths below approximately 25 feet bgs using a sealed-screen sampler (Hydropunch or equivalent). This water sampling tool remains sealed to the formation while it is advanced to the target depth, where the protective outer rod is retracted, exposing the screen to groundwater, so that a representative groundwater sample can be collected. The geologist will measure field pH in water samples from depth intervals above and below the planned screened interval for the intermediate zone. The geologist will identify the depth range at which pH is depressed consistent with mining-affected water and select a 10-foot screened interval from within this range based on the observed permeability and saturation.

Placement of the screened interval in the deep zone will be determined based on field observation of approximate bedrock depth. The rotary sonic method will be advanced until the retrieved core includes indication of bedrock. The geologist will select the 10-foot screened interval based on observed permeability and saturation in the interval above the contact with bedrock.

Compliance with Applicable Regulations, Rules, and Procedures

Floyd|Snider has contracted Cascade Drilling, LP (Cascade), to facilitate the installation and development of new groundwater monitoring wells. Cascade is a Washington-licensed well driller and has previous experience at the Site. All drilling, borehole logging, well installation, and well development will occur according to the approved Baseline Characterization and Monitoring Work Plan Standard Operating Procedures (SOP) for Drilling, Logging, Well Installation, and Well Development (Attachment 1; Appendix C of the Holden Mine Site Baseline Characterization and Monitoring Plan, Final Workplan [MWH 2010]) and in accordance with applicable regulations in the Washington Administrative Code, including a notice of intent for drilling to be filed by Cascade with Ecology. Following field activities, Cascade will file appropriate well permits for newly installed wells. All field work will be conducted in accordance with the Forest Service Fire Protection and Suppression requirements, and all equipment will be cleaned and inspected for noxious weeds prior to mobilizing to the Site.

All work will be conducted in accordance with a Health and Safety Plan developed by Floyd|Snider that addresses potential safety hazards associated with the scope of work. The Health and Safety Plan will be provided to the Agencies prior to the start of work. Daily safety meetings will be used to discuss the planned activities, safety considerations, administrative and engineering controls, appropriate personal protective equipment, and health stewardship responsibilities shared by all staff. The applicable requirements of the Occupational Safety and Health Administration (OSHA) specified under 29 CFR 1910.120 and Rio Tinto's Critical Risk Program will be followed by all personnel. Standard personal protective equipment will include a reflective high visibility safety vest, hard hat, steel toe boots, safety glasses, long sleeve shirt, and long pants, as well as hearing protection when working near the drilling rig. Work is expected to occur in 12-hour days for 7 days per week. The duration of drilling, well construction, and well development is expected be less than 20 days; therefore, only one shift is expected for completion of the planned scope of work.

A Washington-licensed professional geologist will oversee well installations and document well construction. During borehole advancement, the geologist will log borehole cuttings using standard geologic methods (i.e., soil type, Unified Soil Classification Symbol group name, particle size information, gradation, shape, color, consistency, moisture content, plasticity, cementation, and presence of foreign material) and complete a borehole log and well completion diagram. The geologist will be responsible for determining the borehole depth and well screen placement using existing Site information and field observations as described above.

Following the well installations, the Floyd|Snider geologist will monitor well development in collaboration with Cascade in accordance with the Drilling, Logging, Well Installation and Well Development SOP (Attachment 1; Appendix C of MWH 2010).

Drilling, Development, and Surveying Methods, and Monitoring Well Construction

Groundwater monitoring well installation, development, and surveying will be conducted in accordance with the existing Baseline Characterization and Monitoring Work Plan SOP for Drilling, Logging, Well Installation and Well Development (Attachment 1; Appendix C of MWH 2010).

Boreholes will be advanced to total depth using a 6-inch-diameter rotary sonic drilling method using a track-mounted drilling rig. The track-mounted drilling rig was selected to limit disturbance to the surrounding area. It is not expected that drill rig access will require tree removal, road building, or drilling pad installation. The drilling will produce a continuous core to be logged by the Floyd|Snider geologist. Groundwater monitoring wells will be constructed of 2-inch-diameter Schedule 40 polyvinyl chloride (PVC) production casing and well screen. Monitoring wells will be 2 inches in diameter, to provide sufficient capacity for groundwater sampling volume and to allow sufficient annular space for water level measurement, sampling equipment, and potential instrumentation with pressure transducer dataloggers. Screens will consist of 0.01-inch standard machine slotted PVC screens with a bottom cap. Well screen filter packs will consist of 10/20-sized washed silica sand. Above the screen filter pack, the borehole annulus will be sealed with approximately 5 feet of hydrated 3/8-inch bentonite followed by a Portland-cement/bentonite mix grout. Well surface completions will include a minimum 6-inch-diameter steel well stick-up vault and locking cover surrounded by a 3-foot by 3-foot concrete well apron to allow surface drainage away from the well. Well surface completions will be protected by steel bollards painted yellow for high visibility.

New wells will be developed using a combination of surging and bailing followed by pumping. Purged water will be monitored for standard field parameters (i.e., specific conductance, temperature, pH, turbidity, oxygen-reduction potential). Monitoring well development will be considered complete following removal of five well volumes, stabilized field parameters, and achieving discharge less than 10 nephelometric turbidity units per the Drilling, Logging, Well Installation and Well Development SOP (Attachment 1; Appendix C of MWH 2010). Soil cuttings and development/purge water will be placed on the ground near the well location consistent with the SOP (MWH 2010). Purged water will not be allowed to infiltrate the ground surface immediately near the well or to runoff to Railroad Creek.

The newly installed monitoring wells, the four monitoring wells installed in the fall of 2018 that have not yet been surveyed (NRC-3SR, NRC-3IR, NRC-3DR, and DS-4I), and all site monitoring wells will be surveyed relative to the site datum (Washington State Plane North/NAD 83 US feet, horizontal; and mean sea level [MSL], vertical) and vertical datum NAVD 88 in accordance with Ecology requirements for Environmental Information Management submittal. The location and elevation of the well top of casing and the adjacent ground surface will be surveyed by a Washington-licensed professional surveyor consistent with the Attachment 1 (Appendix C of MWH 2010).

REFERENCES

Arcadis U.S., Inc. (Arcadis). 2018a. Memorandum to Craig Stevens, Rio Tinto, from Joe Gilbert and Aaron Kempf, Arcadis re: Holden Mine Planned Fall 2018 Groundwater Monitoring Well Installation. September 25.

_____. 2018b. Memorandum to Craig Stevens, Rio Tinto AuM, from Joe Gilbert and Nasrin Erdelyi, Arcadis re: Fall 2018 Groundwater Monitoring Well Installation, Holden Mine, Chelan County, Washington. December 28.

MWH. 2010. *Holden Mine Site Baseline Characterization and Monitoring Plan, Final Workplan*. September 3.

_____. 2013. *Draft 2012 Baseline Water Quality Conditions Report for Holden Mine, Chelan County, Washington*. April.

LIST OF ATTACHMENTS

Table 1	Proposed Monitoring Well Construction Details
Figure 1	Proposed Monitoring Well Locations
Figure 2	Preliminary Cross-Section A-A’
Figure 3	Preliminary Cross-Section B-B’
Attachment 1	Standard Operating Procedures: Drilling, Logging, Well Installation, and Well Development (From Appendix C, MWH 2010)

Table

Table 1
Proposed Monitoring Well Construction Details

Proposed Well ID	Planned Location Description	Target Monitoring Zone	Approximate Northing [1]	Approximate Easting [1]	Approximate Ground Surface in Elevation (ft amsl)	Total Well Depth (ft bgs)	Screen Interval (ft bgs) [1][2]	Screen Interval Elevation (ft amsl) [1][2]
DS-15S	Eastern boundary of barrier wall and eastern portion of TP-2 and south of Railroad Creek	Shallow Zone	437210	1656562	3165	20	5–20	3160–3145
DS-15I		Intermediate Zone				40	30–40	3135–3125
DS-16S	Near the boundary of TP-2 and TP-3 and south of Railroad Creek	Shallow Zone	437168	1657041	3165	23	8–23	3157–3142
DS-16I		Intermediate Zone				50	40–50	3115–3125
DS-16D		Deep Zone				75	65-75	3100–3090
DS-17S	Near the center of the toe of TP-3 and south of Railroad Creek	Shallow Zone	437073	1657519	3160	23	8–23	3152–3137
DS-17I		Intermediate Zone				70	60–70	3090–3100
DS-18S	North-northeastern margin of TP-3	Shallow Zone	436874	1657974	3160	23	8–23	3152–3137
DS-18I		Intermediate Zone				70	60–70	3090–3100
DS-18D		Deep Zone				100	90-100	3060–3070

Notes:

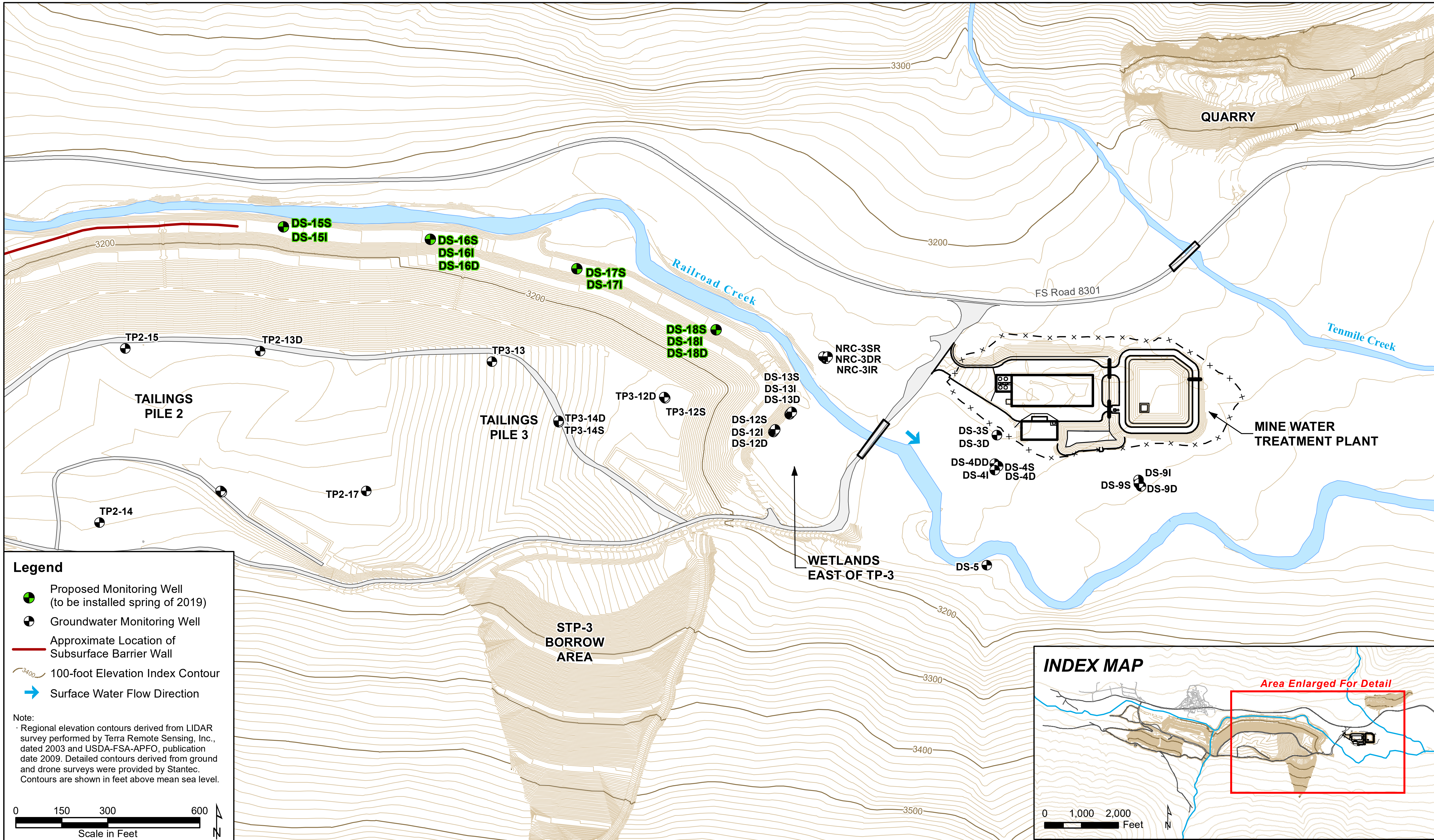
1 Washington State Plane North/NAD 83, US feet.

2 Screen intervals are approximate and are based on previous cross-section figures and estimated ground surface elevation. Final screen intervals will be based on field observations. For Shallow Zone monitoring wells, the well screen will intersect the water table, and observations will include the depth to water at time of drilling. For intermediate Zone monitoring wells, observations will include pH measurement of water using a Hydropunch during well installation activities. Deep well borings will be drilled to bedrock, and observations will be made based on retrieved core.

Abbreviations:

amsl Above mean sea level
bgs Below ground surface
ft Feet
NAD 83 North American Datum of 1983

Figures



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Planned Spring 2019 Groundwater Monitoring Well Installation Memorandum
Holden Mine Site
Chelan County, Washington

Figure 1
Proposed Monitoring Well Locations

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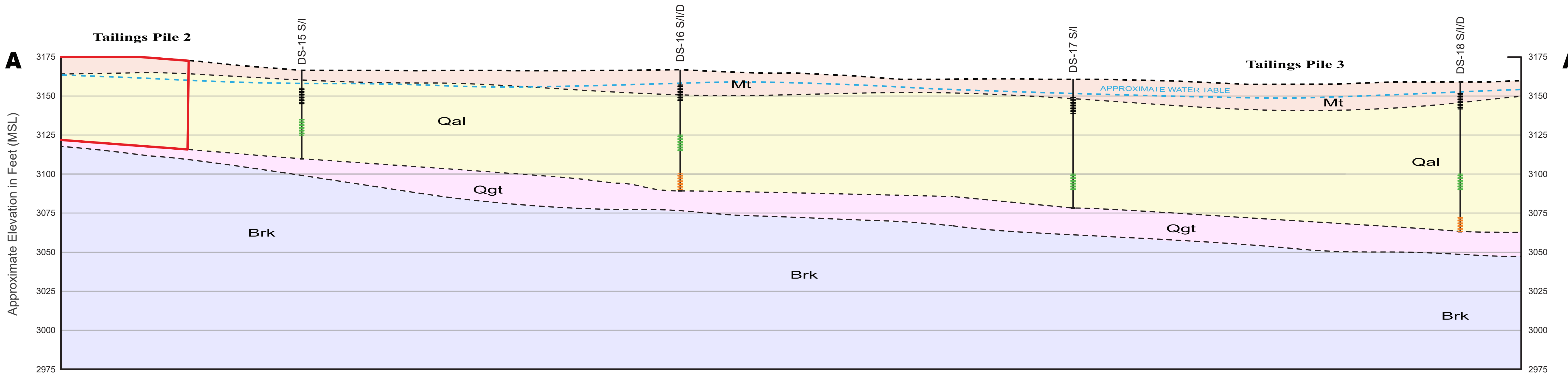
5/23/2019



Legend

- Mt — Tailings/Riprap
- Qal — Alluvium (undifferentiated)
- Qgt — Glacial till
- Brk — Bedrock

Color Code: Shallow, Intermediate, Deep

Barrier Wall

Proposed well locations

Proposed screen intervals

VERTICAL 0 25 50

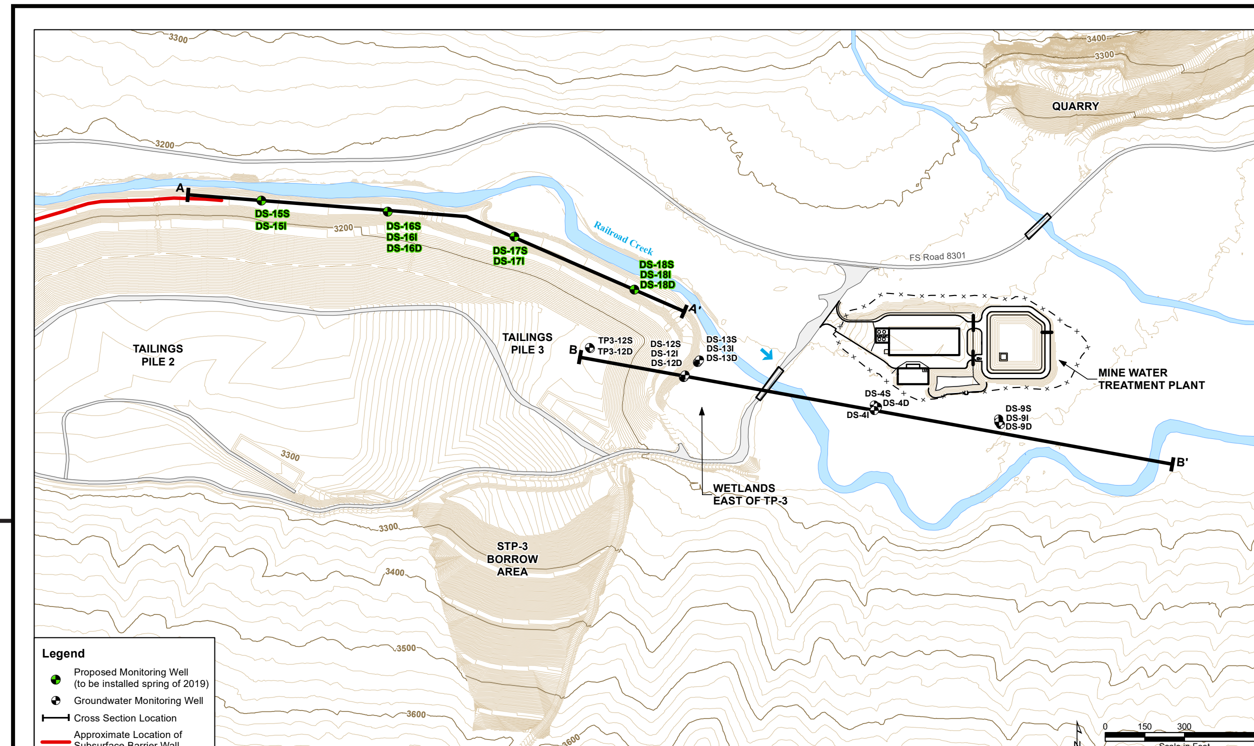
HORIZONTAL 0 50 100

SCALE IN FEET

Notes:

- Lithology based on previous cross-sections taken from Baseline Water Quality Conditions Report for Holden Mine (MWH 2013).
- Proposed locations are approximate.
- Approximate location and installation depth of barrier wall based on As-Builts by Magnus Pacific's 11/3/2015 survey.
- Actual screen depth intervals will be determined based on field observations.

MSL = Mean Sea Level



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Planned Spring 2019 Groundwater Monitoring Well Installation Memorandum
Holden Mine Site
Chelan County, Washington

Figure 2
Preliminary Cross-Section A-A'

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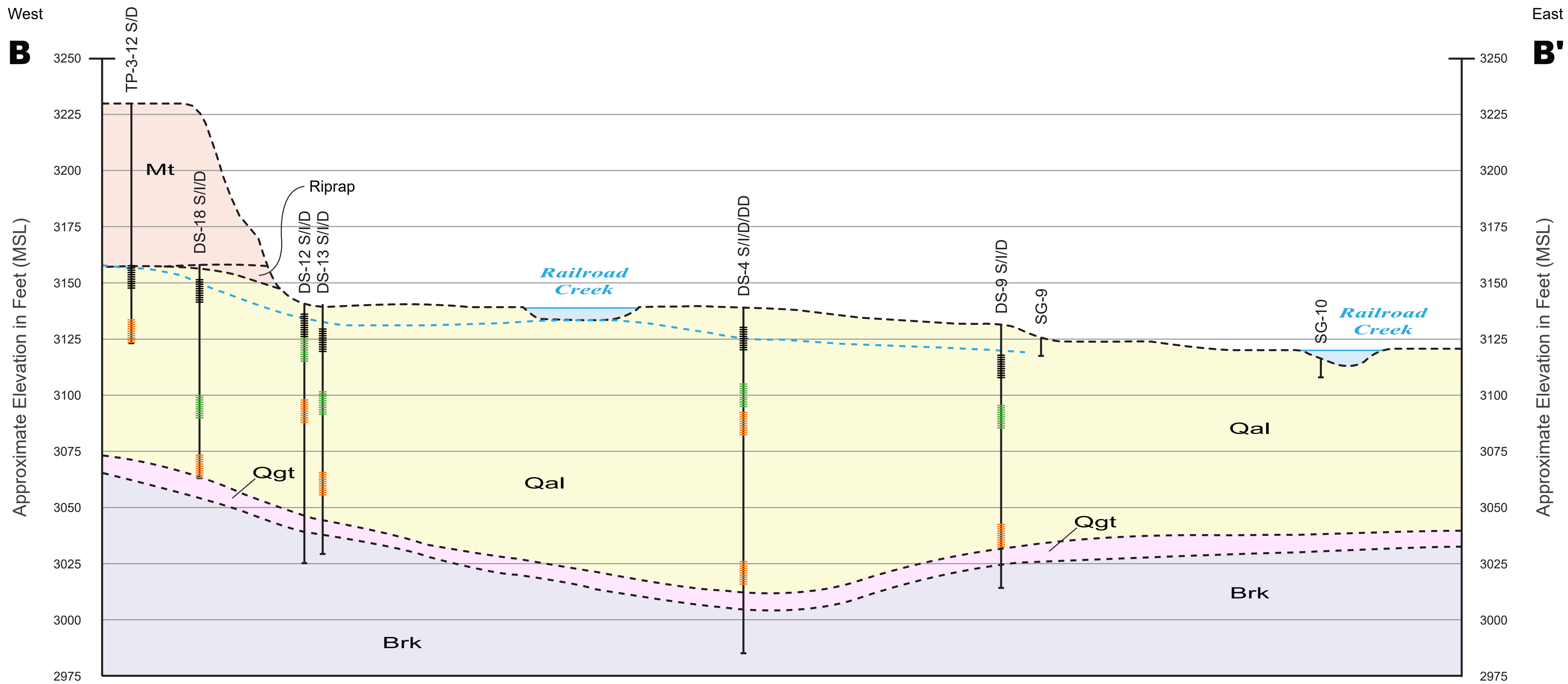
05/21/2019



Legend

Mt	Tailings/Riprap
Qal	Alluvium (undifferentiated)
Qgt	Glacial till
Brk	Bedrock

Color Code: Shallow, Intermediate, Deep

Existing and proposed well locations

Existing and proposed screen intervals

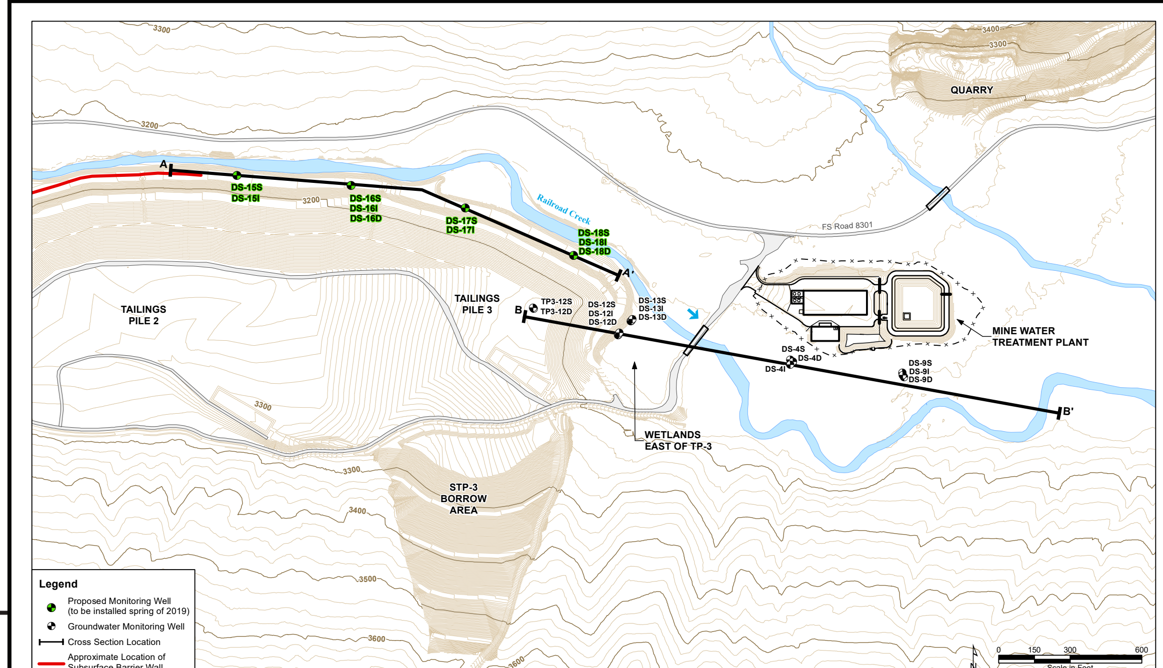
VERTICAL 0 25 50

HORIZONTAL 0 100 200

SCALE IN FEET

Notes:
- Lithology based on previous cross-sections taken from Baseline Water Quality Conditions Report for Holden Mine (MWH 2013).
- DS-18 shown at approximate ground surface elevation.
- Approximate location and screen interval depths for proposed well DS-18.
- Actual screen depth intervals will be determined based on field observations.

MSL = Mean Sea Level



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Planned Spring 2019 Groundwater Monitoring Well Installation Memorandum
Holden Mine Site
Chelan County, Washington

Figure 3
Preliminary Cross-Section B-B'

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05/21/2019

Attachment 1
Standard Operating Procedures:
Drilling, Logging, Well Installation, and Well Development

STANDARD OPERATING PROCEDURES
DRILLING, LOGGING, WELL INSTALLATION & WELL DEVELOPMENT

Prepared by:

MWH

10619 South Jordan Gateway, Suite 100
Salt Lake City, Utah 84095

TABLE OF CONTENTS

LIST OF ATTACHMENTS

1.0 INTRODUCTION

This Drilling and Well Installation Plan (DWIP) has been prepared to augment the Site Characterization Plan/Sampling and Analysis Plan (SCP/SAP). The purpose of this document is to define the standard procedure for the drilling, logging, testing, documentation, and installation of boreholes and monitoring wells. This standard operating procedure (SOP) gives descriptions of equipment, field procedures, and technical procedures necessary to perform the proposed drilling and sampling activity.

This DWIP describes procedures for conducting the tasks listed below.

- Drilling boreholes
- Sampling soil and bedrock for lithologic description
- Borehole logging
- Equipment decontamination
- Well design and construction
- Well development
- Topographic surveying
- Aquifer testing (sieve, packer and pumping tests)

Procedures for other related tasks (e.g., environmental sampling, direct push and waste management) are included in the SCP/SAP.

Many terms included in this DWIP may be unfamiliar to the reader. A glossary of terms is included in Attachment A.

2.0 DRILLING OPERATIONS

Drilling methods can be separated into two general types - techniques that do not use circulating fluids and techniques that use circulating fluids. The following sections discuss the drilling methods that fall into each of these two general categories that are most likely to be used for this project.

This section provides a description of the principles of operation and the applicability and implementability of the drilling methods that are proposed for this investigation. It focuses on methods and equipment that are readily available and typically applied. It is not intended to provide an all-inclusive discussion of drilling methods. Drilling will be conducted using an air rotary drilling rig fitted with a Tubex bit, hollow stem auger (HSA) drilling rig, and direct push Cone Penetrometer (CPT) drill rig. Other alternatives that will be available are dual-tube percussion hammer and Rotary-sonic drilling. These methods are discussed below. All drillers and drilling personnel working onsite will be 40 hour OSHA (CFR 1910) certified and 24 hour MSHA certified. Drillers will also be available to provide additional services for minor repair or servicing of existing wells.

2.1 DRILLING METHODS WITHOUT CIRCULATING FLUIDS

2.1.1 Hollow-Stem Auger Drilling

Hollow-stem augers (H.S.A.) are commonly used in unconsolidated materials up to 150 feet in depth. Drilling is accomplished by the drill rig applying downward pressure on the rotating augers. The lead auger has a cutting bit that breaks up as cuts through the soil. A key advantage of H.S.A. drilling is that undisturbed soil samples can be collected through the auger, which acts as a temporary outer casing during drilling. The auger also acts as a temporary outer casing during monitoring well installation.

Hollow-stem augers consist of two parts: a steel tube with spiral flights attached to the outside and an inner pilot or center rod and bit which is removable from the center of the auger. A cutting bit on the lead auger displaces soil, rock and other material as the augers are advanced. The removable inner plug which typically consists of a small bit attached to the inner drill rod is the primary advantage of this drilling method. Withdrawing the plug while leaving the auger in place provides an open, cased hole into which soil sampler equipment, instruments and well construction material, or other items can be inserted. Replacing the center bit and plug allows for continuation of the borehole.

Hollow-stem augers are specified by the inside diameter of the hollow stem, not by the hole size it drills. Hollow-stem augers are available in a variety of diameters, such as 2.5, 3.25, 3.375, 4.0, 4.25, 6.25, 6.625, 8.25, and 10.25 inches. The most commonly used sizes are 3.25 inches and 4.25 inches for soil borings that may be completed as 2-inch monitoring wells, and 6.625 inches for soil borings that may be completed as 4-inch monitoring wells.

The rotation of the augers causes the cuttings to move upward and be "smeared" along the borehole walls. This smearing may effectively seal off the upper zones thereby reducing the possibility of cross contamination of the upper zones to the deeper zones but increases the possibility of deep to shallow contamination. Conversely, smearing of clays on the borehole walls may seal off aquifers to be monitored.

Applications

- Suitable for all types of soil investigations.
- Allows good soil sampling with split-spoon samplers or Shelby tubes.
- Monitoring well installation in all unconsolidated formations.
- Can serve as temporary casing.
- Can be used in stable formations to set surface casing.

Limitations

- Difficulty in preserving sample integrity in heaving formations.
- Difficulty drilling through boulders, cobles and dense coarse gravel.
- Formation invasion by water or drilling mud if used to control heaving.
- Possible cross contamination of aquifers where annular space not positively controlled by water or drilling mud or surface casing.
- Limited diameter of augers limits casing size.
- Smearing of clays may seal off aquifer to be monitored.

2.1.2 Rotary-sonic Drilling

Rotary-sonic or rotasonic drilling is a dual-cased drilling system that uses high frequency vibration to take continuous core samples and advance casing into the ground. The hydraulically powered drill head applies vibration to the drill string. This energy is directed down the drill string to the face of the core bit. No mud pump or air compressor is used to force cutting away from the borehole. The drill string and drill bit are rotated to increase the cutting action of the drill bit. The inner core barrel is advanced in increments into the formation, and then the outer casing is advanced down over the core barrel. The core barrel is then removed and the sample extruded into a plastic sleeve.

Applications

- Suitable for all types of soil investigations.
- Allows undisturbed soil sampling and recovery with continuous coring.
- Monitoring well installation in all unconsolidated formations.
- Waste minimization.
- Prevents cross contamination and formation mixing.

Limitations

- Slower through hard dense formations.
- Large rig and requires a support vehicle.
- Vibration and rotation of the drill bit causes the core sample to heat up.

2.2 DRILLING METHODS WITH CIRCULATING FLUIDS

Many drilling techniques use a circulating fluid, such as water, drilling mud, air, a combination of air and water, or even a surfactant to create foam. Circulation fluids flow from the surface either through the drill pipe, out through the bit, and up the annulus between the borehole wall and the drill pipe (direct rotary) or down the borehole annulus, into the bit, and up the drill pipe (reverse rotary). Generally the up-hole velocity needed to transport cuttings to the surface is between 100 to 150 feet per minute for plain water with no additives, 80 to 120 feet per minute for high-grade bentonite drill muds, 50 to 1,000 feet per minute for foam drilling, and up to 3,000 feet per minute for air with no additives. Additives decrease the required minimum velocity. Excessive velocities can cause erosion of the borehole wall. For this project, air is the expected fluid.

The use of circulating fluids may involve the addition of chemicals to the borehole. Drilling mud utilizes bentonite clay or polymers. Additives to air drilling may include surfactants (detergents) and water mist to generate foam. Compressed air may also contain various amounts of hydrocarbon lubricants. Therefore, attention should be given to the circulating fluids and any possible additives that are used when using drilling methods utilizing circulation fluids

2.2.1 Dual-Tube Percussion Drilling

Dual-tube percussion drilling is very similar to dual-tube rotary with the exception that the two drive pipes do not rotate during drilling. The two concentric drive pipes are driven into the ground with a hammer. The hammer is similar to the mechanisms mounted on pile drivers. The typical outside diameter of the outer drive pipe is 7 to 12 inches. The typical inside diameter of the inner pipe, where well materials are normally inserted, is 4.25 to 8 inches. This drilling system is also a center stem recovery system and is used primarily in hazardous waste investigations. It is rapid and effective to depths of about 250 feet.

The outer pipe effectively seals off the formation while drilling, reducing the chance of cross contamination. Air is pumped between the annulus of the two pipes to the bit where it is deflected upward into the inner pipe. Cuttings are transported to the surface through the inner pipe.

In general, three systems are available: 7-inch OD/4.25-inch ID, 9-inch OD/6-inch ID, and 12-inch OD/8-inch ID. A 2-inch diameter monitoring well can be constructed in the 7-inch system, a 4-inch diameter monitoring well can be constructed in the 9-inch system, and a 5- or 6-inch diameter monitoring well can be constructed in the 12-inch system.

Applications

- Very rapid drilling through both unconsolidated and consolidated formations.
- Allows continuous sampling for lithologic logging in all types of formations.
- Representative samples can be obtained with minimal risk of contamination of sample and/or water bearing zone.
- In stable formations, wells with diameters as large as 6 inches can be installed in open hole completions.
- Soil samples can be easily obtained for chemical analysis.

Limitations

- In unstable formations wells are limited to approximately 4 inches.
- Air may modify chemical or biological conditions; recovery time is uncertain.

2.2.2 Air Rotary Down-the-Hole Hammer

This method combines percussion and air rotary drilling methods to drill. The borehole is drilled using the air rotary drilling method. A pneumatic drill, “down-the-hole”, at the end of the drill pipe strikes the rock while the drill pipe is gradually rotated. Rotation helps to insure even penetration.

The air used to run the drill is used to remove cuttings. Casing or drive pipe follows closely behind the rotary bit to prevent the erosion of the borehole wall.

Applications & Advantages

- Rapid drilling of unconsolidated sands, silts, and clays.
- Drilling in alluvial materials (including boulder formations).
- Casing supports borehole thereby maintaining borehole integrity and minimizing inter-aquifer cross contamination.
- Eliminates circulation problems common with direct mud rotary method.
- Good formation samples for stratigraphic evaluation.
- Minimal formation damage as casing is pulled back.

Limitations

- Thin, low pressure water bearing zones easily overlooked if drilling not stopped at appropriate places to observe whether or not water levels are recovering.
- Samples pulverized as in all rotary drilling.
- Air may modify chemical or biological conditions.
- Difficult to obtain soil samples for chemical analysis.

2.3 PERMITTING

All monitoring wells and piezometers proposed to be installed during this SCP/SAP will be installed and constructed in accordance with all applicable the Washington State Department of Ecology rules and regulations. For each monitoring well and geotechnical boring, a Notice of Intent (NOI) must be filed with the Washington State Department of Ecology prior to the start of drilling. Fees will be paid for each NOI, and must be paid at the time the NOI is filed. All well installations will follow the guidelines in the Washington State Department of Ecology Chapter 173-160WAC Minimum Standards for Construction and Maintenance of Wells. All drilling and well installation will be completed by a licensed drilling subcontractor possessing a valid Washington State Well Operators License.

2.4 SAMPLING METHODS

2.4.1 Spoon Samplers

Split-spoon samplers are the most commonly used samplers for monitoring and geotechnical work and can be applied to a variety of drilling methods. Split-spoon samplers are usually steel or stainless steel, are tubular in shape, and are split longitudinally into two semi-cylindrical halves. They may be lined or unlined. Liners are made of brass, aluminum, stainless steel, or various synthetic materials. Split-spoon samplers are generally available in 2-, 2.5-, 3-, 3.5-, and 4-inch outside diameters (OD). Lengths range between 12 and 60 inches. The 18-inch long sampler is the most commonly used. Three 6-inch liners are generally used with this sampler. Sixty-inch samplers are used when continuous coring is necessary.

Driving (hammering) is the usual method of obtaining split-spoon samples up to 2.5 feet in length. Samples are collected from the split-spoon sampler by driving the sampler into undisturbed material beneath the bottom of the casing or borehole with a weighted hammer. For most sampling, a 140-pound hammer is used. The hammer may either be at the ground surface or in-hole. The number of blow counts per 6-inch increment of total drive is recorded. An estimate of the density and consistency of the subsurface soils can be made from the relationships among the hammer weight, drop, and number of blows required to advance the split spoon in 6-inch increments.

If the sampler cannot be advanced 6 inches with a reasonable number of blows (usually about 50), sampler refusal occurs and the sampling effort at that particular interval is terminated. If "auger refusal" has not occurred, the hole is advanced to the next sampling interval where another attempt at sample retrieval is made.

After the split spoon is removed, it is opened for visual inspection and classification. If an adequate volume of sample has not been retrieved, additional sample shall be collected from a second sampler from the interval immediately below the preceding interval.

If VOCs are to be analyzed, the sample is immediately transferred into the appropriate sampling jars upon retrieval of the split spoon from the borehole. Following sample description, sample material for non-VOC analyses may be composited, homogenized, or collected from discrete intervals as provided in the project work plan. Care shall be taken to ensure that the sample collected is representative of the sample interval of interest, and not slough material. All slough material shall be discarded. If a representative sample is to be retained for future reference, the sample must be stored in a container that is compatible with potential contaminants in the sample and minimizes the potential for accidental spillage.

2.4.2 Thin-Walled Tube Samplers

The thin-walled tube (Shelby tube) sampler is a 18-, 30-, or 36-inch long, thin-walled steel, aluminum, brass, or stainless steel tube equipped with a connector head. It is primarily used in soft or clayey formations where it will provide more sample recovery than a split-spoon sampler and when relatively undisturbed samples are desired. The most commonly used sampler has a 3-inch OD and a 2.81-inch cutting diameter, and is 30 inches long.

Pressing or pushing without rotation is the normal mode of advance for the thin-walled sampler. If pressing cannot advance the tube, it may become necessary to drive the sample with drill rods and hammers without rotation. The tubes are generally allowed to stay in the hole 10 to 15 minutes to allow the buildup of skin friction prior to removal. The tube is then rotated to separate it from the soil beneath it, prior to being brought to the surface.

After removal, the sample is inspected to ensure an adequate sample volume has been collected. If an inadequate volume has been collected, the above sampling procedure is repeated.

Upon retrieval, a description of the soil core is recorded in the logbook and any disturbed soil removed from the end of the tube. VOC samples are removed and placed in the appropriate sample containers immediately upon sample retrieval. Thin-walled tubes are capped with non-reactive material for transport.

2.4.3 Continuous Coring

Continuous coring is usually performed with a 60-inch split-spoon sampler that is advanced by pressing without rotating while the drill bit is rotating. The sampling tube is lowered into and retrieved from the augers or drill stem using wireline or drill rods.

The sampling tube is locked into place so the sampler protrudes slightly ahead of the drill bit. As the bit is advanced, the auger is pressed into the formation. After the hole has been advanced the length of the sampling tube, the full sampler is retrieved and an empty sampler is put down the hole. Sampling procedures will follow those described in Section 4.2.2.

2.5 BOREHOLE OR WELL ABANDONMENT

Any borehole that will not be converted into a well (e.g., soil borings, bedrock boreholes) will be abandoned according to all applicable ADWR rules and regulations. The borehole will be abandoned by pumping cement-bentonite grout to the bottom of the borehole through a tremie pipe until the borehole is filled to the ground surface with undiluted grout. Dry holes less than 15 feet deep can be filled with grout poured from the surface. After 24 hours, the abandoned borehole will be checked for grout settlement. Any settlement will be filled in with grout, using a tremie pipe if it is deeper than 15 feet. This process will be continued until firm grout remains at the ground surface. Under no circumstances, will the borehole be backfilled with the soil removed during drilling and sampling operations.

There are currently no monitoring wells slated for abandonment during this SCP. However, if circumstances develop where a monitoring well needs to be abandoned, the well will be abandoned according to ADWR's Well Abandonment Handbook, and the proper forms will need to be filed with ADWR prior to commencement of abandonment procedures. A NOI to Abandon a Well, form 55-38 will be filed prior to abandonment and the licensed drilling contractor will file a Well Abandonment Completion report.

2.6 DRILLING EQUIPMENT DECONTAMINATION

The purpose of decontamination and cleaning procedures during excavation, drilling and sampling is to prevent contamination of the samples and cross-contamination between sites. A decontamination area and clean zone will be established for the preparation and breakdown of equipment prior to each sampling task, as described in the Accident Prevention Plan (Volume III). The decontamination area will be large enough to accommodate equipment to be used for invasive work and that will allow decontamination rinsate to be pumped off for temporary storage and subsequent disposal. Before use and between each site, all equipment and other non-sampling equipment will be decontaminated with high-pressure steam, or scrubbed with a non-phosphate detergent and rinsed with water from an approved water source. If appropriate, equipment will be covered in plastic to protect it from the elements.

All equipment that may directly contact samples, such as split-spoon samples or core barrels, will be decontaminated on-site. The following sampling-specific decontamination procedures will be utilized.

- Wash and scrub with detergent (laboratory grade, non-phosphate detergent)
- Rinse with potable water
- Rinse with deionized water
- Rinse with another batch of deionized water
- Air dry
- Protect from fugitive dust and vapors

3.0 BOREHOLE LOGGING - SOILS

3.1 GENERAL

The procedures described her are applicable to logging soils and are based on the Unified Soils Classification System (USCS); ASTM Standard D 2488-93, Standard Practice for Description and Identification of Soils (Visual Manual); and ASTM Standard D 5434-93, Standard Guide for Field Logging of Subsurface Explorations of Soil and Rock (ASTM, 1993).

Much of the information described in this section is summarized on several tables and a USCS field guide, as shown in Attachment B. Other field guidance references also may be used according to personal preference; however, such references must be based on the USCS. Note: Many references (for example, AGI Data Sheet grain size scales) are soil classifications based on the Wentworth Scale. Such scales may vary significantly from the USCS and will lead to inaccurate or inconsistent soil descriptions.

All soil logging will be documented using the Soil Boring Log Form included in Attachment C.

3.2 GEOLOGIST/HYDROGEOLOGIST

One or more geologists or hydrogeologist will accompany each operating drill rig for inspection of drilling and borehole testing work. Each individual will be responsible for only one operating rig. Once assigned to an individual borehole, that person will remain as the geologist or hydrogeologist until that borehole is completed, unless approved for replacement by the USACE. The geologist or hydrogeologist will be present during the entire time that the drill rig is operating and during casing and screen installation, developing and clean-out operations.

The geologist or hydrogeologist will observe and record the drilling operations along with the characteristics of the subsurface materials. This individual will be responsible for the preparation of a separate log for each boring and will sign each log.

3.3 DEFINITIONS

Use of the USCS requires familiarity with the grain size ranges that define a particular type of soil, as well as several other physical characteristics. The grain size definitions and physical characteristics upon which soil descriptions are based are presented below.

3.3.1 Grain Sizes

USCS grain sizes are based on U.S. standard sieve sizes, which are listed below.

- Standard sieves with larger openings are named according to the size of the openings in the sieve mesh. For example, a "3-in." sieve contains openings that are 3 inches square.
- Standard sieves with smaller openings are given numbered designations that indicate the number of openings per inch. For example, a "No. 4" sieve contains 4 openings per inch.

The following grain size definitions are paraphrased from the ASTM Standard D 2488-93. Field personnel should familiarize themselves with the grain size definitions.

Boulders - Particles of rock that will not pass a 12-in. (300-mm) square opening.

Cobbles - Particles of rock that will pass a 12-in. (300-mm) square opening and be retained on a 3-in. (75-mm) sieve.

Gravel - Particles of rock that will pass a 3-in. (75-mm) sieve and be retained on a No. 4 (4.75-mm) sieve with the following subdivisions:

- *Coarse Gravel* - passes a 3-in. (75-mm) sieve and is retained on a 3/4-in. (19-mm) sieve
- *Fine Gravel* - passes a 3/4-in. (19-mm) sieve and is retained on a No. 4 (4.75-mm) sieve

Sand - Particles of rock that will pass a No. 4 (0.19 in. or 4.75-mm) sieve and be retained on a No. 200 (0.003 in. or 75-µm) sieve with the following subdivisions:

- *Coarse Sand* - passes a No. 4 (0.19 in. or 4.75-mm) sieve and is retained on a No. 10 (0.08 in. or 2-mm) sieve
- *Medium Sand* - passes a No. 10 (0.08 in. or 2-mm) sieve and is retained on a No. 40 (0.017 in. or 425-µm) sieve
- *Fine Sand* - passes a No. 40 (0.017 in. or 425-µm) sieve and is retained on a No. 200 (0.003 in. or 75-µm) sieve

Silt - Soil passing a No. 200 (0.003 in. or 75-µm) sieve that is nonplastic or very slightly plastic and that exhibits little or no strength when air-dried. Individual silt particles are not visible to the naked eye.

Clay - Soil passing a No. 200 (0.003 in. or 75-µm) sieve that can be made to exhibit plasticity within a range of water contents and that exhibits considerable strength when air-dried. Individual clay particles are not visible to the naked eye.

3.3.2 Physical Characteristics

The following physical characteristics are used in the USCS classification for fine-grained soils. A brief definition of each physical characteristic is presented below. A determination of the type of fine-grained soil present in the sample can generally be made on the basis of plasticity, as described in Section 3.4.1.2.

Dry Strength - The ease with which a dry lump of soil crushes between the fingers.

Dilatancy Reaction - The speed with which water appears in a moist pat of soil when shaking in the hand and disappears while squeezing.

Toughness - The strength of a soil, moistened near its plastic limit, when rolled into a 1/8-inch diameter thread.

Plasticity - The extent to which a soil may be rolled into a 1/8-inch thread and re-rolled when drier than the plastic limit.

3.4 SOIL LOGGING PROCEDURES

The following aspects of a project must be understood before sampling and soil logging commences.

- Purpose of the soil logging (e.g., initial investigation, subsequent investigation, remediation)
- Known or anticipated hydrogeologic setting including presence of fill material, lithology, physical characteristics of the aquifer, type of aquifer, recharge/discharge conditions, aquifer thickness and ground water/conditions
- Drilling conditions
- Previous soil boring or borehole geophysical logs
- Soil sampling and geotechnical testing program
- Characteristics of potential chemical release(s) (chemistry, density, viscosity, reactivity and concentration)
- Health and Safety protection requirements
- Regulatory requirements

The procedures used to determine the correct soil sample classification are described below. These procedures are presented in Attachment B1.

The soils should be described in terms of lithologic units, rather than on a sample-by-sample basis. Thus, a single description may cover several sample intervals, or conversely, several units may occur within a single sample interval. For a specific unit, the primary classification is described and then variations or minor changes are noted below the main description at the depth where they occur.

3.4.1 Field Classification of Soils

When naming soils, the proper USCS soil group name is given followed by the group symbol. For clarity, it is recommended that the group symbol be placed in parentheses after the written soil group name.

Soil identification using the visual-manual procedures is based on naming the portion of the soil sample that will pass a 3-in. (75-mm) sieve. Therefore, before classifying a soil, any particles larger than 3 inches (cobbles and boulders) should be removed, if possible. Estimate and note the percentage of cobbles and boulders.

Using the remaining soil, the next step of the procedure is to estimate the percentages by dry weight of the gravel, sand and fine fractions (particles passing a No. 200 sieve). The percentages shall be estimated to the closest 5%. In general, the soil is *fine-grained* (e.g., a silt or a clay) if it contains 50% or more fines and *coarse-grained* (e.g., a sand or a gravel) if it contains less than 50% fines. If one of the components is present but estimated to be less than 5%, its presence is indicated by the term *trace*. For example, "trace of fines" would be added as additional information following the formal USCS soil description.

3.4.1.1 Procedure for Identifying Coarse-Grained Soils (contain less than 50% fines)

If it has been determined that the soil contains less than 50% fines, the soil is a *gravel* if the percentage of gravel is estimated to be more than the percentage of sand. The soil is a *sand* if the percentage of gravel is estimated to be equal to or less than the percentage of sand.

If the soil is predominantly sand or gravel but contains an estimated 15% or more of the other coarse-grained constituent, the words "with gravel" or "with sand" shall be added to the group name. For example: "gravel with sand (GP)." If the sample contains any cobbles or boulders, the words "with cobbles" or "with cobbles and boulders" shall be added to group name. For example: "silty gravel with cobbles (GM)."

5% or less fines. The soil is a "clean gravel" or "clean sand" if the percentage of fines is estimated to be 5% or less. "Clean" is not a formal USCS name but rather a general descriptor for implying little to no fines. Clean sands and gravels are given the USCS designation as either *well-graded* or *poorly-graded*, as described below.

Identify the soil as a *well-graded gravel* (GW) or as a *well-graded sand* (SW), if it has a wide range of particle sizes and substantial amounts of the intermediate particle sizes. Identify the soil as a *poorly-graded gravel* (GP) or as a *poorly-graded sand* (SP) if it consists predominantly of one grain size (uniformly graded) or has a wide range of sizes with some intermediate sizes obviously missing (gap- or skip-graded).

Note: When using the USCS, keep in mind the difference between grading and sorting. The term grading is used to indicate the range of particles contained in the sample. For example, a poorly-graded sand containing predominantly one grain size would be considered well-sorted and vice-versa. One notable exception to this general rule is a skip-graded (bimodally distributed) sample: a sand containing two distinct grain sizes would be considered both poorly-sorted and poorly-graded. The USCS uses only the *GRADING* descriptor in soil naming, not the sorting descriptor.

≥ 15% fines. The soil is a *silty* or *clayey gravel* or a *silty* or *clayey sand* if the percentage of fines is estimated to be 15% or more. For example, identify the soil as *clayey gravel* (GC) or a *clayey sand* (SC) if the fines are clayey. Identify the soil as a *silty gravel* (GM) or a *silty sand* (SM) if the fines are silty. The coarse-grained descriptor "poorly-graded" or "well-graded" is not included in the soil name, but rather, should be included as additional information following the formal USCS soil description.

>5% but <15% fines. If the soil is estimated to contain greater than 5% and less than 15% fines, give the soil a dual identification using two group symbols. The first group symbol shall correspond to a clean gravel or sand (GW, GP, SW, SP) and the second symbol shall correspond to a clayey/silty gravel or sand (GC, GM, SC, SM). The group name shall correspond to the first group symbol and include the words "poorly-graded" or "well-graded", plus the words "with clay" or "with silt" to indicate the character of the fines. For example, "poorly-graded gravel with silt (GP-GM)".

3.4.1.2 Procedure for Identifying Fine-Grained Soils (contain 50% or more fines)

The USCS classifies inorganic fine-grained soils according to their degree of plasticity (no or low plasticity - indicated with an "L", or high plasticity - indicated with an "H"). The field tests used to determine dry strength, dilatancy and toughness are generally too time consuming to be performed on a routine basis. Field personnel should be familiar with the definitions of the physical characteristics and the concepts of the field tests; however, field classifications will generally be based primarily on plasticity, as described in Attachment B2.

Lean clay (CL) - soil has medium to high dry strength, no or slow dilatancy and medium toughness and plasticity.

Fat clay (CH) - soil has high to very high dry strength, no dilatancy and high toughness and plasticity.

Silt (ML) - the soil has no to low dry strength, slow to rapid dilatancy and low toughness and plasticity, or is nonplastic.

Elastic silt (MH) - the soil has low to medium dry strength, no to slow dilatancy and low to medium toughness and plasticity; will air dry more quickly than lean clay and have a smooth, silky feel when dry.

Organic soil (OL or OH) - the soil contains enough organic particles to influence the soil properties. Organic soils usually have a dark brown to black color and may have an organic odor.

Often, organic soils will change color, for example, from black to brown, when exposed to the air. Organic soils normally will not have a high toughness or plasticity.

Other Modifiers for Use with Fine-Grained Soils:

15% to 25% coarse-grained material. If the soil is estimated to have 15% to 25% sand or gravel, or both, the words "with sand" or "with gravel" (whichever is predominant) shall be added to the group name. For example: "lean clay with sand (CL)" or "silt with gravel (ML)." If the percentage of sand is equal to the percentage of gravel, use "with sand."

≥30% coarse-grained material. If the soil is estimated to have 30% or more sand or gravel, or both, the words "sandy" or "gravelly" shall be added to the group name. Add the word "sandy" if there appears to be the same or more sand than gravel. Add the word "gravelly" if there appears to be more gravel than sand. For example: "sandy silt (ML)", or "gravelly fat clay (CH)."

3.4.1.3 Procedure for Identifying Borderline Soils

To indicate that the soil may fall into one of two possible basic groups, a borderline symbol may be used with the two symbols separated by a slash. For example, a soil containing an estimated 50% silt and 50% fine grained sand may be assigned a borderline symbol "SM/ML." Borderline symbols should not be used indiscriminately. Every effort should be made to first place the soil into a single group and then to estimate percentages following the USCS soil description.

3.4.2 Descriptive Information for Soils

After the soil name and symbol are assigned, the soil color, consistency/density and moisture content shall be described in that order. Other information is presented later in the description, as applicable.

3.4.2.1 Color

Describe the color using the Munsell Soil Color Chart (1992). Color is an important property in identifying organic soils and may also be useful in identifying materials of similar geologic or depositional origin in a given location.

When using the Munsell Soil Color Charts, first attempt to assign the soil a general color, such as brown, gray, red, etc. Then go to the correct area in the charts and assign the applicable color name and Munsell symbol. The ability to detect minor color differences varies among people and the chance of finding a perfect color match in the charts is rare. Keeping this in mind should help field personnel avoid spending unnecessary time and confusion going through the chart pages. In addition, attempting to describe detail beyond the reasonable accuracy of field observations could lead to making poorer soil descriptions than by expressing the dominant colors simply (Munsell Soil Color Chart, 1992).

If the color charts are not being used or are unavailable, again attempt to assign general colors to soils. Comparing a particular soil sample to samples from different locations in the borehole will help keep the eye "calibrated." For example, by holding two soils together, it may become evident that one is obviously greenish-brown, while another is reddish.

3.4.2.2 Consistency & Density

For intact fine-grained soil, describe consistency as very soft, soft, medium stiff, stiff, very stiff, or hard, based on the blows per foot using a 140-pound hammer dropped 30", as described in Attachment B3. If blow counts are not available then use the thumb test, as described in Attachment B3 to determine consistency.

For coarse-grained soils, describe density based on blows per foot as very loose, loose, medium dense, dense and very dense, as described in Attachment B3. If blow counts are not available, attempt to estimate the soil density by observation, since a practical field test is not available. Be sure to clearly indicate on the field boring log if blow counts could not be obtained.

3.4.2.3 Moisture

Describe the moisture condition of the soil as dry (absence of moisture, dusty, dry to the touch), moist (damp but no visible water, even in interstices) or wet (visible free water, saturated).

3.4.2.4 Maximum Grain Size

Describe the maximum particle size found in the sample in accordance with the information listed below.

- **Sand Size** - If the maximum particle size is a sand size, describe as fine, medium, or coarse.
- **Gravel Size** - If the maximum particle size is a gravel size, describe the diameter of the maximum particle size in inches.
- **Cobble or Boulder Size** - If the maximum particle size is a cobble or boulder size, describe the maximum dimension of the largest particle.

For gravel and sand components, describe the range of particle sizes within each component. For example, "about 20% fine to coarse gravel, about 40% fine to coarse sand."

3.4.2.5 Odor

Due to health and safety concerns, <u>NEVER</u> intentionally smell the soil. This could result in exposure to volatile contaminants that may be present in the soil. If, however, an odor is incidentally noticed, it should be described if organic or unusual. Soils containing a significant amount of organic material usually have a distinctive odor of decaying vegetation (sometimes a hydrogen sulfide ["rotten egg"] smell). If the odor is unusual (petroleum product, chemical, etc.), it should be described. Organic vapor readings from an OVM or similar instrument should be noted on the field boring log. The project-specific Accident Prevention Plan (Volume III) should then be consulted to determine the appropriate level of protection necessary for the continuation of fieldwork.

3.4.2.6 Cementation

Describe the cementation of intact coarse-grained soils as weak, moderate or strong, in accordance with the criteria listed below.

- **Weak** - Crumbles or breaks with handling or little finger pressure
- **Moderate** - Crumbles or breaks with considerable finger pressure
- **Strong** - Will not crumble or break with finger pressure

The presence of calcium carbonate may be confirmed on the basis of effervescence with dilute hydrochloric acid, HCl, if calcium carbonate or caliche is believed to be present in the soil. Proper health and safety precautions must be followed when mixing, handling, storing, or transporting HCl.

3.4.2.7 Angularity

Describe the angularity of the sand (coarse sizes only), gravel, cobbles and boulders, as angular, subangular, subrounded, or rounded in accordance with the criteria listed below.

- **Angular** - Particles have sharp edges and relatively planar sides with unpolished surfaces
- **Subangular** - Particles are similar to angular description but have rounded edges
- **Subrounded** - Particles have nearly plane sides but have well-rounded corners and edges
- **Rounded** - Particles have smoothly curved sides and no edges

A range of angularity may be stated, such as "subrounded to rounded".

3.4.2.8 Structure

Describe the structure of intact soils in accordance with the criteria in Attachment B4.

3.4.2.9 Lithology

Describe the primary lithologies (rock or mineral type) of the sand, gravel, cobbles and boulders, if possible. It may be difficult to determine the lithology of fine and medium-grained sand or particles that have undergone alteration.

3.4.2.10 Additional Comments

Additional comments may include the presence of roots or other vegetation, fossils or organic debris, staining, mottling, or oxidation; difficulty in drilling and caving or sloughing of the borehole walls. Also, when drilling in an area known or suspected to contain imported fill material, every effort should be made to identify the contact between fill and native soils. If a soil is suspected to be fill, this should be clearly indicated on the log following the soil description. Stratigraphic units and their contacts should be noted wherever possible.

3.4.3 Additional Boring Log Information

In addition to soil descriptions, there are several other items that should be included on all soil boring log forms, included in Attachment C. Information in the log heading should be complete and accurate. The information listed below should be included, at a minimum.

- Boring or monitoring well number
- Project name and job number
- Site name
- Name of individual who logged the boring
- Drilling contractor
- Drill rig type and method of drilling (for example, "CME 75, hollow stem auger")
- Name of drilling company
- Name of driller and helper
- Borehole diameter and drill bit type
- Type of soil sampler (for example, Modified California, continuous core, etc.)
- Time and date that drilling started and finished
- Time and date that the well was completed or the soil boring backfilled, as appropriate
- Method of borehole abandonment, if applicable
- Sketch map of boring or well location with estimated distances to major site features such as property lines or buildings and north arrow

Soil sample information should include the depth interval that was sampled, the blow counts per six inches, the amount of soil recovered and the portion submitted for analysis or testing, if any. The sample identification number may also be noted on the log.

The degree to which soil samples are collected during a field effort depends on the overall scope and purpose of the investigation, which should be clearly defined before the field effort commences. Additional soil samples may need to be collected if, for example, soils are very heterogeneous or unexpected conditions such as perched water zones or zones of contamination are encountered.

If groundwater is encountered during drilling, the depth to water and the time and date of the observation should be recorded. If the first water encountered is a perched zone, the depth, time and date that any additional groundwater zones are encountered should also be recorded. Depth to water after drilling, the measuring point and the date and time of the measurement(s) must be noted. Additional measurements of depth to groundwater, including depth and time, may be beneficial.

4.0 BOREHOLE LOGGING - BEDROCK

4.1 GENERAL

This discussion has been prepared to assist geologists in the recovery of geologic and hydrogeologic data from boreholes drilled through bedrock. Drilling is expensive and it is therefore appropriate to obtain as much relevant information from each borehole as possible. Core logging is often a slow process; the program described herein has been designed to utilize simple observations and tests in order to keep the effort required to a minimum.

4.2 BEDROCK LOGGING PROCEDURES

A Rock Core Log Form is included in Attachment D. This form contains columns for recording virtually all information of geologic or hydrogeologic significance that is available from rock core.

4.2.1 Header Information

Information required at the top of the sheet includes the following.

Date Date record prepared

Borehole Location Brief description of physical location of borehole. May be grid coordinates, chainage and offset, or geographical description. Should not simply say "see plan."

Logged by First initial and surname of logger

Elevation Reference elevation below which all down-hole depths are measured. This is not always available at the time of drilling.

Ref. Point The reference point, below which all down-hole depths are measured; normally below ground surface (bgs). If the reference point is not the ground surface, the height of the reference point above the ground surface should be noted.

Datum The survey datum to which the reference elevation is referred (e.g., State Plane NAD 83).

Drill Rig Drill rig manufacturer and model number (e.g., Longyear 44).

Inclination Surveyed inclination from horizontal of borehole at collar (90 degrees for vertical drill hole).

Azimuth Surveyed azimuth of inclined borehole at collar (use N/A - not applicable for vertical drill holes). (If the drill hole inclination or azimuth are not surveyed, this should be noted and the method of estimating [e.g., with an inclinometer and compass] should be described.)

Bit Type Brief description of type of diamond core bit used (e.g., "face discharge, surface set").

Flush Medium used to cool the drill bit and flush cuttings out of the hole (e.g., water, compressed air).

Feed The method by which pressure/force is applied to advance the bit in the hole (e.g., hydraulic, screw).

4.2.2 Drilling Information

The first (left-hand) four columns in the data section of the form record pertinent drilling information regarding hole size, casing and water conditions.

Core dia.: Depth This column records the standard core descriptor (e.g., NQ3) over the applicable depth interval shown graphically.

Casing dia.: Depth This column records the standard casing descriptor (e.g., NW) or nominal diameter of steel drill casing (e.g., 4 in.), if used (if none, insert "uncased") and the cased depth interval shown graphically. Any notes on telescoping or withdrawing casing should also be recorded.

Water Notes Any observations related to groundwater conditions in the hole should be noted (e.g., "hole made water at 19 meters [62 ft]," "lost circulation at 14 meters [47 ft.]"). This column should also include an estimate (usually by visual observation) of the flush return, or rate of return of drilling fluid. It is expressed as a percentage of fluid pumped into the hole (100 equals full return; 0 equals total loss of circulation). The depth interval over which the return rate is applicable should be indicated graphically. The color, particularly changes in color, of the return drill fluid should also be noted.

4.2.3 Rock Type

The next three columns on the form present the lithologic information from the drill hole. This description should be complete, although due to lack of space, reference to additional detail found on the geologic log is often appropriate. The rock type should be described in terms of lithologic units rather than on a run-by-run basis. Thus, a single description may cover several runs, or conversely, several rock types may occur within a single run.

Depth The depth below ground surface of all boundaries between lithologic units (rock types). Boundaries should be plotted at scaled depths and should be extended horizontally across the "Description" column, as described below. Identification/recording of boundaries between lithologic units is one of the **primary responsibilities** of the logger.

Description This section of the log provides a complete description of each lithologic unit encountered by the drill hole. Soil, if included in the rock log, or soil infillings should also be described.

Contacts between rock types are represented as listed below.

- *Sharp* - solid horizontal line at contact location
- *Gradational* - solid slanted line from start of gradational change to end of gradational change
- *Inferred contact* - dashed slanted line extending over depth range of inferred contact
- *Erosion* - solid wavy line at contact location (depth)
- *Fault* - heavy solid horizontal line at contact location (depth)

The description should include the items shown in the list below.

- Rock type (e.g., basalt)
- Formation name, if known
- Modifiers (e.g., shaly, calcareous, siliceous, micaceous, vesicular)
- Bedding characteristics (e.g., laminated, thin bedded, massive)
- Color (based on USGS Rock Color Chart)
- Hardness (soft, very hard)
- Degree at cementation (poorly cemented, well cemented)
- Texture (dense, fine-, medium-,or coarse-grained; glassy; porphyritic; crystalline)
- Solution or void conditions (solid, cavernous, vuggy with partial infilling by clay)
- Primary and secondary permeability

4.2.4 Depth Scale

The vertical scale, generally in feet, to which the drilling information, lithologic description and core data are plotted on the log. Typically, the log is set up to handle 8 meters (27.5 ft.) of hole but any scale can be used as long as it is clearly documented. The units to which the scale is plotted (e.g., feet, meters) should always be marked in the space provided in the column header.

4.2.5 Core Recovery Data

This portion of the form records pertinent data regarding the condition of the recovered core. This information is recorded on a "per run" basis. Accordingly, for each core run, the "run interval" should be indicated by solid horizontal lines plotted at the start and end depths of the run and extending across all of the "Core Recovery Data" columns. The actual cored interval should be indicated on the log, not the length of recovered core.

Details regarding drilling conditions ("hard drilling," "easy drilling," "machine off pressure," etc.), core blockages or any other factors which could effect or indicate the condition of the core should be noted.

For each run the following information should be recorded within the core interval (or immediately above the interval in the case of very short runs).

Run No. Core runs should be numbered consecutively (from-to) with increasing depth. If the overburden portion of the drill hole was sampled, the core runs should be numbered consecutively with the soil samples. The start and end depths of the core run should also be recorded in this column.

T.C.R. The Total Core Recovery of each run should be recorded as both the actual lengths cored and recovered and as the calculated percentage recovery.

R.Q.D. The Rock Quality Designation should be recorded as both the actual lengths cored and recovered and as the calculated percentage recovery.

$$\text{RQD} = \frac{\text{Sum of 10 cm (4 in) Lengths}}{\text{Total Length of Run}} \text{ (expressed as \%)}$$

Fractures This column is used to record the number of natural (not drilling induced) fractures per foot (or other appropriate interval) in a given length of core. If more than ten naturally occurring fractures are counted in the interval, record ">10" in the "Fractures per ____" column.

4.2.6 Discontinuity Data

This section of the form records information regarding the orientation and physical characteristics of each significant natural discontinuity in the core. When similar natural fractures occur regularly along pre-existing weakness planes such as bedding or foliation, it is not necessary to record the orientation and characteristics of each fracture individually. An explanatory note such as "unless otherwise noted fractures to 83.5 meters (274 feet), are along foliation; planar; smooth" should be included to eliminate the need to repeat the description for each fracture. With this convention, only fractures that do not meet the stated criteria need to be described individually, although the location and dip of all fractures should be recorded. The following additional information should also be recorded:

- Dip W.R.T - the dip with respect to the core axis of each significant natural discontinuity should be measured and recorded numerically (i.e., 90 degrees for horizontal).
- Type and surface - the type of discontinuity and the surface description characteristics should be determined and recorded using the abbreviations included in the footer section of the log form.

4.2.7 Strength Data

Weathering Index Weathering Index is recorded in this column. Changes in the Weathering Index are indicated by a solid, horizontal line at the point of change for an abrupt change, or a solid slanting line covering the range of weathering change. The classification scheme for weathering index is shown in Attachment E, Weathering and Intact Rock Strength Classification.

Strength Index: Strength Index is recorded in this column. Any change in the Strength Index should be indicated by a solid horizontal line at the point of change. The classification scheme for strength index is shown in Attachment E.

4.2.8 Additional Notes

The final column on the form is used to record any additional notes for performed on the core or in the hole. This might include data such as drilling equipment malfunction, core blockage or data that did not fit in the other columns.

4.3 DRILL CORE PHOTOGRAPHY

Each box of bedrock core will be photographed as soon as possible. Photographic records will be acquired using 35mm slides and/or digital cameras. A separate bound field logbook (see Section 8.1 of the QAPP for instructions on the use and control of field logbooks) shall be assigned to each camera for recording the photographer's name, subject matter, borehole identification number, interval and other pertinent information for each frame or digital image. The photography is a routine process and care must be taken to ensure that sharp focus and proper exposure settings are maintained throughout. A setup which utilizes daylight photo flood lamps or sunlight at an appropriate angle (e.g., directly overhead with no shadows) should be used for the best color. A signboard should be included in each picture which contains identifying information. This would include the project name, borehole number, box number, depth interval and a scale. An engineer's scale or tape and standard Munsell/Geological Society of America (GSA) soil or rock color reference charts will be included in any photographs taken of rock core or soil. Any wasted frames or images in a roll of film or sequence of digital images shall be so noted in the field logbook. The core can be photographed either wet or dry depending on which condition reveals the most detail.

The core photography provides a permanent record of the core condition as it came out of the ground. It is easier to access for review than the core itself and contains information that is otherwise lost as the core is handled for logging, split for assaying, samples taken for testing, etc. It may turn out that the photographic file is the only record behind the logs for a number of reasons, including core storage facilities have collapsed, core has been discarded after the initial logging because storage is expensive, or due to time pressures some core may not be logged at all. When a project changes hands, the new owner or lessor often receives an incomplete collection for one reason or another. In such cases, the photographic record will prove invaluable.

5.0 MONITORING WELL DESIGN AND INSTALLATION

5.1 GENERAL

This guideline is applicable to the design and installation of permanent monitoring wells at the Holden mine Site. Each monitoring well will be designed to suit the hydrogeologic setting of the site, the type of contaminants to be monitored, the overall purpose of the monitoring program and other site-specific variables. During all phases of well design, attention must be given to clear documentation of the basis for design decisions, the details of well construction and the materials to be used. A blank Well Construction Diagram is provided in Attachment F.

5.2 WELL LOCATIONS

The locations and rationale of new monitoring wells are discussed in the MWH Baseline Monitoring Work Plan.

5.3 WELL DESIGN

5.3.1 Casing Diameter and Screen Length

Monitoring well casing diameter is dependent on the purpose of the well and the amount and size of downhole equipment that must be accommodated. All of the wells are designed to be multipurpose monitoring wells. Therefore, they will all be constructed with 2-inch diameter PVC well casing and screen.

5.3.2 Casing and Screen Materials

The two most commonly used material for monitoring wells is polyvinyl chloride (PVC). PVC is inexpensive, widely available, lightweight and easy to work with. Many studies have been conducted concerning the effect of PVC on water quality data. Adsorption of some chlorinated species to PVC was found to be too slow to effect data quality. Because a sample is generally taken shortly after the purging of stagnant water in contact with the casing, the contaminants in the water will have minimal time to be influenced by sorption or leaching effects. Therefore, potential sample bias effects due to interactions with PVC are negligible (Reynolds, et al, 1990. Wells less than 150 feet deep are generally constructed of schedule 40 PVC, while deeper wells are generally constructed of schedule 80 PVC.

The hydraulic efficiency of a well screen depends primarily upon the amount of open area available per unit length of screen. The two screen types commonly used for monitoring wells are machine-slotted for PVC and continuous-slot wire-wound for stainless steel. The continuous-slot, wire-wound screen has a greater area opening per length and diameter than is available with any other screen type. The percentage of open area in continuous-slot screen is often more than twice that provided by standard slotted well screen. The triangular shaped wire makes these screens non-clogging. The monitoring wells installed at the site will be constructed with machine-slotted PVC screens, except ones installed for conducting pumping tests, which will be installed with continuous-slot wire-wound PVC screen.

Additional construction specifications are listed below.

- Threaded, flush-joint casing
- Well caps that are vented to prevent the accumulation of gases and to allow water levels in the well to respond to barometric and hydraulic pressure changes
- Threaded end-caps

5.3.3 Decontamination of Casing and Screen Materials

During the production of PVC casing, a wax layer can develop on the inner wall of the casing; protective coatings may also be added to enhance casing durability. All of these represent potential sources of chemical interference and must be removed with either a laboratory-grade non-phosphate solution or by steam cleaning prior to installation. Factory cleaning of casing and screen in a controlled environment by standard detergent washing, rinsing and air-drying procedures is superior to any cleaning efforts attempted in the field. Factory cleaned and sealed casing and screen that is certified by the supplier will be used if available.

5.3.4 Filter Pack and Well Screen Design

A properly designed monitoring well requires that a well screen be placed opposite the zone to be monitored and be surrounded by materials that are coarser and of greater hydraulic conductivity than the natural formation material. Filter packs are installed to create a permeable envelope around the well screen. The selection of the filter pack grain size should be based on the grain size of the finest layer to be screened and the slot size of the screen.

If conditions warrant, filter pack grain size and well screen slot size should be determined by the grain size distribution of the formation material. The filter pack should be designed first. It is recommended to use a filter pack grain size that is three to five times the average (D50) size of the formation materials. D50 will be estimated based on the lithologic description made by the site geologist or hydrogeologist. However, this method may be misleading in coarse, well graded formation materials. Another way to determine filter pack grain size is to take the D30 grain size of the formation materials and multiplying it by a factor of between 3 and 6, with 3 used if the formation is fine and uniform and 6 used if the formation is coarse and non-uniform. For both methods, the uniformity coefficient of the filter pack materials should be as close to 1.0 as possible to minimize particle size segregation during filter pack installation.

The filter pack will extend from the bottom of the well screen to approximately 2 to 5 feet above the top of the screen to account for settlement of the pack material during development and to act as a buffer between the well screen and the annular seal. Filter pack thickness must be sufficient to surround the well screen but thin enough to minimize resistance to the flow of fine-grained formation material and water into the well during development.

The materials comprising the filter pack are chemically inert. It should be comprised of clean quartz sand or glass beads. Filter pack materials usually come in 50 to 100-pound bags; these materials are washed, dried and factory packaged.

The casing string should be installed in the center of the borehole. This will allow the filter-pack materials to evenly fill the annular space around the screen and ensure that annular seal materials fill the annular space evenly around the casing. Where a dual-tube rig is used, the inner tube of the dual tube will adequately centralize the casing string. For other types of drilling, centralizers will be used to ensure the casing string is positioned in the center of the borehole. Centralizers are typically expandable metal or plastic that attaches to the outside of the casing and are adjustable along the length of the casing. Centralizers will be attached immediately above the well screen and at 20-foot intervals along the casing to the surface.

Methods for filter pack emplacement normally used for monitoring wells include: 1) gravity (free-fall); and 2) tremie pipe. Gravity emplacement is only possible in relatively shallow wells (less than ~50 feet) with an annular space of more than 2 inches where the potential occurrence of bridging is minimized. Bridging can result in the occurrence of large unfilled voids in the filter pack or the failure of filter pack materials to reach their intended depth. Gravity emplacement may also cause filter pack gradation. Additionally, formation materials from the borehole wall can become incorporated into the filter pack, potentially contaminating it.

With the tremie emplacement method, the filter pack is poured or slurried into the annular space adjacent to the well screen through a rigid pipe, usually 1.5 inches in diameter. Initially the pipe is positioned so that its end is at the bottom of the annulus. If the filter pack is being installed in a temporarily cased borehole (e.g., dual-tube percussion) the temporary casing is pulled to expose the screen as the filter-pack material builds up around the well screen. In unconsolidated formations the temporary casing should only be pulled out 1 to 2 feet at a time to prevent caving. In consolidated or well-cemented formations or in cohesive unconsolidated formations, the temporary casing may be raised well above the bottom of the borehole prior to filter pack emplacement. For deep wells and/or nonuniform filter pack materials, the filter pack may be pressure fed through a tremie pipe with a pump. Emplacement will be continuously monitored with a weighted measuring tape accurate to the nearest 0.1 foot to determine when the filter pack has reached the desired height.

5.3.5 Annular Seal

Proper annular seal formulation and placement results in the complete filling of the annular space and envelopes the entire length of the well casing to ensure that no vertical migration can occur within the borehole.

Annular seal materials typically consist of bentonite chips or bentonite pellets. The annular seal material can include a high solids (approximately 10%) bentonite grout with a weight in the range of eleven to thirteen pounds per gallon of sealant. The grout will be mixed using the manufacturer's directions. The bentonite seal will be at least 2 feet thick will be emplaced immediately above the filter pack. The use of bentonite as a sealing material depends on its efficient hydration (if above water) following placement. Expansion of bentonite in water can be on the order of 8 to 10 times the volume of dry bentonite. This expansion causes the bentonite to provide a tight seal between the casing and the adjacent formation. Bentonite pellets expand in water at relatively slow rates, thus reducing the potential for bridging compared to chips or granules. If the bentonite seal will be above the saturated zone, several gallons of clean distilled water will be poured down the annulus to hydrate the bentonite. A minimum of 30 minutes should pass to allow for hydration before additional annular seal materials are placed above the bentonite.

The high solids grout will be mechanically blended in an aboveground rigid container and pumped through a tremie pipe to within a few inches of the bottom of the space to be sealed. This allows the grout to displace groundwater and loose formation materials up the hole. The end of the tremie pipe should always remain in the grout without allowing air spaces. After emplacement, the tremie pipe should be removed immediately. The grout should be emplaced in one continuous mass before initial setting of the cement or before the mixture loses its fluidity.

Cement is a highly alkaline substance (pH from 10 to 12) and introduces the possibility of altering the chemistry of the water it contacts. Thinner slurries may infiltrate an unprotected filter pack. After a borehole annulus is filled with grout a sample of water may be obtained and the pH determined in the field. A pH reading of 12 or higher may indicate an invasion of cement grout into the well.

5.3.6 Surface Completions

Two types of surface completions will be used: aboveground and flush mounted. Aboveground completions will be used wherever practical. Flush mounted completions will be used in areas where there may be vehicle traffic or where low visibility is preferred. The primary purpose of either type of completion is to prevent surface runoff from entering and infiltrating down the annulus of the well and to protect the well from accidental damage or vandalism. The surface seal may be an extension of the annular seal installed above the filter pack, or a separate seal emplaced atop the annular seal.

For aboveground completions, a protective steel casing fitted with a locking cover will be set into the uncured cement surface seal. Four guard posts (bollards) will be spaced around each well with above ground completions to afford additional protection.

In a flush-mount surface completion, a water-tight monitoring well Christy box or its equivalent will be set into the cement surface seal before it has cured. This type of completion is used in high-traffic areas. A low, gently sloping mound of cement will discourage surface runoff. A locking well cap will be used to secure the inner well casing.

5.3.7 Summary of Well Design

In summary, the filter pack and well design criteria for the 1999 Investigation are listed below.

- PVC screen and casing
- Schedule 40 casing for wells less than 150 feet deep
- Schedule 80 casing for wells greater than 150 feet deep
- 0.010 or 0.020-inch machine slotted screen
- 2-inch diameter casing
- Threaded flush joint casing and end-caps
- Centralizers in uncased holes
- filter pack up to 2 to 5 feet above the top of the screened interval
- Bentonite plug at least 2 feet thick on top of filter pack
- Annular seal to the surface to consist of neat cement
- Both filter pack and annular seal are to be emplaced using a tremie pipe
- Surface completions will be aboveground stand-pipes with bollards unless in a vehicle traffic right-of-way of area where low visibility is preferred

6.0 WELL DEVELOPMENT

The goal of monitoring well development is to remove fines and drilling fluid residue from the gravel pack and the natural formation in the vicinity of the screened interval, this will assure good communication between the aquifer and the well. The result of well development is assurance that a sample collected will be a true representative of the quality of water moving through the formation.

The well development process is composed of: (1) the application of sufficient energy in a monitoring well to create groundwater flow reversals (surging) in and out of the well and the gravel pack to release and draw fines into the well; and (2) pumping or bailing to draw drilling fluids out of the borehole and adjacent natural formation along with fines that have been surged into the well.

6.1 GENERAL

The following general guidelines are applicable to well development regardless of method.

6.1.1 Decontamination

It is essential that every effort be made to avoid outside contamination and the cross-contamination of monitoring wells. This can best be done by ensuring that all equipment to be introduced into a well is clean. Before use and between each site, all equipment and other non-sampling equipment will be decontaminated with high-pressure steam or scrubbed with a non-phosphate detergent and rinsed with water from an approved water source. If appropriate, equipment will be covered in plastic to protect it from the elements.

6.1.2 Documentation

A critical part of monitoring well development is recording of significant details and events; a Well Development Record is provided in Attachment G. Listed are some important details to document.

- Well identification number
- Installation date
- Date and time of development
- Quantity of drilling fluid lost during well installation
- Measured well depth (pre-development and post-development)
- Water level
- Height of water column
- Pumping rate and water level draw down (if applicable)
- Recharge rate (poor, good, excellent)
- Periodic parameter readings
- Sample observations
- Type of equipment used
- Total amount of water removed
- Completion time

6.1.3 Well Purging

The total volume of water purged during the development process will be based on two factors: (1) indicator parameters and (2) minimum purge volume.

6.1.3.1 Indicator Parameters

During the development process, the indicator parameters pH, temperature, electrical conductivity and turbidity will be measured. The parameters pH, temperature and electrical conductivity will be measured with a field meter while turbidity will be described qualitatively. Other observations of the water, such as color and odor, will also be recorded. Measurement of the indicator parameters will be taken at the beginning and end of the development process and at least once every ½-casing-volume with a minimum of 4 measurements. Once the minimum required volume is reached, as described in Section 6.1.3.2, purging will continue until three consecutive measurements of the stabilization parameters meet the stabilization requirements shown below.

pH	± 0.2 units	
Conductivity	± 3% of span	(i.e., ± 0.03 for span of 0 to 1 mS/cm)
Temperature	± 1° C	
Turbidity	± 10%	

However, if the indicator parameters have stabilized, but there are still significant changes in color or some other qualitative characteristic, purging will continue until it has stabilized, if practical.

6.1.3.2 Purge Volume

Before the development process begins, the minimum number of gallons to be removed will be calculated. The minimum number of gallons to purge will be equal to three casing volumes or one purge volume (described below), whichever is larger.

Information needed to calculate purge volume is listed below.

1. Total depth of well (TD)
2. Measured static water level (WL)
3. Screen length (SL)
4. Well casing inner diameter (ID)
5. Borehole Diameter (BD)
6. Number of gallons of water used during well drilling/construction
7. If the standing water column (SC) is longer then the screen length, you will need to note how many feet of filter pack was installed above the screen.

Calculating one well volume:

- To calculate standing water column (SC), TD - WL = SC
- Use a well volume chart to find a multiplier in the "gallons per foot" column that coincides with the wells ID
- SC x ID multiplier = gallons of water in one well volume

Calculating one annulus volume (2 Options):

Option 1, if SC is shorter then the screen length

- Portion of saturated annulus = SC
- Use a volume chart to find a multiplier in the "Gallons per foot" column that coincides with the wells BD
- BD multiplier - ID multiplier = annulus multiplier
- Feet of saturated annulus x annulus multiplier x 30% (assumed porosity) = gallons of water in one annulus volume

<u>Option 2, if SC is longer then the screen length</u>

- Portion of saturated annulus is = to the screen length + the number of feet of sand above the top of the screen
- Use a volume chart to find a multiplier in the "Gallons per foot" column that coincides with the wells BD
- BD multiplier - ID multiplier = annulus multiplier
- Feet of saturated annulus x annulus multiplier x 30% (assumed porosity) = gallons of water in one annulus volume

Calculating the minimum gallons to be removed: well volume + annulus volume + number of gallons lost during well drilling/construction = one purge volume

<u>Example:</u>

You are to develop a 4-inch well. From the Well Construction Diagram you note the borehole diameter was 11 inches, the screen is 15 feet long and the driller used 75 gallons of water during well construction. With a water level indicator you measure the static water level at 59.45 feet and with a well tagger you measure the well depth at 71.21 feet.

Record in log book: TD = 71.25'
WL = 59.45'

TD -WL = SC
Log book: SC = 11.8'

From a Volume chart, the "gallons per foot" multiplier for a 4-inch well is 0.653 and 11.8 x 0.653 = 7.71 (gallons of water in one well volume).

Log book, One well vol. = 7.71 gallons

From a Volume chart, the "gallons per foot" for an 11-inch borehole is 4.937. Therefore, 4.937(BD multiplier) - 0.653(ID multiplier) = 4.284(annulus multiplier). And, 11.8 x 4.284 x 30% = 15.17 (gallons of water in one annulus volume).

Log book, One annulus vol. = 15.17 gallons
Drilling fluid lost = 75 gallons

7.71(one well volume) + 15.17(one annulus volume) + 75(fluid lost) = 97.88 gallons (one purge volume). A minimum of 3 well volumes must be removed during development. Additional water may need to be purged to allow the parameters to stabilize and the water to clear up.

Log book, One purge vol. = 97.88 gallons
97.88 x 3 = 293.64 (minimum number of gallons to be purged).
Log book, Min. gal. to be purged = 293.64 gallons

6.2 WELL DEVELOPMENT

Development will be accomplished using surge and bail/pump. In relatively clean, permeable formations where water flows freely into the borehole, bailing, surging and pumping is an effective development technique. First, the bottom of well will be tagged to measure the amount of sand/silt before and after surging that may be present at the bottom of the well. Then a bailer will be lowered down the well to clean out any fines that have settled on the bottom of the well. Then a surge block, slightly smaller than the inside diameter of the well casing, will be used to agitate the water, causing it to move in and out of the screen, thus drawing in fines from the gravel pack and surrounding formation and breaking up any bridges that may have occurred during the placement of the gravel pack. After surging for a few minutes (depending on the height of the water column and length of screen), the bailer will then be lowered again to clean out any fines that were drawn into the casing as a result of surging. This surge/bail technique will continue until minimal fines are being pulled out with the bailer. A submersible pump will then be lowered down the well. Pumping will begin at the top of the saturated portion of the screened interval to prevent sand locking of the pump. The pump will be lowered at intervals of 5 feet or less until the pump is resting approximately 1 foot off the bottom of the casing. The water level will be monitored continuously during the first few minutes of pumping so as not to draw the water level below the pump intake and break the suction. The discharge flow rate will be increased (if possible) until the well is pumping at its maximum yield without draw down beneath the pump.

Developing low-yield wells is a very lengthy process. If development exceeds five hours, the remaining development will be done in stages (demobilize and remobilize), not to exceed three casing volumes or two return trips to the well. For wells installed in clay or fine-grained silt, the method of development will be bailing only. Surging of such wells has been found to substantially increase the turbidity of the water and does not significantly improve hydraulic well response. These wells will be bailed dry and a record kept on the time it takes for the well to recharge 80 percent.

7.0 TOPOGRAPHIC SURVEYING

These are recommended surveying methods. All surveying will be completed by a State of Washington licensed surveyor. All new and possibly existing monitoring wells, staff gauges, well points and pore water samplers may be surveyed. Each point should be surveyed to determine its map coordinates with reference to the State Plane Coordinate System (SPCS), based on North American Datum, 1983 Adjustment (NAD 83) Zone 10 North. All points should have a horizontal accuracy of at least ±1 foot.

The elevation of a designated point on the top of the well casing (not protective casing) and/or the ground surface (not the top of the cement well apron) should be surveyed for each monitoring well or soil boring. The elevations should be surveyed to within 0.01 feet and referenced to the National Geodetic Vertical Datum, 1988 Adjustment (NGVD 88).

8.0 SIEVE TESTS

Sieve tests will be conducted in accordance with ASTM D 422-63, Standard Test Method for Particle-Size Analysis of Soils. Ten tests will be conducted. A copy of the ASTM procedure is included in Appendix II-C of the FSP. The tests will be used determine the grain-size distribution of the saturated shallow alluvium and the Ringold Formation. These data will further be used to estimate the hydraulic conductivity of these formations. During drilling, a minimum of two samples of sufficient volume for a sieve test will be collected from each borehole (one Ringold Formation sample and one of the shallow alluvium). Then, the ten most representative samples will be chosen for sieve testing towards the end of the field investigation.

9.0 PACKER TESTS

Packer tests (borehole pressure tests) will be performed while drilling through saturated bedrock to assess the hydraulic conductivity of the bedrock. A description of the procedures for conducting packer tests is included in the following sections. Additionally, standard operating procedures are included in Appendix II-C.

Packer tests will be conducted during drilling using a double-packer system. The borehole will be drilled to total depth and then the most representative interval of the borehole will be tested. The interval to be tested will be determined based on in-field review of the description of the core, as discussed in Section 4.0. Packer tests will generally be performed on one ten-foot interval per borehole that is advanced through bedrock. However, if a specific interval is observed that is not representative of the borehole as a whole, but probably has an unusually high transmissivity that could have a significant impact on groundwater flow through bedrock, it may also be tested. The intervals to be tested will normally be 10 feet long, although some may be from 5 to 20 feet, if conditions warrant (discussed below). Water will be pumped at a constant rate into the test interval, while pressure and flow rate are measured. These parameters will then be used to compute an average hydraulic conductivity value for the tested interval.

The equation used to analyze the packer tests data is (*Bureau of Reclamation, 1963*) shown here.

$$K = \frac{Q}{2\pi LH} \ln\left(\frac{L}{r}\right); L \geq 10r$$

K = hydraulic conductivity
Q = constant rate of flow into the hole
L = length of the portion of the hole tested
H = differential head of water (net pressure)
r = radius of hole tested
ln = natural logarithm

This formula is more accurate when the thickness of the stratum tested is at least 5L and for tests below rather than above the groundwater table.

9.1 FLOW RATE

Two in-line water meters will be used to measure the flow rate: a high-flow meter for measuring flow rates greater than approximately 0.25 gallons per minute (gpm); and a low-flow meter for measuring flow rates from 0.1 to 1 gpm. After flow is initiated at the desired pressure, the high-flow meter will be read at the beginning and end of a specific time interval. Generally, readings will be collected at 2-minute intervals for the first 10 minutes and then at 4- to 5-minute intervals until a constant water loss is observed for three consecutive time periods. For the high-flow meter, the flow rate will be determined by dividing the total flow volume over the interval by the time interval. For example:

$$Q = \frac{62.4\text{gals}}{10\,\text{min}} = 6.24\text{ gpm}$$

If measured flow rates are less than 1 gpm, then flow will be switched to the low-flow meter. The low-flow meter is a direct reading instrument. Flow rates will be converted from gpm to cubic feet per minute (cfm) using the following conversion:

$$Q = \frac{62.4\text{gals}}{10\,\text{min}} = 6.24 \text{ gpm}$$

Based on a comparison of flow measurements within the overlapping flow range of both flow meters and on observations of flow fluctuations during testing at other sites, flow readings are generally accurate to about 5 percent.

9.2 TEST SECTION LENGTH

The test section length will be defined as the current borehole depth (since packer tests are performed as the hole is advanced) minus the depth to the base of the packer. In most cases, this length will be set at approximately 10 feet. If permeable zones are encountered during drilling, as determined by significant loss of circulation water, the bottom 5 feet of borehole will be tested.

9.3 NET PRESSURE

The net pressure applied to the borehole test section (also referred to as the "differential head of water") is the sum of the following three pressure terms:

Net pressure = gauge pressure + column pressure - friction losses

All pressure terms are expressed in units of feet of water. Gauge pressure, column pressure and friction losses are described below.

9.4 GAUGE PRESSURE

The gauge pressure is the water pressure measured on a gauge at or above the ground surface. Gauge pressures are read to +/-1 pound per square inch (psi). However, due to pump vibrations, the gauge pressure may fluctuate up to +/-2 psi. For calculating the net pressure, the gauge pressure is converted from psi to feet of water using the following factor:

Gauge Pressure (psi) x 0.433 = Gauge Pressure (feet of water)

9.5 COLUMN PRESSURE

The column pressure is the static pressure due to the weight of water in the test pipe above the water table. Column pressure is therefore equal to either the depth to the bottom of the packer or the depth to groundwater, whichever is smaller.
Below the water table, the column pressure is always equal to the depth of the water table with respect to the surface reference point. The depth to groundwater is usually measured in the well borehole within a week or two of packer testing.

9.6 FRICTION LOSS

The head loss from friction of the pipe causes a back pressure that is recorded on the pressure gauge but is not applied to the formation. Friction loss is a function of the flow rate and the length of pipe between the pressure gauge and the packer. Friction losses will be obtained from the equipment manufacturer, if available. If they are not available, friction losses will be estimated by performing calibration tests in the field. Flow rates versus head loss are plotted on log-log paper for different lengths of pipe. Values of the gauge pressure (the pressure required to produce a target flow rate) for the target flow rate are then recorded.

9.7 EQUIPMENT AND MEASUREMENT

The basic equipment for packer tests consists of an inflatable wireline packer, ¾-inch galvanized pipe, flexible air and water hoses, water pump, water pressure gauge, water flow meters, water level indicator and stop watch. The water pump will be capable of injecting water at a uniform flow rate. The basic measurements consist of gauge pressures, flow meter readings, time reading and equipment height and dimension values.

The packer assembly basically consists of two cylindrically shaped, inflatable rubber seals separated by a larger-diameter steel cylinder. The rubber packer is tightened against the borehole walls to prevent water from leaking between the walls of the rock and the rubber sea. The packer is then inflated using compressed nitrogen or other appropriate gas/air.

The packer test is performed using the following procedure (for a typical 10-foot test section).

- The borehole is advanced approximately 10 feet using water rotary and diamond bit coring.
- After the last core barrel is retrieved from within the drill rods, the entire drill string is raised approximately 12.5 feet from the base of the hole.
- The packer assembly is lowered down the drill string until it rested on the backside of the drill bit. The upper seal of the packer remains inside the drill string, while the lower seal extends 2.5 feet from the bottom of the bit.
- Ten-foot galvanized pipe sections attached to the packer are screwed together as the packer is lowered down the hole. All screwed connections are first wrapped with Teflon tape to minimize leakage at the connections.
- Once the packer is in place, compressed nitrogen is fed to the packer through high pressure air hose until the packers seal against the drill string and the borehole walls. Typical packer inflation pressures range form 120 to 160 psi.
- The water pump, gauging assembly (water pressure and flow gauges) and the uppermost galvanized pipe are connected using flexible hoses.
- After pumping startup, water is allowed to flow through the packer and into the borehole until the desired test pressure is achieved. Typical pressures range from 10 to 30 psi depending on the depth of the packer test.
- Water flow rates are monitored upon initiation of flow down the borehole until steady-state conditions are achieved for a minimum of 5 minutes. Afterward, the pressure is increased 5 to 10 psi and the measurements re-started for an additional test, or the test is terminated.

During a packer test, there is a potential for leakage around the packer. Leakage around the packer is monitored in two ways.

- Leakage moving up through the inside of the drill string is initially monitored using a water level indicator placed down the drill string.
- Leakage moving up along the annular space between the drill string and the borehole walls is visually monitored by watching for return flow into the water circulation pit.

Tests in which leakage is observed will be immediately discontinued.

Calculated hydraulic conductivities below roughly $5x10^{-6}$ cm/sec, which result from flow rates less than 0.1 gpm, are very approximate due to flow-gauging limitations of the packer test equipment. These conductivity values would represent average values for the interval of borehole being tested.

10.0 PUMPING TESTS

The 1999 investigation will include one pumping test including a 4-hour step test followed by a 24-hour constant discharge test and 24 hours of recovery monitoring. The test will be conducted in accordance with EPA Document No. EPA/540/S-93/503, Suggested Operating procedures for Aquifer Pumping Tests. A copy of this procedure is included in Appendix II-C.

Determining the hydraulic properties of an aquifer is a fundamental component of the site characterization process. The procedure detailed here includes descriptions of three types of aquifer tests that will be implemented to help characterize the a-basalt aquifer. These tests are listed below.

- Step-tests
- Constant discharge tests
- Recovery tests

These tests involve determining the hydraulic characteristics of the aquifer by applying a stress to the aquifer and recording the response to that stress through time. The data generated from these tests can then be used in standard well flow equations to determine the hydraulic parameters of the aquifer and the pumping well. Because each method involves testing a relatively representative portion of the aquifer, they are generally considered more accurate than "ex-situ" (laboratory) soil permeability testing.

10.1 AQUIFER TESTING METHODS

In general, step tests, pumping tests and recovery tests require pumping groundwater from an aquifer and are therefore most feasible for relatively high transmissivity zones such as alluvial sand and gravel aquifers or extensively fractured aquifers. In these types of aquifers, a long-term pumping test is the most accurate means of evaluating aquifer properties and for evaluating other hydrogeologic factors such as boundary conditions, heterogeneity and anisotropy.

Within transmissive zones, groundwater can be removed at a rate that will stress the aquifer and therefore water level changes can be monitored in the pumping well and observation wells. Conversely, pumping tests are less effective, or even infeasible, for lower transmissivity zones sites due to difficulties in removing sufficient groundwater to stress the aquifer and measure a response in observation wells without dewatering the pumping well. For low to moderately transmissive zones, a more viable aquifer test method is a slug test. In general, the a-basalt aquifer is considered a good candidate for a pumping test due to its relatively high hydraulic conductivity and saturated thickness.

10.1.1 Overview of Pumping Tests

This section details the following elements of pumping tests.

- The Principle
- Assumptions and Limitations
- Test Method Selection
- Equipment Requirements
- Personnel Requirements

10.1.1.1 The Principle - Pumping Tests

Several different types of pumping tests can be conducted to determine aquifer properties although the fundamental principles of all tests remain similar. The principle of a pumping tests involves applying a stress to an aquifer by extracting groundwater from a pumping well and measuring the aquifer response by monitoring draw down as a function of time in the pumping well and/or observation wells at known distances from the well. These measurements are incorporated into an appropriate well-flow equation to calculate the hydraulic characteristics of the aquifer and pumping well.

10.1.1.2 General Assumptions and Limitations for Pumping Tests

Numerous different types of pumping tests and well-flow equations exist that may be implemented for nearly all hydrogeologic settings. Each method has a different set of limitations and assumptions. Different assumptions and limitations exist for confined, semi-confined (leaky) and unconfined (water-table) aquifers. In general, the assumptions listed below apply to most well-flow equations and hydrogeologic settings.

- The aquifer is of infinite areal extent.
- The aquifer is of uniform thickness over the entire thickness.
- Prior to pumping, the potentiometric surface is horizontal (or nearly so) over the area that will be influenced by the pumping test.
- The aquifer is pumped at a constant discharge rate, or for variable discharge rate tests, the rate is known.
- The pumping well fully penetrates the entire thickness of the aquifer and thus receives water by horizontal flow.

10.1.1.3 Pumping Test Method Selection

The three types of pumping tests shown below are detailed in this section.

- Step Tests (variable discharge tests)
- Constant Discharge Pumping Tests
- Recovery Tests

The overall approach for each test, including capabilities, limitations and assumptions are detailed below.

- **Step Test**: Involves pumping from a single well at a relatively low rate until draw down has stabilized. The pumping rate is then increased to a higher discharge rate until draw down once again stabilizes. This procedure is continued for at least three steps. Each step is typically 20 to 40 percent greater than the previous step, with a duration of typically 30 minutes to 120 minutes (Kruseman and de Ridder, 1991; Driscoll, 1986).

  In general, step-tests are relatively short duration tests that are capable of providing general well performance characteristics and aquifer transmissivity and storativity in the vicinity of the pumping well. A step-test provides specific capacity data and therefore should always be conducted prior to conducting a long-term pumping test if no previous pumping data for the well exist. Step-tests are generally considered less effective for determining hydraulic anisotropy, leakage between layers, boundary conditions and recharge areas than long-term pumping tests.

- **Constant Discharge Pumping Test**: Involves pumping from a well at a continuous, known, constant discharge rate over an extended period of time. This type of test typically involves monitoring draw down in several observation wells or piezometers, although the test may also be performed as a single-well test. Long-term, constant discharge pumping tests are the most accurate means of evaluating aquifer hydraulic properties. If properly designed and conducted, these types of aquifer tests are capable of evaluating transmissivity, storativity, hydraulic anisotropy, leakage from overlying or underlying layers, boundary effects and recharge areas. Additionally, well performance characteristics such as well capacity, well yield and well efficiency may be determined using a constant discharge pumping test.

- **Recovery Test**: Constant discharge tests and step tests should generally be accompanied by a recovery test. A recovery test measures the residual draw down following the pumping test. The recovery test provides the data required to calculate the transmissivity of the aquifer, thus providing an independent check on the results of the pumping test while costing very little in terms of the total cost of the pumping test (Freeze and Cherry, 1979; and Kruseman and de Ridder, 1991). A recovery test is invaluable if the pumping test is performed without the use of piezometers or observation wells to evaluate potential borehole storage effects of the pumping well. Additionally, residual draw downs are more reliable than draw downs measured during pumping due to difficulties in the field of maintaining absolutely constant discharge from a pumping well (all pumps have a level of discharge variability).

10.1.1.4 Equipment Requirements

Electric Submersible Pump: A pump will be used that is capable of pumping for extended periods of time at a constant discharge rate. Discharge pipe or hose will be fitted with a valve to provide the ability to adjust flow. Adjusting the discharge rate by adjusting the speed of the pump is less desirable than use of a valve. An exception is the variable-speed 2-inch-OD Grundfos submersible pumps which are designed for adjustable speed (flow) settings. A shroud is recommended if a 2-inch pump is used in a 4-inch or greater diameter well to ensure long-term cooling of the pump motor. The pump will require a reliable power source.

Flow Gauge: An in-line "turbine type" flow meter is recommended for most moderate to high flow-rate applications. Other means of gauging flow are use of calibrated orifice weirs or orifice bucket (Driscoll 1986; Kruseman and de Ridder, 1991). For low flow applications, a container and stopwatch method may be suitable. The container method requires measuring the time it takes to fill a container of known volume such as large bucket or 55-gallon drum. The flow gauging method should be accurate to +/- 5%. Since it is expected that the pumping test performed at Moses Lake will require high flow rates (e.g., 100 gpm), an in-line "turbine type" flow meter will be used. As a backup, the in-line flow meter will be augmented by the use of another method (e.g., orifice weir or bucket and stopwatch) at least twice per work shift.

Water Level Indicator: To be used for measuring static water levels. A conductivity-based water level indicator capable of measuring to 0.01 foot accuracy is required for all hazardous waste field investigations. Manual water level data will always be invoked as a back-up to electronic water levels recorded using pressure transducers and data loggers. Water level data will be recorded on an aquifer test data sheet.

Pressure Transducer: A pressure transducer will be installed in the pumping well above the pumping level and a nearby observation well. This device will be capable of continuously providing very accurate water level measurements. The transducer will be connected to a continuous data logger (described below). Transducers are available in different pressure (and accuracy) ranges. Higher range pressure transducers are less accurate than lower range pressure transducers. The transducers should never be lowered into a water column below the operating pressure range of the transducer. For example, if a 10-psi transducer is installed at the bottom of the well with 100 feet of water above it, it will no longer function properly. As a rule of thumb, a multiplier of 2.3 can be used to estimate the maximum total amount of water above a transducer (a 10-psi transducer can have 23 feet of water above it, a 50-psi transducer can have 106 feet of water above, etc.). The transducer only needs to record the draw down resulting from pumping. A 10-psi transducer is capable of measuring up to 23 feet of change in water levels to 0.01 foot accuracy and is therefore the recommended transducer for all observation wells used in the pumping test network. Transducers will operate improperly if lowered into sediment and therefore the transducer should never be lowered to the bottom of the well. The target depth of the transducer should be identified prior to lowering into the well. The transducer cable should be marked with duct tape to demarcate the target depth.

Data Logger: A data logger will be hooked up to each transducer during the pumping test. A data logger is a small field computer capable of recording a wide range of physical measurements such as pressures, temperatures, electrical conductivities and flow. The data logger converts the pressure value sent by the transducer into feet of water above the transducer and records the values in its memory. The data will be "dumped" from the logger to a laptop or desktop computer.

Each transducer has specific parameters that must be input to the data logger to make the appropriate conversions from pressure units to feet. It is extremely important that the person operating the data logger has been properly trained and has sufficient experience with the instruments to eliminate compromising or even loss of test data.

Watch: All project team members must have an accurate wrist watch or stop watch. All watches must be synchronized prior to starting any pumping test. The importance of accurate time measurements cannot be overstated.

Duct Tape: Used to affix the transducer cable to an immobile object such as the top of the well casing.

Health and Safety Equipment: Based on the requirements of the APP.

10.1.1.5 Personnel Requirements

The pumping test will initially require three to four people. More staff is generally required for long-term constant rate tests than for step tests and recovery tests, which generally can be completed with two field team members.

One person will be responsible for monitoring the flow gauge and adjusting the discharge rate of the pump and for ensuring that the data logger is triggered and operating. Other team members will be responsible for taking manual (back-up) water level measurements with a conductivity-based water level indicator.

10.2 STEP TESTS

Provided below is a detailing of the design and field methodology for completion of a step-draw down test.

10.2.1 Design of the Step Test

The following design components must be evaluated prior to completion of the step-test.

- **Choice of pumping well:** The well will be fully developed and capable of sustained prolonged pumping. Ideally, the well chosen will be located in the geographic center of the area of interest.
- **Size of pump:** Will be based on the estimated specific capacity, desired total draw downs and head requirements. If no previous pumping data are available, development logs or other field observation data should be assessed to aid in sizing the pump.

- **Duration of each step:** Ideally, the step-test will consist of a total of four steps of progressively increasing discharge rate, followed by one step for recovery. Each step will be of the same duration and will generally range from 30 minutes to 2 hours.
- **Initial Discharge Rate:** The first step discharge rate will ideally produce approximately 25 percent of the maximum anticipated draw down estimated from the well specific capacity. The second step will be approximately 50 percent of the anticipated draw down and so on. An example is provided below.

  Assume: A 100-foot-deep well is constructed with a screened interval 80 to 100 feet below the top-of-casing (TOC). The aquifer is confined. The water column in the well is 50 feet (depth to water is 50 feet below TOC). The pump will be set at 90 feet, allowing 40 feet of water column above the pumping level. The specific capacity is estimated from development data to be approximately 5 gpm/foot of draw down.

  The desired draw down for the first step is:

  (0.25)(40 feet) = 10 feet of draw down,

  Therefore, the desired pumping rate for the first step is:

  (10 feet)(5 gpm/feet of draw down) = 50 gpm

  The second step would therefore be 100 gpm, the third step would be 150 gpm, etc.

  The above calculation does not consider well losses from turbulent flow that will likely occur at higher flow rates. A factor of safety may therefore be incorporated in the design of the discharge rates for each step. Given the above conditions and assumptions, a first step pumping rate may be 40 gpm, a second step 80 gpm, etc. Flexibility in the design of the step-test is recommended due to uncertainties associated with estimating specific capacity and well efficiency. Actually pumping rates for the second and successive steps should be based on field observations of draw down vs. discharge rate.

10.2.2 Step-Testing Methods

1. Remove the well head expansion cap and allow the well to equilibrate to atmospheric conditions.

2. Record the static water level using a conductivity-based water level indicator. Sound the well. Note potential sediment at bottom.

3. Determine the appropriate depth of the transducer. Generally a 10-psi transducer (capable of measuring 23 feet of head change) or 50-psi transducer (capable of measuring 106 feet of head change) are well suited for step-testing. The transducer should be targeted for a level 3 to 5 feet above the pumping level whenever possible to minimize interference with the pump. Connect duct tape to the transducer cable to indicate the target depth below top of casing.

4. The pump should be set in the well at the desired pumping level. This is usually the screened interval for shallow wells (<100 feet total depth). For deeper wells, the pumping depth only needs to be greater than the anticipated draw down. All water disposal options and permitting must be in-place prior to conducting the test. A water disposal option will be chosen that does not impinge on the groundwater flow system during the test via infiltration recharge, etc.

5. Lower the transducer to the target depth. The transducer and transducer cable will hang plumb in the well to minimize entanglement with the pump discharge pipe/hose. Duct tape the transducer cable to an immovable object such as the top of casing, Christy box, or stovepipe. Allow the well to equilibrate to static water levels.

6. Connect the pressure transducer to a continuous data recorder. Input the required transducer parameters and other test parameters in the data logger. The data logger will typically prompt the user to record water levels below the TOC or surface. Surface refers to a static water level datum. The instrument is therefore "referenced" or "zeroed" to the static water level and will therefore measure changes relative to static water level (the desired mode for step-testing). Water levels below static water level will be recorded as negative values. The step-test requires only measuring draw down relative to static (and residual draw down during recovery, if desired). TOC refers to measuring the absolute value (total head) of the water level relative to the TOC datum. This is an unnecessary step that may introduce error in the field and is therefore not recommended for step-tests. An accurate record of all input parameters and field observations must be included on the Aquifer Test Form and a field logbook.

7. "Zero" the pressure transducer/data logger to static water levels. Confirm static levels with a water level indicator. At this point, you are ready to begin the test. The data logger should be set to begin the test in the "immediate" mode (no time delay). The data logger should be set to record water levels as frequently as possible (using the "log" mode).

8. *STEP #1*. ***This is the critical step***. On a pre-determined count, one person must simultaneously trigger the data logger and the pump. The pump operator must quickly stabilize the discharge rate to the desired pumping rate. At the same time, another team member should begin recording water levels as rapidly as possible in the pumping well (every 15 to 30 seconds for the first 5 minutes). It usually helps to have the data table constructed with water level time intervals pre-determined. The water level measuring interval may be lengthened to every minute or every five minutes as the test progresses. Field observations suggest that 70-80 percent of the total draw down for each step will occur within the first 15 to 20 minutes following commencement of pumping. The data recorded by the transducers and data logger can be viewed following completion of the logarithmic data recording cycle (approximately 2-3 minutes). Water levels recorded by the transducer/data logger system should be similar to the manually recorded water levels. It is always beneficial to plot the time and draw down data in the field to ensure that the pumping rate and the draw downs are adequate. Allow the test to run until the water level in the pumping well stabilizes to a steady state (or nearly so). This typically requires 30-120 minutes. Field plotting of data is helpful in determining when pseudo-steady state draw down is achieved.

9. *STEP #2*. ***This is also a critical step***. On a pre-determined count, one person must step-up the pumping discharge rate to the desired level (usually by opening a control valve located upstream of the flow gauge) and a second person should restart the "logarithmic data recording cycle" on the data logger. It is highly desirable to have a third field team member manually record water levels at each "Step". Each of these successive steps will be of the same duration as the first step.

10. *STEP #3 and STEP #4*. ***Critical Steps***. Repeat item 9. above. Make sure to not draw the water level down to the pumping level. It is more desirable to abbreviate the duration of any step and get accurate recovery data (see item 11., below) than to draw the water level down to the pumping level.

11. *STEP #5*. ***Critical Step***. On a pre-determined count, simultaneously turn off the pump, "Step" the data logger and manually record recovery (residual draw down) data. Continue

recording the recovery data until the water level returns to static water levels (or nearly so). The test is completed.

12. ***This is a very important step***. Carefully download the field data logger. Obtain a hard copy and retain a master electronic copy inviolate.

10.3 CONSTANT RATE PUMPING TESTS

Provided below is a detailing of the design and field methodology for the completion of a constant rate pumping test.

10.3.1 Pumping Test Well Design and Spacing

As discussed above, one pumping test will be conducted in the a-basalt. The pumping test will be conducted in a new well installed at a location that maximizes the chance of obtaining draw down data in one or more observation wells. The most likely location for the pumping test is well 99-BW17, as shown on Figure 4-1 of the Work Plan. Due to the high transmissivity of the a-basalt, it will be necessary to place the pumping well relatively close to an appropriate observation well to maximize the chances of measuring draw down in the observation well within the time planned for pumping (24 hours).

Montgomery Watson used preliminary design calculations to estimate the probable well capacity and appropriate spacing between the pumping well and an observation well. Three steps were taken in the preliminary design calculations.

1. Estimate of pumping well discharge based on expected well efficiency
2. Estimate of expected draw down in an observation well
3. Estimate of expected draw down in the pumping well

Each of these steps is described below.

The first step was to estimate an optimum pumping rate based on expected well efficiency. In order to maximize the pumping rate possible with a 4-inch diameter PVC screened well, the well design will include a 20-foot continuous wire-wrapped screen with a 1-inch annulus and #3 Monterey sand or equivalent. A shorter screen length gives rise to an insufficient pumping rate, while a longer screen length is generally not prudent in a potentially contaminated fractured bedrock aquifer. Using the casing diameter, percent open area of screen and expected percent of clogged filter pack, the open area of the screen was calculated. The open area of the screen was used with the screen length to calculate the optimum pumping rate. The optimum pumping rate was calculated to be approximately 1,000 m^3/day (185 gpm).

The second step was to calculate the expected draw down in an observation well using the above pumping rate and the transmissivity (5,270 m^2/day) and probable storativity (0.005) of the a-basalt aquifer for a 24-hour constant discharge test. The calculation was performed using the Theis equation and the assumptions that the well would be fully penetrating and the a-basalt a fully confined aquifer. The result was 0.152 meters of draw down in an observation well 10 meters from the pumping well.

The third step was to calculate the expected draw down in the pumping well. At 70% well efficiency the draw down was calculated to be approximately 1.46 feet and at 10% efficiency, 10.22 feet. Both of these values are well below the saturated thickness of the a-basalt in the areas that are being considered for the pumping test.

The actual pumping test will probably be run at a pumping rate of around 100 gpm due to pump limitations. Due to that limitation and that the above-mentioned assumptions give rise to approximate results, the pumping well will be designed with a 20-foot continuous wire-wrapped screen and will be placed within 15 to 25 feet of an observation well (closer to 25 feet if feasible).

10.3.2 Design Considerations for Constant Rate Pumping Tests

The following design components must be evaluated prior to completion of a pumping test.

- **Choice of pumping well:** The well will be designed as a pumping well (as described in the previous section), although any monitoring wells can be "converted" to a pumping well for use in a pumping test. In either case, the well will be fully developed and capable of sustained prolonged pumping. Ideally, the well chosen will be located in the geographic center of the area of interest, or in a downgradient location, if remediation will involve hydraulic containment and collection downgradient. However, a location will also be chosen to minimize extracting potentially contaminated groundwater. Nearby observation wells or piezometers are required for distance-draw down calculations. If an existing pumping well is used in the test, the pumping history of the well should be known.
- **Choice of observation wells:** Ideally, water levels will be monitored in as many nearby observation wells as feasible. Wells screened at different depth intervals should also be monitored to evaluate hydraulic communication across aquitards. It is advantageous to equip observation wells that are located nearby the pumping well with continuous data recording instruments and manually record water levels for wells located at greater distances. Prior to conducting the pumping test, estimated zones of influence may be completed using well-flow equations to determine which wells will likely to show a draw down response (see Section 0.3.1). It is beneficial to use observation wells located upgradient, downgradient and across gradient from the pumping well to evaluate hydraulic anisotropy.
- **Size of pump:** Will be based on the draw down requirements and estimated specific capacity determined from a step-draw down test or from actual long-term pumping data. It is considered inappropriate to conduct a pumping test without completing a step-draw down test, particularly without existing knowledge of the pumping characteristics of the pumping well.
- **Duration of Pumping Test - Confined Aquifer:** Confined aquifers respond to pumping relatively quickly due to small storativity values. A pumping test for a confined aquifer should be conducted over a period of 24 hours (one day) to provide sufficient data for analysis. It is noted that there is no fixed time for pumping tests. Preliminary plotting of data in the field may indicate how the aquifer is responding, thus determining the duration of the test.
- **Duration of Pumping Test - Unconfined Aquifer:** The cone of depression that results from pumping expands much more slowly for unconfined aquifers prior to reaching a steady state. The generally accepted minimum duration pumping test for an unconfined aquifer is therefore 72 hours (three days) to provide sufficient data for analysis.
- **Discharge Rate:** The discharge rate should be based on the results of the step-draw down testing program. The specific capacity calculated from the step test should be used to estimate the desired draw down and pumping rate. Because of the uncertainty in the step test calculations, a level of safety should be factored into the desired draw down level to ensure that the water level is not draw down to the minimum head required by the pump. The discharge rate will be monitored with a flow meter, which will be checked throughout the duration of the test every ½ hour.
- **Contingency for Test Interruptions**: **Contingency for Test Interruptions**: If there is an interruption in the test (e.g., failure of the pump or generator or greater than 5 percent variation in the pumping rate) the following responses should be made:

- Immediately record the time and totalizer reading and then notify the Field Coordinator;
- If it happens early (first 8 hours for 24 hour test, first 16 for 72 hour test - 8 [16]), the test should be restarted after full water level recovery.
- If it happens late (last 16 [56] hours of the test) and is less than 2 hours in duration, the test should be continued with the total test duration extended by an amount equal to the interruption time.
- If it happens late (last 16 [56] hours) and is longer than 2 hours, the test should be terminated and restarted after full recovery.

If one of the data loggers fails and cannot be immediately replaced or repaired without interrupting the test or water levels, the field coordinator should be notified and manual measurements should be made according to the schedule presented in Groundwater and Wells (Driscoll, 1986).

- **Discharge Location:** The pumping test location is designed to be in an area where no contamination is expected. Consequently, the pump water can be discharged to the ground surface. However, due to recharge considerations, the point of discharge must be at least a couple hundred feet away from the test in order not to impact the test. Prior to initiation of the test, Montgomery Watson will calculate and appropriate distance using a recharge well solution.
- **Frequency of Water Level Measurements:** Water levels should be recorded electronically using continuous pressure transducers and a data logger and manually using a conductivity-based water level indicator. Following the "logarithmic data recording cycle," the pressure transducer can be set to record water levels every minute. Time intervals for manual measurements of draw down are presented below:

Elapsed Time (minutes)	Time Intervals (minutes)
0-10	0.5
10-15	1
15-60	5
60-120	30
120-end of test	60

- **Control Points:** It is recommended for control purposes that water levels be monitored in a well located at a distance beyond the area of influence of the test. All measurements recorded in observation wells should also be taken for the control station to evaluate instrument drift and error.
- **Background Water Level Data:** Levels in the proposed pumping well and observation well will be read at least daily for at least 3 days before the start of the step-discharge test and 3 days after recovery from the constant-discharge test. Background barometric pressures and precipitation events will also be recorded for at least 3 days before and after the pumping tests.
- **Background Pumping Data:** It is extremely important to understand regional or site-specific groundwater pumping to evaluate well interference, relic draw down, etc. If a production zone is used for the pumping test, a well canvas should be completed to determine aquifer groundwater uses.
- **Collection of Water Samples:** In many cases, groundwater should be collected during the pumping test to gather data required for treatability testing. At a minimum, groundwater should be monitored during pumping for pH, temperature, electrical conductivity and turbidity.
- **Miscellaneous:** Precipitation events must be recorded in the field notes, including time of onset, duration and rainfall total. **Barometric readings should be checked and recorded**

hourly. For shallow zone wells, the passing of heavy equipment or trains should be noted on the field logs.

10.3.3 Constant Rate Pumping Test Methods

The description of the pumping test outlined below assumes that at least one observation well will be used in the test. Continuous data logging equipment will be used in at least the pumping well and one observation well and manual backup measurements will also be taken periodically. All of the data loggers will be synchronized to the correct day, date and time. All project team members will synchronize their watches to the correct time datum.

In order to ensure that the wells involved in the test have reequilibrated subsequent to the step test, the elapsed time between the end of the step test and the beginning of the pumping test will be at least the total duration of the step test.

1. Remove the well head expansion cap from all observation wells and piezometers, as well as the pumping well. Allow all wells to equilibrate to atmospheric conditions.

2. Record the static water level using a conductivity-based water level indicator. Sound the well. Note potential sediment at bottom.

3. Determine the appropriate depth of the transducer for the pumping well. Generally a 50-psi transducer (capable of measuring 106 feet of head change) is well suited for the pumping well. The transducer should be targeted for a level 3 to 5 feet above the pumping level whenever possible to minimize interference with the pump. In some instances, installation of the transducer below the pump may be required. Care must be taken to not entangle the transducer with the pump, or to lower the transducer into sediment at the bottom of the well. Affix duct tape to transducer cable to indicate the target depth below top of casing.

4. The pump should be set in the well at the desired pumping level. This is usually the screened interval for shallow wells (<100 feet total depth). For deeper wells, the pumping depth only needs to be greater than the anticipated draw down (it is wise to consider a margin of error - be conservative). All disposal options and permitting must be in-place prior to conducting the test. A water disposal option should be chosen that does not impinge on the groundwater flow system during the test via infiltration recharge, etc.

5. Lower the transducer to the target depth in the pumping well. The transducer and transducer cable must hang plumb in the well to minimize entanglement with the pump discharge pipe/hose. Duct tape the transducer cable to an immovable object such as the top of casing, Christy box, or stovepipe. Allow the well to equilibrate to static water levels.

6. Connect the pressure transducers to the data loggers. A single, multi-channel data logger may suffice if observation wells are nearby one another, or several "remote" loggers may be required for wells separated by great distances. Input the required transducers parameters and other test parameters in the data logger. The data logger will typically prompt the user to record water levels below the top of casing (TOC) or surface. Surface refers to a static water level datum. The instrument is therefore "referenced" or "zeroed" to the either a static water level or to a value input by the operator. Water levels below static water level will be recorded as negative values. For pumping test purposes, water levels can be recorded relative to either "TOC" or "surface". It is noted that referencing to "surface mode" minimizes mistakes in the field. Additionally, nearly all data reduction techniques evaluate draw down, not absolute water levels.

An accurate record of all input parameters and field observations must be included in a field log.

7. "Zero" the pressure transducer/data logger to static water levels (or, alternatively, enter the TOC value for each well). Confirm static levels (or TOC-adjusted values) with a water level indicator.

   All data loggers must be synchronized to a common day-date-time (plus/minus 15 seconds). Because all loggers are synchronized, it is not absolutely necessary to trigger each logger simultaneously. In many instances, remote data loggers may not show an immediate draw down response and therefore it is acceptable to trigger these loggers prior to starting the pump and simply allow them to run. An alternative is to set the each logger on the "delayed start mode" set to begin at a pre-determined time (when the pump is started). Field experience indicates that this requires an extremely high level of coordination and timing.

   For the pumping well and for observation wells close by the pumping well, it will be advantageous to record the early time data at very frequent intervals. This is best accomplished using the "logarithmic data recording mode" for each transducer, with manual triggering of each data logger at the time the pump is started. This may require a project team member per well at the beginning of the test.

8. ***TEST START-UP. This is the critical step. Once the pump is started, there is no going back.*** On a pre-determined count, one person must simultaneously start the pump and quickly stabilize the discharge rate to the desired gpm (determined from a step test). Other project team members must simultaneously trigger the data loggers not yet running. At the same time, another team member should begin recording water levels as rapidly as possible in the pumping well (see frequencies above). It usually helps to have the data table constructed with water level time intervals pre-determined. The data recorded by the transducers and data logger can be viewed following completion of the logarithmic data recording cycle (approximately 2-3 minutes). Water levels recorded by the transducer/data logger system should be similar to the manually recorded water levels. It is always beneficial to plot the time and draw down data in the field to ensure that the pumping rate and the draw downs are adequate.

   The first couple of hours of the pumping test can be very hectic. It is recommended that "more" rather than "less" project team staff be on site to assist in the early stages of the test. The size of the field team can generally be greatly reduced following the initial few hours of the test.

9. *Monitoring Water Levels and Discharge Rates.* Water levels should be monitored on the frequency detailed above. The discharge rate should be monitored at least every 30 to 60 minutes and recorded on a field log.

10.4 RECOVERY TESTS

A recovery test should always be completed following a constant rate pumping test and run for as long as the duration of the pumping test. As stated above, a recovery test is invaluable if the pumping test is performed without the use of piezometers or observation wells to evaluate potential borehole storage effects in the pumping well. Additionally, residual draw downs are more reliable than draw downs measured during pumping due to difficulties in the field of maintaining absolutely constant discharge from a pumping well.

10.4.1 The Principle - Recovery Tests

When the pump is shut down following a pumping test, water levels in the pumping well and observation wells will begin to rise. This rise is known as residual draw down, s'. As with other types of aquifer tests, the relationship between discharge rate, time and draw down measured during the step test can be used in well-flow equations and corresponding "recovery equations" to determine the aquifer transmissivity and storage coefficient and well characteristics.

10.4.2 Recovery Test Methods

1. Complete a step-test or constant rate pumping test in the manner detailed above.

2. ***This is the critical step***. On a pre-determined count, simultaneously turn off the pump, "Step" the data logger and manually record recovery (residual draw down) data. The early time data should be recorded using the "log" data recording mode (high data logging frequency). Continue recording the recovery data until the water level returns to static water levels (or nearly so). The test is completed.

3. *This is an important step*. Carefully download the field data to a PC computer. Obtain a hard copy and a master electronic copy to be stored inviolate.

10.5 DATA ANALYSIS METHODS

The procedures discussed so far have focused on the actual conduct of aquifer tests. However, it is also important for the project team to determine which methods will be used for data analysis prior to completion of the test in the field. Additionally, it will be important to analyze the results of each step-test to determine optimum pumping rates for the constant discharge tests, which will be conducted the day after completion of the step-test. Many aquifer analysis methods have assumptions that may limit or even invalidate the use of certain types of aquifer test methods. A brief list of test methods is provided below, although please note that numerous other methods are available. Montgomery Watson will consult with the USACE to determine the most appropriate data analysis method.

Many commercially available, PC-based aquifer analysis programs exist to ease data reduction and analysis. It is important for the user to understand the fundamental principles involved in each method of aquifer analysis. Three commonly used programs are outlined below.

- Graphical Well Analysis Package (GWAP) (Dansby and Price, 1987). Uses curve-matching methods for pumping tests and slug tests. Report-ready output to HP Laser Jets.
- Aquifer Test Solver (AQTESOLV) (Geraghty and Miller, 1991). Similar to GWAP, uses curve-matching for most pumping test applications and slug tests, including Bouwer-Rice unconfined method.
- Step-Test Program (public domain) for analysis of Step-Draw down tests. Program written by Dr. David Huntley of San Diego State University. This program provides relatively quick entry of time-draw down data, as well as completion of the required calculations. The method involves a Taylor series and manual data analysis is extremely tedious.

Montgomery Watson will consult with the USACE to determine if a preference exists for the computer-aided analysis of the pump test data.

11.0 REFERENCES

Aller, L., Bennett, T.W., Hackett, G., Petty, R.J., Lehr, J.H., Sedoris, H. and Nielsen, D.M., 1989. Handbook of suggested practices for the design and installation of groundwater monitoring wells, National Water Well Association, Dublin, Ohio, 397 pp.

ASTM, 1990, Standard D 2488-90, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure).

Bouwer, H. and Rice, R.C., 1976. A slug test method for determining the hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells, Water Resources Research, vol. 12, no. 3, pp. 423-428.

Cooper, H.H. and Jacob, C.E., 1946. A generalized graphical method for evaluating formation constants and summarizing well field history, Am. Geophys. Union Trans. vol 27, pp. 526-534.

Cooper, H.H., Bredehoeft, J.D. and Papadopulos, S.S., 1967. Response of a finite-diameter well to an instantaneous charge of water, Water Resources Research, vol. 3, no. 1, pp. 263-269.

Dansby, D.A. and Price, C.A., 1987. Graphical Well Analysis Package "GWAP" v.2.0, Groundwater Graphics, 5209 Windmill Street, Oceanside, CA 92056. ph. (619) 940-9473.

Driscoll, F.G., 1987. Groundwater and wells; Johnson Division; St. Paul, Minnesota, 1089 pp.

Fetter, C.W., Jr., 1980. Applied Hydrogeology, Charles Merrill Publishing, Columbus, Ohio.

Freeze, R.A. and J.A. Cherry, 1979. Groundwater, Prentice-Hall, Inc., Englewood Cliffs, N.J.

Geraghty and Miller, 1991. Aquifer Test Solver "AQTESOLV" v.1.1, Geraghty and Miller, 10700 Parkridge Blvd., Suite 600, Reston, Virginia, 22091. ph. (703) 758-1200.

Hantush, M.S. and C.E. Jacob, 1955. Non-steady radial flow in an infinite leaky aquifer, Am. Geophys. Union Trans., vol. 36, pp. 95-100.

Hantush, M.S., 1960. Modification of the theory of leaky aquifers, Jour. of Geophys. Res., vol. 65, no. 11, pp. 3713-3725.

Kruseman, G.P. and N.A. de Ridder, 1991. Analysis and Evaluation of Pumping Test Data, 2nd Ed., Nat'l Institute for Land Reclamation and Improvement/ILRI, Wageningen, The Netherlands, 377p. Available through the NWWA Bookstore.

Lohman, S.W., 1979. Ground-Water Hydraulics, USGS Prof. Paper 708. Available through the USGS "Books and Open-File Reports Section, Federal Center, Box 25425 Denver, Colorado 80225.

Macbeth, 1992, Munsell Soil Color Charts.

Neuman, S.P., 1975. Analysis of pumping test data from anistropic unconfined aquifers considering delayed yield, Water Resources Research, Vol 11, No. 2, pp. 329-342.

Neuman, S.P. and P.A. Witherspoon, 1972. Field Determination of Hydraulic Properties of Leaky Multiple-Aquifer Systems. Water Resources Res. Vol. 8, No. 5, October 1972, pp. 1284 - 1298.

Nielsen, D. ed., 1991. Ground-water monitoring; Lewis Publishers, Chelsea, Michigan, 717 pp.

Reynolds, G.W., J.T. Hoff and R.W. Gillham, 1990. Sampling Bias Caused by Materials Used to Monitor Halocarbons in Groundwater. Environmental Science and Technology, Vol. 24, No. 1.

Theis, C.V., 1935. The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage, Am. Geophys. Union Trans., Vol. 16, pp. 519-524.

Thiem, G., 1906. Hydrologische Methoden. Gebhardt, Leipzig, 56p.

United States Army Corps of Engineers (USACE), EM 200-1-3, 1998. Requirements for the Preparation of Sampling and Analysis Plans.

USACE, EM 1110-1-4000, 1998. Monitoring Well Design, Installation and Documentation at Hazardous, Toxic and Radioactive Waste Sites.

U.S. Environmental Protection Agency (USEPA), 1987. A Compendium of Superfund Field Operations Methods, EPA/540/p-87/001.

United State Environmental Protection Agency (USEPA), EPA/540/G-89/004, 1988. Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA, Interim Final.

USEPA, SW846, Test Methods for Evaluating Solid Waste Physical/Chemical Methods Third Edition, 1986.

ATTACHMENTS

ATTACHMENT A

GLOSSARY OF TERMS

Absorption - The penetration or apparent disappearance of molecules or ions of one or more substances into the interior of a solid or liquid.

Adsorption - The process by which atoms, ions, or molecules are held to the surface of a material through ion-exchange processes.

Annular Sealant - Material used to provide a positive seal between the borehole and the casing of the well. Annular sealants should be impermeable and resistant to chemical or physical deterioration.

Annular Space - The space between the borehole wall and the well casing, or the space between a casing pipe and a liner pipe.

Annulus - The gap between the well and borehole where the sand, seal and grout are installed.

Aquifer - A geologic formation, group of formations, or part of a formation that can yield water to a well or a spring.

Backwashing - A method of filter pack emplacement whereby the filter pack material is allowed to fall freely through the annulus while clean fresh water is simultaneously pumped down the casing.

Bentonite - Hydrous aluminum silicate available in powder, granular, or pellet form. It is used to provide a tight seal between the well casing and the borehole.

Bailer - A cylindrical tool designed to remove material, both solid and liquid, from a well or borehole. A valve at the bottom of the bailer retains the material in the bailer. The three types of bailers are flat-valve bailer, a dart-valve bailer and the sand pump with rod plunger.

Blow Counts - Number of hammer blows needed to advance a split spoon sampler. Blow counts are usually counted in 6-inch increments.

Borehole - The hole created by drilling through the subsurface.

Bridge - A wedge or build up of sand that occurs when the driller is pouring the sand pack around the screened interval, thus leaving a gap or "open zone" where the natural formation could possibly clog the screen. Also the development of gaps or obstructions in either grout or filter pack materials during emplacement.

Cone Penetrometer - An instrument used to identify the underground conditions by measuring the differences in the resistance and other physical parameters of the strata. The cone penetrometer consists of a conical point attached to a drive rod of smaller diameter. Penetration of the cone into the formation forces the soil aside, creating a complex shear failure. The cone penetrometer is very sensitive to small differences in soil consistency.

Continuous Slot Wire-Wound Intake - A well intake that is made by winding and welding triangular-shaped, cold-rolled wire around a cylindrical array of rods. The spacing of each successive turn of wire determines the slot size of the intake.

Core Barrel - A steel tube used to collect rock core samples. The core barrel receives the rock core cut by the outer barrel as the borehole is advanced.

Cuttings - Formation particles obtained from a borehole during the drilling process.

Drill Rod - The rigid steel rod used to lower and retrieve cutting, coring and sampling equipment down the borehole.

Draw down - Distance between the static water level and water level while the well is being pumped or bailed at a constant rate.

Drilling Fluids_- A water-based or air-based fluid used in the well drilling operation to remove cuttings from the borehole, to clean and cool the bit, to reduce friction between the inner barrel and the sides of the borehole and to seal the borehole.

Dual-Purpose Well - A well that can be used as both a monitoring and extraction or injection well.

Filter Pack - Sand, gravel, or glass beads that are uniform, clean and well-rounded that are placed in the annulus of the well between the borehole wall and the well intake to prevent formation material from entering through the well intake and to stabilize the adjacent formation.

Fines - Silt, clay, fine sand.

Grout - A fluid mixture of neat cement and water with various additives or bentonite of a consistency that can be forced through a pipe and emplaced in the annular space between the borehole and the casing to form an impermeable seal.

Heaving Formation - Unconsolidated saturated substrate encountered during drilling where the hydrostatic pressure of the formation is greater than the borehole pressure causing the sands to move up into the borehole.

Inner Barrel - The tool lowered through the inside of the outer barrel that can be configured for cutting, coring, or sampling.

Kelly Bar - A hollow steel bar or pipe that is the main section of drill string to which the power is directly transmitted from the rotary table to rotate the drill pipe and bit. The cross section of the kelly is either square, hexagonal, or grooved. The kelly works up and down through drive bushings in the rotary table.

Neat Cement - A mixture of Portland cement and water in the proportion of 5 to 6 gallons of clean water per bag (94 pounds) of cement.

Outer Barrel - The steel piping that serves to both cut downwards and to line the borehole walls to prevent hole collapse.

Overshot Tool - The tool that attaches to the inner barrel so that the barrel may be lowered through the outer barrel to depth on the wireline. The overshot tool is designed to attach to, or release from, the inner tube at depth.

Parameters - Groundwater variables, pH, specific conductivity, temperature, turbidity.

Pitch - The distance along the axis of an auger flight that it takes for the helix to make one complete 360 degree turn.

Purge water - Any water removed from the well via bailing, pumping, or air lift.

Rotary Table - A mechanical or hydraulic assembly that transmits rotational torque to the kelly, which is connected to the drill pipe and the bit. The rotary table has a hole in the center through which the kelly passes.

Saturated annulus - The portion of the annulus that is below the aquifer.

Sieve Analysis - Determination of the particle-size distribution of soil, sediment, or rock by measuring the percentage of the particles that will pass through standard sieves of various sizes.

Split-Spoon Sampler - A thick-walled steel tube split lengthwise used to collect soil samples. The sampler is commonly lined with metal sample sleeves and is driven or pushed downhole by the drill rig to collect samples.

Thin-Walled Sampler - A sampling devise used to obtain undisturbed soil samples made from thin-wall tubing. The sampler is also known as a Shelby tube. The thin-wall sampler minimizes the most serious sources of disturbance: displacement and friction.

Tremie Pipe - A device, usually a small-diameter pipe, that carries grouting materials to the bottom of the borehole and that allows pressure grouting from the bottom up without introduction of appreciable air pockets.

VOCs - Volatile organic compounds.

Wireline - The steel cable used to lower and retrieve cutting, coring and sampling equipment down the borehole.

Yield - The rate at which a well will produce water.

ATTACHMENT B

UNIFIED SOIL CLASSIFICATION SYSTEM AND USCS CHART

ATTACHMENT B1

CRITERIA FOR DESCRIBING PLASTICITY

CRITERIA FOR DESCRIBING PLASTICITY	
Description	**Criteria**
Nonplastic	A 1/8-in. (3-mm) thread cannot be rolled at any water content
Low	The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit
Medium	The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit.
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rerolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit.

ATTACHMENT B2

CRITERIA FOR DESCRIBING DENSITY AND CONSISTENCY

DENSITY/CONSISTENCY BASED UPON BLOW COUNTS							
Density (Sand and Gravel) Blows/ft*				Consistency (Silt and Clay) Blows/ft*			
Term	**1.4" ID**	**2.0" ID**	**2.5" ID**	**Term**	**1.4" ID**	**2.0" ID**	**2.5" ID**
very loose	0-4	0-5	0-7	very soft	0-2	0-2	0-2
loose	4-10	5-12	7-18	soft	2-4	2-4	2-4
medium dense	10-29	12-37	18-51	medium stiff	4-8	4-9	4-9
dense	29-47	37-60	51-86	stiff	8-15	9-17	9-18
very dense	>47	>60	>86	very stiff	15-30	17-39	18-42
				hard	30-60	39-78	42-85
				very hard	>60	>78	>85
* 140 lb. hammer dropped 30 inches							

CRITERIA FOR DESCRIBING CONSISTENCY BASED UPON THUMB TEST	
Description	**Criteria**
Very soft	Thumb will penetrate soil more than 1 in. (25 mm)
Soft	Thumb will penetrate soil about 1 in. (25 mm)
Firm	Thumb will indent soil about 1/4 in. (6 mm)
Hard	Thumb will not indent soil but readily indented with thumbnail
Very Hard	Thumbnail will not indent soil

ATTACHMENT B3

CRITERIA FOR DESCRIBING STRUCTURE

CRITERIA FOR DESCRIBING STRUCTURE	
Description	**Criteria**
Stratified	Alternating layers of varying material or color with layers at least 6 mm thick; note thickness
Laminated	Alternating layers of varying material or color with the layers less than 6 mm thick; note thickness
Fissured	Breaks along definite planes of fracture with little resistance to fracturing
Slickensided	Fracture planes appear polished or glossy, sometimes striated
Blocky	Cohesive soil that can be broken down into small angular lumps which resist further breakdown
Lensed	Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay; note thickness
Homogeneous	Same color and appearance throughout

ATTACHMENT C

SOIL BORING LOG FORM

SOIL BORING / LITHOLOGY FORM

MWH

Project No: ______________________ Site ID: ______________________ Location ID: ______________________

Drill Date: ______________________ Field Geologist/Personnel: ______________________

Drilling Company/Driller: ______________________

SOIL BORING

Total Boring Depth (feet): ______________________

Depth Refusal: ______________________

Borehole Diameter (inches): ______________________

Borehole Angle Drilled: ______________________

Borehole Azimuth *(degrees on compass)*: ______________________

Cumulative Feet Drilled: ______________________

Drill Method: ______________________

***C** California Split Spoon Sampler (2.5" I.D.)
S Standard penetration test sampler
C Cuttings
▼ Elevation of ground water

BORING LOCATION

N

LOCATION DESCRIPTION

DEPTH (FEET)	Grain Size			Max. PID Reading (ppm)	Blows (6 in.)	Sample Type	Sample Recovery	USCS/ASTM Classification	Graphic Log	LITHOLOGIC DESCRIPTION (USCS name; color; size and angularity of each component or plasticity; density; moisture content; additional facts)	ELEVATION (FEET)
	% Gravel	% Sand	% Fines								
0											

SOIL BORING / LITHOLOGY FORM *(Continued)*

MWH

Drill Date: ______________________ Site ID: ______________ Location ID: __________

DEPTH (FEET)	Grain Size			Max. PID Reading (ppm)	**Blows (6 in.)**	Sample Type	Sample Recovery	USCS/ASTM Classification	Graphic Log	LITHOLOGIC DESCRIPTION (USCS name; color; size and angularity of each component or plasticity; density; moisture content; additional facts)	ELEVATION (FEET)
	% Gravel	% Sand	% Fines								

ATTACHMENT D

ROCK CORE LOG FORM

Project: ______	Boring Number: ______
Project Location: ______	
Project Number: ______	Sheet 1 of ___

Date(s) Drilled:	**Logged By:**	**Checked By:**
Drilling Method:	**Drill Bit Size/Type:**	**Total Depth Drilled (feet):**
Drill Rig Type:	**Drilled By:**	**Ground water Level (feet):**
Coordinates:		**Surface Elevation (feet):**
Comments:		**Borehole Abandonment:**

Depth (feet)	Elevation (feet)	Run No.	Recovery (%)	RQD (%)	Fractures/Foot	Lithology (Graphic Symbol)	Structure	Discontinuity Number	Lithologic Descriptions	Packer Test	Notes and Observations (Sample/Test Data, Water Levels, Drilling Characteristics, Casing Depths, Core Box No.)

PROJECT NO. 41005328.070101.ai 04/10/08 SLC

ATTACHMENT E

WEATHERING AND INTACT ROCK STRENGTH CLASSIFICATION

WEATHERING CLASSIFICATION		
TERM	**DESCRIPTION**	**SYMBOL**
Fresh	No visible sign of rock material weathering; perhaps slight discoloration on major discontinuity surfaces.	W1
Slightly Weathered	Discoloration indicates weathering of rock material on discontinuity surfaces. All the rock material may be discolored by weathering and may be somewhat weaker than in its fresh condition	W2
Moderately Weathered	Less than half of the rock material is decomposed and/or disintegrated to soil. Fresh or discolored rock is present either as a discontinuous framework or as corestones.	W3
Highly Weathered	More than half of the rock material is decomposed and/or disintegrated to a soil. Fresh or discolored rock is present either as a discontinuous framework or as corestones.	W4
Completely Weathered	All rock material is decomposed and/or disintegrated to soil. The original mass structure is still largely intact.	W5

INTACT ROCK STRENGTH CLASSIFICATION		
TERM	**DESCRIPTION**	**SYMBOL**
Extremely Weak Rock	Indented by thumbnail	R0
Very Weak Rock	Crumbles under firm blows with point of geological hammer, can be peeled by a pocket knife.	R1
Weak Rock	Can be peeled by a pocket knife with difficulty, shallow indentations made by firm blow with point of geological hammer	R2
Medium Strong Rock	Cannot be scraped or peeled with a pocket knife, specimen can be fractured with a single firm blow of geological hammer to fracture it.	R3
Strong Rock	Specimen requires more than one blow of geological hammer to fracture it.	R4
Very Strong Rock	Specimen requires many blows of geological hammer to fracture it.	R5
Extremely Strong Rock	Specimen can only be chipped with geological hammer.	R6

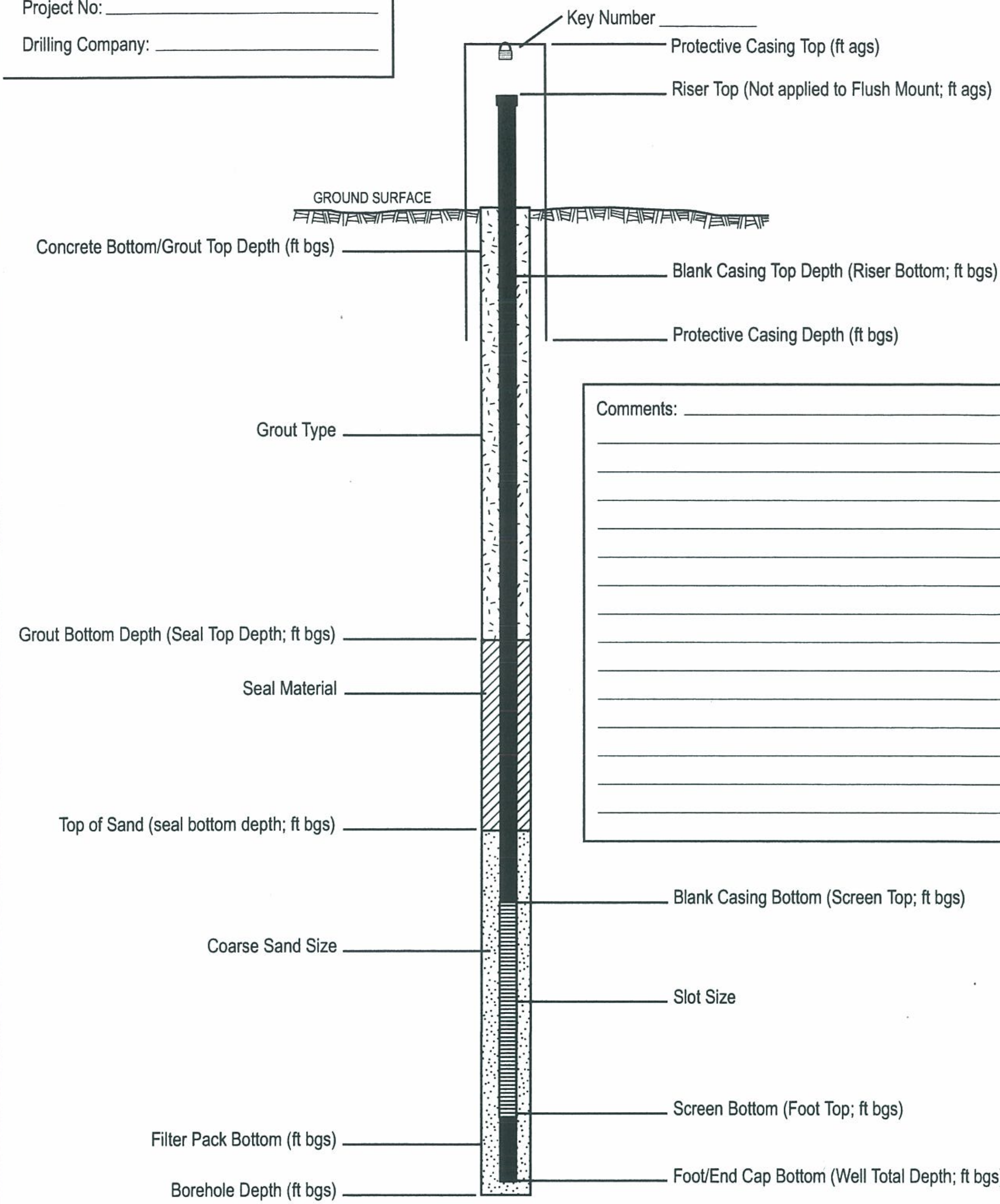
ATTACHMENT F

WELL CONSTRUCTION DIAGRAM

MONITORING WELL COMPLETION FORM

Project No: ______________________________

Drilling Company: ______________________________



Comments: ______________________________

NOT TO SCALE

Loc ID/Well ID ______________________________

Geologist ______________________________

Date Construction Started ______________________________

Date Construction Completed ______________________________

LOC Type (i.e. Monitoring Well) ______________________________

Riser Material/Diameter ______________ / ______________

Blank Casing Material/Diameter ______________ / ______________

Screen Material/Diameter ______________ / ______________

Protective Casing Type ______________________________

Borehole Diameter ______________________________

Above Ground Completion ☐ Flush Mount ☐

USCS Classification of Screened Interval ______________________________

ATTACHMENT G

WELL DEVELOPMENT RECORD

MONITORING WELL DEVELOPMENT

DATE: ______________________ WEATHER: ______________________

WELL DESIGNATION: ______________________ PROJECT NO: ______________________

FIELD PERSONNEL: ______________________ SUBCONTRACTOR: ______________________

WELL SUMMARY:

Depth to NAPL: ______________________

Depth of water: ______________________

Total well depth: ______________________

Construction: ______________________

____

Start Time_____(a)

End Time______(b)

Total Time_____(b-a)

Location Map

INSTRUMENTATION

pH meter (model): ______________________ Calibrated with buffers: ______4 ______7 ______10

SC meter (model): ______________________ Calibrated with standard solution: ____________ μmhos/cm

Turbidity meter (model): ______________________ Calibrated with: ______________________

DEVELOPMENT SUMMARY:

Development method: Bailer____________ Pump (type) __________ Surge Block (type) __________

5 purge volume calculation: ______________________

Time	pH	SC (μmhos/cm)	Temp (°C)	Turbidity (NTU)	Pumping Rate	Gals. Evacuated	Visual Appearance/Comments

Final

Time	pH	SC (μmhos/cm)	Temp (°C)	Turbidity (NTU)	Pumping Rate	Gals. Evacuated	Visual Appearance/Comments

ATTACHMENT H

WATER LEVEL READINGS FORM

Groundwater Levels

Client: ______________________________

Description/Operable Unit: ______________________

Month: ____________________ **Task/Delivery Order #:** ______________

Personnel: ____________________ **Project #:** ____________________

Loc_ID	Date	Time (4-digit military)	Static Depth* (depth to water)	Well Condition/Remarks (Well "OK", missing caps, lids, bolts, not accessible, well dry, etc.)

Form Revision: July 2005

ATTACHMENT I

SIEVE ANALYSIS FORM

Designation: D 2487 – 00

Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)[1]

This standard is issued under the fixed designation D 2487; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope *

1.1 This practice describes a system for classifying mineral and organo-mineral soils for engineering purposes based on laboratory determination of particle-size characteristics, liquid limit, and plasticity index and shall be used when precise classification is required.

NOTE 1—Use of this standard will result in a single classification group symbol and group name except when a soil contains 5 to 12 % fines or when the plot of the liquid limit and plasticity index values falls into the crosshatched area of the plasticity chart. In these two cases, a dual symbol is used, for example, GP-GM, CL-ML. When the laboratory test results indicate that the soil is close to another soil classification group, the borderline condition can be indicated with two symbols separated by a slash. The first symbol should be the one based on this standard, for example, CL/CH, GM/SM, SC/CL. Borderline symbols are particularly useful when the liquid limit value of clayey soils is close to 50. These soils can have expansive characteristics and the use of a borderline symbol (CL/CH, CH/CL) will alert the user of the assigned classifications of expansive potential.

1.2 The group symbol portion of this system is based on laboratory tests performed on the portion of a soil sample passing the 3-in. (75-mm) sieve (see Specification E 11).

1.3 As a classification system, this standard is limited to naturally occurring soils.

NOTE 2—The group names and symbols used in this test method may be used as a descriptive system applied to such materials as shale, claystone, shells, crushed rock, etc. See Appendix X2.

1.4 This standard is for qualitative application only.

NOTE 3—When quantitative information is required for detailed designs of important structures, this test method must be supplemented by laboratory tests or other quantitative data to determine performance characteristics under expected field conditions.

1.5 This standard is the ASTM version of the Unified Soil Classification System. The basis for the classification scheme is the Airfield Classification System developed by A. Casagrande in the early 1940's.[2] It became known as the Unified Soil Classification System when several U.S. Government Agencies adopted a modified version of the Airfield System in 1952.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This practice offers a set of instructions for performing one or more specific operations. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this practice may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 117 Test Method for Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing[3]

C 136 Test Method for Sieve Analysis of Fine and Coarse Aggregates[3]

C 702 Practice for Reducing Field Samples of Aggregate to Testing Size[3]

D 420 Guide to Site Characterization for Engineering, Design and Construction Purposes

D 421 Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants[4]

D 422 Test Method for Particle-Size Analysis of Soils[4]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[4]

[1] This standard is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.07 on Identification and Classification of Soils.

Current edition approved March 10, 2000. Published May 2000. Originally published as D 2487 – 66 T. Last previous edition D 2487 – 98.

[2] Casagrande, A., "Classification and Identification of Soils," *Transactions*, ASCE, 1948, p. 901.

[3] *Annual Book of ASTM Standards*, Vol 04.02.

[4] *Annual Book of ASTM Standards*, Vol 04.08.

***A Summary of Changes section appears at the end of this standard.**

D 1140 Test Method for Amount of Material in Soils Finer than the No. 200 (75-µm) Sieve[4]
D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock[4]
D 2217 Practice for Wet Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants[4]
D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[4]
D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction[5]
D 4083 Practice for Description of Frozen Soils (Visual-Manual Procedure)[4]
D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils[4]
D 4427 Classification of Peat Samples by Laboratory Testing[4]
E 11 Specification for Wire-Cloth Sieves for Testing Purposes[6]

3. Terminology

3.1 *Definitions*—Except as listed below, all definitions are in accordance with Terminology D 653.

NOTE 4—For particles retained on a 3-in. (75-mm) U.S. standard sieve, the following definitions are suggested:

Cobbles—particles of rock that will pass a 12-in. (300-mm) square opening and be retained on a 3-in. (75-mm) U.S. standard sieve, and

Boulders—particles of rock that will not pass a 12-in. (300-mm) square opening.

3.1.1 *clay*—soil passing a No. 200 (75-µm) U.S. standard sieve that can be made to exhibit plasticity (putty-like properties) within a range of water contents and that exhibits considerable strength when air dry. For classification, a clay is a fine-grained soil, or the fine-grained portion of a soil, with a plasticity index equal to or greater than 4, and the plot of plasticity index versus liquid limit falls on or above the "A" line.

3.1.2 *gravel*—particles of rock that will pass a 3-in. (75-mm) sieve and be retained on a No. 4 (4.75-mm) U.S. standard sieve with the following subdivisions:

Coarse—passes 3-in. (75-mm) sieve and retained on ¾-in. (19-mm) sieve, and

Fine—passes ¾-in. (19-mm) sieve and retained on No. 4 (4.75-mm) sieve.

3.1.3 *organic clay*—a clay with sufficient organic content to influence the soil properties. For classification, an organic clay is a soil that would be classified as a clay except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

3.1.4 *organic silt*—a silt with sufficient organic content to influence the soil properties. For classification, an organic silt is a soil that would be classified as a silt except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

3.1.5 *peat*—a soil composed of vegetable tissue in various stages of decomposition usually with an organic odor, a dark-brown to black color, a spongy consistency, and a texture ranging from fibrous to amorphous.

3.1.6 *sand*—particles of rock that will pass a No. 4 (4.75-mm) sieve and be retained on a No. 200 (75-µm) U.S. standard sieve with the following subdivisions:

Coarse—passes No. 4 (4.75-mm) sieve and retained on No. 10 (2.00-mm) sieve,

Medium—passes No. 10 (2.00-mm) sieve and retained on No. 40 (425-µm) sieve, and

Fine—passes No. 40 (425-µm) sieve and retained on No. 200 (75-µm) sieve.

3.1.7 *silt*—soil passing a No. 200 (75-µm) U.S. standard sieve that is nonplastic or very slightly plastic and that exhibits little or no strength when air dry. For classification, a silt is a fine-grained soil, or the fine-grained portion of a soil, with a plasticity index less than 4 or if the plot of plasticity index versus liquid limit falls below the "A" line.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *coefficient of curvature, Cc*—the ratio $(D_{30})^2/(D_{10} \times D_{60})$, where D_{60}, D_{30}, and D_{10} are the particle sizes corresponding to 60, 30, and 10 % finer on the cumulative particle-size distribution curve, respectively.

3.2.2 *coefficient of uniformity, Cu*—the ratio D_{60}/D_{10}, where D_{60} and D_{10} are the particle diameters corresponding to 60 and 10 % finer on the cumulative particle-size distribution curve, respectively.

4. Summary

4.1 As illustrated in Table 1, this classification system identifies three major soil divisions: coarse-grained soils, fine-grained soils, and highly organic soils. These three divisions are further subdivided into a total of 15 basic soil groups.

[5] *Annual Book of ASTM Standards*, Vol 04.09.
[6] *Annual Book of ASTM Standards*, Vol 14.02.

TABLE 1 Soil Classification Chart

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests[A]				Soil Classification: Group Symbol	Soil Classification: Group Name[B]
COARSE-GRAINED SOILS	Gravels	Clean Gravels	$Cu \geq 4$ and $1 \leq Cc \leq 3^C$	GW	Well-graded gravel[D]
More than 50 % retained on No. 200 sieve	More than 50 % of coarse fraction retained on No. 4 sieve	Less than 5 % fines[E]	$Cu < 4$ and/or $1 > Cc > 3^C$	GP	Poorly graded gravel[D]
		Gravels with Fines	Fines classify as ML or MH	GM	Silty gravel[D,F,G]

TABLE 1 *Continued*

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests[A]				Soil Classification Group Symbol	Soil Classification Group Name[B]
		More than 12 % fines[E]	Fines classify as CL or CH	,urule;1>GC	Clayey gravel[D,F,G]
	Sands	Clean Sands	Cu ≥ 6 and 1 ≤ Cc ≤ 3[C]	SW	Well-graded sand[H]
	50 % or more of coarse	Less than 5 % fines[I]	Cu < 6 and/or 1 > Cc > 3[C]	SP	Poorly graded sand[H]
	fraction passes No. 4 sieve	Sands with Fines	Fines classify as ML or MH	SM	Silty sand[F,G,H]
		More than 12 % fines[I]	Fines classify as CL or CH	SC	Clayey sand[F,G,H]
FINE-GRAINED SOILS	Silts and Clays	inorganic	PI > 7 and plots on or above "A" line[J]	CL	Lean clay[K,L,M]
50 % or more passes the No.	Liquid limit less than 50		PI < 4 or plots below "A" line[J]	ML	Silt[K,L,M]
200 seive		organic	Liquid limit − oven dried> < 0.75	OL	Organic clay[K,L,M,N]
			Liquid limit − not dried	OL	Organic silt[K,L,M,O]
	Silts and Clays	inorganic	PI plots on or above "A" line	CH	Fat clay[K,L,M]
	Liquid limit 50 or more		PI plots below "A" line	MH	Elastic silt[K,L,M]
		organic	Liquid limit − oven dried < 0.75	OH	Organic clay[K,L,M,P]
			Liquid limit − not dried		Organic silt[K,L,M,Q]
HIGHLY ORGANIC SOILS	Primarily organic matter, dark in color, and organic odor			PT	Peat

[A] Based on the material passing the 3-in. (75-mm) sieve.
[B] If field sample contained cobbles or boulders, or both, add "with cobbles or boulders, or both" to group name.
[C] $Cu = D_{60}/D_{10}$ $Cc = (D_{30})^2 / D_{10} \times D_{60}$
[D] If soil contains ≥15 % sand, add "with sand" to group name.
[E] Gravels with 5 to 12 % fines require dual symbols:
GW-GM well-graded gravel with silt
GW-GC well-graded gravel with clay
GP-GM poorly graded gravel with silt
GP-GC poorly graded gravel with clay
[F] If fines classify as CL-ML, use dual symbol GC-GM, or SC-SM.
[G] If fines are organic, add "with organic fines" to group name.
[H] If soil contains ≥15 % gravel, add "with gravel" to group name.
[I] Sands with 5 to 12 % fines require dual symbols:
SW-SM well-graded sand with silt
SW-SC well-graded sand with clay
SP-SM poorly graded sand with silt
SP-SC poorly graded sand with clay
[J] If Atterberg limits plot in hatched area, soil is a CL-ML, silty clay.
[K] If soil contains 15 to 29 % plus No. 200, add "with sand" or "with gravel," whichever is predominant.
[L] If soil contains ≥30 % plus No. 200, predominantly sand, add "sand " to group name.
[M] If soil contains ≥30 % plus No. 200, predominantly gravel, add "gravelly" to group name.
[N] PI ≥ 4 and plots on or above "A" line.
[O] PI < 4 or plots below" A" line.
[P] PI plots on or above "A" line.
[Q] PI plots below "A" line.

4.2 Based on the results of visual observations and prescribed laboratory tests, a soil is catalogued according to the basic soil groups, assigned a group symbol(s) and name, and thereby classified. The flow charts, Fig. 1 for fine-grained soils, and Fig. 3 for coarse-grained soils, can be used to assign the appropriate group symbol(s) and name.

5. Significance and Use

5.1 This standard classifies soils from any geographic location into categories representing the results of prescribed laboratory tests to determine the particle-size characteristics, the liquid limit, and the plasticity index.

5.2 The assigning of a group name and symbol(s) along with the descriptive information required in Practice D 2488 can be used to describe a soil to aid in the evaluation of its significant properties for engineering use.

5.3 The various groupings of this classification system have been devised to correlate in a general way with the engineering behavior of soils. This standard provides a useful first step in any field or laboratory investigation for geotechnical engineering purposes.

5.4 This standard may also be used as an aid in training personnel in the use of Practice D 2488.

5.5 This standard may be used in combination with Practice D 4083 when working with frozen soils.

NOTE 5—Notwithstanding the statements on precision and bias contained in this standard: The precision of this test method is dependent on the competence of the personnel performing it and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing. Users of this test method are cautioned that compliance with Practice D 3740 does not in itself assure reliable testing. Reliable testing depends on several factors; Practice D 3740 provides a means for evaluating some of those factors.

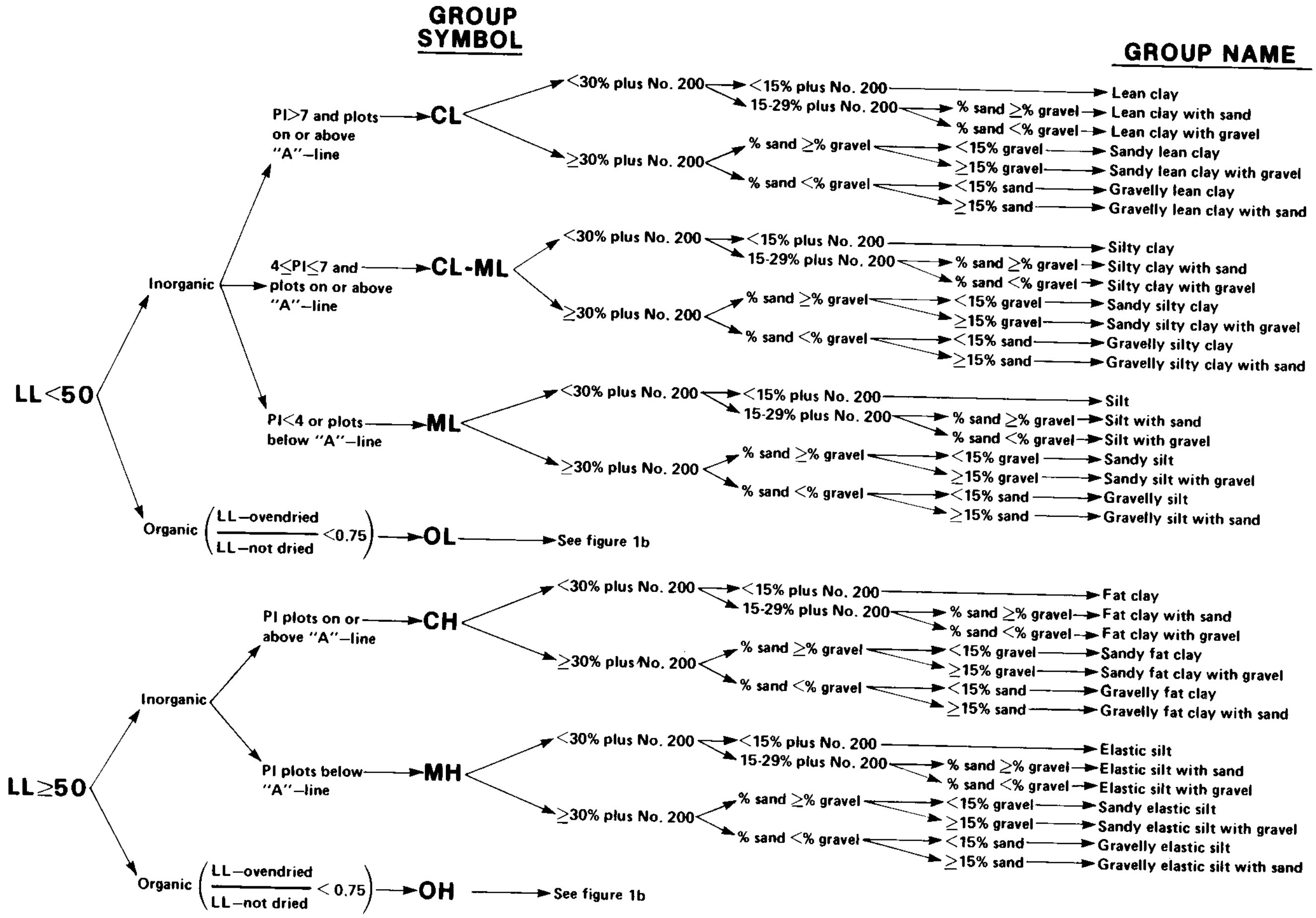


FIG. 1 Flow Chart for Classifying Fine-Grained Soil (50 % or More Passes No. 200 Sieve)

6. Apparatus

6.1 In addition to the apparatus that may be required for obtaining and preparing the samples and conducting the prescribed laboratory tests, a plasticity chart, similar to Fig. 4, and a cumulative particle-size distribution curve, similar to Fig. 5, are required.

NOTE 6—The "U" line shown on Fig. 4 has been empirically determined to be the approximate "upper limit" for natural soils. It is a good check against erroneous data, and any test results that plot above or to the left of it should be verified.

7. Sampling

7.1 Samples shall be obtained and identified in accordance with a method or methods, recommended in Guide D 420 or by other accepted procedures.

7.2 For accurate identification, the minimum amount of test sample required for this test method will depend on which of the laboratory tests need to be performed. Where only the particle-size analysis of the sample is required, specimens having the following minimum dry weights are required:

Maximum Particle Size, Sieve Opening	Minimum Specimen Size, Dry Weight
4.75 mm (No. 4)	100 g (0.25 lb)
9.5 mm (⅜ in.)	200 g (0.5 lb)
19.0 mm (¾ in.)	1.0 kg (2.2 lb)
38.1 mm (1½ in.)	8.0 kg (18 lb)
75.0 mm (3 in.)	60.0 kg (132 lb)

Whenever possible, the field samples should have weights two to four times larger than shown.

7.3 When the liquid and plastic limit tests must also be performed, additional material will be required sufficient to provide 150 g to 200 g of soil finer than the No. 40 (425-μm) sieve.

7.4 If the field sample or test specimen is smaller than the minimum recommended amount, the report shall include an appropriate remark.

8. Classification of Peat

8.1 A sample composed primarily of vegetable tissue in various stages of decomposition and has a fibrous to amorphous texture, a dark-brown to black color, and an organic odor should be designated as a highly organic soil and shall be classified as peat, PT, and not subjected to the classification procedures described hereafter.

8.2 If desired, classification of type of peat can be performed in accordance with Classification D 4427.

9. Preparation for Classification

9.1 Before a soil can be classified according to this standard, generally the particle-size distribution of the minus 3-in. (75-mm) material and the plasticity characteristics of the minus No. 40 (425-μm) sieve material must be determined. See 9.8 for the specific required tests.

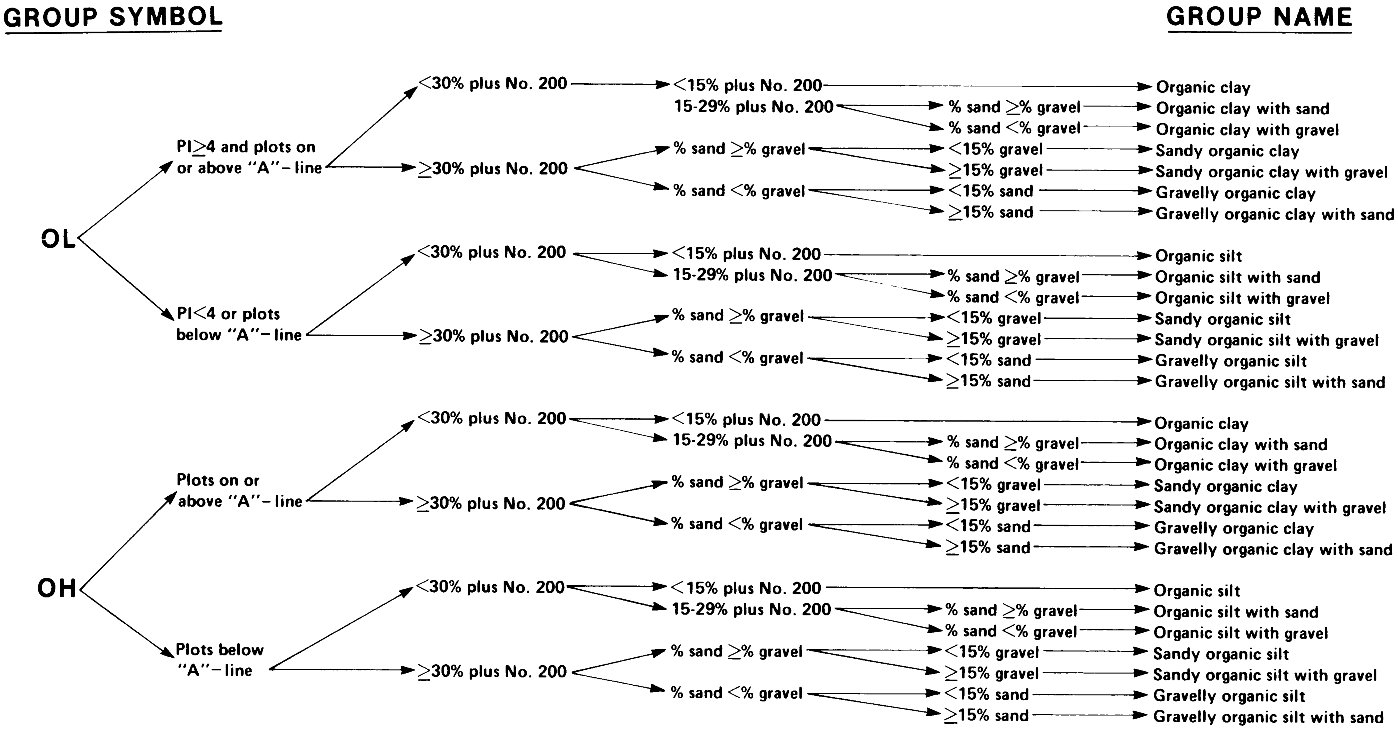


FIG. 2 Flow Chart for Classifying Organic Fine-Grained Soil (50 % or More Passes No. 200 Sieve)

9.2 The preparation of the soil specimen(s) and the testing for particle-size distribution and liquid limit and plasticity index shall be in accordance with accepted standard procedures. Two procedures for preparation of the soil specimens for testing for soil classification purposes are given in Appendixes X3 and X4. Appendix X3 describes the wet preparation method and is the preferred method for cohesive soils that have never dried out and for organic soils.

9.3 When reporting soil classifications determined by this standard, the preparation and test procedures used shall be reported or referenced.

9.4 Although the test procedure used in determining the particle-size distribution or other considerations may require a hydrometer analysis of the material, a hydrometer analysis is not necessary for soil classification.

9.5 The percentage (by dry weight) of any plus 3-in. (75-mm) material must be determined and reported as auxiliary information.

9.6 The maximum particle size shall be determined (measured or estimated) and reported as auxiliary information.

9.7 When the cumulative particle-size distribution is required, a set of sieves shall be used which include the following sizes (with the largest size commensurate with the maximum particle size) with other sieve sizes as needed or required to define the particle-size distribution:

3-in. (75-mm)
¾-in. (19.0-mm)
No. 4 (4.75-mm)
No. 10 (2.00-mm)
No. 40 (425-µm)
No. 200 (75-µm)

9.8 The tests required to be performed in preparation for classification are as follows:

9.8.1 For soils estimated to contain less than 5 % fines, a plot of the cumulative particle-size distribution curve of the fraction coarser than the No. 200 (75-µm) sieve is required. A semi-log plot of percent passing versus partical-size or sieve size/sieve number is plotted as shown in Fig. 5.

9.8.2 For soils estimated to contain 5 to 15 % fines, a cumulative particle-size distribution curve, as described in 9.8.1, is required, and the liquid limit and plasticity index are required.

9.8.2.1 If sufficient material is not available to determine the liquid limit and plasticity index, the fines should be estimated to be either silty or clayey using the procedures described in Practice D 2488 and so noted in the report.

9.8.3 For soils estimated to contain 15 % or more fines, a determination of the percent fines, percent sand, and percent gravel is required, and the liquid limit and plasticity index are required. For soils estimated to contain 90 % fines or more, the percent fines, percent sand, and percent gravel may be estimated using the procedures described in Practice D 2488 and so noted in the report.

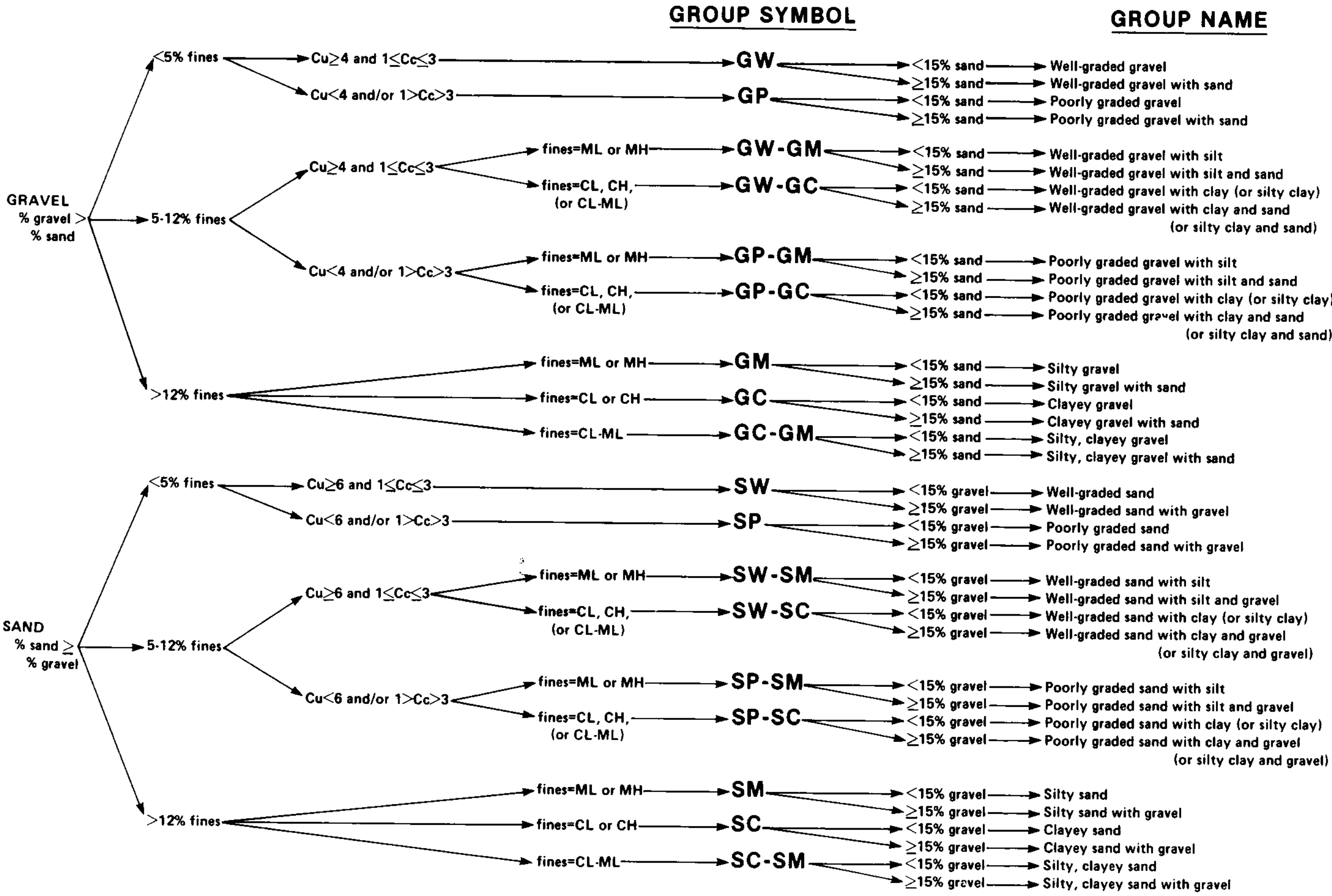


FIG. 3 Flow Chart for Classifying Coarse-Grained Soils (More Than 50 % Retained on No. 200 Sieve)

10. Preliminary Classification Procedure

10.1 Class the soil as fine-grained if 50 % or more by dry weight of the test specimen passes the No. 200 (75-µm) sieve and follow Section 3.1.2.

10.2 Class the soil as coarse-grained if more than 50 % by dry weight of the test specimen is retained on the No. 200 (75-µm) sieve and follow Section 12.

11. Procedure for Classification of Fine-Grained Soils (50 % or more by dry weight passing the No. 200 (75-µm) sieve)

11.1 The soil is an inorganic clay if the position of the plasticity index versus liquid limit plot, Fig. 4, falls on or above the "A" line, the plasticity index is greater than 4, and the presence of organic matter does not influence the liquid limit as determined in 11.3.2.

NOTE 7—The plasticity index and liquid limit are determined on the minus No. 40 (425 µm) sieve material.

11.1.1 Classify the soil as a *lean clay,* CL, if the liquid limit is less than 50. See area identified as CL on Fig. 4.

11.1.2 Classify the soil as a *fat clay,* CH, if the liquid limit is 50 or greater. See area identified as CH on Fig. 4.

NOTE 8—In cases where the liquid limit exceeds 110 or the plasticity index exceeds 60, the plasticity chart may be expanded by maintaining the same scale on both axes and extending the "A" line at the indicated slope.

11.1.3 Classify the soil as a *silty clay,* CL-ML, if the position of the plasticity index versus liquid limit plot falls on or above the "A" line and the plasticity index is in the range of 4 to 7. See area identified as CL-ML on Fig. 4.

11.2 The soil is an inorganic silt if the position of the plasticity index versus liquid limit plot, Fig. 4, falls below the "A" line or the plasticity index is less than 4, and presence of organic matter does not influence the liquid limit as determined in 11.3.2.

11.2.1 Classify the soil as a *silt,* ML, if the liquid limit is less than 50. See area identified as ML on Fig. 4.

11.2.2 Classify the soil as an *elastic silt,* MH, if the liquid limit is 50 or greater. See area identified as MH on Fig. 4.

11.3 The soil is an organic silt or clay if organic matter is present in sufficient amounts to influence the liquid limit as determined in 11.3.2.

11.3.1 If the soil has a dark color and an organic odor when moist and warm, a second liquid limit test shall be performed on a test specimen which has been oven dried at 110 ± 5°C to a constant weight, typically over night.

11.3.2 The soil is an organic silt or organic clay if the liquid limit after oven drying is less than 75 % of the liquid limit of the original specimen determined before oven drying (see Procedure B of Practice D 2217).

11.3.3 Classify the soil as an *organic silt* or *organic clay,* OL, if the liquid limit (not oven dried) is less than 50 %.

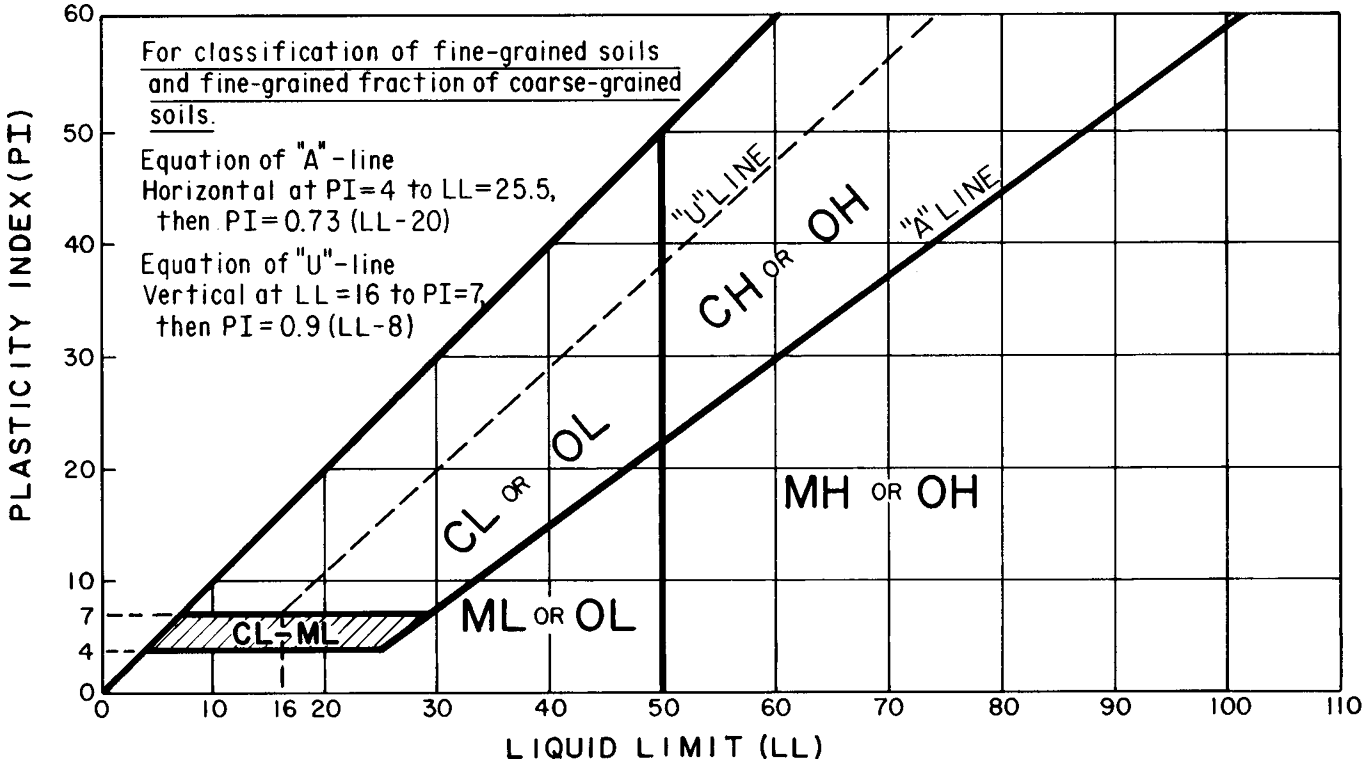


FIG. 4 Plasticity Chart

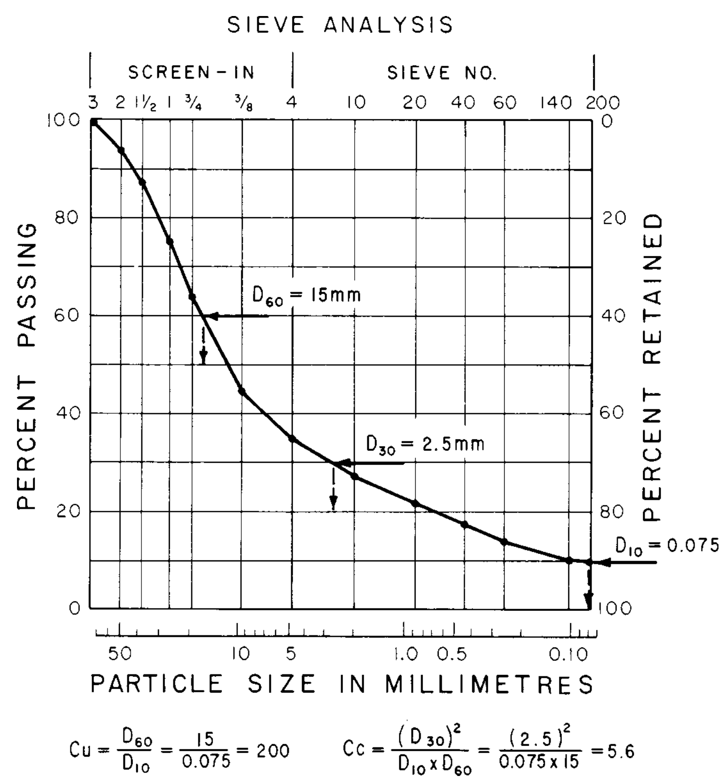


FIG. 5 Cumulative Particle-Size Plot

Classify the soil as an *organic silt,* OL, if the plasticity index is less than 4, or the position of the plasticity index versus liquid limit plot falls below the "A" line. Classify the soil as an *organic clay,* OL, if the plasticity index is 4 or greater and the position of the plasticity index versus liquid limit plot falls on or above the "A" line. See area identified as OL (or CL-ML) on Fig. 4.

11.3.4 Classify the soil as an *organic clay* or *organic silt,* OH, if the liquid limit (not oven dried) is 50 or greater. Classify the soil as an *organic silt,* OH, if the position of the plasticity index versus liquid limit plot falls below the "A" line. Classify the soil as an *organic clay*, OH, if the position of the plasticity index versus liquid-limit plot falls on or above the "A" line. See area identified as OH on Fig. 4.

11.4 If less than 30 % but 15 % or more of the test specimen is retained on the No. 200 (75-µm) sieve, the words" with sand" or "with gravel" (whichever is predominant) shall be added to the group name. For example, lean clay with sand, CL; silt with gravel, ML. If the percent of sand is equal to the percent of gravel, use "with sand."

11.5 If 30 % or more of the test specimen is retained on the No. 200 (75-µm) sieve, the words "sandy" or" gravelly" shall be added to the group name. Add the word "sandy" if 30 % or more of the test specimen is retained on the No. 200 (75-µm) sieve and the coarse-grained portion is predominantly sand. Add the word "gravelly" if 30 % or more of the test specimen is retained on the No. 200 (75-µm) sieve and the coarse-grained portion is predominantly gravel. For example, sandy lean clay, CL; gravelly fat clay, CH; sandy silt, ML. If the percent of sand is equal to the percent of gravel, use "sandy."

12. Procedure for Classification of Coarse-Grained Soils (more than 50 % retained on the No. 200 (75-µm) sieve)

12.1 Class the soil as gravel if more than 50 % of the coarse fraction [plus No. 200 (75-µm) sieve] is retained on the No. 4 (4.75-mm) sieve.

12.2 Class the soil as sand if 50 % or more of the coarse fraction [plus No. 200 (75-µm) sieve] passes the No. 4 (4.75-mm) sieve.

12.3 If 12 % or less of the test specimen passes the No. 200 (75-µm) sieve, plot the cumulative particle-size distribution, Fig. 5, and compute the coefficient of uniformity, *Cu*, and coefficient of curvature, *Cc*, as given in Eqs 1 and 2.

$$Cu = D_{60}/D_{10} \tag{1}$$

$$Cc = (D_{30})^2/(D_{10} \times D_{60}) \tag{2}$$

where:

D_{10}, D_{30}, and D_{60} = the particle-size diameters corresponding to 10, 30, and 60 %, respectively, passing on the cumulative particle-size distribution curve, Fig. 5.

NOTE 9—It may be necessary to extrapolate the curve to obtain the D_{10} diameter.

12.3.1 If less than 5 % of the test specimen passes the No. 200 (75-µm) sieve, classify the soil as a *well-graded gravel*, GW, or *well-graded sand,* SW, if Cu is greater than or equal to 4.0 for gravel or greater than 6.0 for sand, and Cc is at least 1.0 but not more than 3.0.

12.3.2 If less than 5 % of the test specimen passes the No. 200 (75-µm) sieve, classify the soil as *poorly graded gravel*, GP, or *poorly graded sand,* SP, if either the *Cu* or the *Cc* criteria for well-graded soils are not satisfied.

12.4 If more than 12 % of the test specimen passes the No. 200 (75-µm) sieve, the soil shall be considered a coarse-grained soil with fines. The fines are determined to be either clayey or silty based on the plasticity index versus liquid limit plot on Fig. 4. (See 9.8.2.1 if insufficient material available for testing) (see Note 7).

12.4.1 Classify the soil as a *clayey gravel*, GC, or *clayey sand*, SC, if the fines are clayey, that is, the position of the plasticity index versus liquid limit plot, Fig. 4, falls on or above the "A" line and the plasticity index is greater than 7.

12.4.2 Classify the soil as a *silty gravel*, GM, or *silty sand*, SM, if the fines are silty, that is, the position of the plasticity index versus liquid limit plot, Fig. 4, falls below the "A" line or the plasticity index is less than 4.

12.4.3 If the fines plot as a silty clay, CL-ML, classify the soil as a *silty*, *clayey gravel*, GC-GM, if it is a gravel or a *silty*, *clayey sand*, SC-SM, if it is a sand.

12.5 If 5 to 12 % of the test specimen passes the No. 200 (75-µm) sieve, give the soil a dual classification using two group symbols.

12.5.1 The first group symbol shall correspond to that for a gravel or sand having less than 5 % fines (GW, GP, SW, SP), and the second symbol shall correspond to a gravel or sand having more than 12 % fines (GC, GM, SC, SM).

12.5.2 The group name shall correspond to the first group symbol plus "with clay" or "with silt" to indicate the plasticity characteristics of the fines. For example, well-graded gravel with clay, GW-GC; poorly graded sand with silt, SP-SM (See 9.8.2.1 if insufficient material available for testing).

NOTE 10—If the fines plot as a *silty clay*, CL-ML, the second group symbol should be either GC or SC. For example, a poorly graded sand with 10 % fines, a liquid limit of 20, and a plasticity index of 6 would be classified as a poorly graded sand with silty clay, SP-SC.

12.6 If the specimen is predominantly sand or gravel but contains 15 % or more of the other coarse-grained constituent, the words "with gravel" or "with sand" shall be added to the group name. For example, poorly graded gravel with sand, clayey sand with gravel.

12.7 If the field sample contained any cobbles or boulders or both, the words "with cobbles," or "with cobbles and boulders" shall be added to the group name. For example, silty gravel with cobbles, GM.

13. Report

13.1 The report should include the group name, group symbol, and the results of the laboratory tests. The particle-size distribution shall be given in terms of percent of gravel, sand, and fines. The plot of the cumulative particle-size distribution curve shall be reported if used in classifying the soil. Report appropriate descriptive information according to the procedures in Practice D 2488. A local or commercial name or geologic interpretation for the material may be added at the end of the descriptive information if identified as such. The test procedures used shall be referenced.

NOTE 11—*Example: Clayey Gravel with Sand and Cobbles* (GC)—46 % fine to coarse, hard, subrounded gravel; 30 % fine to coarse, hard, subrounded sand; 24 % clayey fines, LL = 38, PI = 19; weak reaction with HCl; original field sample had 4 % hard, subrounded cobbles; maximum dimension 150 mm.

In-Place Conditions—firm, homogeneous, dry, brown,
Geologic Interpretation—alluvial fan.

NOTE 12—Other examples of soil descriptions are given in Appendix X1.

14. Precision and Bias

14.1 Criteria for acceptability depends on the precision and bias of Test Methods D 422, D 1140 and D 4318.

15. Keywords

15.1 Atterberg limits; classification; clay; gradation; gravel; laboratory classification; organic soils; sand; silt; soil classification; soil tests

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLES OF DESCRIPTIONS USING SOIL CLASSIFICATION

X1.1 The following examples show how the information required in 13.1 can be reported. The appropriate descriptive information from Practice D 2488 is included for illustrative purposes. The additional descriptive terms that would accompany the soil classification should be based on the intended use of the classification and the individual circumstances.

X1.1.1 *Well-Graded Gravel with Sand (GW)*—73 % fine to coarse, hard, subangular gravel; 23 % fine to coarse, hard, subangular sand; 4 % fines; Cc = 2.7, Cu = 12.4.

X1.1.2 *Silty Sand with Gravel (SM)*—61 % predominantly fine sand; 23 % silty fines, LL = 33, PI = 6; 16 % fine, hard, subrounded gravel; no reaction with HCl; (field sample smaller than recommended). *In-Place Conditions*—Firm, stratified and contains lenses of silt 1 to 2 in. thick, moist, brown to gray; in-place density = 106 lb/ft^3 and in-place moisture = 9 %.

X1.1.3 *Organic Clay (OL)*—100 % fines, LL (not dried) = 32, LL (oven dried) = 21, PI (not dried) = 10; wet, dark brown, organic odor, weak reaction with HCl.

X1.1.4 *Silty Sand with Organic Fines (SM)*—74 % fine to coarse, hard, subangular reddish sand; 26 % organic and silty dark-brown fines, LL (not dried) = 37, LL (oven dried) = 26, PI (not dried) = 6, wet, weak reaction with HCl.

X1.1.5 *Poorly Graded Gravel with Silt, Sand, Cobbles and Boulders (GP-GM)*—78 % fine to coarse, hard, subrounded to subangular gravel; 16 % fine to coarse, hard, subrounded to subangular sand; 6 % silty (estimated) fines; moist, brown; no reaction with HCl; original field sample had 7 % hard, subrounded cobbles and 2 % hard, subrounded boulders with a maximum dimension of 18 in.

X2. USING SOIL CLASSIFICATION AS A DESCRIPTIVE SYSTEM FOR SHALE, CLAYSTONE, SHELLS, SLAG, CRUSHED ROCK, ETC.

X2.1 The group names and symbols used in this standard may be used as a descriptive system applied to materials that exist in situ as shale, claystone, sandstone, siltstone, mudstone, etc., but convert to soils after field or laboratory processing (crushing, slaking, etc.).

X2.2 Materials such as shells, crushed rock, slag, etc., should be identified as such. However, the procedures used in this standard for describing the particle size and plasticity characteristics may be used in the description of the material. If desired, a classification in accordance with this standard may be assigned to aid in describing the material.

X2.3 If a classification is used, the group symbol(s) and group names should be placed in quotation marks or noted with some type of distinguishing symbol. See examples.

X2.4 Examples of how soil classifications could be incorporated into a description system for materials that are not naturally occurring soils are as follows:

X2.4.1 *Shale Chunks*—Retrieved as 2- to 4-in. pieces of shale from power auger hole, dry, brown, no reaction with HCl. After laboratory processing by slaking in water for 24 h, material classified as "Sandy Lean Clay (CL)"—61 % clayey fines, LL = 37, PI = 16; 33 % fine to medium sand; 6 % gravel-size pieces of shale.

X2.4.2 *Crushed Sandstone*—Product of commercial crushing operation; "Poorly Graded Sand with Silt (SP-SM)"—91 % fine to medium sand; 9 % silty (estimated) fines; dry, reddish-brown, strong reaction with HCl.

X2.4.3 *Broken Shells*—62 % gravel-size broken shells; 31 % sand and sand-size shell pieces; 7 % fines; would be classified as "Poorly Graded Gravel with Sand (GP)".

X2.4.4 *Crushed Rock*—Processed gravel and cobbles from Pit No. 7; "Poorly Graded Gravel (GP)"—89 % fine, hard, angular gravel-size particles; 11 % coarse, hard, angular sand-size particles, dry, tan; no reaction with HCl; Cc = 2.4, Cu = 0.9.

X3. PREPARATION AND TESTING FOR CLASSIFICATION PURPOSES BY THE WET METHOD

X3.1 This appendix describes the steps in preparing a soil sample for testing for purposes of soil classification using a wet-preparation procedure.

X3.2 Samples prepared in accordance with this procedure should contain as much of their natural water content as possible and every effort should be made during obtaining, preparing, and transportating the samples to maintain the natural moisture.

X3.3 The procedures to be followed in this standard assume that the field sample contains fines, sand, gravel, and plus 3-in. (75-mm) particles and the cumulative particle-size distribution plus the liquid limit and plasticity index values are required (see 9.8). Some of the following steps may be omitted when they are not applicable to the soil being tested.

X3.4 If the soil contains plus No. 200 (75-μm) particles that would degrade during dry sieving, use a test procedure for determining the particle-size characteristics that prevents this degradation.

X3.5 Since this classification system is limited to the portion of a sample passing the 3-in. (75-mm) sieve, the plus 3-in. (75-mm) material shall be removed prior to the determination of the particle-size characteristics and the liquid limit and plasticity index.

X3.6 The portion of the field sample finer than the 3-in. (75-mm) sieve shall be obtained as follows:

X3.6.1 Separate the field sample into two fractions on a 3-in. (75-mm) sieve, being careful to maintain the natural water content in the minus 3-in. (75-mm) fraction. Any particles adhering to the plus 3-in. (75-mm) particles shall be brushed or wiped off and placed in the fraction passing the 3-in. (75-mm) sieve.

X3.6.2 Determine the air-dry or oven-dry weight of the fraction retained on the 3-in. (75-mm) sieve. Determine the total (wet) weight of the fraction passing the 3-in. (75-mm) sieve.

X3.6.3 Thoroughly mix the fraction passing the 3-in. (75-mm) sieve. Determine the water content, in accordance with Test Method D 2216, of a representative specimen with a minimum dry weight as required in 7.2. Save the water-content specimen for determination of the particle-size analysis in accordance with X3.8.

X3.6.4 Compute the dry weight of the fraction passing the 3-in. (75-mm) sieve based on the water content and total (wet) weight. Compute the total dry weight of the sample and calculate the percentage of material retained on the 3-in. (75-mm) sieve.

X3.7 Determine the liquid limit and plasticity index as follows:

X3.7.1 If the soil disaggregates readily, mix on a clean, hard surface and select a representative sample by quartering in accordance with Practice C 702.

X3.7.1.1 If the soil contains coarse-grained particles coated with and bound together by tough clayey material, take extreme care in obtaining a representative portion of the No. 40 (425-μm) fraction. Typically, a larger portion than normal has to be selected, such as the minimum weights required in 7.2.

X3.7.1.2 To obtain a representative specimen of a basically cohesive soil, it may be advantageous to pass the soil through a ¾-in. (19-mm) sieve or other convenient size so the material can be more easily mixed and then quartered or split to obtain the representative specimen.

X3.7.2 Process the representative specimen in accordance with Procedure B of Practice D 2217.

X3.7.3 Perform the liquid-limit test in accordance with Test Method D 4318, except the soil shall not be air dried prior to the test.

X3.7.4 Perform the plastic-limit test in accordance with Test Method D 4318, except the soil shall not be air dried prior to the test, and calculate the plasticity index.

X3.8 Determine the particle-size distribution as follows:

X3.8.1 If the water content of the fraction passing the 3-in. (75-mm) sieve was required (X3.6.3), use the water-content specimen for determining the particle-size distribution. Otherwise, select a representative specimen in accordance with Practice C 702 with a minimum dry weight as required in 7.2.

X3.8.2 If the cumulative particle-size distribution including a hydrometer analysis is required, determine the particle-size distribution in accordance with Test Method D 422. See 9.7 for the set of required sieves.

X3.8.3 If the cumulative particle-size distribution without a hydrometer analysis is required, determine the particle-size distribution in accordance with Method C 136. See 9.7 for the set of required sieves. The specimen should be soaked until all clayey aggregations have softened and then washed in accordance with Test Method C 117 prior to performing the particle-size distribution.

X3.8.4 If the cumulative particle-size distribution is not required, determine the percent fines, percent sand, and percent gravel in the specimen in accordance with Test Method C 117, being sure to soak the specimen long enough to soften all clayey aggregations, followed by Test Method C 136 using a nest of sieves which shall include a No. 4 (4.75-mm) sieve and a No. 200 (75-μm) sieve.

X3.8.5 Calculate the percent fines, percent sand, and percent gravel in the minus 3-in. (75-mm) fraction for classification purposes.

X4. AIR-DRIED METHOD OF PREPARATION OF SOILS FOR TESTING FOR CLASSIFICATION PURPOSES

X4.1 This appendix describes the steps in preparing a soil sample for testing for purposes of soil classification when air-drying the soil before testing is specified or desired or when the natural moisture content is near that of an air-dried state.

X4.2 If the soil contains organic matter or mineral colloids that are irreversibly affected by air drying, the wet-preparation method as described in Appendix X3 should be used.

X4.3 Since this classification system is limited to the portion of a sample passing the 3-in. (75-mm) sieve, the plus 3-in. (75-mm) material shall be removed prior to the determination of the particle-size characteristics and the liquid limit and plasticity index.

X4.4 The portion of the field sample finer than the 3-in. (75-mm) sieve shall be obtained as follows:

X4.4.1 Air dry and weigh the field sample.

X4.4.2 Separate the field sample into two fractions on a 3-in. (75-mm) sieve.

X4.4.3 Weigh the two fractions and compute the percentage of the plus 3-in. (75-mm) material in the field sample.

X4.5 Determine the particle-size distribution and liquid limit and plasticity index as follows (see 9.8 for when these tests are required):

X4.5.1 Thoroughly mix the fraction passing the 3-in. (75-mm) sieve.

X4.5.2 If the cumulative particle-size distribution including a hydrometer analysis is required, determine the particle-size distribution in accordance with Test Method D 422. See 9.7 for the set of sieves that is required.

X4.5.3 If the cumulative particle-size distribution without a hydrometer analysis is required, determine the particle-size distribution in accordance with Test Method D 1140 followed by Method C 136. See 9.7 for the set of sieves that is required.

X4.5.4 If the cumulative particle-size distribution is not required, determine the percent fines, percent sand, and percent gravel in the specimen in accordance with Test Method D 1140 followed by Method C 136 using a nest of sieves which shall include a No. 4 (4.75-mm) sieve and a No. 200 (75-µm) sieve.

X4.5.5 If required, determine the liquid limit and the plasticity index of the test specimen in accordance with Test Method D 4318.

X5. ABBREVIATED SOIL CLASSIFICATION SYMBOLS

X5.1 In some cases, because of lack of space, an abbreviated system may be useful to indicate the soil classification symbol and name. Examples of such cases would be graphical logs, databases, tables, etc.

X5.2 This abbreviated system is not a substitute for the full name and descriptive information but can be used in supplementary presentations when the complete description is referenced.

X5.3 The abbreviated system should consist of the soil classification symbol based on this standard with appropriate lower case letter prefixes and suffixes as:

Prefix	Suffix
s = sandy	s = with sand
g = gravelly	g = with gravel
	c = cobbles
	b = boulders

X5.4 The soil classification symbol is to be enclosed in parentheses. Some examples would be:

Group Symbol and Full Name	Abbreviated
CL, Sandy lean clay	s(CL)
SP-Sm, Poorly graded sand with silt and gravel	(SP-SM)g
GP, poorly graded gravel with sand, cobbles, and boulders	(GP)scb
ML, gravelly silt with sand and cobbles	g(ML)sc

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (1998) that may impact the use of this standard.

(1) Added Practice D 3740 to Section 2.

(2) Added Note 5 under 5.5 and renumbered subsequent notes.

ATTACHMENT J

PACKER TEST FORM

SLUG TEST FIELD FORM

Well ID: ____________________ **Date:** ____________________

Arrival Time: ____________________ **Field Personnel:** ____________________

Project: ____________________ **Static DTW:** ____________________

Job Number: ____________________ **Well Depth (ft):** ____________________

Measuring Point: ____________________

Slug Type: ____________________ **Well Diameter:** ____________________

TRANSDUCER REFERENCE DATA

After the transducer has been inserted into the well and the water level has stabilized, reset the reference to 0 ft and note the following information:

Submerged Reading (ft): ____________________ **Reference (ft):** ____________________

WL Indicator DTW: ____________________

FIRST SLUG TEST

Test ID: ____________________

Data Collection Rate: ____________________

Input Channel: ____________________

Rising Head   Falling Head   (circle one)

Start Time: ____________________

Submerged Reading at Start: ____________________

Reference Reading at Start: ____________________

DTW at Start ____________________

Stop Time: ____________________

Submerged Reading at Stop: ____________________

Reference Reading at Stop: ____________________

DTW at Stop: ____________________

SECOND SLUG TEST

Test ID: ____________________

Data Collection Rate: ____________________

Input Channel: ____________________

Rising Head   Falling Head   (circle one)

Start Time: ____________________

Submerged Reading at Start: ____________________

Reference Reading at Start: ____________________

DTW at Start ____________________

Stop Time: ____________________

Submerged Reading at Stop: ____________________

Reference Reading at Stop: ____________________

DTW at Stop: ____________________

TRANSDUCER DATA

Model: ____________________

Serial Number: ____________________

Scale: ____________________

Linearity: ____________________

Offset: ____________________

Range/Proof: ____________________

DATA LOGGER DATA

Model: ____________________

Serial Number: ____________________

WATER LEVEL INDICATOR DATA

Model: ____________________

Serial Number: ____________________

ATTACHMENT K

AQUIFER TEST FORM

AQUIFER TEST DATA SHEET
(OBSERVATION WELLS)

Page ___ of ___

PROJECT NAME: ______________ PROJECT NO: ____________________________ PIEZO NO: ______________________________________
DATE: __________________________ PUMP DEPTH: ____________________________ TEST NO: _____________________________________
TYPE OF TEST: ________________ PUMPED WELL NO: ________________________ DISTANCE FROM PUMPING WELL: ________________
MEASURING EQUIPMENT: ________________________ HYDROGEOLOGIST: _____________________________

Time Data	Water Level Data	Time Data Continuation	Water Level Data Continuation
Pump On: Date/Time________ Pump Off: Date/Time________ Duration of Aquifer Test: Pumping:________ Recovery:________	Pretest Water Level_______________ Static Water Level:_______________ Measuring Point:_________________ Elevation of Measuring Point:_________		

Date	Time	Depth to Water (ft)	Pressure Transducer (XD)	Flow Rate (gpm)	Date	Time	Depth to Water (ft)	Pressure Transducer (XD)	Flow Rate (gpm)

Conversion Factors: 1 PSI = 2.31 feet 1 cubic foot = 7.48 gallons