DEPARTMENT OF TOXIC SUBSTANCES CONTROL
CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

DRILLING, LOGGING, AND SAMPLING AT CONTAMINATED SITES

June 2013

Edmund G. Brown Jr.

Governor

State of California

Matthew Rodriquez

Secretary

California Environmental Protection Agency

Deborah Raphael

Director

Department of Toxic Substances Control

The California Environmental Protection Agency:

Department of Toxic Substances Control
State Water Resources Control Board
CalRecycle
Air Resources Board
Department of Pesticide Regulation
Office of Environmental Health Hazard Assessment

FOREWORD

The California Environmental Protection Agency (Cal/EPA) is charged with the responsibility of protecting the state's environment. Within Cal/EPA, the Department of Toxic Substances Control (DTSC) has the responsibility for managing the State's Hazardous Waste and Cleanup programs to protect human health and the environment. The State Water Resources Control Board and Regional Water Quality Control Boards (RWQCB), also part of Cal/EPA, have the responsibility for coordination and control of water quality, including the protection of the beneficial uses of the waters of the state. Therefore, RWQCB and DTSC work closely together in protecting the environment.

To aid in characterizing and remediating contaminated sites, DTSC has developed several guidance documents and recommended procedures for use by its staff, local governmental agencies, responsible parties, and their contractors. This document (and the document it supersedes) has been prepared by the Geological Services Branch staff to provide guidelines for drilling, logging and sampling soil at contaminated sites. The Geological Services Branch within DTSC provides geologic assistance, training and guidance to DTSC staff.

This document supersedes the July 1995 Cal/EPA document titled:

Drilling, Coring, Logging and Sampling at Hazardous Substances Release Sites

Trade names or commercial products are occasionally used by name within this document. Such use does not constitute Cal/EPA endorsement or recommendation and is only meant for clarification purposes.

Comments and suggestions for improvement of Drilling, Logging and Sampling Soils at Contaminated Sites should be submitted to:

Dot Lofstrom, PG
Department of Toxic Substances Control
8800 Cal Center Drive
Sacramento, California 95826
Dot.Lofstrom@dtsc.ca.gov

ACKNOWLEDGMENTS

Preparation of this guidance document was achieved through the efforts of many individuals. The following people had primary responsibility for research, editing, and writing:

- Dot Lofstrom, PG
- Randy Adams, PG, CEG
- Alice Campbell, PG, CEG, CHG
- John Karachewski, PG, CHG
- Jerod Randall, PG

The support and encouragement of Karen Baker, Chief, Geological Services Branch, was fundamental to the success of this project.

This guidance has benefited greatly through input received from several sources, including the following DTSC staff: Eileen Hughes and Thomas Skaug. Administrative support was provided by Sarah Berry, Rosa Boyer, and Shannon Garrett.

The revised guidance relies heavily on the work of the authors of the original guidance. Their contributions continue to be appreciated. The primary authors of the original document include:

- Steve Belluomini
- Bill Owen
- John Woodling

Funding for this guidance document was provided by a USEPA CERCLA Section 128 (a) State Implementation Support Grant.

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1.0 INTRODUCTION

This document provides guidelines for drilling, sampling and describing soil from boreholes drilled to characterize contaminated sites. The information in this document provides a brief description of various drilling methods, soil sampling, and a summary of the Unified Soil Classification System (USCS) and American Society for Testing and Materials (ASTM) D 2488 - "Standard Practice for Description and Identification of Soils, Visual-Manual Procedure" used for describing soil and creating boring and trenching logs.

This document revises and replaces the previously published "Drilling, Coring, Sampling and Logging at Hazardous Substance Release Sites" (Cal/EPA 1995). The recommendations are a subset of the site characterization process as outlined in the recently revised "Guidelines for Planning and Implementing Groundwater Characterization of Contaminated Sites" (Cal/EPA 2012a).

Application

Drilling, trenching, and sampling provide a means to directly observe subsurface soils and rock. With this information, geology and hydrogeology can be characterized, contamination defined, and remedies designed to mitigate environmental contamination. Geologists describe soil based on visual examination and manual tests, and write this description for a boring/trench log using USCS terminology. A detailed description of the USCS is provided in the Engineering Geology Field Manual (US Bureau of Reclamation, 1998) and various ASTM publications, as listed in Section 6.0 References. The following guidelines are presented in an effort to help responsible parties and their consultants select an appropriate drilling method for site characterization and remediation. Additionally, this guidance summarizes the USCS to assist in completing accurate and complete boring logs for environmental investigations and remedial design.

Limitations

It is the obligation of the responsible parties and qualified professionals performing the site investigations and remedial design to consult with pertinent regulatory agencies, identify all requirements, and meet them appropriately.

This document discusses broad categories of methods and devices that can be used in drilling and sampling investigations. It does not define specific operating procedures for drilling and sampling. Nor does this document propose guidelines for every available drilling method or sampling device. The qualified professional in charge of the field investigation should specify the methods, equipment, and operating procedures in a work plan and document any significant changes that were implemented in the field.

This document does not supersede existing statutes and regulations. Federal, state and local regulations, statutes, and ordinances should be identified and site characterization and remedial design activities performed in accordance with the most stringent of these requirements where applicable or relevant and appropriate.

2.0 SUBSURFACE BORING PROGRAM

Borehole information is used to characterize the subsurface and identify potential contaminant migration pathways. When there is little or no information about a site, reconnaissance or screening level investigations are frequently used prior to launching a subsurface boring program. In comparison to past practices, groundwater monitoring wells are used less often for characterization and are more often installed for long-term monitoring of known plume areas, as sentry wells, and for performance monitoring of remedial actions. Data collected from screening level investigations are used to focus the efforts of subsequent detailed studies. For example, grab-groundwater samples may be collected during initial investigations to determine the extent of groundwater contamination before installing monitoring wells.

Borings are typically drilled to obtain various types of samples, including: lithologic, geotechnical, soil gas, soil, sediment, and groundwater samples. The number, location, and spacing of borings should be based on the Conceptual Site Model (CSM), which evolves as data are acquired. Decision rules of the data quality objectives (DQOs) process ensure that the data are acceptable for decision-making.

Boreholes should be spaced closely enough so that accurate cross-sections can be constructed in order to understand site geology and to evaluate potential contaminant migration pathways. The number of borings will depend on the complexity of the subsurface, including: the lateral/vertical continuity and geometry of geologic units; the presence of faults or fractures; and the identification of preferential pathways (such as sand/gravel lenses, utility trenches, and channel deposits) for contaminant migration.

Accurate location data of samples, borings, and wells are necessary for delineation of areal and three-dimensional contaminant distribution and hydrogeological characteristics. All boreholes should be accurately located with reference to a permanent or semi-permanent feature onsite, and all monitoring wells should be professionally surveyed. DTSC recommends following the California State Water Board's Geotracker requirements for surveying and reporting of electronic geographic information. Detailed information can be found on the State Water Board's GeoTracker website. In general, transient or one-time sampling points (such as direct push technologies, piezometers, or grab samples) do not need to be professionally surveyed and Global Positioning System (GPS) coordinates will suffice.

2.1 Continuous Cores

One or more boreholes per site should be drilled for the purpose of collecting continuous cores to accurately describe the physical soil properties and to identify the subsurface stratigraphy. The locations for these designated boreholes should be chosen to represent the lithologic variation over the entire study area, and a complete boring log prepared as described below. Photographs of representative samples should be taken and included in field reports. Core samples may be archived for later evaluation, providing proper care is taken in handling potentially contaminated cores.

2.2 Geophysical Techniques

Geophysical techniques can be used to plan and supplement the drilling program. Application of Borehole Geophysics at Contaminated Sites (Cal/EPA 2012b) contains guidance for the use of surface geophysical techniques and data acquisition.

2.3 Borehole Decommissioning and Sealing

Any boring that will not be completed as a monitoring well should be decommissioned by sealing it to avoid creating a conduit for contaminant migration, either from the surface to the subsurface or between subsurface units. The objective of sealing a borehole is to prevent migration of contaminants through the borehole. The vertical permeability of the sealed borehole should be equal to or less than the natural vertical permeability of the surrounding geologic formation (USEPA 1997). This is usually accomplished by filling the boring with a grout made of cement or bentonite slurry. Dry products such as bentonite powder may be used but should be hydrated at the surface first. The slurry is then pumped into the borehole through a rigid pipe (tremie pipe), often under pressure. The bottom of the tremie pipe is placed into the bottom of the open hole, and is kept below the surface of the slurry as the grout fills the hole. Some borings may need to be overdrilled before being filled with grout. Boring decommissioning should be performed in compliance with California Department of Water Resources' *Water Well Standards, Bulletin 74-81 and Bulletin 74-90*. Additionally, county ordinances and regulations should be consulted to ensure compliance with local agency concerns.

Direct Push Technology (DPT) Decommissioning. If the borehole was created with a DPT method, the resultant borehole may be too small in diameter to push grout through it. Several methods are available for decommissioning DPT holes, but the method chosen should be capable of backfilling the hole completely with grout or bentonite slurry, from bottom to top and without gaps (USEPA 2005).

Retraction Grouting. Retraction grouting allows for DPT rods to act as a tremie pipe for grout that is either poured or pumped down the hole, ensuring a complete seal of the borehole. Retraction grouting typically involves pumping a high-solids bentonite slurry or a neat cement grout through the rod and tool string and out the bottom of the sampling tool as the tool is withdrawn from the hole. To use this method, a port is needed at the end or sides of the tool and/or an expendable tip is necessary on the terminal end of the tool through which the grout can be pumped. Because the hole is grouted as the tool is withdrawn, this method ensures that the borehole is sealed throughout its length. Retraction grouting is generally considered the most reliable borehole sealing technique (USEPA 1997; USEPA 2005).

Re-entry Grouting. Re-entry grouting typically involves pumping grout through a tremie pipe inserted into the borehole immediately following withdrawal of the rod string. Alternatively, the rod string may be reinstalled in the borehole without the sampling tool, so that grout may be pumped through the open rods. The grout should be pumped continuously from the bottom of the hole to the top as the tremie pipe (or rod string) is withdrawn to avoid gaps and bridging. Typically, re-entry grouting is effective only if the borehole remains open until tremie pipe or rods can be extended to the bottom of the borehole. If a portion of the borehole collapses, the tremie pipe or rods will not penetrate to the total depth of the borehole. In this situation, it may be necessary to put an expendable tip on the end of the rod string. The rods are then pushed through soil bridges to the bottom of the borehole. The probe rods are withdrawn slightly, and the expendable tip is knocked out by lowering a small diameter steel rod inside the direct push rods. Alternatively, the tip may be blown off by applying pressure with the grout pump. Grout is then pumped through the direct push rods as they are withdrawn from the borehole. Re-entry grouting may not provide a reliable seal if the DPT rods do not follow the original borehole. In most circumstances, the original borehole will provide the path of least resistance and this will not be a concern (USEPA 1997; USEPA 2005).

Both re-entry grouting and retraction grouting can be successfully used with DPT, cone penetrometer tests (CPTs), and sonic drilling.

2.4 Confining Layers

In some situations, it may be necessary to drill through actual or possible confining layers at a site. Extreme care should be taken when drilling into confining units so that the borehole does not create a pathway for the migration of contaminants between upper and lower hydraulically-separated zones. Particular care should be taken if dense, non-aqueous phase liquids (DNAPLs) are present. In all cases, the investigator should prevent mobilization of DNAPLs when drilling boreholes. Responsible parties should obtain approval of the lead regulatory agency prior to implementing a plan to drill through a possible confining layer. There are at least two approaches for drilling through confining layers. Based on site-specific conditions, one or both of these approaches may be appropriate:

> Extreme care should be taken when drilling into confining units so that the borehole does not create a pathway for the migration of contaminants between upper and lower hydraulically-separated zones.

- Install initial boreholes on the perimeter of the site, in less-contaminated or uncontaminated areas, to allow characterization of the lower units. Boreholes may be drilled through the possible confining layer to characterize the geology of the site providing the boreholes are located upgradient of the source of DNAPL or a dissolved-phase plume.

- Drill the boreholes using techniques that minimize the danger of cross-contamination between water-bearing zones. Such techniques typically involve drilling a borehole partially into the possible confining layer, installing an exterior conductor casing, sealing the annular space in the cased portion of the borehole, and drilling a smaller-diameter borehole through the confining layer.

DPT methods that may penetrate confining layers include: single-wall and dual-walled probes; DPT well installation (dual-walled only); real-time measurement tools (such as CPTs, Membrane Interphase Probes [MIPs]); and, sampling tools such as Hydropunch™. Sonic drilling, using dual-walled methods, is similar in approach. In each case, proper grouting protocols and materials should be used to minimize the potential for cross-contamination between water-bearing zones. When penetrating confining layers or source zones, dual tube direct push installations (analogous to conductor casing) may be prudent. Detailed information regarding sealing DPT boreholes is provided in:

- *Expedited Site Assessment Tools for Underground Storage Tank Sites, A Guide for Regulators EPA 510-B-97-001*. USEPA, March 1997.
- *Use of Direct Push Technologies for Soil and Ground Water Sampling*. Chapter 15 in *Technical Guidance Manual for Ground Water Investigations*. State of Ohio Environmental Protection Agency, February 2005.
- *Techniques for sealing cone penetrometer holes.* Lutenegger, Alan J. and DeGroot, Don J. Can Geotech. J. 32: 880-891. 1995.

3.0 BOREHOLE DRILLING METHODS

The drilling method chosen for a given site application will depend on: data quality objectives; site-specific geology; presence/absence of subsurface contamination; depth of penetration; data quality requirements such as detection limits; and, the type of data to be collected (such as soil samples, geotechnical or lithologic logging, groundwater samples, well installation, soil gas monitoring). Ancillary considerations include: cost, waste generation, noise, site access constraints, and speed of work. The following drilling methods have been identified as the most commonly used in the environmental industry. Table 1 presents the drilling methods that are discussed in the following subsections. Information below is based on USEPA 1996 and ASTM 2005.

3.1 Direct Air Rotary

Direct air rotary uses compressed air that flows through the inside of a drill rod to a rotating bit. The air exits the drilling bit at the bottom of the borehole and forces the cuttings back to the surface where they are discharged to a roll off bin for disposal. Drilling and well installation are readily accomplished in partially-lithified rock and hard rock. Drilling in rock or soil is relatively fast, with almost unlimited depth. The resulting borehole is accessible for geophysical logging prior to monitoring well installation. The annulus formed between the well casing and borehole wall is readily gravel packed and grouted. Well development is relatively easy. Direct air rotary is compatible with the casing-advancement method.

Table 1 Environmental Drilling Methodologies[1]

Drilling Method	Drilling Fluid	Casing	Type of Material Drilled	Typical Depths (Feet)	Borehole Diameter (Inches)	Samples	Coring Possible	Tools
Direct air rotary	air, water, foam	yes	soil, rock	>1500	2–36	soil, rock, fluid	yes	
Direct mud rotary	water, mud	yes	soil, rock	>1000	2–36	soil, rock	yes	e-logging
Direct-push	none	yes	soil	Typical 20-25 Max <100	1.5–3	soil, fluid	yes	MIP, CPT, Hydraulic Profiling
Hand auger	none	no	soil	70 (above water table only)	2–6	soil	yes	None
Hollow-stem auger	none, water, mud	yes	soil, weathered rock	150	5–22	soil, fluid	yes	
Sonic (vibratory)	none, water, mud, air	yes	soil, rock, boulders	<500	4–12	soil, rock, fluid	yes	

[1] Adapted from *ASTM D6286-98 Standard Guide for Selection of Drilling Methods for Environmental Site Characterization*.

Air rotary drilling usually does not require introduction of fluids other than air down the borehole. However, water, foam, or other fluids may be injected once the saturated zone is encountered to prevent mud rings from forming on the drill rod, to stabilize weak zones, or to fill fractures or other voids. One potential drawback of air rotary drilling is that water-bearing zones may be difficult to detect using this drilling method. Adding drilling fluids or foam to the air stream can affect groundwater quality. The discharged compressed air may contain hydrocarbons. Additionally, the air stream can strip volatile contaminants from the borehole wall during drilling, temporarily affecting the groundwater quality. Air exiting the borehole may pose a health risk due to particulates and contaminants when drilling through contaminated soil and rock; thus a health and safety officer may need to be present to monitor the site.

3.2 Direct Mud Rotary

In the direct mud rotary drilling method, the borehole is advanced by rotation of a drill bit mounted on the end of the drill rods. The bit cuts and breaks the material at the bottom of the hole into small pieces known as cuttings. The cuttings are removed by pumping drilling fluid down through the drill rods and bit and up the annulus between the borehole and the drill rods. The drilling fluid carries the cuttings back to the surface.

The drilling fluid is water or water mixed with an amendment, such as bentonite. Amendments are added to increase the drilling fluid weight and viscosity to help keep the borehole open and bring the cuttings to the surface. The drilling mud forms a cake on the borehole wall to keep the surrounding formation from collapsing into the borehole.

Drilling is readily accomplished in both soils and hard rock. Drilling depth is essentially unlimited for all environmental drilling and sampling purposes. Drilling is relatively fast. Lithologic logging uses drill cuttings obtained from drilling fluid return and is moderately reliable. However, heavier fragments may be returned more slowly than lighter fragments, fines may not be recognized in the mud, and the nature of contacts is generally indeterminable. This method is compatible with the casing-advancement drilling method.

The drilling fluid has the potential to alter borehole fluid chemistry; lubricants used during the drilling process can contaminate the borehole fluid and soil/rock samples; and drilling fluids can dilute contaminants in samples. Detecting water-bearing zones during the drilling process can be difficult. Drilling fluid circulation can be lost or difficult to maintain in fractured rock, root zones, gravels, and cobbles. Additional equipment and space are required to install the mud pit, which may need a liner. There is difficulty drilling through boulders or cobbles.

During drilling, the aquifer or formation near the borehole is damaged. Well development is a critical activity for repairing the damage to the formation and borehole wall by removing the “mud cake” (aka “clay smear”), flushing out drilling fluids, reversing chemical or physical changes to the formation, and improving near-well permeability and water yield.

Figure 1 Mud Rotary Drill (Courtesy of Talon/LPE Products)

3.3 Hollow-Stem Auger

The hollow-stem auger method uses continuous flight augers which mechanically excavate soil cuttings from the borehole. The augers are built with a large axial opening to allow access to the bottom of the hole without withdrawing the auger string. The augers act as temporary casing and can be used to collect discrete soil/groundwater samples and/or to install monitoring wells. The maximum depth of drilling is about 200-300 feet.

The combination of downward pressure and the rotation of continuous auger flights are used to drill the borehole. Auger drilling equipment is relatively mobile and drilling moderately fast. Drilling fluids or lubricants are typically not necessary. Continuous sampling is possible during drilling using continuous, split-barrel, or thin-walled samplers. Monitoring wells can be installed through the hollow stem. Groundwater samples can be collected during drilling, using screened auger flights).

Pressure equalization of water-bearing sands or silts may cause these fluid-like materials to flow into the hollow-stem auger column, requiring use of fluid in the hollow-stem auger to equalize the pressure head and keep the materials from entering the hollow stem auger. Cuttings returned by auger flight are disturbed, making it difficult to determine the precise depth from which they originate. Upward vertical mixing of groundwater and soil cuttings can occur. Gravel pack and grout seal can be difficult to install.

Borings are limited to relatively shallow depths in unconsolidated soils and soft rock. There is difficulty drilling in extremely dry, fine materials such as playa-lake deposits. Hollow-stem auger drilling is difficult in saturated soils and soils containing very coarse gravels, cobbles, or boulders.

Excessive down-pressure during drilling can compact loose materials resulting in decreased formation permeability adjacent to the boring. The borehole wall can be smeared by previously-drilled clay, which can make complete development of the well difficult.

Figure 2 Hollow Stem Auger Flight (Courtesy of Gregg Drilling**)**

3.4 Sonic (Vibratory)

Sonic drilling employs the use of high frequency resonant energy to advance a core barrel or casing into subsurface formations. With dual wall casing, continuous cores are collected and removed as drilling progresses. Sonic drill rigs can penetrate cobbles, boulders, and rock. Large-diameter continuous cores of almost any soil type can be collected without the use of drilling fluids, such as air or water-based fluids and additives. Drilling and sampling are possible through wood, concrete, and other construction debris. The sonic-drilling system can drill and sample softer rock, such as sandstone, limestone, shale, and slate with a high rate of core recovery. Drilling can be faster than most other drilling methods, depending on depth and material drilled. Uniform boreholes with minimal drift are ideal for monitoring-well installation and corresponding well development time. Investigation-derived waste is also minimized with sonic drilling.

Extraction of casing can cause smearing of borehole wall in silts or clays. Soil may be displaced into the borehole wall during drilling. The vibration of the drilling bit and rod creates excess heat. Collecting soil samples that will be analyzed for volatile constituents can result in analytical results that are biased low.

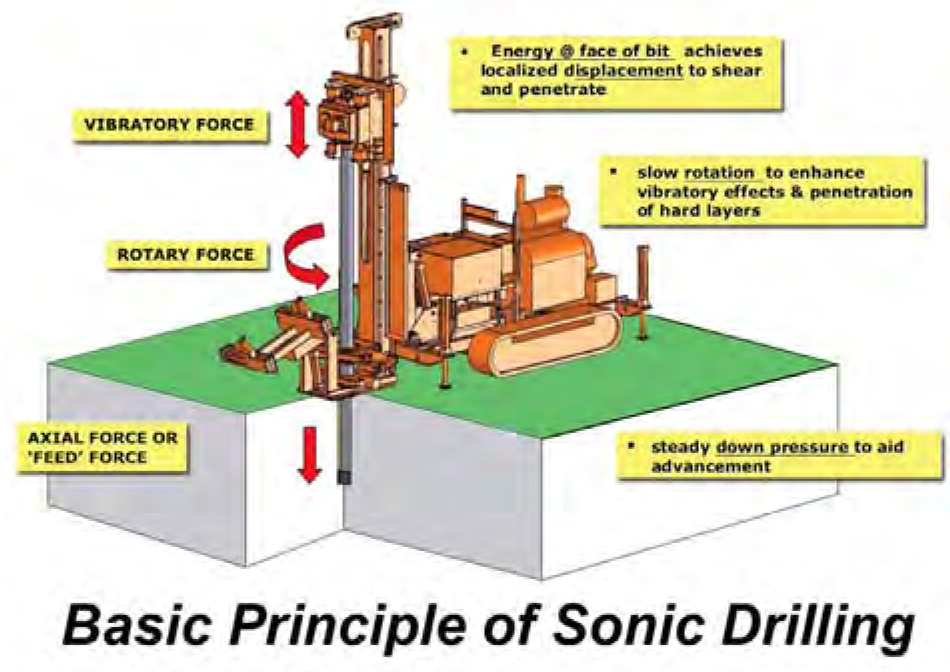

Figure 3 Sonic Drilling Rig (Courtesy of Solinst Canada Ltd.)

3.5 Direct Push Technologies

Direct push technologies (DPT, also known as “direct drive,” “drive point,” or “push technology”) refers to a group of tools used for performing subsurface investigations by driving or pushing, small-diameter hollow steel rods into the ground. DPT allows for cost-effective, rapid sampling and data collection from unconsolidated soils and sediments (USEPA 2005). The drill stem and bit can be advanced using a hammer or the weight of the vehicle to which it is mounted. Continuous soil cores and discrete groundwater and soil gas samples can be collected. No drilling fluids or lubricants are required. The equipment is highly mobile and can be small enough for access within buildings. There is minimal disturbance of geochemical conditions during drilling. There is minimal disturbance of the drilling site because the equipment is light-weight, drilling is fast, and minimal soil cuttings are produced.

Depending on site conditions and the type of drilling rig, continuous cores can be collected to depths of up to 50 feet or more, with depths of 200 feet at ideal locations. Well screens can be emplaced without being exposed to overlying zones that will not be sampled. A variety of characterization tools can be deployed with direct push such as CPTs, membrane interface probes (MIPs), and hydraulic profiling tools.

The DPT method is generally limited to unconsolidated clay, silt, sand, and gravel. Direct push was not designed to penetrate rock but some penetration of weakly lithified or highly weathered rock is possible. The small diameter drive pipe generally precludes conducting geophysical logging.

Well screens are either exposed-screen or protected-screen. Exposed well screens are not covered during driving and may become clogged, which makes well development difficult. The small-diameter direct-push monitoring wells and sampling devices are not designed to yield large volumes of water as would be required for an aquifer test, or for an extensive groundwater sampling program.

Figure 4 Direct Push Rig (Courtesy of Geoprobe® Systems)

3.6 Hand Auger

A hand auger is manually rotated by a technician to collect shallow samples. Cuttings are removed from the borehole by removing the bit and rod. The process of manually rotating the bit and extracting the cuttings is repeated until the target depth is achieved. No drilling fluids or lubricants are required. Intact soil samples are typically collected from the borehole using soil-sampling devices and sampling barrels from the open hole after first removing the hand auger assembly. The equipment is portable and easy to use in remote locations.

Borehole collapse can occur during hand-augering operations, especially below the water table. Hand-auger drilling is slow and labor intensive with drilling limited to relatively shallow depths, usually less than 20 feet. Borehole diameter is typically limited to about 6 inches. The depth of the borehole may be limited by hardpan layers or large gravels, cobbles, boulders or roots which stop further penetration. Soils containing platy particles, such as a mica or loose sand, are not easily retrieved from the borehole as they tend to slide freely out of the hand-auger barrel. Casing cannot be advanced with this methodology. Hand-augering to collect shallow soil samples for volatile organic compound (VOC) analyses may result in low-biased samples and is not recommended.

4.0 SOIL SAMPLING

Collecting soil and rock samples for geotechnical and chemical laboratory analysis is a critical component of site investigation and remediation. For environmental characterization purposes, soil sampling may be divided into two categories, disturbed and undisturbed. Disturbed samples, such as drill cuttings and surface scrapings, consist of disaggregated material that is not representative of initial conditions. In contrast, undisturbed samples, such as rock and soil cores, are more representative of their initial condition. Although all samples are somewhat disturbed in the process of collection, undisturbed (also referred to as “intact”) samples have been collected in a manner that minimizes disturbance and allows them to retain much of their original structure.

Devices or equipment commonly used during drilling include split-spoon samplers, thin wall samplers, core barrels, and DPT core liners. Sample collectors may be driven by successive percussion impacts or pushed by pneumatic ram, or other direct push methods. Metal or plastic liners placed inside the sampler barrel are often used for ease of retrieval and sample preservation.

Split spoon, or split barrel, samplers are generally used to collect relatively undisturbed soil cores that are 18 or 24 inches in length. A series of consecutive cores may be extracted with a split spoon sampler to give a complete soil column profile, or an auger may be used to drill down to the desired depth for sampling. The split spoon is then driven to its sampling depth through the bottom of the augered hole and the core extracted. For specific information, refer to *ASTM D-1586-98*, *Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils*.

Figure 5 Split-Barrel Sampler (courtesy of Geoprobe® systems)

Sample compaction is usually acceptable for cores collected for visual identification or chemical analysis. Soil samples intended for VOC analysis should be collected in accordance with USEPA's *Method 5035 Closed-System Purge-and-Trap and Extraction for Volatile Organics in Soil and Waste Samples*. Method 5035 describes several methods for preserving soil samples in the field, including preservatives such as methanol and sodium bisulfate, and sub-sampling devices which preserve or seal the sample from the atmosphere, such as the En Core® sampler.

Figure 6 En Core® sampler (courtesy of En Novative Technogies)

Cores intended for physical testing should be collected with minimal disturbance. Thin-wall push samplers such as Shelby tubes or core barrels should be used. The sampler should be able to sample at least several inches ahead of the drill bit, to minimize disturbance from drilling action or drilling fluid circulation.

5.0 LOGGING OF SOILS

Detailed and well-prepared boring logs are critical for preparing the CSM, which serves as a basis for communication and decision-making throughout the life of an environmental project. Thus, accurate and complete boring logs, using standard procedures, are critical to successful characterization and remediation of contaminated sites.

This section recommends standard procedures for visual soil classification and preparation of borehole logs.

This section focuses on:

- Soil classification;
- Trench log format (with examples provided in Appendix B, C, and D - Test Pit/Trench Log Examples 1, 2, and 3 respectively); and
- Boring log format (with examples provided in Appendix E and F -Borehole Log Examples 1 and 2 respectively)

There are several excellent and detailed guidance documents that discuss the correct use of the USCS such as documents released by: United States Bureau of Reclamation (USBR), United States Army Corps of Engineers (USACE), California Department of Transportation (CalTrans), and California Department of Water Resources (DWR). However, the goal of this section is to focus on those elements within the USCS that are useful for environmental investigations, and less on those elements whose primary use is for geotechnical evaluations. Although the final boring or trench log is often created using software packages, the geologist needs to have sufficient field experience to prepare accurate and complete logs.

5.1 Logging Boreholes

The boring log provides a fundamental foundation for the CSM. Essential decisions regarding site characterization and remediation will be based on boring logs, and the logs will be used and referred to throughout the life of the project. A log may present important data for immediate interpretation and use or it may provide data that are used over a number of years. The purpose of the log is to provide a factual description of the subsurface as encountered. The person preparing the log should keep in mind the purpose of installing the boring and preparing the log, and selectively include information that is pertinent to the project. Certain petrologic features or geologic conditions, for example, may have geotechnical significance but be less important to either site characterization or remediation.

5.1.1 Boring Log Descriptions Using the USCS

All boring logs should have the following information in the header:

- Project and/or site name;
- Name of logger;
- Borehole ID;
- Beginning and completion date;
- Borehole location and survey coordinates (including latitude/ longitude or easting/northing and datum);
- Borehole diameter;
- Total depth of borehole;
- Elevation;
- Depth to groundwater (during and after drilling, including date and time);
- Time; and
- Weather.

Additional information associated with the method of hole advancement and sampling includes:

- Drilling contractor;
- Drill rig and model;
- Drilling methods (coring, standard penetration, DPT, flight auger, rock bit);
- Drilling conditions (slow, fast, rough, smooth);
- Estimated drilling fluid return, if applicable;
- Caving conditions (none, moderate, heavy);
- Casing use (diameter, depth, and type of casing);
- Core recovery (cored interval, percent sample recovered); and,
- Borehole completion (grout or type of well).

Each log should be logged by a California-licensed professional geologist.

The following items should be described for soils:

- Depth of strata and changes in lithology;
- USCS Group Name and Symbol (in capitals);
- Approximate percentage of coarse grained soils and fine grained soils (for the special case of soils with cobbles and boulders, see information below);
- Plasticity characteristics of fines (Table 6);
- Grain size distribution and maximum particle size;
- Sorting;
- Angularity and shape of coarse grained particles;
- Moisture, color, odor;
- Cementation;
- Sedimentary structures (bedding, hardpans or calcrete, roots, color mottling, nodules, etc.),
- Reaction with hydrochloric acid (HCL); and,
- In-place conditions such as consistency, structure, et cetera.

A small drawing showing well/borehole location in relation to landmarks (such as buildings) is recommended.

5.1.2 Special Case of Soils with Cobbles and Boulders

When soil contains cobble and/or boulder size particles, the minus 3-inch fraction of the soil is described in one paragraph, while the total sample is describe in a separate paragraph. This format is used because the USCS is intended to classify particles less than 3 inches in diameter (less than cobble size) in terms of mass. Particles larger than 3 inches in diameter are classified based on the volume percentages of the total material. When soil contains cobbles and/or boulders, the differentiation between cobbles and boulders and the minus 3- inch fraction is necessary to avoid confusion.

<u>Soils With Less Than 50 percent (by Volume) Cobbles and Boulders</u>

The first paragraph describes the minis 3-inch fraction (that is, the soil without cobbles and boulders). The minus 3-inch fraction must add up to 100 percent. The maximum size is not included in this paragraph, but is provided in the second paragraph. The second paragraph describes the total sample and includes information on the cobbles and boulders, including hardness, shape, and angularity. The maximum size is provided in the second paragraph and the percentages of minus 3-inch fraction and cobbles/boulders is given by volume. The words “With Cobbles” or “With Cobbles and Boulders” is included with the group name in the first paragraph. Examples: “Clayey Sand (SC) with Cobbles” or “Clayey Sand (SC) with Cobbles and Boulders.”

<u>Soils With More Than 50 Percent (by Volume) Cobbles and Boulders</u>

The first paragraph describes the total sample and includes the characteristics of the cobbles and boulders as described above. The second paragraph describes the fine-grained and coarse-grained soils. The words “Cobbles” or “Cobbles and Boulders” are listed first in the group name. Examples: “Cobbles with poorly graded Gravel” or “Cobbles and Boulders with Silty Gravel.” A USCS group name and symbol are not provided.

5.2 Field Classification of Coarse-Grained Soils

Field identification[2] of soil is accomplished by assigning a group symbol and group name to the soil based on particle size. Additional information is added to the group name by the term “with” where appropriate. If the soil is coarse-grained, the field geologist must determine whether it is a sand or a gravel. If the percent of sand is equal to or more than the percent of gravel, the soil is defined as a sand. If the percent of gravel is more than the percent of sand, the soil is defined as a gravel. A set of simple particle distribution rules are followed to classify soil.

Field classification of soils begins with a visual estimate of the particle size distribution by a geologist. For critical decisions, the particle size distribution can be verified by a geotechnical laboratory. The most basic division for soil classification are:

- Coarse-Grained Soils (50 percent or more of sand and gravel particles);
- Fine-Grained Soils (50 percent or more of silt and clay particles); and
- Highly Organic Soils.

> When soil contains cobble and/or boulder size particles, the minus 3-inch fraction of the soil is described in one paragraph, while the total sample is describe in a separate paragraph.

5.2.1 Particle Distribution Rules

1) Select a representative sample.

2) Remove all particles larger than 75 mm (3 inches). Estimate and record the percentage of particles, by volume, greater than three inches as “Cobbles and Boulders.” Use the remaining sample for classification.

3) Estimate the percentage of gravel in the sample.

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[2] The soil classification system in Section 5.2 is based on the Engineering Geology Field Manual published by the Bureau of Reclamation, the American Society for Testing and Materials (ASTM) *D-2488 Standard Practice for Description and Identification of Soils (Visual Manual Procedure)*, and *Soil and Rock Logging, Classification, and Presentation Manual*, California Department of Transportation, 2010.

4) Estimate the percentage of sand in the sample. The lower limit of sand is placed at the No. 200 sieve (0.075 mm). A particle that is retained on the No. 200 sieve is typically the smallest particle size that can be seen with the unaided eye.

5) Estimate the percentage of fines (silt and clay) in the sample.

6) Estimate percentages to the nearest 5 percent. If any components are present in the sample but consist of less than 5 percent, list these as "trace."

7) The percentages of gravel, sand and fines must add up to 100 percent.

Once the percentages are estimated, the soil is classified as either sand or gravel, depending on which is greatest. If soil is primarily fine-grained, further classification is based on its plasticity. The following practical definitions for soil classification and descriptions, based on the USCS and ASTM's Visual-Manual Procedure, will help estimate the components of soil. Because soil symbols for USCS and ASTM are identical, the log should clearly state whether the USCS or ASTM's Visual-Manual Procedure is used.

5.2.2 Particle Size

Cobbles and Boulders:

- A cobble is a rock fragment that is between 75 mm (3 inches) and 300 mm (12 inches) in diameter. For comparison, the diameter of a softball varies but is about 87.5 mm (3½ inches).
- A boulder is a rock fragment that has a diameter greater than 300 mm (12 inches) in diameter. For comparison, most basketballs are about 225 mm (9 inches) in diameter.

Gravel: Gravel is defined as particles of rock that are between 4.75 mm (0.18 inches) and 75 mm (3 inches) in diameter.

- The diameter of coarse gravel is between 75 mm (3 inches) and 19 mm (0.75 inches). For comparison, the typical adult fist has a diameter of just less than 3½ inches).
- The diameter of fine gravel is between 19 mm (0.75 inches) and 4.75 mm (0.18 inches). Marbles are typically between 0.5 and 0.6 inches, so marbles would be considered fine gravel.

Sand: Sand is defined as rock particles that are between 4.75 mm and 0.75 µm in diameter.

- Coarse sand is between 4.75 mm (0.18 inches) and 2.00 mm (.076 inches).
- Medium sand is between 2 mm to 425 µm (.076 to .017 inches).

- Fine sand is just barely visible 425 µm to 75 µm (.017 to 003 inches).

Table 2 below is useful for a quick description of particle size distribution estimates.

Table 2 **Description of Particle Sizes**		
Descriptive Term	**Size Ranges**	**Example Size Ranges**
Boulder	300 mm or more	Larger than a basketball
Cobble	300 mm to 75 mm	Volleyball, grapefruit, orange
Coarse Gravel	75 mm to 20 mm	Tennis ball to grape
Fine Gravel	20 mm to 4.75 mm (No. 4 sieve)	Pea
Coarse Sand	4.75 mm to 2mm (No. 4 sieve to No. 10 sieve)	Ice cream salt
Medium Sand	2mm to 420 µm (No. 10 Sieve to No. 40 Sieve)	Openings in window screen
Fine Sand	420 µm to 75 µm (No. 40 sieve to No. 200 sieve)	Sugar, table salt

<u>Clean Coarse-Grained Soils</u>. After determining that a soil is coarse-grained, then the percentage of fines (silt and clay) should be estimated. If the percentage of fines is less than 5 percent, the coarse-grained soil is classified as “clean.” There are four UCSC/ ASTM categories of clean, coarse-grained soils. These are:

Well-Graded Gravel (Symbol: GW)
Poorly Graded Gravel (GP)
Well-Graded Sand (SW)
Poorly Graded Sand (SP)

A well-graded coarse-grained soil has a broad range of particle sizes. A poorly graded coarse-grained soil has a uniform particle size. (The engineering term “well graded” is an antonym of the geologic term “well-sorted”). Therefore, clean coarse-grained soil with uniform particle size will be classified as GW or SW. A clean coarse-grained soil which does not have a broad range of particle sizes will be classified as either GP or SP. (Because “well-graded” in UCSC’s and ASTM’s engineering terminology is equivalent to “poorly-sorted” in geological terminology, some confusion may occur. Therefore, for the sake of consistency, the UCSC terminology for grading should be used on all logs).

> A well-graded coarse-grained soil has a broad range of particle sizes. A poorly graded coarse-grained soil has a uniform particle size

A Check list for Coarse Grained Soils is included as Appendix H.

5.3 Field Classification of Fine-Grained Soils

Fine-grained soils include clay, silt, and organic matter (organic clay, organic silt, and peat). Fine-grained soils are those in which 50 percent or more of the material is smaller than No. 200 sieve size (75 µm). Unlike coarse-grained soils, particles of fine-grained soils are not visible to the unaided eye. Therefore, fine-grained soils are classified based on physical characteristics of the fine-grained portion of the soil, primarily plasticity. A soil with high plasticity is capable of being molded or deformed continuously or permanently. A soil with higher plasticity is generally clay, whereas a soil with lower or no plastic characteristics is generally a silt.

The physical characteristics of fine-grained soils are determined by field tests for: 1) dry strength; 2) dilatancy; and, 3) toughness. These three characteristics and their tests are described below and summarized in Tables 3 to 7 below. Based on test results, fine-grained soil are classified are classified based on the plasticity characteristics of the fine grained portion of the soil, specifically, fat clay (elastic clay), lean clay, elastic silt, or silt.[3]

A soil with higher plasticity is generally clay, whereas a soil with lower or no plastic characteristics is generally a silt.

<u>Dry Strength Test</u>

Soil strength is the ability to withstand force without rupture or flow. Soil strength is a measure of the character and quantity of clay particles contained in the soil. Because dry strength increases with plasticity, high dry strength is a characteristic of clay (CL) whereas a typical inorganic silt (ML) has no to low dry strength. A silty fine sand also has no to low dry strength. Silty fine sands and silts can be distinguished by powdering the dry sample and feeling the resultant powder between the fingers. Fine sand feels gritty whereas silt has the feel of flour. In general, medium to very high dry strength is associated with clays and no to low dry strength suggests silts.

The dry strength test is performed by using a natural lump of dry soil or making a small ball of soil for the test. The small ball is formed by adding water to the soil until it is the consistency of putty, and then rolling it into a ball about ¼ inch in diameter. After drying, the strength of the soil cube is tested by breaking/crumbling it between the fingers. If the ball crumples easily it has low dry strength. If it resists, it has higher dry strength.

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[3] [3] For laboratory analysis, the plastic limit is used in conjunction with the liquid limit to calculate the plastic index to classify fine grained soils. The laboratory definitions are as follows:

- Plastic Limit (PL) is defined as the moisture content at which soil begins to behave as a plastic material, based on specific analytical criteria.
- Liquid Limit (LL) is defined as the moisture content at which soil begins to behave as a liquid material and begins to flow, based on specific analytical criteria.
- Plasticity Index (PI) is the difference between the liquid limit and plastic limit of a soil. (PI =LL-PL).

Using the LL and PI, a plasticity chart is used classify the fined grained soils based on laboratory results. (See Appendix G, Plasticity Chart)

Table 3 Criteria for Describing Dry Strength	
<u>Descriptive Term</u>	**Criteria**
None	The dry specimen crumbles into powder with mere pressure of handling.
Low	The dry specimen crumbles into powder with some finger pressure.
Medium	The dry specimen breaks into pieces or crumbles with considerable finger pressure.
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface.
Very High	The dry specimen cannot be broken between the thumb and a hard surface.

<u>Dilatancy Test</u>

Dilatancy describes a soils reaction to shaking. After removing particles larger than a No. 40 sieve (medium sand), a ball of moist soil about ½ inch in diameter is prepared, adding enough water to make the soil moist but not sticky. The ball of soil is placed in the palm of one hand. The palm holding the soil is shaken horizontally by using the other hand to strike vigorously against the first hand several times. If water appears on the surface then it is a positive response. When water first appears on the surface, the soil will appear glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface; the ball stiffens, and finally cracks or crumbles. The geologist gauges how rapidly water appears during shaking and how quickly it disappears during squeezing. The range of dilatancy is described as slow to rapid. If dilatancy is very rapid and distinct, the soil is a very clean sand. If dilatancy ranges from slow to rapid, it is likely silt, and if there is no reaction, the soil is a clay.

Table 4 Criteria for Describing Dilatancy	
Descriptive Term	**Criteria**
None	No visible change in the specimen
Slow	Water appears slowly on the surface of the specimen during shaking and does not disappear, or disappears slowly upon squeezing
Rapid	Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing.

Table 5 **Criteria for Describing Toughness**	
Descriptive Term	Criteria
Low	Only slight pressure is required to roll the thread near the plastic limit. The thread and lump are weak and soft
Medium	Medium pressure is required to roll the thread near the plastic limit. The lump and thread have medium stiffness.
High	Considerable pressure is required to roll the thread to near the plastic limit. The thread and lump have very high stiffness.

Plasticity

Use the observations made during the toughness test to describe the plasticity of the material, as follows:

Table 6 **Criteria for Describing Plasticity**	
Descriptive Term	**Criteria**
Non-Plastic	A 1/8 inch (3 mm) thread cannot be rolled at any water content
Low	The thread can barely be rolled and the lump can barely 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.
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit.

Summary

Using the results of the manual tests described above (Dry Strength, Dilatancy, and Toughness), make a determination as follows:

Table 7 Identification of Fine-Grained Soils From Manual Tests			
Soil Classification and Symbol	**Dilatancy**	**Toughness**	**Dry Strength**
Silt (ML)	Slow to Rapid	Low or thread cannot be formed	None to Low
Lean Clay (CL)	None to Slow	Medium	Medium to High
Elastic Clay (MH)	None to Slow	Low to Medium	Low to Medium
Fat Clay (CH)	None	High	High to Very High

<u>Organic Soils (PT, OL, and OH)</u>

Organic soils are those soils that contain enough organic particles to influence the soil properties. Organic soils are usually dark brown or black and may have an organic odor. Organic material has no specific grain size. Particle sizes may range from colloidal-size to fibrous pieces several millimeters in length. Organic soils normally do not have high toughness or plasticity, but may seem spongy instead.

Peat (PT). Soils with more than 50 percent organic matter are termed “peat.” Peat soils are usually very dark to black in color with a strong organic odor. Original plant forms may or may not be readily recognized. In general, the greater the organic content the greater the water content, void ratio, and compressibility of the peat.

Organic Silts and Clays (OL and OH). It may be difficult to distinguish between organic silts and organic clays without laboratory tests. In general, for environmental work, the generic term of “organic soil” is sufficient.

Also, see Appendix I “Description of Fine-Grained and Organic Samples”.

5.4 USDA Soil Classification

The USCS system was developed as a way of describing the engineering properties of soil for construction, including roads, dams and foundations. Hence, the data collected and descriptions largely focus on the soil’s moisture content, density, strength, and workability. A classification system developed by the United States Department of Agriculture to describe agricultural soils is used as input parameters in some models. Notably, the Johnson-Ettinger (1991) *Model for Subsurface Vapor Intrusion into Buildings* uses the USDA system for its input parameters. The nomenclature of the USDA system reflects primarily the water-holding, water-releasing, and workability of the soil, and thus focuses on the proportion of sand, silt, and clay (Figure 7). Gravel is not plotted on the ternary diagram, but is used as a modifier to the main classification.

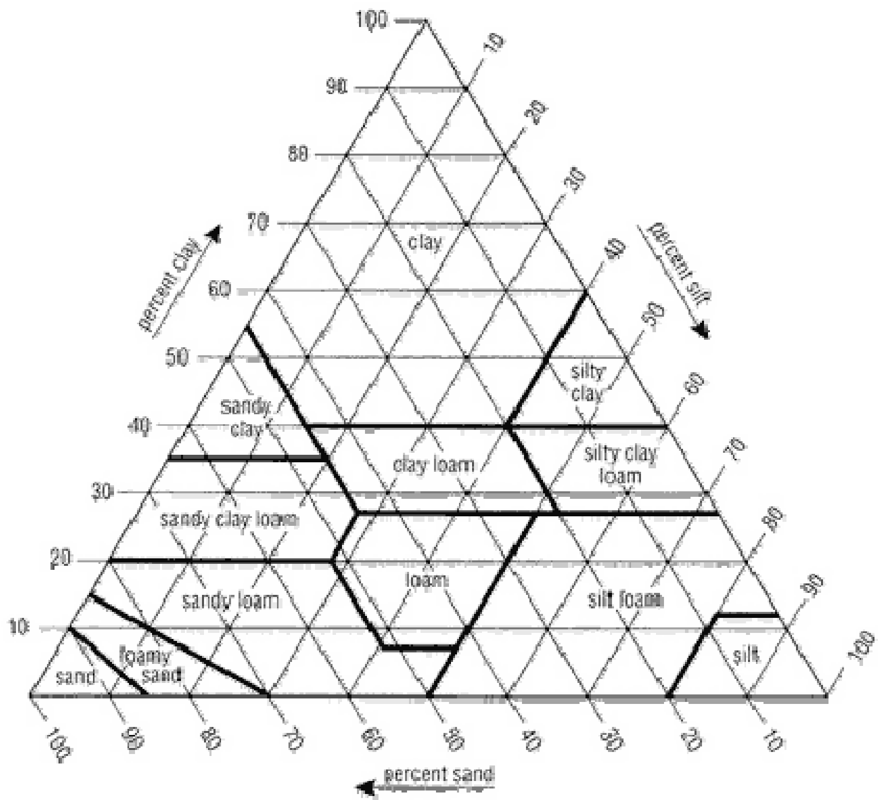


Figure 7: USDA Soil Classification Chart

The following table shows approximate conversion from USDA to USCS classifications:

Table 8 **Conversion USCS to USDA**	
USCS Group Name	**USDA Classification**
Poorly graded gravel (SP), well-graded gravel (GW), or silty gravel	Gravel, very gravelly loamy sand
Poorly graded sand (SP); well-graded sand (SW)	Sand, coarse sand, fine sand
Silty gravel (GM)	Loamy gravel, very gravelly sandy loam, very gravelly loam
Silty sand (SM)	Loamy sand, gravelly loamy sand, very fine sand
Silty gravel (GM)	Gravelly loam
Clayey gravel (GC)	Very gravelly sandy clay loam
Silty sand (SM)	Sandy loam, fine sandy loam, loamy very fine sand, gravelly sandy loam
Silt (ML)	Silt loam, very fine sandy clay loam
Silt (ML) or elastic silt (MH)	Silt

Silt (ML) or elastic silt (MH)	Loam
Clayey sand (SC)	Sandy clay loam
Lean clay (CL)	Silty clay loam, clay loam
Sandy clay (SC)	Sandy clay
Gravelly clay (GC)	Gravelly clay loam, gravelly clay
Gravelly clay (GC)	Very gravelly clay loam, very gravelly sandy clay loam, very gravelly silty clay loam, very gravelly silty clay
Fat clay (CH)	Silty clay, clay
Peat (PT)	Muck and peat

6.0 TEST PIT AND TRENCH LOGGING USING THE USCS

The referenced format for trench logs is specific to "in-place conditions" and the description of cobbles and boulders is based on volume. Logging test pits and trenches is similar to logging boreholes in terms of applying the USCS. However, there are differences in terms of excavation conditions, in-place (undisturbed) conditions, and identifying the section to be logged and sampled. Additionally, there are preferred approaches to preparing test pit/trench cross-sections for geologic logs.

Format of Test Pit and Trench Logs. Similar to boring logs, test pit and trench logs should include standard information in the header such as:

- Date;
- Time;
- Weather;
- Name of Individual Logger;
- Project/Site Name;
- Location;
- Elevation; and,
- Coordinates.

Additional information associated with the test pit/trench excavation includes:

- Method of Excavation (name and model of excavator);
- Approximate Dimensions (length and width because depth can be identified in cross-section);
- Excavation conditions (ease and pace of excavation, such as easily and rapidly vs. slow and difficult);
- Caving Conditions;
- Depth to Water (if none indicate dry); and,
- Completion (e.g., backfilled with excavated material).

A Test Pit Log with soils more than 50 percent by volume is provided in Appendix C, Example Test Pit Log No. 2.

7.0 REFERENCES

American Society for Testing and Materials (ASTM), *D-2488, Standard Practice for Description and Identification of Soils, Visual-Manual Procedure*.

ASTM D-2487-11. *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*.

ASTM D-6286-98, *Standard Guide for Selection of Drilling Methods for Environmental Site Characterization.*

California Department of Transportation. 2010. *Soil and Rock Logging, Classification, and Presentation Manual*.

California Environmental Protection Agency (Cal/EPA), 2012a, *Guidelines for Planning and Implementing Groundwater Characterization of Contaminated Sites*.

California Environmental Protection Agency (Cal/EPA), 2012b, *Application of Borehole Geophysics at Contaminated Sites.*

South Dakota Department of Environment and Natural Resources, Division of Water Rights, 2003. *Standard Operating Procedure Nine, Drilling Methods, SOP 2150*

United States Department of the Interior, Bureau of Reclamation, 1998 (reprinted 2001), *Engineering Geology Field Manual, Volume I, Second Edition*.

USEPA, 1996. *Monitor Well Installation, SOP#2048*. Emergency Response Team.

USEPA, 1997. *Expedited Site Assessment Tools for Underground Storage Tank Sites, A Guide for Regulators. EPA 510-B097-001*. March.

USEPA. 2005. *Groundwater Sampling and Monitoring With Direct Push Technologies, OSWER No. 9200.1-51*. August.

APPENDICES

Appendix A **Classifying Visual Manual Flowcharts**

Appendix B **Geologic Logs**

Appendix C **Plasticity Chart**

Appendix D **Checklists**

APPENDIX A

Figure 1a. Visual-Manual Method Flowchart for Classifying Inorganic Fine-Grained Soil (50% or more fines)

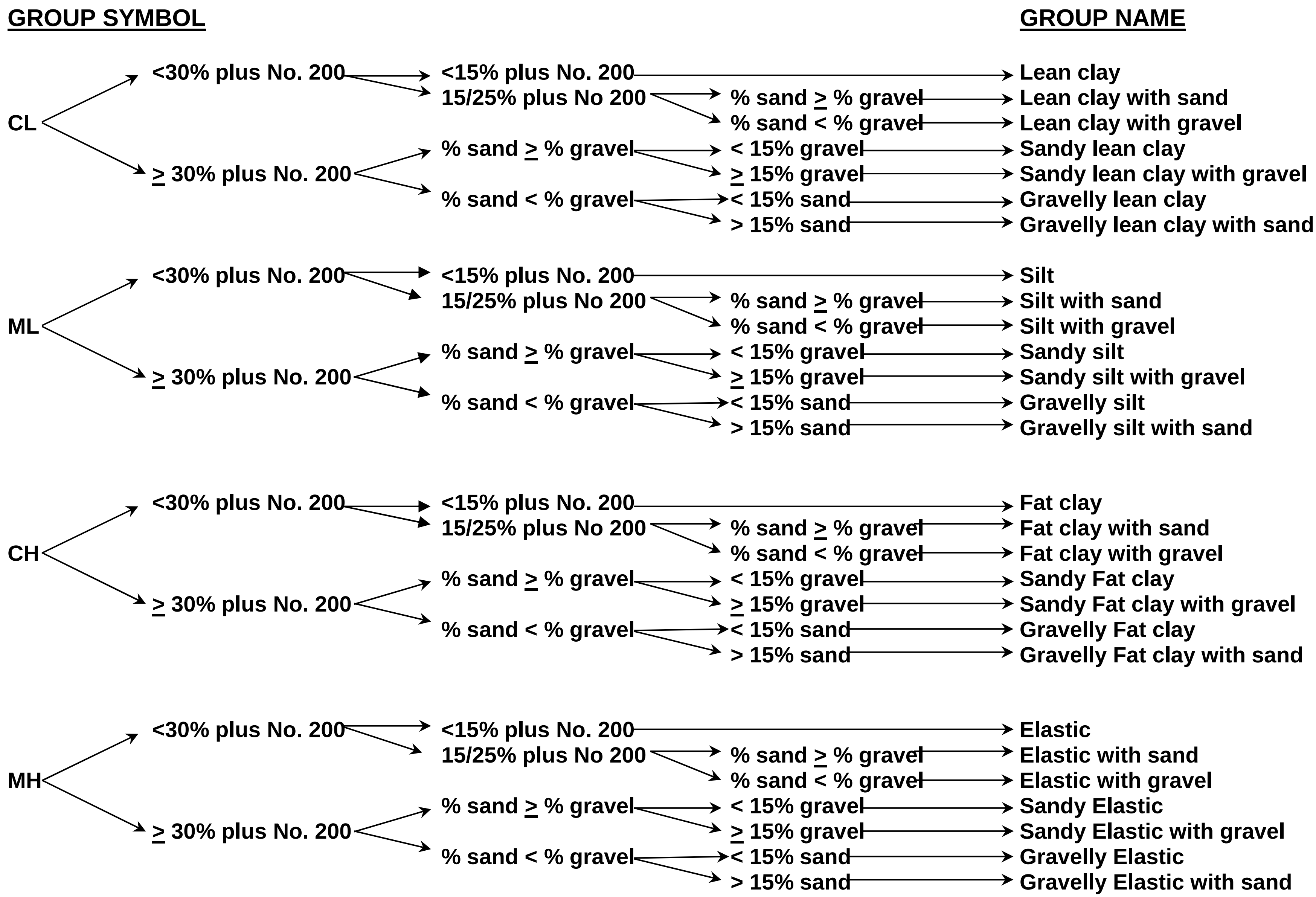


Figure 1b. Visual-Manual Method Flowchart for Classifying Organic Soils

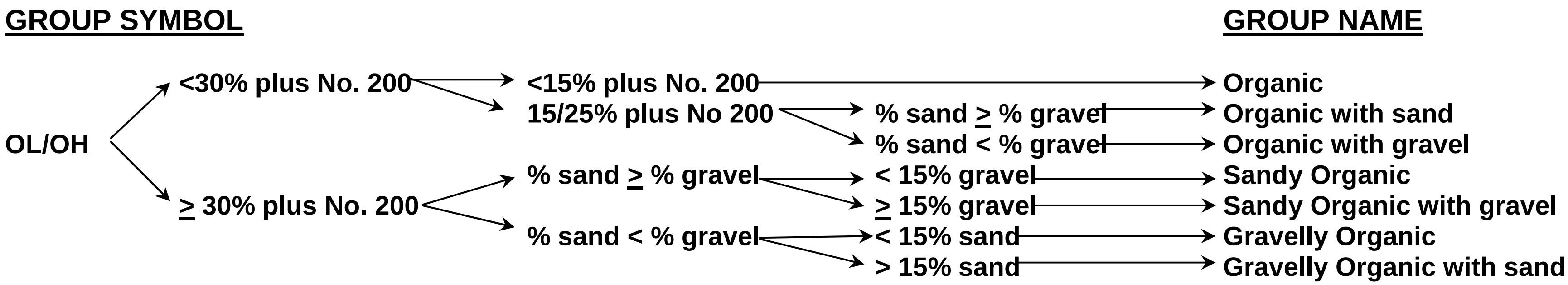
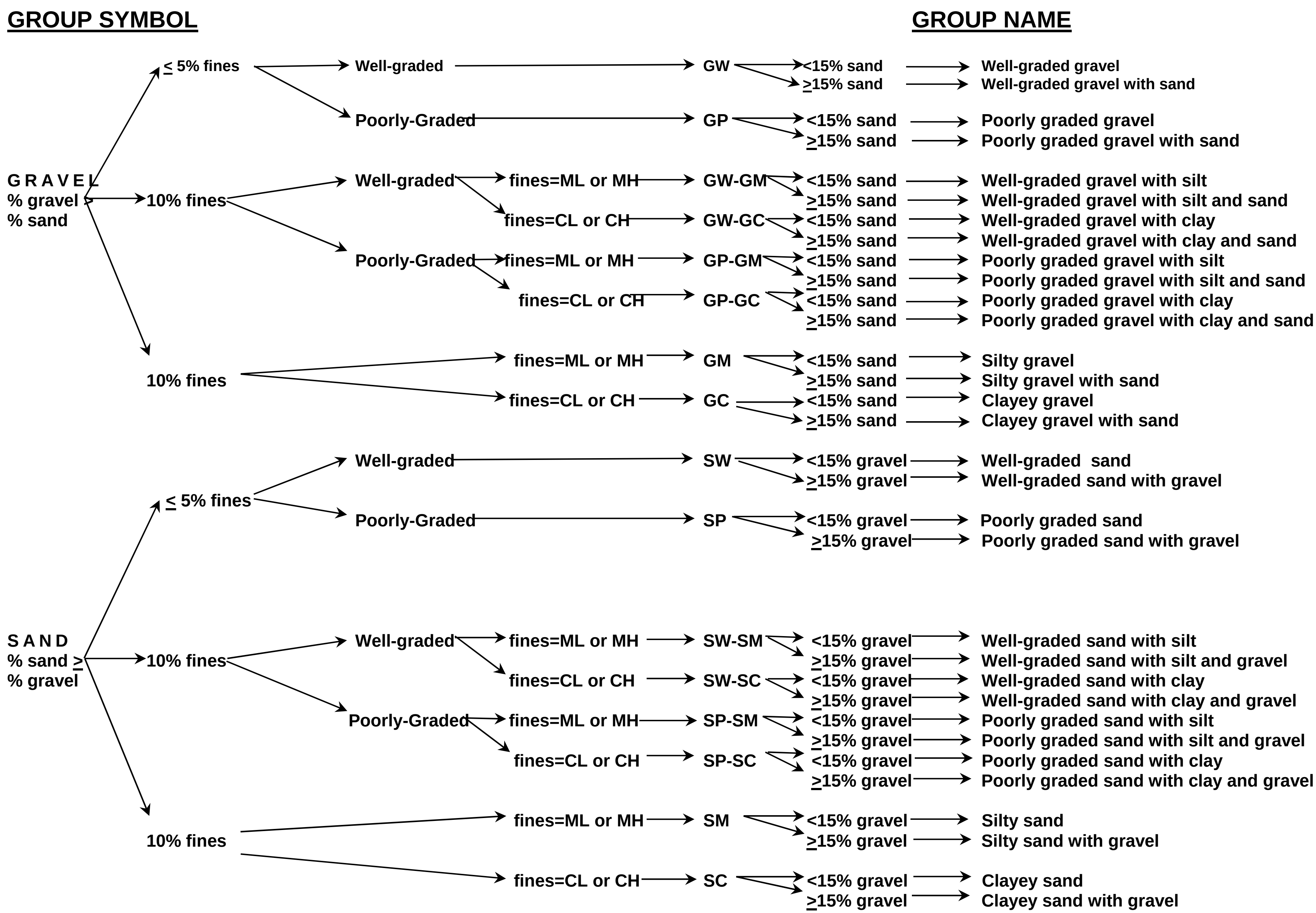


Figure 2. Visual-Manual Method Flowchart for Classifying Coarse-Grained Soils (less than 50% fines)



APPENDIX B

<table>
<tr><td colspan="4">Geologic Log of Trench /Test Pit</td><td>Trench/Test Pit I.D. <u>No. 1</u></td></tr>
<tr><td colspan="4">Site: Lost Mine, Little Town, California
Location: Sand Dam
Approximate Dimensions: 8 ft. long x 2 ft. wide
Coordinates: Lat. 39.2034613; Long. -121.0519698
Elevation: 2522.1 ft. msl</td><td>Date: 9/21/09
Time: 2:30 PM to 3:30 PM
Weather: Clear
Method of Excavation: Kabota KX 121-3 Excavator
Logged By: John Leung</td></tr>
<tr><td rowspan="2">Classification and Description of Material
(Visual Classification)</td><td colspan="3">% Plus 3 inch</td><td></td></tr>
<tr><td>3-5 in</td><td>5-12 in</td><td>Plus 12 in</td><td></td></tr>
<tr><td><u>Mill Tailings</u>
0.0 to 4.0 ft

0.0 to 0.2 ft. <u>Silty Sand (SM)</u>. About 70% fine sand; about 30% nonplastic fines, low toughness, rapid dilatancy. Strong to moderate reaction with HCL.

In-place Condition: Firm, dry. Reddish yellow (7.5YR 7/6)*.

0.2 to 0.4 ft. <u>Silty Sand (SM)</u>. About 70% fine sand; about 30% nonplastic fines, low toughness, rapid dilatancy. Strong to moderate reaction with HCL.

In-Place Condition: Firm; dry; white (7.5YR 8/1)* to pinkish white (7.5YR 8/2)*.

0.4 to 4.0 ft. <u>Poorly Graded Sand (SP)</u>. About 95% fine sand; about 5% nonplastic fines, low toughness, rapid dilatancy. Strong to moderate reaction with HCL.

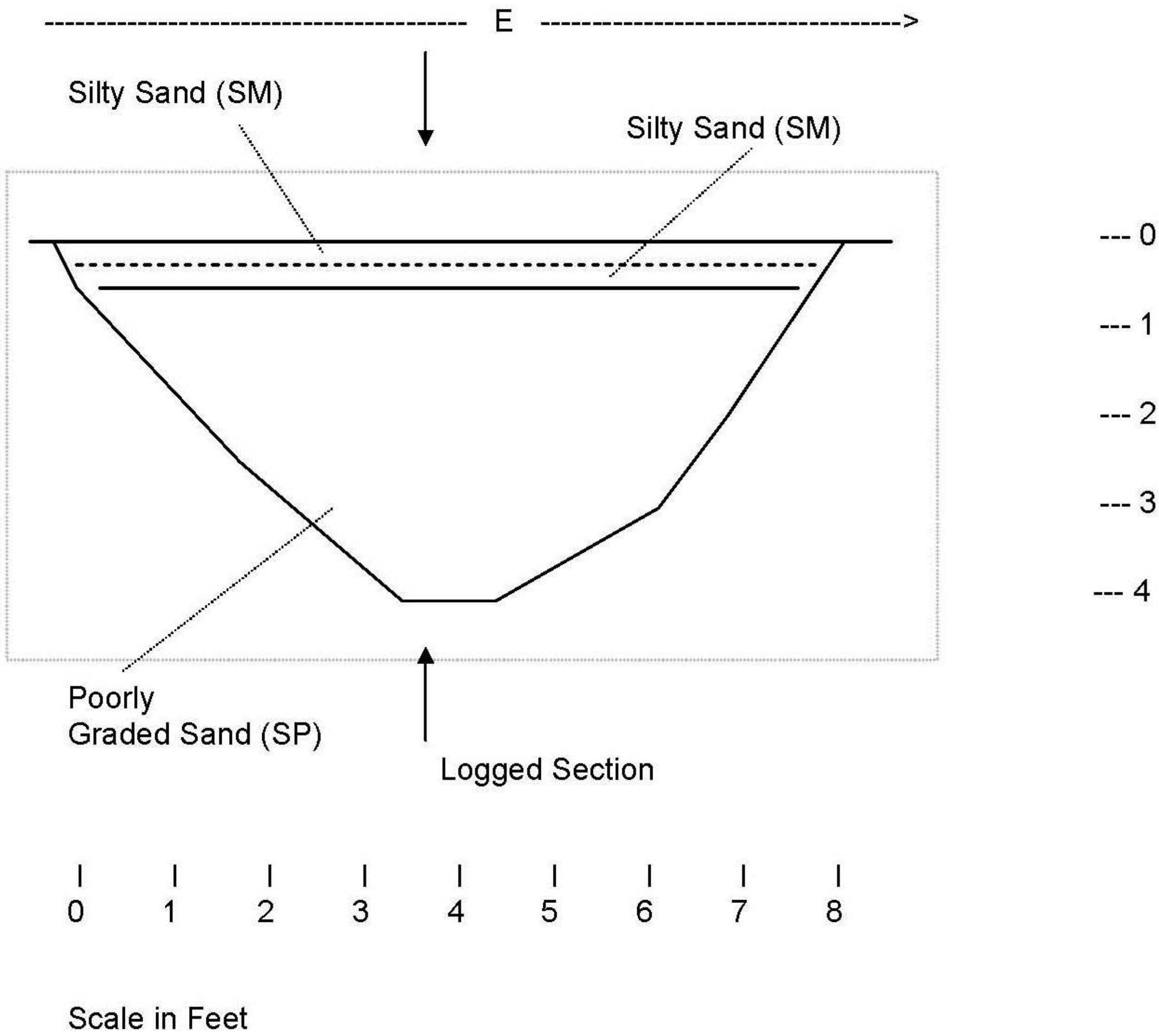
In-Place Condition: Firm, dry with increasing moisture at depth; light greenish gray

(N 8/1)*. Laminations about ¼ inch thick due to slight variations in color and percentage of silt verses fine sand.</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">REMARKS: Easy excavation, no caving. Trench walls held vertical. No water encountered. Backfilled trench with excavated material. Samples Collected: EM-08-0-2 (0.0 to 0.2 ft.) and EM-09-2-4 (0.2 to 4.0 ft.). All samples sieved with No. 4 screen. <u>Geologic Interpretation</u>: Mill tailings consist of crushed/processed undifferentiated Paleozoic and Mesozoic Rocks (massive diabase and granodiorite).

* Munsell Soil Color. Geologic cross-section of excavation is located on page 2.</td></tr>
</table>

Geologic Log of Trench /Test Pit	Trench/Test Pit I.D. No. 1
Site: Lost Mine, Little Town, California Location: Sand Dam Approximate Dimensions: 8 ft. long x 2 ft. wide Coordinates: Lat. 39.2034613; Long. -121.0519698 Elevation: 2522.1 ft. msl	Date: 9/21/09 Time: 2:30 PM to 3:30 PM Weather: Clear Method of Excavation: Kabota KX 121-3 Excavator Logged By: John Leung

Geologic Cross Section of Excavation, North Wall



Geologic Log of Trench /Test Pit	**Trench/Test Pit I.D. No. 2**
Site: Rock Estates, Hill City, California Location: Former Storage Area Approximate Dimensions: 8.5 ft. long x 2 ft. wide Coordinates: Lat. 39.1998147; Long. -121.0416240 Elevation: 2708.6 ft. msl	Date: 9/23/10 Time: 11:30 AM to 12:30 PM Weather: Clear Method of Excavation: Kabota BHB0-X Excavator Logged By: Sarah Jones

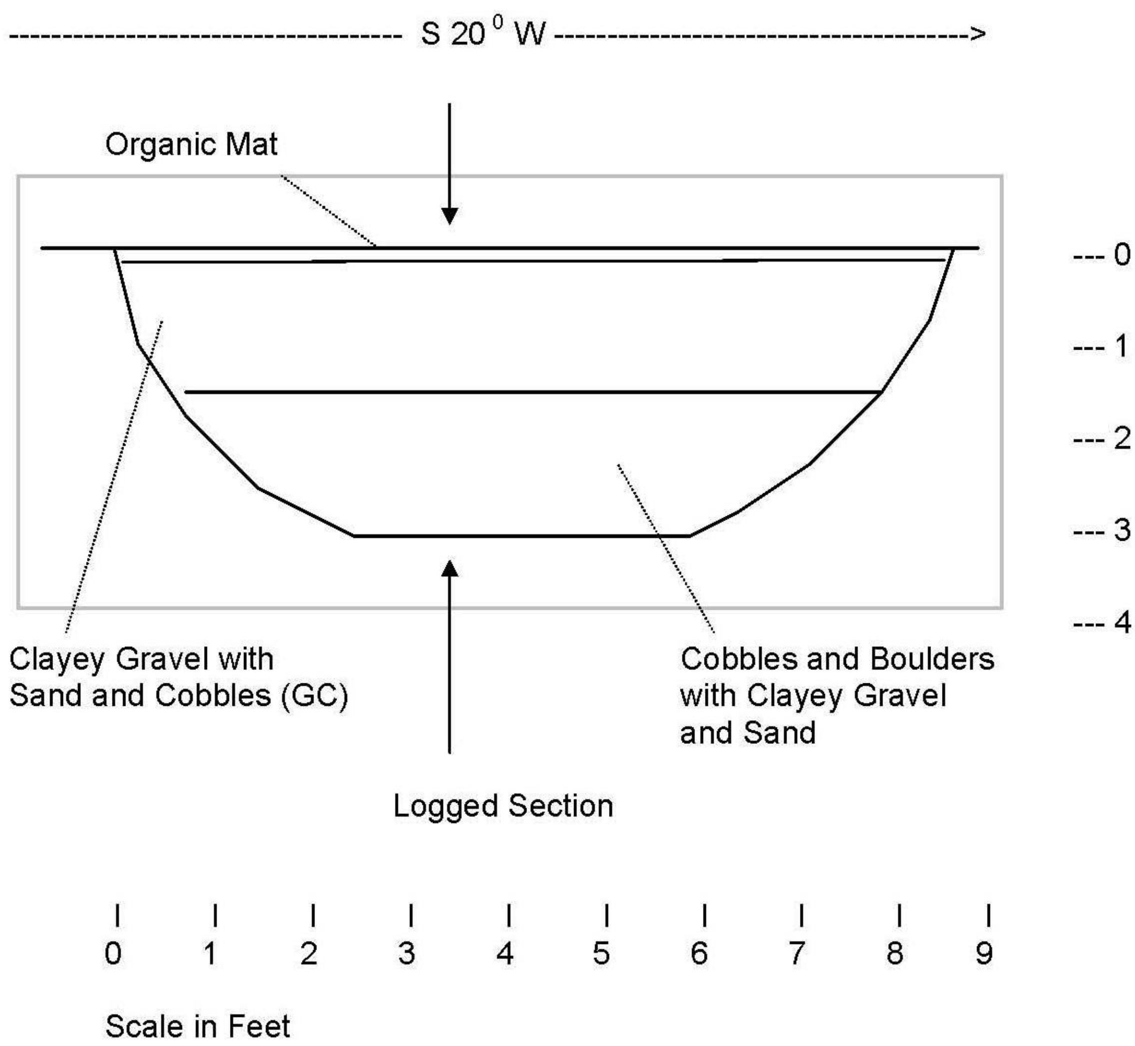
Classification and Description of Material (Visual Classification)	% Plus 3 inch		
	3-5 In.	5-12 In.	Plus 12 in.
Organic Mat (expired grass, fine roots, pine needles, and leaves) 0.0 to 0.1			
Fill 0.1 to 3.0 ft.			
0.1 to 1.5 ft. Clayey Gravel with Sand and Cobbles (GC). About 50% fine to coarse mostly angular lightly weathered diabase gravel; about 30% fine to coarse angular sand; about 20% fines with medium plasticity, medium toughness. Moderate reaction to HCL on broken surfaces of some cobbles and boulders, only. Total Sample (by Volume): About 15% 3-5 inch mostly angular lightly weathered diabase cobbles: about 5% 5-12 inch mostly angular lightly weathered diabase cobbles; maximum dimension 12 inches. In-Place Condition: Dry; fines/sand dark yellowish brown (10YR 3/6)*; gravel, cobbles and boulders – grey to reddish brown. Fine roots to about 12 inches below ground surface. Cobbles fracture with moderate to heavy blows from hammer.	15	5	
1.5 – 3.0 ft. Cobbles and Boulders with Clayey Gravel and Sand: Total Sample (By Volume): About 35% 3-5 inch mostly angular lightly weathered diabase cobbles: about 20% 5-12 inch mostly angular lightly weathered diabase cobbles; about 5% mostly angular lightly weathered to moderately weathered diabase boulders; maximum dimension 16 inches. Minus 3 - inch fraction (by Mass): About 50% fine to coarse mostly angular lightly weathered diabase gravel; about 30% fine to coarse angular sand; about 20% fines with medium plasticity, medium toughness. Moderate reaction to HCL on broken surfaces of some cobbles and boulders only. In-Place Condition: Dry; fines and sand – yellowish red (5YR 4/6)*; gravel, cobbles and boulders – grey to reddish brown. Cobbles fracture with moderate to heavy hammer blows.	35	20	5

REMARKS: Light to moderate ease of excavation and light raveling of trench walls. No water encountered. Backfilled trench with excavated material. Samples collected: EM-20-0-1 (0.0-1.0 ft. excludes organic mat), EM-21-1-3 (0.0-3.0 ft.). All samples sieved with No. 4 screen. Geologic Interpretation: Fill consists of primarily of Paleozoic and Mesozoic Rocks (massive diabase).

* Munsell Soil Color. Geologic cross-section of excavation is located on page 2.

Geologic Log of Trench /Test Pit	Trench/Test Pit I.D. No. 2
Site: Rock Estates, Hill City, California Location: Former Storage Area Approximate Dimensions: 8.5 ft. long x 2 ft. wide Coordinates: lat. 39.1998147; Long. -121.0416240 Elevation: 2708.6 ft. msl	Date: 9/23/10 Time: 11:30 AM to 12:30 PM Weather: Clear Method of Excavation: Kabota KX 121-3 Excavator Logged By: Sarah Jones

Geologic Cross Section of Excavation, Southeast Wall



Geologic Log of Trench /Test Pit	**Trench/Test Pit I.D. No. 3**
Site: Community Park, Lake Town, California Location: Former Burn Dump Area Approximate Dimensions: 7 ft. long x 2 ft. wide Coordinates: Lat. 39.223610; Long. -121. Elevation: 2747.7 ft. msl	Date: 9/22/08 Time: 10:30 AM to 11:30 AM Weather: Clear Method of Excavation: Kabota BHBO-X Backhoe Logged By: Karen Phillips

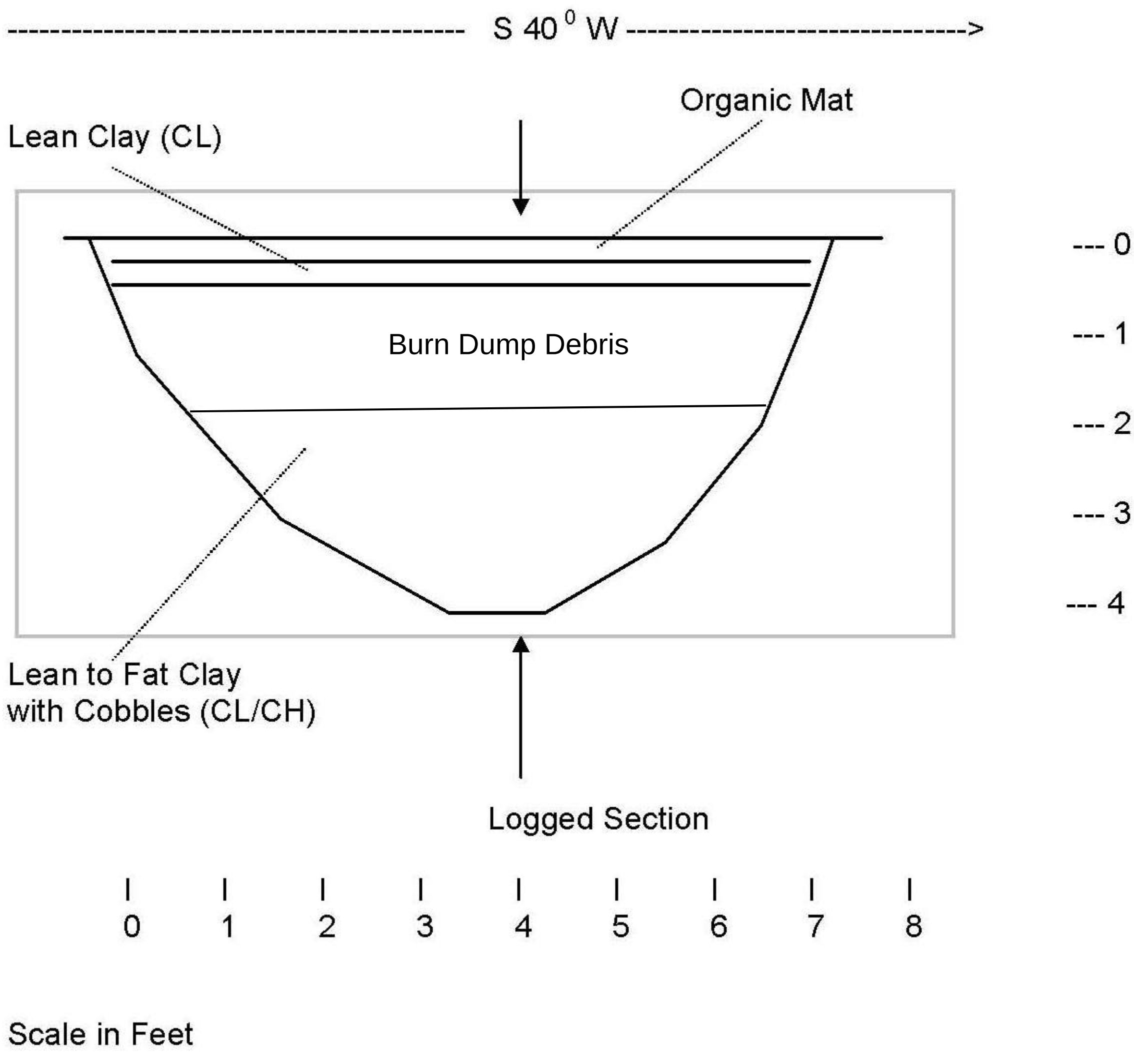
Classification and Description of Material (Visual Classification)	% Plus 3 inch 3-5 in	5-12 in	Plus 12 in
Organic Mat (expired grass and pine needles) 0.0 to 0.2 ft.			
Fill 0.2 to 0.4 ft.			
0.2 to 0.4 ft. Lean Clay (CL). About 85% fines with medium plasticity, medium toughness; about 15% fine sand. No reaction with HCL.			
In-Place Condition: Soft to firm, dry; strong brown (7.5YR 4/6)*. Fine roots to about 1½ inches long.			
Burn Dump Debris 0.4-1.9 ft.			
0.4 to 1.9 ft. Debris. Consists of broken glass, thin gauge copper wire up to 3 inches long; angular fragments of red brick and concrete ranging in size from ¼ to 2 inches; burned wood fragments ranging in size from 1/4 to 2 inches; and dark gray ash mixed with lean brown clay, fine to coarse angular sand, and coarse hard angular gravel up to 2 inches in diameter.			
In-Place Condition: lightly to moderately compacted, dry.			
Native Soil (Slopewash) 1.9 to 4.0 ft. .			
1.9 to 4.0 ft. Lean to Fat Clay with Cobbles (CL/CH). About 95% fines with medium to high plasticity, medium to high toughness; about 5% fine sand; trace coarse angular moderately to intensely weathered diabase gravel; trace moderately to intensely weathered angular to subangular diabase cobbles; maximum dimension 8 inches. No reaction with HCL.	trace	trace	
In-Place Condition: Hard to firm, dry; fines/sand - red (2.5YR 4/8)*; gravel and cobbles – light yellowish brown. Fine roots to about 12 inches below ground surface. Cobbles fracture with light hammer blows.			

REMARKS: Easy excavation, no caving. Trench walls held vertical. No water encountered. Backfilled trench with excavated material and cover with 6 inches of clean fill. Samples Collected: EM-11-0-1(0.0 – 1.0 ft -excludes organic mat), EM-12-2-3.5 (2.0-3.5 ft.); EM-12 (1.0 -2.0 ft.). All samples sieved with No. 4 screen. Geologic Interpretation: Fill over Burn Dump debris and native soil developed over Paleozoic and Mesozoic Rocks (massive diabase).

* Munsell Soil Color. Geologic cross-section of excavation is on located on page 2.

Geologic Log of Trench /Test Pit	Trench/Test Pit I.D. No. 3
Site: Community Park, Lake Town, California Location: Former Burn Dump Area Approximate Dimensions: 7 ft. long x 2 ft. wide Coordinates: Lat. 39.223610; Long. -121.979214 Elevation: 2747.7 ft. msl	Date: 9/22/08 Time: 10:30 AM to 11:30 AM Weather: Clear Method of Excavation: Kabota BHBO-X Backhoe Logged By: Karen Philips

Geologic Cross Section of Excavation, Southeast Wall



Geologic Log of Borehole	**Borehole No. DH-01**
Site: IFFY Manufacturing, Lostville, California Location: Former Storage Area Coordinates: Lat. 39.251929; Long. -121.040154 Ground Elevation: 2012 ft. msl Total Depth: 11.0 ft. bgs	Date: 9/21/09 to 9/22/09 Time: 1:45 PM to 4:00 PM Weather: Clear Drilling Method: See notes Logged By: Frank Alfaro

Notes on, drilling method, fluid return, character of drilling, water table, etc.

Purpose of Hole: Site Characterization

Drill Rig: Mobile B-16

Drillers: Eric Johnson and Sara Smith

Drilling Methods:
0.0- 4.0: 3" drive tube sampler
0.0-7.0: 7" OD., 3" ID flight auger
7.0-11.0: 3" drive tube sampler

Drilling Conditions:
(pressure gauge reading for push tubes)

0.0-2.0: 800 lbs/ft^2
2.0-4.0: 400 lbs/ ft^2
7.0-11: 800 lbs/ft^2

Caving Conditions:
0.0-2.0: light
2.0-4.0: none
7.0-11.0: light

Casing Record:
Type : 7:OD 3" ID flight auger

Depth	Interval Drilled
---	0.0-4.0 ft
0.0-4.0 ft	4.0-11.0 ft

Estimate Fluid Return:
N/A

Depth to Water:
Not encountered

Hole Completion:
Backfilled boring with bentonite slurry

Type/ Size of Hole	% Recovery	Depth (Feet)	Graphic Log
3" Drive Tube	95	1, 2	SM
3" Drive Tube	100	3, 4	CL-CH
Flight Auger		5, 6, 7	CL-CH grading to SP-SM
3" Drive Tube	90	8, 9	SP-SM
3" Drive Tube	85	10, 11	SP
		12	

Classification and Description of Material (Visual Classification)

0.0 - 2.0 Fill

0.0 – 2.0 Silty Sand (SM). About 65% fine to coarse subangular to subrounded sand; about 30% nonplastic fines; about 5% fine hard angular gravel; maximum dimension ¾ inches. Crumbles with moderate thumb pressure; moist to dry; brown. No reaction with HCL.

2.0 - 11.0 Slope Wash/Alluvial Sediments

2.0 – 4.0 Lean to Fat Clay (CL-CH). About 90% fines with moderate plasticity; about 10% fine sand; maximum dimension (fine sand). Hard to firm, indents less than ¼ inch with heavy thumb pressure; moist; gray-green. Weak with reaction with HCL.

4.0 – 7.0 Flight Auger (Cuttings consists Lean to Fat Clay grading to Poorly Graded Sand)

7.0- 8.9 Poorly Graded Sand (SP-SM). About 90% fine sand; about 10% nonplastic fines; maximum dimension (fine sand). Crumbles with moderate thumb pressure; moist; gray. No reaction with HCL.

8.9-11.0 Poorly Graded Sand with Gravel (SP). About 80% fine sand; about 15% fine subrounded hard gravel; about 5% nonplastic fines; maximum dimension ½ inch. Crumbles with moderate thumb pressure; moist; gray. No reaction with HCL.

REMARKS: Geologic Interpretation: 0- 2.0: Uncompacted fill; 2.0 - 11.0: Undisturbed Slope Wash/ Alluvial Sediments. Environmental l soil samples collected at: 0.0 -0.3 ft; 2.0 – 2.3 ft; 3.7 -4.0 ft; 7.0-7.3 ft; 8.6-8.9 ft; 9.0-9.3 ft; 10.7-11.0 ft.

Geologic Log of Borehole

Borehole No. DH-02

Site: Alltype Chemical Storage, Valley Town, California	Date: 9/21/10 to 9/22/10
Location: Former Storage Area	Time: 10:30:AM PM to 4:00 PM
Coordinates: Lat. 37.474656; Long. -120.630738	Weather: Clear
Ground Elevation: 155 ft. msl	Drilling Method: See notes/Type of hole
Total Depth: 35 ft. bgs	Logged By: Lamarr Clayton

Notes on, drilling method, fluid return, character of drilling, water table, etc.

Purpose of Hole:
Characterization

Drill Rig: Mobile B-61

Drillers: Susan Platter and Bill Smith

Drilling Methods:
0.0- 35.0: Continuous Tube System - 7.0'' OD, 3.5" ID Flight Auger with 3.0" x 5.0 ft long split tube

Drilling Conditions:
(Continuous Tube System)

0.0-5.0	smooth
5.0-10.0	smooth
10.0-15.0	smooth
15.0-20.0	smooth to rough
20.0-25.0	smooth
25.0-30.0	smooth to rough
30.5-35.0	rough

Caving Conditions:
(N/A)

Casing Record:
Type : 7.0", 3.0 ' ID flight auger

Depth	Interval Drilled
0.0-5.0	5.0-10.0
5.0-10.0	10.0-15.0
5.0-20.0	20.0-25.0
25.0-30.0	30.0-35.0

Estimate Fluid Return:
(N/A)

Depth to Water : 29.3 ft bgs

Hole Completion:
Backfilled hole with bentonite slurry

Type/ Size of Hole	% Recovery	Depth	Graphic Log
Continuous Tube System	95	5	SP-SC / SC
	95	10	SC
	90	15	CL
	95	20	CL
	95	25	CL
	100	30	CL
	85	35	CL / SM
		40	

Classification and Description of Material
(Visual Classification)

0.1 - 0.1 Organic Mat (expired grass, fine roots, and leaves)

0.0- 35.0 Alluvium

0.1 – 3.5 Poorly Graded Sand (SP-SC). About 90% fine sand; about 10% fines with low plasticity; maximum dimension (fine sand). Crumbles with moderate thumb pressure; dry; reddish brown. Weak reaction with HCL.

3.5- 12.1 Clayey Sand (SC). About 75% fine to medium rounded sand; about; 20 % fines with low plasticity; about 5 fine subrounded hard gravel; maximum dimension 3/8 inch. Crumbles with heavy thumb pressure; dry; reddish brown. Weak reaction with HCL.

12.1-23.7 Sandy Clay (CL). About 70% fines with low plasticity; about 20 % fine to coarse subrounded sand; about 10% subrounded hard gravel; maximum dimension size 3/8 inch. Firm, indents about ¼ with heavy thumb pressure; moist, brown. Weak reaction with HCL.

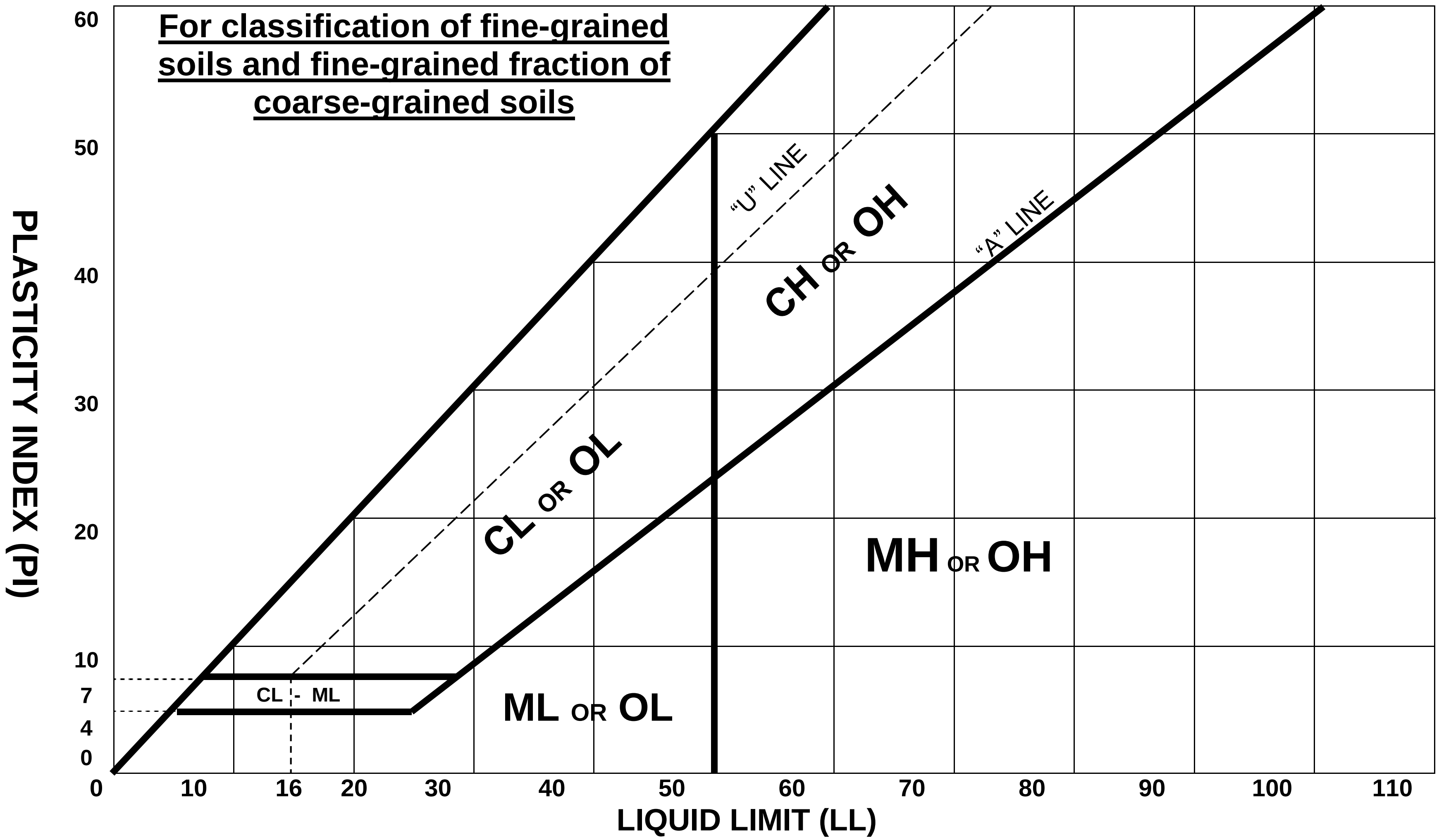
23.7 -32.1 Sandy Clay with Gravel (CL). About 65% fines with low plasticity; about 20% fine to medium subrounded sand; about 15% fine hard subrounded gravel; maximum dimension 3/8 inch. Firm, indents about ¼ inch with heavy thumb pressure, moist brown. Weak reaction with HCL.

32.1- 35.0 Gravelly Silt with Sand (ML). About 60% non-plastic fines; 25% fine subrounded fine gravel; 15% fine to coarse subrounded sand maximum; dimension ½ inch. Loose, crumbles with moderate thumb pressure, wet. No reaction with HCL.

REMARKS: Geologic Interpretation: 0.0-35.0 ft: Alluvium. Soil samples collected: 0.1- 0.3 ft; 3.2-3.6 ft; 5.5-5.9 ft; 8.0-8.4 ft; 12.2-12.6 ft; 16.0-16.4 ft; 22.4-22.8 ft; 28.0-28.4 ft; and 32.4-34.8 ft. One unfiltered and one filtered water samplecollected from below water table using teflon disposable bailer.

APPENDIX C

Plasticity Chart



APPENDIX D

CHECKLIST FOR DESCRIPTION OF COARSE-GRAINED SOILS

Items of descriptive data	Typical information desired for sand and gravel
Group name	WELL-GRADED GRAVEL WITH SAND, ETC.., include cobbles and boulders in typical name when applicable
Gradation	Describe range of particle sizes, such as fine to medium sand or fine to coarse gravel, or the predominant size or sizes as coarse, medium, fine sand or coarse or fine gravel.
Size distribution	Approximate percent of gravel, sand, and fines in the fraction finer than 3 inch; must add to 100 percent.
Plasticity of fines	Nonplastic; low; medium; high
Maximum particle size	Note percent of boulders and cobbles (by volume) as well as maximum particle size.
Particle shape	Flat, elongated, or flat and elongated (if applicable)
Particle angularity	Angular; subangular; subrounded; rounded
Moisture condition	Dry; moist; wet
Color	Use one basic color, if possible.
Odor	Only mention if organic or unusual.
Structure	Stratified; lensed; heterogeneous; homogeneous
Cementation	Weak; moderate; strong
Group symbol	GP, GW, SP, SW, GM, GC, SM, SC, or the appropriate symbol when applicable; should be compatible with typical name used above.
Mineralogy	Rock hardness for gravel and coarse sand. Note presence of mica flakes, particles of shale, or organic matter.

CHECKLIST FOR DESCRIPTION OF FINE-GRAINED AND ORGANIC SOILS

Items of descriptive Data	Typical information desired for silt and clay
Group name	SILT, LEAN CLAY, ETC. , include cobbles and boulders in typical name when applicable.
Size distribution	Approximate percent of fines, sand, and gravel of fraction less than 3 inch in size; must add to 100 percent.
Plasticity of fines	Nonplastic; low; medium; high
Dry strength	None; low; medium; high, very high
Dilatancy	None; slow; rapid
Toughness near plastic limit	Low; medium; high
Maximum particle size	Note percentage of cobbles and boulders (by volume) as well as maximum particle size.
Moisture condition	Dry: moist; wet
Color	Use one basic color, if possible; note presence of mottling or banding.
Odor	Only mention of organic.
Reaction with HCL	Stratified; laminated; fissured; slicken sided; blocky; lensed; homogeneous.
Consistency	Very soft; soft; firm; hard; very hard
Group symbol	CL, CH ML, MH, OL/OH, or the appropriate borderline symbol when applicable with typical names used above.