FINAL

Work Plan
Geotechnical Field Investigation and Bench Scale Treatability Study

USG Interiors Highway 99 Site
Milton, Washington

USG Interiors Puyallup Site
Puyallup, Washington

Prepared for:

USG Corporation
550 West Adams Street
Chicago, Illinois 60661-3676

September 17, 2020

CDM Smith

A Report Prepared for:

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USG INTERIORS HIGHWAY 99 SITE
MILTON, WASHINGTON

and

USG INTERIORS PUYALLUP SITE
PUYALLUP, WASHINGTON

September 17, 2020

Meredith L. Passaro
Geotechnical Engineer

Pam J Morrill

Pamela Morrill, LHG, PMP
Project Manager

Hydrogeologist
1650
Pamela Jeanne Morrill

CDM Smith

Prepared by:
14432 SE Eastgate Way, Suite 100
Bellevue, Washington 98007
425-519-8300

CDM Smith Project No. 19921.233028

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Acronyms and Abbreviations

ASTM	American Society of Testing and Materials International
bgs	feet below ground surface
CAP	cleanup action plan
CDM Smith	CDM Smith Inc.
CDR	Conceptual Design Report
cm/s	centimeters per second
Ecology	Washington State Department of Ecology
EPA	United States Environmental Protection Agency
ft	feet
FS	feasibility study
GPR	ground-penetrating radar
HASP	health and safety plan
ID	inner diameter
IDW	investigative-derived waste
ISCO	in situ chemical oxidation
ISS	in situ solidification and stabilization
Lafarge	Lafarge North America
mL:g	milliliters to grams
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MTCA	Washington State Model Toxics Control Act
ppm	parts per million
RI	remedial investigation
RV	recreational vehicle
SDL	semi-dynamic leaching

SOP	standard operating procedure
SPLP	synthetic precipitation leaching procedure
SPT	standard penetration testing
S/S	solidification/stabilization
TDS	Total Dissolved Solids
UCS	Unconfined Compression Strength
USCS	Unified Soil Classification System
USG	USG Interiors, LLC
µg/L	micrograms per liter
XRF	X-ray fluorescence

Section 1

Introduction

CDM Smith Inc. (CDM Smith) has prepared this work plan to detail the Geotechnical Investigation and Bench Scale Treatability Study to be completed at the USG Interiors' Highway 99 site located in Milton, Washington and the Puyallup site in Puyallup, Washington. The activities described in this work plan are being performed on behalf of USG Interiors, LLC (USG). These activities are being performed in support of the modifications to the Cleanup Action Plans (CAPs) for the Highway 99 (Washington State Department of Ecology [Ecology] 2016) and the Puyallup sites (Ecology 2019). The modifications were identified in the Conceptual Design Reports (CDR) for the Highway 99 site (CDM Smith 2020a) and Puyallup site (CDM Smith 2020b). This work is being performed in accordance with Agreed Order No. DE 11099 (Highway 99 site) and DE 11098 (Puyallup site). The work plan provides a detailed description of the approach and methodology to be employed for the geotechnical investigation and bench scale treatability study.

1.1 Site Location and Description

1.1.1 Highway 99

The USG Highway 99 site is between Pacific Highway East and Interstate 5 (**Figure 1**). It is in a commercial area situated along the east side of Pacific Highway East and is addressed as 7110 Pacific Highway East. Commercial businesses are located to the north and south and residences are located west of the property across Pacific Highway East. The relatively level site is asphalt-paved and is presently occupied by a recreational vehicle (RV) dealership, Discount RV. A mobile office building and a small storage building are situated on the west side of the site. The remainder of the property serves as a lot for RVs. The site plan is presented on **Figure 2**.

1.1.2 Puyallup

The USG Puyallup site is adjacent to the Puyallup River and is generally located at 1005 River Road, as shown on **Figure 3**. The property is currently vacant. The southern portion of the property, adjacent to River Road, is paved and utilized as a parking area by an adjacent used car business. The remainder of the property is overgrown with trees, blackberries, and other vegetation. The northern portion of the property is prone to seasonal overbank flooding of the Puyallup River. A paved bike path extends beside the south bank of the Puyallup River. The site plan is presented on **Figure 4**.

1.2 Purpose and Scope of Work

The purpose of this scope of work is to provide sufficient physical and analytical data for the pilot study, design and implementation of in situ solidification and stabilization (ISS) of soils with arsenic concentrations exceeding 500 parts per million (ppm)[1] remaining at the Highway 99 and Puyallup sites. To achieve this purpose, the scope of work for this work plan is divided into three

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[1] It should be noted that for soil, units described in terms of ppm are equivalent to the unit milligrams per kilogram (mg/kg). For groundwater, units described in terms of ppm are equivalent to milligrams per liter (mg/L).

tasks, the geotechnical investigations, updated site surveys, and bench scale treatability study that are described in further detail below.

1.2.1 Task 1 – Geotechnical Investigations

Geotechnical investigations will be conducted on each site. The objective of the geotechnical investigations is to identify subsurface soil conditions and characterize the engineering properties of soils. These data will be used to finalize design of the bench scale treatability study, to plan the subsequent pilot study, and to conduct constructability evaluations for implementation of the ISS at each site.

1.2.2 Task 2 – Updated Site Survey

The objective of the updated civil surveys will be to identify notable features at each site and to provide a basemap for future design phases of the project.

1.2.3 Task 3 – Bench Scale Treatability Study

The objective of this task is to confirm and/or identify an ISS mix design that meets the project performance criteria, as presented in **Section 1.3**. Data collected from the bench scale treatability study will be used to compare and evaluate similarities in mix designs between the two sites. The feasibility of conducting a single pilot study for both sites will be assessed based on the degree of similarity in mix designs for the two sites.

1.3 Bench Scale Treatability Performance Criteria

The bench scale treatability testing will be conducted to evaluate the physical and analytical properties of the ISS mix designs for the Highway 99 and the Puyallup sites. The performance criteria of the bench scale testing are as follows:

1. Physical tests such as compressive strength can be used to determine the absence of free liquids in treated material and also construction properties of treated material for either site reuse or land disposal (United States Environmental Protection Agency [USEPA] 2009). For this bench scale treatability study, the compressive strength of the ISS samples will be measured using the Unconfined Compression Strength (UCS) Test by American Society of Testing and Materials International (ASTM) method D2166. The UCS performance criteria of the bench scale treatability study is greater than or equal to 50 pounds per square inch.

2. Another physical test used to evaluate performance of the ISS mixes is hydraulic conductivity. A reduction in hydraulic conductivity of the site soils will reduce the groundwater flow through potential source material. The estimated hydraulic conductivity of the site soils is currently 1E-04 centimeters per second (cm/s). The hydraulic conductivity performance criteria of the bench scale treatability study is less than or equal to 1E-06 cm/s (USEPA 2009).

3. Leaching and extraction tests assist in determining the amount of hazardous contaminants that can leach from ISS treated soils. Testing may include synthetic precipitation leaching procedure (SPLP), or dynamic leaching testing depending upon strength and conductivity testing results. The ideal performance criteria would be the MTCA Method A cleanup level of 5 micrograms per liter (µg/L).

1.4 Report Organization

This work plan is organized into the following sections:

Section 1: Introduction – This section provides a summary of site location, planned scope of work, and project performance criteria.

Section 2: Background Information – This section describes the history, modifications made to the CAPs for the USG Highway 99 and Puyallup sites, and the reasoning behind the modifications.

Section 3: Field Investigation and Site Survey Procedures – This section provides a summary of the geotechnical investigation rationale and project procedures. This section also includes the minimum requirements for updating the site survey.

Section 4: Bench Scale Treatability Study Procedures – This section provides a summary of the bench scale treatability study rationale and project procedures.

Section 5: Report Preparation – This section provides an outline of the field investigation and bench scale treatability study reports.

Section 6: Project Management – This section provides an outline for project communications and the proposed schedule.

Section 7: References – This section provides a list of references cited within the work plan.

Figures and Tables supporting the work plan are included, along with relevant appendices which include the site-specific Health and Safety Plans (HASP) and Standard of Operating Procedures (SOPs).

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Section 2

Background Information

2.1 History

2.1.1 Highway 99

The final Remedial Investigation (RI), Feasibility Study (FS), and CAP were issued for the Highway 99 site in June 2016 (CDM Smith 2016a; CDM Smith 2016b; and Ecology 2016, respectively). These documents provide a detailed description of the history of the site, source of contamination, interim remedial actions completed, residual contaminant concentrations, remedial actions considered, and the proposed cleanup action. The proposed cleanup action generally consisted of ISS to treat the vadose fill/soil hot spot area and treating the groundwater hot spot by in situ chemical oxidation (ISCO), combined with groundwater monitoring, installation of permeable pavement, excavation of contaminated sediment, natural attenuation and institutional controls. In June 2016, Agreed Order DE 11099 was issued, which provided for implementation of the remedial action at the site as outlined in the CAP.

2.1.2 Puyallup

The final RI, FS, and CAP were issued for the Puyallup site in 2011, 2013, and 2019, respectively (CDM Smith 2011; CDM Smith 2013a; Ecology 2019). These documents provide a detailed description of the history of the site, source of contamination, interim remedial actions completed, residual contaminant concentrations, remedial actions considered, and the proposed cleanup action. Similar to the Highway 99 site, the proposed cleanup action generally consisted of ISS to treat the vadose fill/soil hot spot area and treating the groundwater hot spot by ISCO, combined with groundwater monitoring, excavation of contaminated sediment, natural attenuation and institutional controls. On April 11, 2019, Agreed Order DE 11098 was issued, which provided for the implementation of the remedial action at the site as outlined in the CAP.

2.2 Modifications to the Cleanup Action Plans

2.2.1 Highway 99 Site

2.2.1.1 Cleanup Action Plan

The CAP, issued on June 23, 2016 for the Highway 99 site presented the preferred alternative (Remedial Action Alternative 2) and included the following components:

- ISS of the fill/soils exceeding 500 mg/kg by injection of a reagent via auger mixing in the vadose zone.
- Groundwater treatment by ISCO, installing permeable pavement in the core remediation area, monitored natural attenuation, and institutional controls.
- Excavation and offsite disposal of impacted sediment in Hylebos Creek. No further studies are required for implementation; therefore, this is not discussed further.

The CAP included the need for the following studies prior to full scale implementation:

- Delineation of the fill/soil hot spot.
- A bench scale study to assess the optimal solidification/stabilization (S/S) mix design.
- Bench scale and pilot testing to assess soil oxidant demand, select the best oxidant, and determine the delivery system for groundwater treatment with ISCO.

2.2.1.2 Additional Studies

USG completed the Hot-Spot Characterization and Bench Scale Testing in December 2016 and issued the report on March 23, 2018 to satisfy implementation of the fill/soil hot spot delineation and bench scale testing (CDM Smith 2018). Bench scale testing was conducted to evaluate ISS mixtures and in situ chemical oxidants for groundwater. Results from the study indicated that cement-based ISS mixtures containing Portland cement (20 percent), bentonite (1 percent), and a 4 to 1 (4:1) iron (FeII) to arsenic mass ratio were most effective in reducing arsenic mobility in soil for purposes of ISS.

The ISCO bench scale study concluded that permanganate and persulfate were more effective chemical oxidants in removing arsenic than hydrogen peroxide and that significant pH reduction occurred with persulfate, but not permanganate. No significant improvements in arsenic removal efficiency were observed at concentrations of permanganate and persulfate greater than 1 times the soil oxidant demand. Recommendations from the bench scale testing included conducting a pilot study to determine the effects of ISCO to remediate site groundwater.

The ISCO pilot study field work at the Highway 99 site was conducted January through March 2019. It was found to be highly complicated to implement and did not reduce arsenic in groundwater to the levels desired. Based on the findings from the ISCO pilot study, USG developed an alternative approach to the cleanup actions that would be less reliant on ISCO. This included enlarging the area for ISS, particularly targeting high arsenic concentration soils situated in the saturated zone.

2.2.1.3 Cleanup Action Plan Modifications

USG proposed modifications to the CAP as presented in a Conceptual Design Report (CDR) (CDM Smith 2020a), based on the findings from the ISCO pilot study. The proposed modifications included conducting ISS over a larger area of the site, targeting all soils with arsenic concentrations exceeding 500 mg/kg to treat residual source material in the core remediation area. Groundwater monitoring after implementation of the ISS will be performed to evaluate the effectiveness of the ISS on the groundwater contaminant plume. These modifications were accepted by Ecology on April 15, 2020. As part of the CDR, a data gap assessment was performed to identify outstanding data needs for design of the ISS at Puyallup. The following data needs were identified, providing the rationale for the geotechnical investigation and additional bench scale treatability studies described herein:

- A geotechnical investigation will include standard penetration testing (SPT) and physical classification of the site soils by index testing. The SPT will be used to identify soil stiffness/density, which will help to assess the means and methods of ISS and provide physical characterization before the bench scale treatability study. Geotechnical index testing will be required for proper design of the bench scale treatability testing and for future planning of the ISS implementation method.

- Additional bench scale treatability studies will be conducted on soils within the unsaturated and saturated zone of the site because of the expanded depth of the ISS area. Testing will be conducted based on the physical and analytical site soil characterization. Previous testing only targeted soils within the vadose zone and composite soils were not physically characterized by index testing for engineering properties.

2.2.2 Puyallup Site

2.2.2.1 Cleanup Action Plan

The CAP (Ecology 2019), issued on April 1, 2019 for the Puyallup site presented the preferred alternative (Remedial Action Alternative 2A) and included the following components:

- ISS of the vadose zone fill/soils exceeding 90 milligrams per kilogram (mg/kg) by injection of a reagent via auger mixing.

- Groundwater treatment by ISCO, install a stormwater infiltration gallery, and re-installation of the monitoring well network.

- Excavation and off-site disposal of impacted sediment in the Puyallup River.

The CAP included the need for the following studies prior to full scale implementation:

- Bench scale and pilot testing to assess soil oxidant demand, select the best oxidant, and determine the delivery system for groundwater treatment with ISCO.

2.2.2.2 Additional Studies

A bench scale treatability study was performed in 2012 (CDM Smith 2012) and a supplemental bench scale treatability study was performed in 2013 (CDM Smith 2013b). Results from the study indicated that cement-based ISS mixtures containing Portland cement (13 percent), bentonite (2 percent), and a 5:1 iron (FeII) to arsenic molar ratio were most effective in reducing arsenic mobility in soil.

Based on the ISCO pilot study performed at USG’s Highway 99 site and the similarities between that site and the Puyallup site, USG similarly concluded that an alternative approach to the cleanup actions that would be less reliant on ISCO and more reliant on ISS, would result in a more cost effective and favorable result.

2.2.2.3 Cleanup Action Plan Modifications

USG proposed modifications to the CAP as part of the CDR prepared for that site (CDM Smith 2020b). The modifications include conducting ISS over a larger area of the site, targeting all soils with arsenic concentrations exceeding 500 mg/kg to treat residual source material in the core remediation area. Groundwater monitoring after implementation of the ISS will be used to evaluate the effectiveness of the ISS on the groundwater contaminant plume. These modifications were accepted by Ecology on March 27, 2020. As part of the CDR, a data gap assessment was performed to identify outstanding data needs for design of the ISS at the Puyallup site. The same data needs were identified for the Puyallup site as the Highway 99 site

Section 3

Field Investigation and Site Survey Procedures

The following section provides a summary of project procedures to perform the geotechnical investigation and site surveys. A summary of the proposed project work is described below:

- Subsurface Investigation– This task will include the drilling and sample collection of all geotechnical investigation borings, as well as the drilling and sample collection of impacted material needed for the bench scale treatability study. The proposed field effort will be conducted sequentially at the Highway 99 and Puyallup sites.

- Updated Survey and Site Plan Development – This phase will include conducting a survey of each site to prepare an updated topographic plan for use in future design phases.

3.1 Geotechnical Field Investigation

The following subsections provide a summary of the pre-investigation activities, scope of work, and proposed laboratory testing for the geotechnical investigations at the Highway 99 and Puyallup sites.

3.1.1 Geotechnical Investigation Data Requirements and Rationale

As indicated in the CDRs, geotechnical investigations were not previously conducted at the Highway 99 or Puyallup sites. The objective of the geotechnical investigations is to identify and properly characterize the engineering properties of the site soils. These data will be used to finalize design of the bench scale treatability study, to plan the future pilot study, and to assess means and methods for implementation of the ISS.

The purpose of conducting the treatability test borings is to collect sample material to be used in the bench scale treatability study. Sampling methodology is currently based on the maximum sample depth at each location, but may be modified in the field based on conditions observed or other site constraints not anticipated at the time of this work plan.

A summary of the geotechnical test boring and treatability test boring rationale is presented in **Table 1** and **Table 2**. Planned drilling and excavation at the sites is presented in the following sections and the locations are shown on **Figures 5** (Highway 99) and **6** (Puyallup).

3.1.1.1 Proposed Investigation - Highway 99

- Geotechnical Test Borings - Up to three borings located within the core remediation area (arsenic concentrations greater than 500 mg/kg). Borings will be a minimum of 10 feet (ft) from all previous site investigation locations. Boring will be drilled up to 15 ft below the maximum depth of proposed ISS treatment zone. A maximum boring depth of 30 ft below ground surface (bgs) is assumed.

- Geotechnical Test Pits - Up to three test pits located within the proposed ISS area will be excavated to a minimum of 12 ft bgs. The purpose of conducting test pits is to identify if larger obstructions such as boulders, cobbles, and/or fill debris exist in the soil profile that could potentially impact future ISS implementation.

- Treatability Test Borings – Up to three borings located within the core remediation area (arsenic concentrations greater than 500 mg/kg). Borings will be a minimum of 10 ft from all previous site investigation locations, but will be co-located within 10 ft of the nearby geotechnical test borings. Borings will be drilled up to 5 ft below the maximum depth of proposed ISS treatment zone. A maximum boring depth of 20 ft bgs is assumed.

3.1.1.2 Proposed Investigation - Puyallup

- Geotechnical Test Borings - Up to three boring located within the core remediation area (arsenic concentrations greater than 500 mg/kg). Borings will be a minimum of 10 ft from all previous site investigation locations. Boring will be drilled up to 15 ft below the maximum depth of proposed ISS treatment zone. A maximum boring depth of 45 ft bgs is assumed.

- Geotechnical Test Pits – Up to three test pits located within the proposed ISS area will be excavated to a minimum of 12 ft bgs.

- Treatability Test Borings - Up to three borings located within the core remediation area (arsenic concentrations greater than 500 mg/kg). Borings will be a minimum of 10 ft from all previous site investigation locations, but will be co-located within 10 ft of the nearby geotechnical test borings. Borings will be drilled up to 5 ft below the maximum depth of proposed ISS treatment zone. A maximum boring depth of 35 ft bgs is assumed.

3.1.2 Field Preparation Activities

3.1.2.1 Existing Data Review

A review of existing data was conducted as part of the CDR development for both the Highway 99 and Puyallup sites. The information obtained from the previous investigations was utilized to develop the scope and rationale of the geotechnical investigation, which is described in further detail herein.

3.1.2.2 Procurement Phase

The procurement phase includes completing the following: (1) procure the subcontractors required for the utility clearance, clearing and grubbing, drilling, analytical laboratory testing, and investigative-derived waste (IDW) off-site disposal at each site; (2) work with subcontractors to the ensure timely completion of the field program; (3) procure materials and equipment to complete the geotechnical bench scale treatability study; and (4) conduct geotechnical and leaching laboratory testing at the CDM Smith Geotechnical Laboratory in Bellevue, Washington.

3.1.2.3 Health and Safety

All field activities will be conducted under the existing site-specific HASP for the Highway 99 and Puyallup sites. The HASPs are included in Appendix A. A site meeting will be held with the proposed project team and the selected subcontractors prior to initiation of the field activities to discuss the project objectives, logistics, and safety.

The field program will require hiring a subcontractor(s) to perform the utility location and clearance, clearing and grubbing, and borings and test pits. The subcontractor(s) will be selected through a pre-qualification process, including demonstration of a health and safety program, review of incident records, and local experience.

All site workers involved with intrusive work whether CDM Smith or subcontractor(s) will have 40-hour Occupational Safety and Health Administration Hazardous Waste Operations and Emergency Response training with current refresher training.

3.1.2.4 Utility Clearance

Prior to the subsurface investigation, all boring and test pit locations will be checked for underground utilities by contacting the Washington One Call hotline (811), using a subcontracted utility locator, reviewing historic site information, and discussing locations with site occupants.

Ground-penetrating radar (GPR) may be used in select areas prior to drill rig mobilization to identify areas containing potential subsurface obstructions that may not be able to be cleared through the public/private utility locate. GPR is a nondestructive, geophysical method that uses radar pulses to image the subsurface by use of reflected signals from subsurface structures.

3.1.2.5 Clearing and Grubbing

It is anticipated that clearing and grubbing will be required to access the proposed test boring and test pit locations at the Puyallup site.

Clearing and grubbing will not be required at the Highway 99 site; all proposed investigation locations are within the extents of a paved/gravel parking lot.

3.1.2.6 Mobilization

This phase will include mobilization of site labor, equipment, and materials required to complete the field activities associated with Task 1. This will include a field geologist(s) for logging the borings and collecting samples. The equipment mobilized to the Highway 99 and Puyallup sites will include, but not be limited to, the following:

- Track-mounted (Puyallup) and/or truck-mounted (Highway 99) drill rig and support vehicle/equipment.
- Rotosonic Drill Sonic drill rig and support vehicle/equipment.
- Excavator and support vehicle/equipment.

The drilling subcontractor will be responsible for securing their equipment on a daily basis. The field geologist will be responsible for maintaining chain-of-custody procedures for samples collected from the investigations at each site.

3.1.3 Test Boring and Test Pit Installation

Boring and test pit locations will all be pre-marked in the field by the field geologist and the final locations will be surveyed by a licensed surveyor in the State of Washington. Prior to subsurface investigation, all boring and test pit locations will be checked for underground utilities, as presented in Section 3.1.2.4.

Soil borings will be drilled by a licensed State of Washington driller. At Puyallup, a track-mounted drill rig may be required to provide access to the geotechnical and treatability test borings. At Highway 99, a truck-mounted drill rig is able to access the geotechnical and treatability test boring locations. The drill rig equipment used for the geotechnical test borings at both sites should be equipped with both a rotary and hammer head for advancing the borehole and conducting SPT in accordance with ASTM D1586. Geotechnical test borings will be advanced using hollow-stem augers with a minimum inner diameter (ID) of four inches. Treatability test borings will be advanced using a rotosonic drill rig with a minimum six-inch ID drill core. Sampling will be conducted in accordance with **Table 1** and **Table 2**, Summary of Proposed Test Boring Rationale for Highway 99 and Puyallup, respectively. Soil borings will be conducted in accordance with the SOPs presented in Appendix B.

Both the geotechnical and treatability test borings will be sampled and logged by the field geologist. For the geotechnical test borings, samples will be collected from the split barrel sampler in 8-ounce glass jars for geotechnical index testing. All soils will be classified using the Modified Burmeister soil classification system and the Unified Soil Classification System (USCS). Arsenic concentrations will be measured from the split spoons using a hand-held x-ray fluorescence (XRF) spectrometer. XRF readings will be collected in accordance with the SOP presented in Appendix B, SW-846 Method 6200, Field Portable X-Ray Fluorescence Spectrometry for the Determination of Elemental Concentrations in Soil and Sediment.

For the treatability test borings, all drill cores will be separated by USCS classification and arsenic concentration and collected in 5-gallon buckets. Arsenic concentrations will be screened using the hand-held XRF in accordance with the SOP presented in Appendix B, SW-846 Method 6200, Field Portable X-Ray Fluorescence Spectrometry for the Determination of Elemental Concentrations in Soil and Sediment.

All test pits excavations will be performed by a State of Washington licensed excavator operator. An excavator with capabilities of reaching a minimum of 12 ft bgs has been selected to be used on-site. Test pits will be logged and sampled by the field geologist in accordance with the SOP for conducting test pits presented in Appendix B.

Equipment will be decontaminated between boring locations and before leaving the project sites. Decontamination procedures will be conducted in accordance with the HASP. At the completion of sampling activities, each borehole will be plugged and abandoned to the ground surface using either bentonite chips or cement-bentonite grout. Test pits will be backfilled with excavated soils and compacted in 12-inch layers. Asphalt surfaces disturbed during drilling will be restored to pre-investigation conditions. Concrete surfaces, if any, will not be replaced.

All geotechnical drill cuttings and decontamination water will be separated and placed in 55-gallon drums. Drill cores obtained by rotosonic drilling for purposes of the bench scale treatability study will be collected in 5-gallon buckets and transported to the CDM Smith Geotechnical Laboratory. All plastic liners, protective equipment, and other miscellaneous trash will be placed in a trash dumpster for disposal off-site in a municipal landfill. IDW sampling, testing, and off-site disposal of waste drums will be coordinated.

3.1.4 Groundwater Collection

Groundwater will be required for the bench scale treatability study and will be collected from an on-site monitoring well during the field investigations at the Highway 99 and Puyallup sites. At the Highway 99 site, groundwater will be collected from monitoring well 99-1 and at Puyallup groundwater will be collected from monitoring well P3-1. It is anticipated that a minimum of 9 gallons from each site will be needed for the bench scale treatability tests. Additionally, groundwater samples will be collected for baseline analyses.

Groundwater quality parameters will be measured during purging using a YSI handheld multiparameter instrument in accordance with the low-flow groundwater sample collection SOP, as presented in Appendix B. Field parameters of pH, specific conductivity, temperature, oxidation-reduction potential, dissolved oxygen and turbidity will be monitored and recorded during purging. Groundwater collection will occur after the field measured parameters have stabilized. Samples to be submitted for analysis of dissolved metals will be field filtered using an inline 0.45 micron filter. Water quality parameters will be measured again at the CDM Smith Geotechnical laboratory to confirm no significant changes during transport. Complete analyses will also be performed at a commercial laboratory (see Section 4.3.2.3).

3.1.5 Boring Identification

Test borings and test pits will be sequentially numbered and identified by the project site, test boring purpose, and unique numeric identifier. For example, test boring 99-GEO-1 indicates that the test boring was conducted at the Highway 99 site, is a geotechnical test boring, and is boring number one. Identification using the prefix PY indicates the Puyallup site. Test pits and treatability test borings are identified using TP and TT respectively.

3.1.6 Geotechnical Laboratory Testing

Geotechnical testing will be performed on representative soil samples collected during Task 1. Testing will be used to characterize changes in the observed stratigraphy and/or soil density. The exact number and type of tests may vary based on field conditions encountered, but the following is anticipated:

- Grain Size without, Hydrometer (ASTM International [ASTM] D6913 and ASTM D1140) – Up to 15 tests.
- Grain Size with Hydrometer (ASTM D7928 and ASTM D1140) – Up to 24 tests.
- Moisture Content (ASTM D2216) – Up to 39 tests.
- USCS Classification (ASTM D2488) – Up to 39 tests.

- Atterberg Limits (ASTM D4318) – Up to 18 tests.
- Organic Content (ASTM D2974) – Up to 10 tests.
- Bulk Density (ASTM D7263) – Up to 6 tests.
- Specific Gravity (ASTM D854) – Up to 6 tests.

Geotechnical samples will be sent to the CDM Smith Geotechnical Laboratory in Bellevue, Washington for testing. Excess soil and wash water from the laboratory testing will be containerized and returned to the site for management.

3.2 Updated Survey and Site Plan Development

An updated site survey will be performed at the Highway 99 and Puyallup sites. The survey will be conducted by a licensed surveyor in the State of Washington. The objective of the updated civil survey will be to identify notable features at each site and to provide a basemap for future design phases of the project.

Photogrammetric basemap and topographic survey will be completed with the following elements:

- The topographic survey basemap will be georeferenced with the horizontal position of the survey based on the Washington State Plane Coordinate System North American Datum of 1983. Elevation will be relative to the North American Vertical Datum of 1988.
- The topographic contour interval for the basemap will be 1 ft, with a 5-ft major contour interval. All physical features, such as buildings, driveways, roads, woodlands, and creeks, will be identified on the map.
- If aerial topographic mapping is used, it will be field-edited and statistically tested in conformance with the horizontal and vertical components of the National Map Accuracy Standards. A minimum of four random baselines throughout each site will be checked to verify that less than 10 percent of horizontal and/or vertical locations exceed the values determined in the National Map Accuracy Standards.

Site civil, property boundary, and tree survey:

- The property boundaries will be based on tax map information. The legal parcel name, legal owner of parcel area, and the source of information will be provided in the property boundary survey.
- The survey will show the jurisdiction, identity, and width of adjoining streets and indicate if any property is located within the floodplain of the Flood Insurance Rate Map. A general description of building structures will be included on the basemap (e.g., “one- story masonry retail building”).

- Public utilities (water, electric, storm, sewer, gas) within the survey area and complete utility infrastructure research will be conducted to include coordinates of utility features (manholes, storm drains, culverts, inverts) and sanitary sewer and storm drain utilities. Additionally, the rim elevations and all surface utilities, valves, boxes, and other surface features of sanitary sewers, storm drains, drainage and irrigation channels, and electrical and telephone vaults will be identified. Coordinates will include Northing, Easting, latitude, longitude, and surface elevation measured in ft with reference to the appropriate datum specified above.

- Trees with a diameter breast height greater than 6 inches within the civil survey boundary will be surveyed using a handheld Global Positioning System unit with sub-1-meter accuracy.

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Section 4

Bench Scale Treatability Study Procedures

The proposed modifications to the CAP for each site included extending the ISS areas vertically and horizontally to target soils with concentrations of arsenic greater than 500 mg/kg to mitigate arsenic leaching from soil to groundwater. This section summarizes the mix design rationale, data requirements, procedures, and anticipated laboratory testing.

4.1 ISS Mix Design Data Requirements and Rationale

Additional bench scale treatability studies will be performed on samples collected at the Highway 99 and Puyallup sites to address the data gaps identified as part of the CDR Reports. The objective of this task is to confirm and/or identify a mix design that meets the project remedial goals to implement as part of the pilot study. Data collected from the bench scale treatability study will be used to evaluate similarities between the two sites to determine the scope of the pilot study implementation. The data requirements and rationale for the bench scale treatability study are as follows:

1. <u>Physical and Analytical Characterization</u> – Soils with similar physical characteristics (i.e. moisture content, organic content, Atterberg limits, etc.) and USCS classifications will be used to create composite soil mixes. Soils with highest concentrations of arsenic, typically greater than or equal to 500 mg/kg will be targeted for the bench scale treatability study.

2. <u>S/S Reagents</u> – Portland cement was used as the solidification agent in the previous bench scale studies. Slag cement is a locally available reagent that will also be evaluated for implementation of ISS. In addition to the evaluation of alternative reagents, the percent bentonite included in the mix design will be further evaluated in an effort to reduce the percent of bentonite necessary and thus reduce swell potential. Ferrous chloride was used as the stabilization agent in the previous bench scale studies. Ferrous sulfate heptahydrate will also be evaluated.

3. <u>Evaluation of Stabilization Reagent</u> – The recommended stabilization reagent and dosage will be evaluated to include both ferrous chloride and ferrous sulfate heptahydrate.

4. <u>Groundwater Compatibility with Proposed Reagents</u> – Previous bench scale studies targeted soils within the vadose zone. Modifications to the CAP included expanding the ISS areas into the saturated zones at each site. For this reason, compatibility testing will be conducted with site groundwater on all proposed reagents to identify any chemical reactions that could negatively affect the soil mixing. Compatibility testing is further described in Section 4.3.1.

5. Impacts of Site Groundwater on Mix Design – With the extension of the ISS areas into the saturated zone, this study will evaluate impacts of site groundwater on the mix designs identified in previous studies for the Highway 99 and Puyallup sites.

6. Strength Testing – The strength of the addendum mix design will be used to evaluate the engineering properties for future implementation of the ISS.

7. Permeability Testing – The permeability of the addendum mix design will be used to determine the effectiveness of the ISS treatment at reducing the hydraulic conductivity of the soil.

8. Leachability Testing – The leachability of arsenic from soil that has been treated will need to be determined to evaluate how effectively the addendum mix design physically or chemically binds or stabilizes the arsenic in the soil and reduces the leachability of arsenic.

4.2 ISS Mix Design Procedures

ISS mixing will be performed at the CDM Smith Geotechnical Laboratory in Bellevue, Washington. Prior to ISS mixing, composite samples will be prepared from the material collected during the geotechnical field investigation. It is assumed that the material collected from the three treatability test borings will be combined to create up to two composite samples for bench scale treatability testing per each site. Two composite samples are estimated for each site because of potential variances in soil conditions below the groundwater table that may impact the mix design. All debris larger than 1 inch in diameter will be removed. All "clumps" of clay (if encountered) exceeding 1 inch in diameter will need to be either shredded or broken up in another way to obtain a uniform, homogenized composite. Physical and analytical of each composite will be collected for composite characterization, in accordance with Section 4.3.2.

ISS mixes will be prepared in accordance with the final mix design schedule (to be developed) and the applicable SOP presented in Appendix B. A preliminary mix design summary is presented for Highway 99 in **Table 3** and for Puyallup in **Table 4**. The preliminary mix design summaries provides ratios of on-site soil and reagents to be added for each evaluation. The reagents may be added as dry (powder form) or as a hydrated "grout," depending upon moisture contents evaluated in the field. Once the reagents are added to the composite soils, samples of the ISS mixes will be cast into 2-inch by 4-inch molds and allowed to cure prior to evaluation of compressive strength, hydraulic conductivity, and leaching. A summary of the proposed laboratory testing is presented in Section 4.3.2. The actual type and number of tests performed will be determined after ISS mixing based on observations of the treated material.

All reagents were chosen based on locally available material, including:

- A sample of Type I/II Portland cement, to be obtained from a local hardware store or a local building materials supplier.
- A sample of NewCem® slag cement, to be obtained from Lafarge North America (Lafarge).

4.3 Laboratory Testing

4.3.1 Reagent Compatibility Testing

The compatibility of the site groundwater and the proposed reagents will be evaluated. One test will be conducted using a sample of Portland cement obtained from the local hardware store and one test will be conducted using a sample of NewCem® slag cement obtained from Lafarge. Tests will be conducted over a 24-hour period to observe how the proposed reagents interact with site groundwater and if they are able to properly solidify. Compatibility testing will be conducted in the CDM Smith Geotechnical Laboratory in Bellevue, Washington.

4.3.2 Preliminary Characterization

4.3.2.1 Geotechnical Soil Composite Characterization (Prior to Soil Mixing)

Geotechnical testing will be performed on composite soil samples for the Highway 99 and the Puyallup sites separately prior to soil mixing. The test methods are presented below. The exact number and type of test may vary based selected soil composites, but the following is anticipated (combined number of tests for both sites):

- Grain Size, without Hydrometer (ASTM D6913 and ASTM D1140) – Up to four tests.
- Grain Size with Hydrometer (ASTM D7928 and ASTM D1140) – Up to four tests.
- Moisture Content (ASTM D2216) – Up to four tests.
- USCS Classification (ASTM D2488) – Up to four tests.
- Atterberg Limits (ASTM D4318) – Up to four tests.
- Organic Content (ASTM D2974) – Up to four tests.
- Bulk Density (ASTM D7263) – Up to four tests.
- Specific Gravity (ASTM D854) – Up to four tests.

4.3.2.2 Analytical Soil Composite Characterization (Prior to Soil Mixing)

Analytical testing will be performed by an Ecology-accredited third-party laboratory (to be determined) and is anticipated to include the tests identified below.

- Total Analyte List, TAL, Metals (EPA SW-846 Method 3050 plus 6010D/6020B/7471B) – Up to four tests.
- SPLP arsenic (EPA SW-846 1312) modified using a liquid to solid ratio of 2:1 (units of milliliters to grams [mL:g]) leaching fluid (#2) to soil ratio – Up to four tests.

4.3.2.3 Site Groundwater Wet Chemistry Characterization

Analytical testing for characterization of the site groundwater at the Highway 99 and Puyallup sites will be performed by a third-party laboratory (to be determined) and is anticipated to include the tests identified below. All laboratory testing will be in accordance with EPA SW-846 methods or other approved EPA (Clean Water Act) methods or Standard Methods (Standard Methods for Examination of Water and Wastewater, American Public Health Association).

- TAL Analyte List Metals plus silica– EPA SW-846 (EPA Method 6020B/7470A) – two tests (dissolved basis, field filtered).
- Anions (EPA SW-846 9056, plus carbonate/bicarbonate (Standard Methods, SM2320B) and nitrate+nitrate (EPA Method 353.2) – two tests.
- General Chemistry– Total Dissolved Solids (TDS) (SM 2540C), Total Suspended Solids, (SM 2540D) – two tests.

4.3.3 ISS Mix Strength Testing

Strength testing will be performed at the CDM Smith Geotechnical Laboratory in Bellevue, Washington and will be performed on ISS soil mix cylinders. The exact number and type of test may vary based final mix design, but the following is anticipated:

- Unconfined Compression Test (ASTM D2166) – Up to 120 tests; 40 conducted after 7 days of curing, 40 conducted after 14 days of curing, and 40 conducted after 28 days of curing.

4.3.4 ISS Mix Permeability Testing

Hydraulic conductivity testing will be performed at the CDM Smith Geotechnical Laboratory in Bellevue, Washington and will be performed on ISS soil mix cylinders. The exact number and type of test may vary based final mix design, but the following is anticipated:

- Hydraulic Conductivity Using Flexible Wall Permeameter (ASTM D5.084) – Up to 40 tests will be conducted on cylinders after a minimum cure time of 7 days

4.3.5 Evaluation of Potential Leaching in ISS Mixes

The SPLP leaching test will be performed using EPA method modified SW-846 1312. The SPLP will be modified using a 2:1 (mL:g) leaching fluid (1312 #2 fluid) to soil ratio. The SPLP is performed to evaluate potential leaching of soils by rain (precipitation) and assist in selecting samples for semi-dynamic leaching (SDL) tests which are more consistent with anticipated site conditions. The SPLP test will be conducted on disaggregated cylinder samples and the SDL test will be conducted on intact cylinders in accordance with the modified SOP DTL-1-10 (Denver Treatability Laboratory 1-10) presented in Appendix B. The SDL testing will follow SW-846 method 1315 (Mass Transfer Rates of Constituents in Monoliths or Compacted Granular Material using a Semi-Dynamic Tank Leaching Procedure) with some modifications (number of samples and times as outlined in SOP DTL-1-10). SDL testing more accurately simulates leaching of S/S samples by groundwater at the site. The results can be used to predict long term concentrations of arsenic. Analysis of the leachates from both the SPLP and SDL tests will be conducted for dissolved arsenic by a third-party laboratory (to be determined) using SW-846 method 6020B.

- SPLP (EPA SW-846 1312) – Up to 8 tests.
- SDL (EPA SW-846 1315) – Up to 2 tests; Also, total arsenic on the tested cylinders using 3050 (digestion) and 6020B (arsenic).

Section 5

Report Preparation

One or more draft reports will be prepared at the conclusion of the geotechnical field investigations and bench scale treatability studies. Depending upon the similarities found between the sites and bench scale studies or lack thereof, the reports for geotechnical investigations and bench scale studies may be combined by site or by study. Report information will include:

- Background Information – Site location and existing conditions, local geology, proposed construction, project objectives, and project datum.
- Field Investigation Activities - Updated survey/utility clearance, overview of drilling, sampling, and test pit findings.
- Analytical Findings - XRF and laboratory testing performed and results, including treatability study preliminary composite soil and groundwater characterization testing.
- Geotechnical Laboratory Testing – Geotechnical tests completed and results.
- Bench Scale Testing- Reagent evaluation, bench scale mix design and procedures, and ISS composite sample testing.
- Field Investigation Findings - Summary and evaluation of the subsurface soil conditions presented in terms of geotechnical engineering properties.
- Bench Scale Treatability Findings - Conclusions from the bench scale treatability testing and the recommendations for the proposed pilot study for the Highway 99 and Puyallup sites, including a recommendation of the optimal mix design for ISS implementation during the pilot study.

Report attachments will include:

- Figures – including an updated site plan based on the survey and a boring/test pit location map.
- Summary Tables - XRF results for arsenic concentrations in soil, analytical laboratory results, physical laboratory testing results, and leaching test results.
- Appendices – Boring logs, analytical reports, and geotechnical physical testing reports.

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Section 6

Project Management

6.1 Project Schedule

The proposed project schedule to complete the fieldwork and testing described in this work plan is presented on **Figure 7**. Fieldwork may begin within 45 days of receiving Ecology's approval of this work plan. However, this is dependent upon successful access negotiations between property owners/occupants (i.e., Kanopy Kingdom, Bonney Lake Used Cars, Market Place Auto, and the City of Puyallup) and USG.

6.2 Communications

It is assumed that, at a minimum, biweekly project status calls will be held between USG and CDM Smith. Monthly status reports will be transmitted via email to the Ecology site manager for each of the USG sites.

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Section 7

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Section 8

Distribution

1 Electronic Copy	USG Corporation 500 West Adams Street, Department 176 Chicago, Illinois 60661-3676 Attention: Ms. Jennifer Brennan
1 Electronic Copy	Washington State Department of Ecology Toxics Cleanup Program Post Office Box 47775 Olympia, Washington 98504-47775 Attention: Mr. Andy Smith, PE Mr. Mohsen Kourehdar, PE

Quality Assurance Review by:

Jagrut Jathal
Principal Geotechnical Engineer

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Figures

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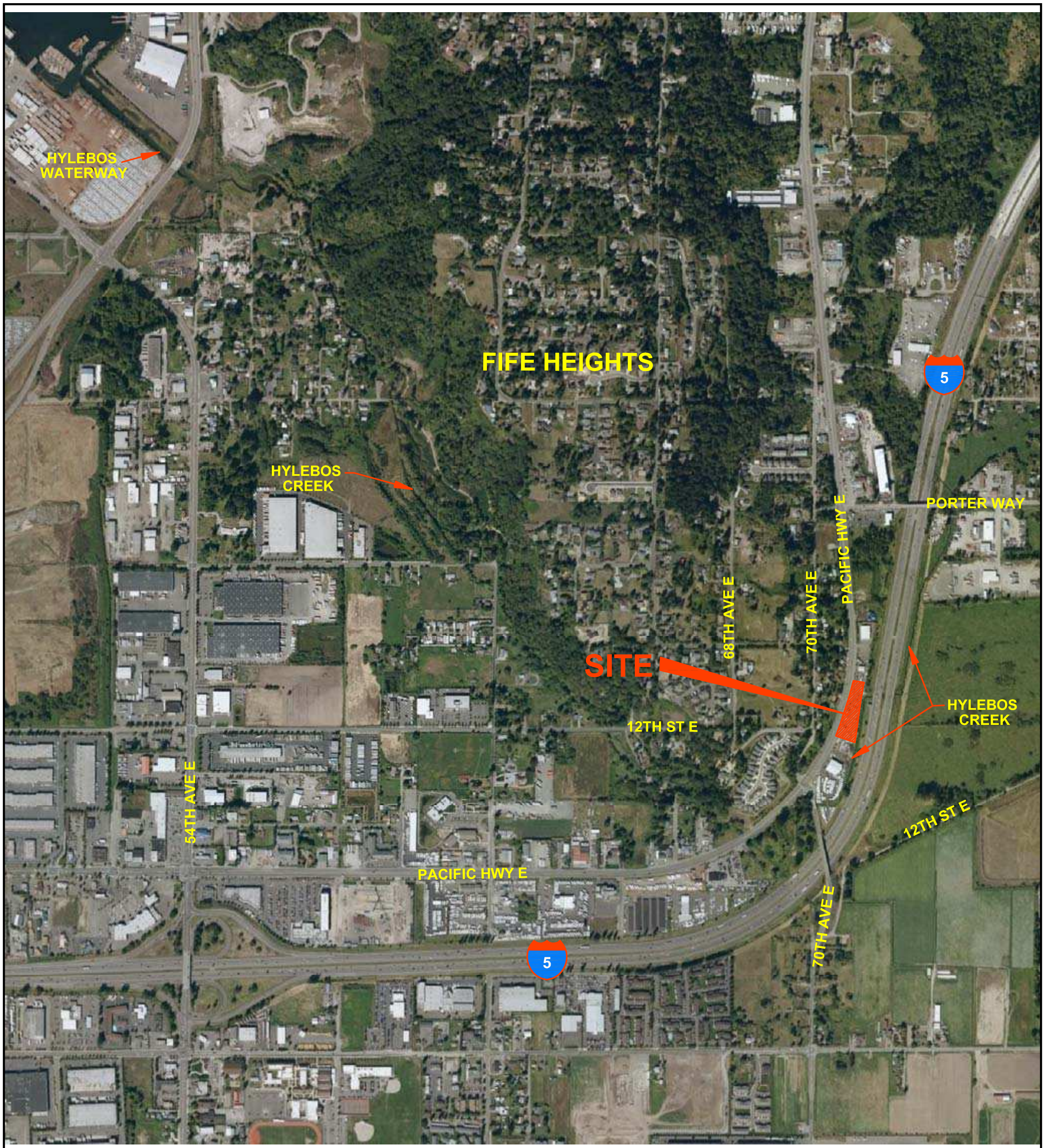

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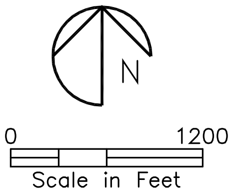

VICINITY MAP

USG Interiors, Inc. - Highway 99 Site
Milton, WA

FIGURE
NO. 1

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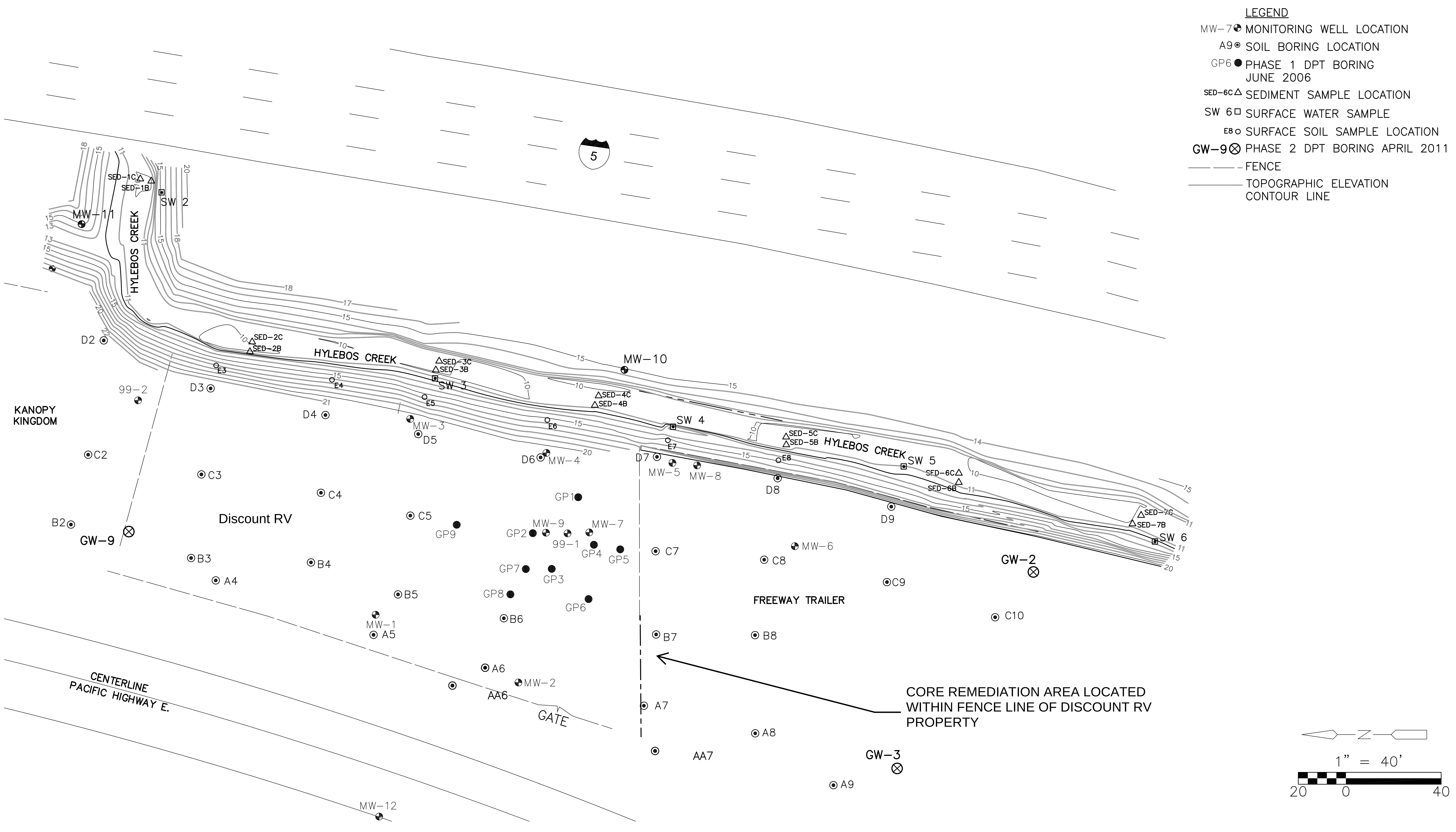

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CDM Smith

SITE PLAN
USG Interiors, Inc. - Highway 99 Site
Milton, WA

FIGURE
NO. 2

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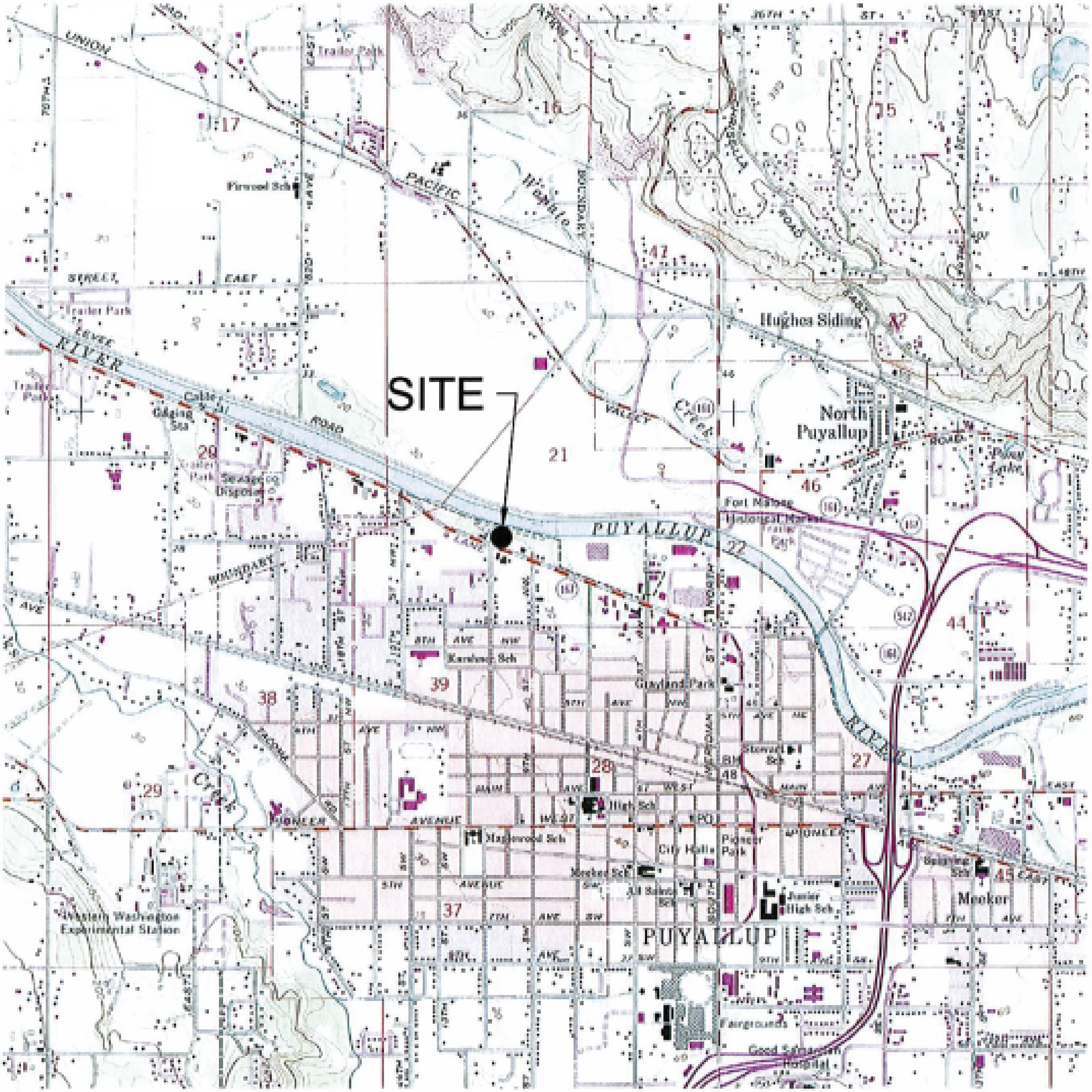
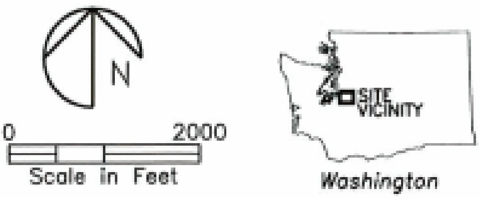


Source: USGS Puyallup, Wash. 7.5' Quadrangle, 1981



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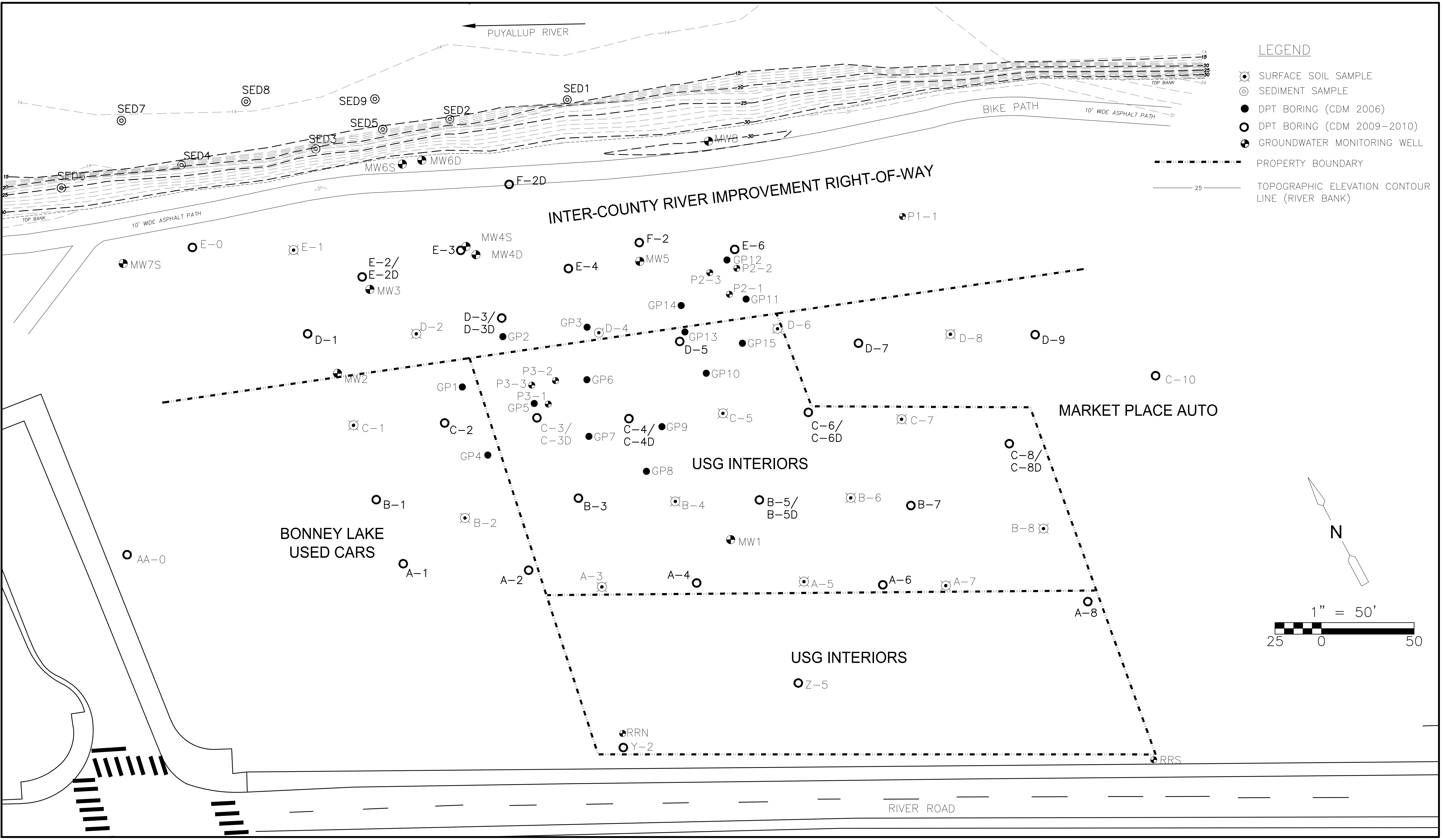
CDM Smith

VICINITY MAP

USG Interiors, Inc. - Puyallup Site

Puyallup, WA

FIGURE NO. 3



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CDM Smith

SITE PLAN
USG Interiors, Inc - Puyallup Site
Puyallup, WA

Figure No. 4

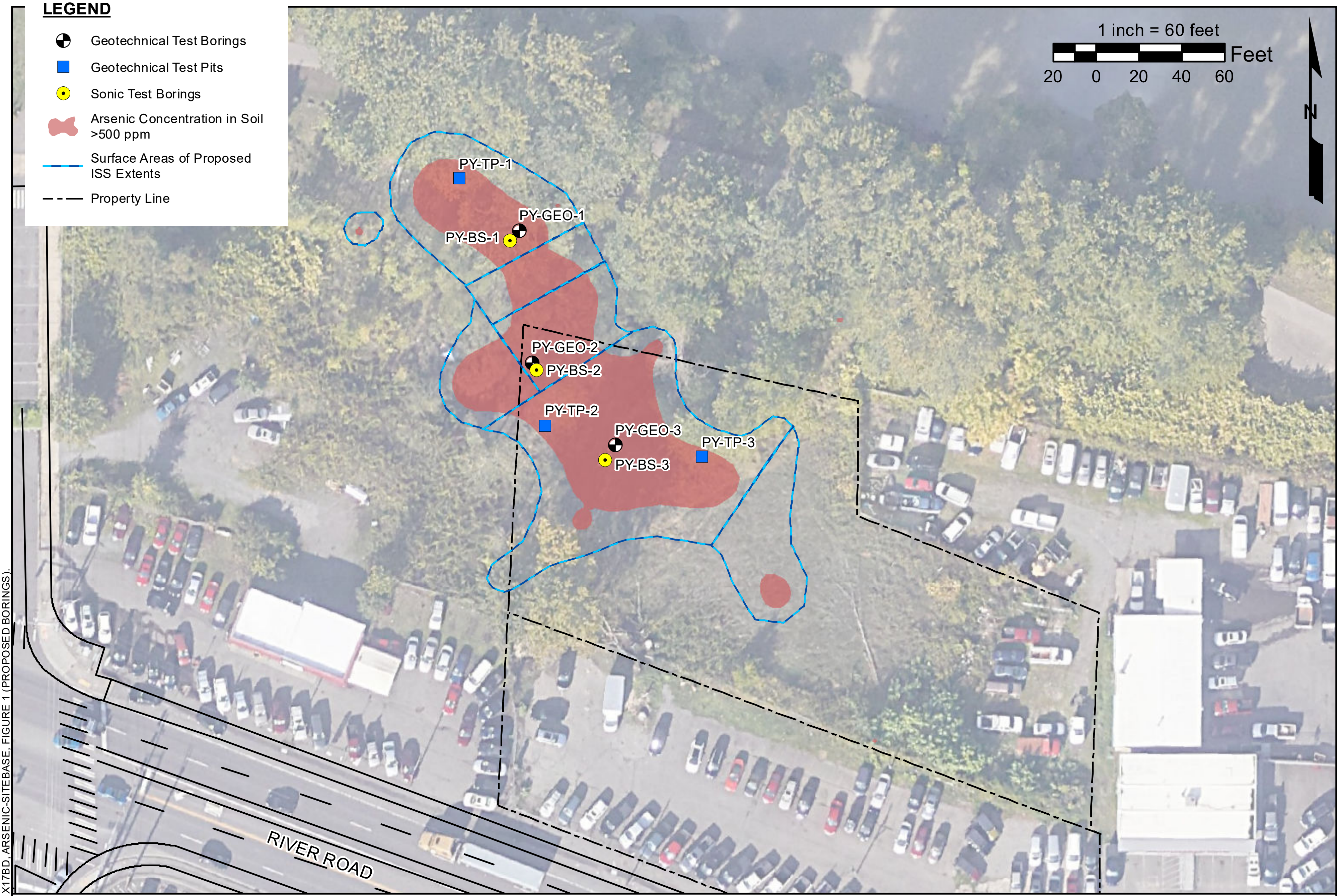
SOURCE: GOOGLE EARTH PRO, 2018

CDM Smith

USG INTERIORS/HIGHWAY 99 SITE
MILTON, WASHINGTON

Figure 5
Proposed Boring Location Plan

DOCUMENT PATH: E:_Projects\USG Interiors - Hwy 99\MapDocuments\Subsurface\Figure-5_Hwy-99_Proposed-Boring-Location-Plan.mxd; 5/1/2020 3:17:24 PM;
CAD XREFS: ARSENIC-11X17BD, ARSENIC-SITEBASE, FIGURE 1 (PROPOSED BORINGS).



SOURCE: GOOGLE EARTH PRO, 2018

USG INTERIORS/PUYALLUP SITE
PUYALLUP, WASHINGTON

Figure 6
Proposed Boring Location Plan

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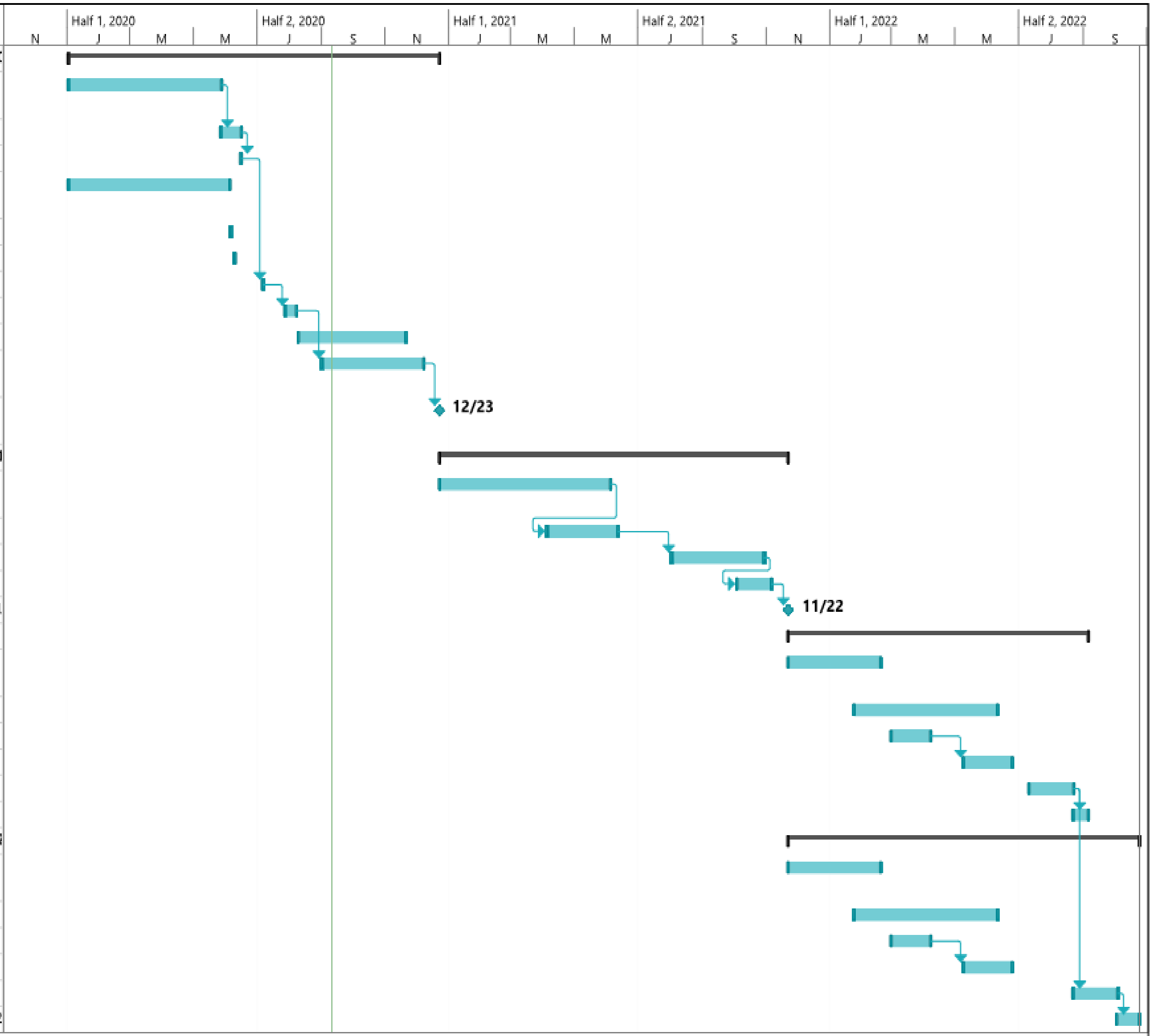
CAD XREFS: ARSENIC-11X17BD, ARSENIC-SITEBASE, FIGURE 1 (PROPOSED BORINGS).

Task Name	Duration	Start	Finish
Data Gaps Field Investigation - Joint	**254 days**	**Thu 1/2/20**	**Wed 12/23/2**
Develop Work Plan for Field Investigation	105 days	Thu 1/2/20	Wed 5/27/20
Ecology Review	14 days	Wed 5/27/20	Mon 6/15/20
Ecology Approval of Work Plan	1 day	Mon 6/15/20	Mon 6/15/20
Obtain Access Agreements from the County and adjacent property owners	111 days	Thu 1/2/20	Thu 6/4/20
Access Agreements Recorded	1 day	Fri 6/5/20	Fri 6/5/20
Site Visit	1 day	Tue 6/9/20	Tue 6/9/20
Land Clearing	1 day	Mon 7/6/20	Mon 7/6/20
Geotechnical Field Investigation	9 days	Tue 7/28/20	Fri 8/7/20
Bench Scale Study	75 days	Mon 8/10/20	Fri 11/20/20
Pre-Design Investigation and Bench Scale Summary Report (Draft to USG)	70 days	Tue 9/1/20	Mon 12/7/20
Submit Draft Pre-Design Investigation and Bench Scale Summary Report to Ecology	0 days	Wed 12/23/20	Wed 12/23/20
Pilot Study - Joint	**238 days**	**Wed 12/23/20**	**Mon 11/22/21**
Pilot Study Work Plan/ Procurement Bid Package and Develop RFP for Pilot Study	118 days	Wed 12/23/20	Fri 6/4/21
Contractor Procurement for Pilot Study	50 days	Mon 4/5/21	Fri 6/11/21
Implement Pilot Study	65 days	Mon 8/2/21	Fri 10/29/21
Draft Report of Pilot Study Findings to Client	25 days	Mon 10/4/21	Fri 11/5/21
Submit Pilot Study Findings to Ecology	0 days	Mon 11/22/21	Mon 11/22/21
Design and Construction - HWY 99	**206 days**	**Mon 11/22/21**	**Mon 9/5/22**
Draft Engineering Design Report (drawings/specs) to Ecology	65 days	Mon 11/22/21	Fri 2/18/22
Permitting	100 days	Mon 1/24/22	Fri 6/10/22
Contractor Procurement	28 days	Tue 3/1/22	Thu 4/7/22
Establish Contract with Contractor	35 days	Mon 5/9/22	Fri 6/24/22
ISS Construction	31 days	Mon 7/11/22	Mon 8/22/22
Site Restoration	11 days	Mon 8/22/22	Mon 9/5/22
Design and Construction - Puyallup	**241 days**	**Mon 11/22/21**	**Mon 10/24/2**
Draft Engineering Design Report (drawings/specs) to Ecology	65 days	Mon 11/22/21	Fri 2/18/22
Permitting	100 days	Mon 1/24/22	Fri 6/10/22
Contractor Procurement	28 days	Tue 3/1/22	Thu 4/7/22
Establish Contract with Contractor	35 days	Mon 5/9/22	Fri 6/24/22
ISS Construction	31 days	Mon 8/22/22	Mon 10/3/22
Site Restoration	16 days	Mon 10/3/22	Mon 10/24/22



Project: USG HWY 99 - Puyallup Joint Conceptual Schedule
Date: Fri 9/11/20

Summary ▬ Task 🟦 Milestone ◆

CDM Smith

USG INTERIORS/PUYALLUP SITE
PUYALLUP, WASHINGTON

Figure 7
Joint Project Schedule

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Tables

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Table 1
Summary of Proposed Borings and Rational - USG Highway 99 Site
Geotechnical Field Investigation and Bench Scale Study Work Plan
Milton, Washington

Boring/Test Pit No.	Estimated Depth (ft bgs)	Surface Condition	Drilling Method	Borehole Diameter	Sampling Method	Target Interval (ft bgs)	Recovered Volume (gal)	No. of Split Spoons	No. of Shelby Tubes	Location Specific Design Rationale	Latitude	Longitude
Highway 99 - Geotechnical Test Borings												
99-GEO-1	30	Asphalt	HSA	4"	Continuous to 15 ft; at 5-ft intervals thereafter	--	--	11	0	Location of proposed ISS area within site. Location to be a minimum of 10 ft from previously disturbed sampling locations to characterize and identify engineering properties of soils for design of ISS implementation. Depth is established at 15 ft below proposed ISS treatment area.	47.2467554	-122.3349133
99-GEO-2	30	Asphalt	HSA	4"		--	--	11	1		47.2465696	-122.3350480
99-GEO-3	30	Asphalt	HSA	4"		--	--	11	0		47.2464469	-122.3349177
Highway 99 - Sonic Test Borings												
99-BS-1	20	Asphalt	Sonic	6"	Grab	7-15	11.7	--	--	Location of highly impacted soils (>500 ppm arsenic) within proposed ISS area at site.	47.2467474	-122.3349151
99-BS-2	20	Asphalt	Sonic	6"		7-15	11.7	--	--		47.2465715	-122.3350578
99-BS-3	20	Asphalt	Sonio	6"		7-15	11.7	--	--		47.2464489	-122.3349270
Highway 99 - Geotechnical Test Pits												
99-TP-1	12-15	Asphalt	Excavator	--	Grab	--	--	--	--	Location of proposed ISS area within site. Test pits will be conducted to confirm no large boulder obstructions exist within the upper portion of the soil profile.	47.2464512	-122.3550394
99-TP-2	12-15	Asphalt	Excavator	--		--	--	--	--		47.2466813	-122.3349108
99-TP-3	12-15	Asphalt	Excavator	--		--	--	--	--		47.2465066	-122.3348967

Total Test Boring Footage (ft)		**90**
Total Sonic Boring Footage (ft)		**60**
Total Test Pit Footage (ft)		**45**

Table 2
Summary of Proposed Borings and Rational - USG Puyallup Site
Geotechnical Field Investigation and Bench Scale Study Work Plan
Puyallup, Washington

Boring/Test Pit No.	Estimated Depth (ft bgs)	Surface Condition	Drilling Method	Borehole Diameter	Sampling Method	Target Interval (ft bgs)	Recovered Volume (gal)	No. of Split Spoons	No. of Shelby Tubes	Location Specific Design Rationale	Latitude	Longitude
Puyallup - Geotechnical Test Borings												
PY-GEO-1	45	Grass Cover	HSA	4"	Continuous to 15 ft; at 5-ft intervals thereafter	--	--	18	0	Location of proposed ISS area within site. Location to be a minimum of 10 ft from previously disturbed sampling locations to characterize and identify engineering properties of soils for design of ISS implementation. Depth is established at 15 ft below proposed ISS treatment area.	47.2030375	-122.3072977
PY-GEO-2	45	Grass Cover	HSA	4"		--	--	18	0		47.2028696	-122.3072683
PY-GEO-3	45	Grass Cover	HSA	4"		--	--	18	0		47.2027660	-122.3071086
Puyallup - Sonic Test Borings												
PY-BS-1	30	Grass Cover	Sonic	6"	Grab	2.5-28	35	--	--	Location of highly impacted soils (>500 ppm arsenic) within proposed ISS area at site.	47.2030249	-122.3073157
PY-BS-2	30	Grass Cover	Sonic	6"		2.5-29	36	--	--		47.2028607	-122.3072609
PY-BS-3	30	Grass Cover	Sonio	6"		2.5-30	37	--	--		47.2027469	-122.3071274
Puyallup - Geotechnical Test Pits												
PY-TP-1	12-15	Grass Cover	Excavator	--	Grab	--	--	--	--	Location of proposed ISS area within site. Test pits will be conducted to confirm no large boulder obstructions exist within the upper portion of the soil profile.	47.2031038	-122.3074125
PY-TP-2	12-15	Grass Cover	Excavator	--		--	--	--	--		47.2027899	-122.3072418
PY-TP-3	12-15	Grass Cover	Excavator	--		--	--	--	--		47.2027545	-122.3069466

Total Test Boring Footage (ft)		**135**
Total Sonic Boring Footage (ft)		**90**
Total Test Pit Footage (ft)		**45**

Table 3
Proposed Mix Design Schedule - USG Highway 99 Site
Geotechnical Field Investigation and Bench Scale Study Work Plan
Milton, Washington

Composite ID	Mix ID	Reagents	Dosage (%)	Unconfined Compression Testing			SPLP	SDL	Permeability Test	Extra	Control
				7-day	14-day	28-day					
Composite 1	Mix 1	TBD	TBD	X	X	X	X	X	X	X	X
	Mix 2	TBD	TBD	X	X	X			X	X	X
	Mix 3	TBD	TBD	X	X	X			X	X	X
	Mix 4	TBD	TBD	X	X	X			X	X	X
	Mix 5	TBD	TBD	X	X	X			X	X	X
	Mix 6	TBD	TBD	X	X	X	X		X	X	X
	Mix 7	TBD	TBD	X	X	X			X	X	X
	Mix 8	TBD	TBD	X	X	X			X	X	X
	Mix 9	TBD	TBD	X	X	X			X	X	X
	Mix 10	TBD	TBD	X	X	X			X	X	X
Composite 2	Mix 1	TBD	TBD	X	X	X	X		X	X	X
	Mix 2	TBD	TBD	X	X	X			X	X	X
	Mix 3	TBD	TBD	X	X	X			X	X	X
	Mix 4	TBD	TBD	X	X	X			X	X	X
	Mix 5	TBD	TBD	X	X	X			X	X	X
	Mix 6	TBD	TBD	X	X	X	X		X	X	X
	Mix 7	TBD	TBD	X	X	X			X	X	X
	Mix 8	TBD	TBD	X	X	X			X	X	X
	Mix 9	TBD	TBD	X	X	X			X	X	X
	Mix 10	TBD	TBD	X	X	X			X	X	X

Notes:

1. Mix design including reagents and doseage will be finalized after completion of the geotechincal investigation and preliminary characterization testing.

2. Testing will be conducted on mixes that meet the performance criteria for SPLP and SDL testing. At this time it is assumed up to 4 tests for SPLP and 1 test for SDL.

Table 4
Proposed Mix Design Schedule - USG Puyallup Site
Geotechnical Field Investigation and Bench Scale Study Work Plan
Puyallup, Washington

Composite ID	Mix ID	Reagents	Dosage (%)	Unconfined Compression Testing			SPLP	SDL	Permeability Test	Extra	Control
				7-day	14-day	28-day					
Composite 1	Mix 1	TBD	TBD	X	X	X	X	X	X	X	X
	Mix 2	TBD	TBD	X	X	X			X	X	X
	Mix 3	TBD	TBD	X	X	X			X	X	X
	Mix 4	TBD	TBD	X	X	X			X	X	X
	Mix 5	TBD	TBD	X	X	X			X	X	X
	Mix 6	TBD	TBD	X	X	X	X		X	X	X
	Mix 7	TBD	TBD	X	X	X			X	X	X
	Mix 8	TBD	TBD	X	X	X			X	X	X
	Mix 9	TBD	TBD	X	X	X			X	X	X
	Mix 10	TBD	TBD	X	X	X			X	X	X
Composite 2	Mix 1	TBD	TBD	X	X	X	X		X	X	X
	Mix 2	TBD	TBD	X	X	X			X	X	X
	Mix 3	TBD	TBD	X	X	X			X	X	X
	Mix 4	TBD	TBD	X	X	X			X	X	X
	Mix 5	TBD	TBD	X	X	X			X	X	X
	Mix 6	TBD	TBD	X	X	X	X		X	X	X
	Mix 7	TBD	TBD	X	X	X			X	X	X
	Mix 8	TBD	TBD	X	X	X			X	X	X
	Mix 9	TBD	TBD	X	X	X			X	X	X
	Mix 10	TBD	TBD	X	X	X			X	X	X

Notes:

1. Mix design including reagents and doseage will be finalized after completion of the geotechincal investigation and preliminary characterization testing.
2. Testing will be conducted on mixes that meet the performance criteria for SPLP and SDL testing. At this time it is assumed up to 4 tests for SPLP and 1 test for SDL.

Appendix A

Health and Safety Plan

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HEALTH AND SAFETY PLAN FORM

CDM Health and Safety Program

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CDM Smith
PROJECT DOCUMENT #:

PROJECT NAME USG - Hwy 99 Geotechnical/Bench Sc
PROJECT# 19921 233028
REGION WST

SITE ADDRESS 7110 Pacific Highway East
Milton, WA

CLIENT ORGANIZATION USG Interiors
CLIENT CONTACT Jennifer Brennan
CLIENT CONTACT PHONE # 312 436 5385

( ) AMENDMENT TO EXISTING APPROVED H&SP?
( ) H&SP AMENDMENT NUMBER? 1
(Y) DATE OF PREVIOUS H&SP APPROVAL

OBJECTIVES OF FIELD WORK:
Conduct a field investigation in accordance with the Highway 99 and Puyallup Work Plan to characterize the soil and collect soil for Bench Scale Testing.
Fieldwork to meet this objective will consist of advancing geotechnical borings, sonic borings, and test pits, collecting soil and groundwater samples for analysis and bench scale testing.

SITE TYPE: *Check as many as applicable*

Active	(X)		( )	Unknown	( )
Inactive	( )	Uncontrolled	( )	Military	( )
Secure	(X)	Industrial	( )	Other (specify)	
Unsecure	( )	Recovery	( )		
Enclosed space	( )	Well Field	( )		

All requirements described in the **CDM Health and Safety Manual** are incorporated in this health and safety plan by reference.

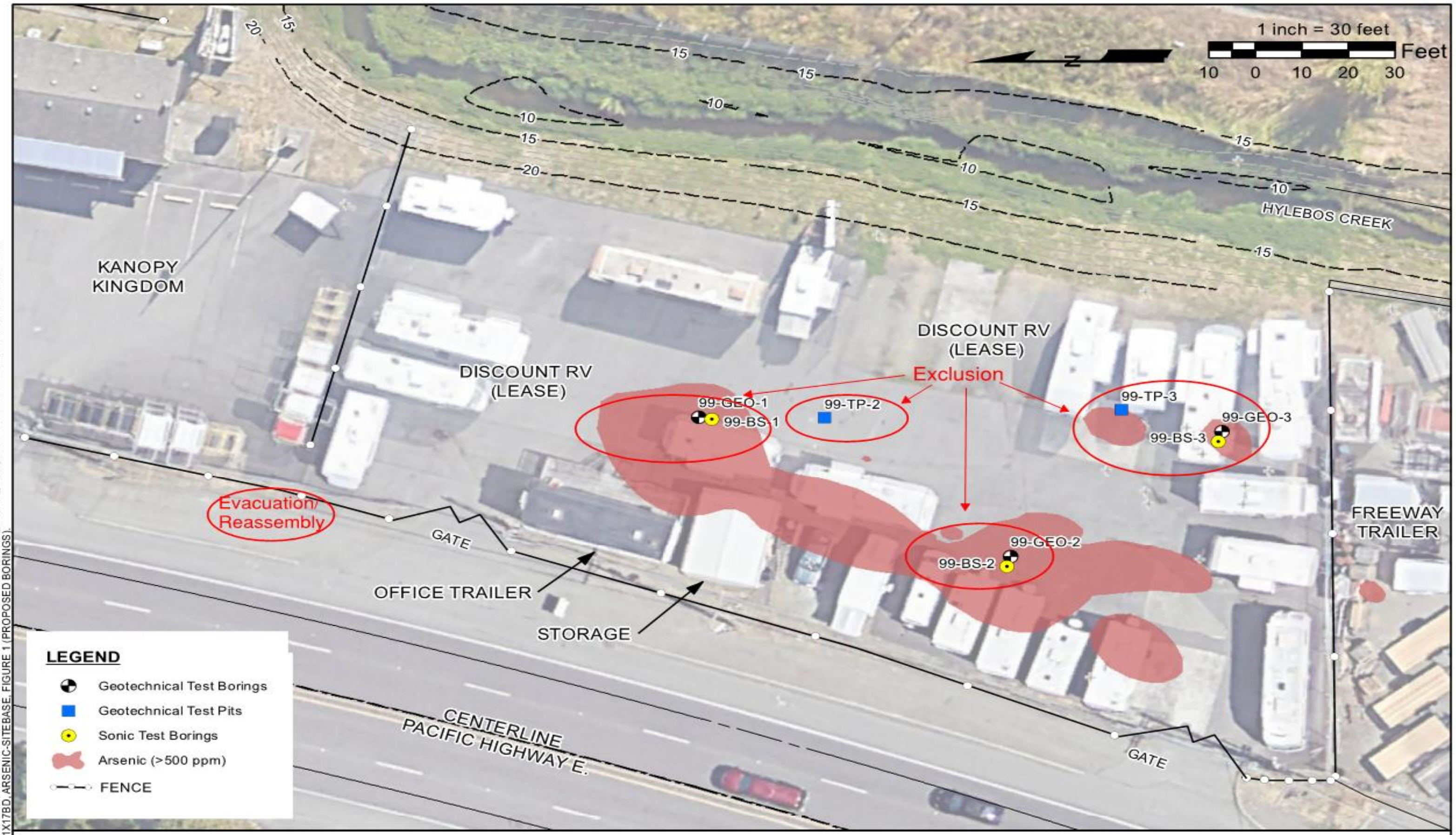
PERSONNEL AND RESPONSIBILITIES

NAMES OF WORK CREW MEMBERS	COMPANY or DIVISION	SUPERVISORY TRAINED?	PROJECT OR SITE RESPONSIBILITIES	Tasks On Site?
Pam Morrill	TSU	Yes	Project Manager	
Pam Morrill	TSU	Yes	Site Health & Safety Coordinator	
Meredith Passaro	TSU		Geotechnical Engineer	
Haley Hutchins	TSU		Geotechnical Engineer	1-2-3
Morgan Simon	TSU	Yes	Environmental Scientist	4-5
				1-2-3-4-5-6
Driller - TPD			Subcontractor	1
Excavator - TPD			Subcontractor	2

BACKGROUND REVIEW: (X) Complete ( ) Incomplete

HEALTH AND SAFETY PLAN FORM *This document is for the exclusive* **CDM Smith**
CDM Health and Safety Program *use of CDM and its subcontractors* **PROJECT DOCUMENT #:**

SITE MAP: *Show Exclusion, Contamination Reduction, and Support Zones. Indicate Evacuation and Reassembly Points*



DOCUMENT PATH: E:_Projects\USG Interiors - Hwy 99\MapDocuments\Subsurface\Figure-X_Hwy-99_Boring--Locations-Plume.mxd; 4/28/2020 10:16:57 PM;
CAD XREFS: ARSENIC-11X17BD, ARSENIC-SITEBASE, FIGURE 1 (PROPOSED BORINGS)

SOURCE: GOOGLE EARTH PRO, 2018

CDM Smith

USG INTERIORS/HIGHWAY 99 SITE
MILTON, WASHINGTON

Boring and Test Pit Locations

HEALTH AND SAFETY PLAN FORM
CDM Smith Health and Safety Program

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CDM Smith
PROJECT DOCUMENT #:

HISTORY: *Summarize conditions that relate to hazard. Include citizen complaints, spills, previous investigations or agency actions, known injuries, etc.*

The site was used to dispose of industrial waste from USG Interior's former mineral fiber manufacturing facility in Tacoma, Washington. In the early 1980s, USG excavated and removed industrial waste material and soil contaminated by industrial waste. The excavation was backfilled, the site later sold, paved and developed for its present use.

WASTE TYPES: (X) Liquid (X) Solid ( ) Sludge ( ) Gas ( ) Unknown ( ) Other, specify:

WASTE CHARACTERISTICS: *Check as many as applicable.*

( ) Corrosive
(X) Toxic
( ) Inert Gas
( ) Other: ______

( ) Flammable
( ) Volatile
( ) Unknown

( ) Radioactive
( ) Reactive

WORK ZONES:

Exclusion: Within 1.5x the drill rig mast height for drilling and for test pits. 5 feet around wells for GW sampling. The contamination reduction zone will be outside the exclusion zone radius. The support zone will be placed in a manner that allow for safe operations

HAZARDS OF CONCERN: *Check as many as applicable.*

( ) Heat Stress CDM Guideline
( ) Cold Stress CDM Guideline
( ) Explosive/Flammable
( ) Oxygen Deficient
( ) Radiological
( ) Biological
(X) Other: COVID-19
( ) Other: ______

(X) Noise CDM Guideline
(X) Inorganic Chemicals
( ) Organic Chemicals
( ) Motorized Traffic
(X) Heavy Machinery
(X) Slips & Falls CDM Guideline

FACILITY'S PAST AND PRESENT DISPOSAL METHODS AND PRACTICES:

See history

This plan incorporates CDM's procedure for: *(Click on the relevant topics to download the hazard guideline. Delete irrelevant topics.)*

Housekeeping
Manual Material Handling
Traffic and Work Zone Safety
Tools and Power Equipment
Working Around Heavy Equipment
Hazardous Waste Site Controls
Working Safely Around Drill Rigs
Hazardous Waste Site Decontamination

HEALTH AND SAFETY PLAN FORM

CDM Smith Health and Safety Program

This document is for the exclusive use of CDM Smith and its subcontractors

CDM Smith
PROJECT DOCUMENT #:

DESCRIPTION AND FEATURES: *Include principal operations and unusual features (containers, buildings, dikes, power lines, hillslopes, rivers, etc.)*

The portion of USG Hwy 99 site that is subject to this assessment are the two southern parcels of the Kanopy Kingdom property, currently occupied by tenant Discount RV. Investigation area is flat and mostly paved. RV's may need to be moved to accomodate drill in some locations.

SURROUNDING POPULATION: ( ) Residential ( ) Industrial (X) Commercial ( ) Rural ( ) Urban OTHER:

HAZARDOUS MATERIAL SUMMARY: ***Highlight or bold waste types and estimate amounts by category.***

CHEMICALS: *Amount/Units:*	**SOLIDS:** *Amount/Units:*	**SLUDGES:** *Amount/Units:*	**SOLVENTS:** *Amount/Units:*	**OILS:** *Amount/Units:*	**OTHER:** *Amount/Units:*
Acids	Flyash	Paints	Ketones	Oily Wastes	Laboratory
Pickling Liquors	Mill or Mine Tailings	Pigments	Aromatics	Gasoline	Pharmaceutical
Caustics	Asbestos	Metals Sludges	Hydrocarbons	Diesel Oil	Hospital
Pesticides	Ferrous Smelter	POTW Sludge	Alcohols	Lubricants	Radiological
Dyes or Inks	Non-Ferrous Smelter	Distillation Bottoms	Halogenated (chloro, bromo)	Polynuclear Aromatics	Municipal
Cyanides	**Metals : Arsenic**	Aluminum	Esters	PCBs	Construction
Phenols	Dioxins		Ethers	Heating Oil	Munitions
Halogens					
Other - *specify*	Other - *specify*	Other - *specify*	Other - *specify*	Other - *specify*	Other - *specify*

HEALTH AND SAFETY PLAN FORM
CDM Smith Health and Safety Program

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CDM Smith
PROJECT DOCUMENT #:

KNOWN CONTAMINANTS	HIGHEST OBSERVED CONCENTRATION	PEL/TLV *ppm or mg/m3 (specify)*	IDLH *ppm or mg/m3 (specify)*	Warning Concentration *(in ppm)*	SYMPTOMS & EFFECTS OF ACUTE EXPOSURE	PHOTO IONIZATION POTENTIAL
Arsenic, inorganic	**13,000 mg/kg (soil) 2.4 mg/L (groundwater)**	10 µg/m3	5 mg/m3	Dust	Nasal ulcers, fever, bronchitis, melanosis, peripheral neuropathy	Dust

NA = Not Available **NE = None Established** **U = Unknown**

Verify your access to an MSDS for each chemical you will use at the site.

S = Soil	SW = Surface Water	T = Tailings	W = Waste	TK = Tanks	SD = Sediment
A = Air	GW = Ground Water	SL = Sludge	D = Drums	L = Lagoons	OFF = Off-Site

HEALTH AND SAFETY PLAN FORM **CDM Smit Health and Safety Program**	*This document is for the exclusive use of CDM Smith and its subcontractors*	**CDM Smith** **PROJECT DOCUMENT #:**	

SPECIFIC TASK DESCRIPTIONS		**Disturbing the Waste?**	**TASK - SPECIFIC HAZARDS**	**HAZARD & SCHEDULE**
1	Soil Sampling using drilling methods (auger drilling and sonic drilling)	***Intrusive***	Mechanical hazards from drill rigs and excavators. Slips, trips, falls. Chemical hazardous from contact with arsenic contaminated soils. Complying with social distancing and personal hygiene measures of COVID-19 safety protocol.	Moderate Hazard Jul-20
2	Monitor and collect soil samples from excavator bucket during test pit excavation	***Intrusive***	Mechanical hazards from drill rigs and excavators. Slips, trips, falls. Chemical hazardous from contact with arsenic contaminated soils. Complying with social distancing and personal hygiene measures of COVID-19 safety protocol.	Moderate Hazard Jul-20
3	Groundwater Sampling using low flow methods	***Intrusive***	Contact with arsenic contaminated groundwater. Slips, trips, falls. Complying with social distancing and personal hygiene measures of COVID-19 safety protocol.	Moderate Hazard Jul-20
4	Disposal of IDW	***Non-intrusive***	Contact with arsenic contaminated soils and purge water. Slips, trips, falls. Strains if moving drums. Complying with social distancing and personal hygiene measures of COVID-19 safety protocol.	Moderate Hazard Sep-20

SPECIALIZED TRAINING REQUIRED: HAZWOPER	**SPECIAL MEDICAL SURVEILLANCE REQUIREMENTS:** None apart from the standard annual medical monitoring required under HAZWOPER

OVERALL HAZARD EVALUATION: ( ) High (X) Medium ( ) Low ( ) Unknov *(Where tasks have different hazards, evaluate each.)*

JUSTIFICATION: Field staff does not operat the equipment. Field Staff to keep distance from operating equipment and maintain eye contact with operators. Potential exposure to contaminants can be mitigated with good hygeine and PPE. Drums will be staged by the drillers in a location that will not require moving until the vendor comes to pick them up.

FIRE/EXPLOSION POTENTIAL: ( ) High ( ) Medium (X) Low ( ) Unknown

HEALTH AND SAFETY PLAN FORM *This document is for the exclusive use of CDM Smith and its subcontractors* **CDM Smith**

CDM Smith Health and Safety Program **PROJECT DOCUMENT #:**

PROTECTIVE EQUIPMENT: *Specify by task. Indicate type and/or material, as necessary. Group tasks if possible. Use copies of this sheet if needed.*

BLOCK A

TASKS: 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10
LEVEL: A - B - C - D - Modified
(X) Primary ( ) Contingency

Respiratory: (X) Not needed
( ) SCBA, Airline:
( ) Escape Mask:
( ) Other:

Head and Eye: ( ) Not needed
(X) Safety Glasses: All Tasks
( ) Face Shield:
( ) Goggles:
(X) Hard Hat: During soil boring and sai
(X) Other: Face masks encouraged if not required by project.

Boots: ( ) Not needed
(X) Steel-Toe: ( ) Steel Shank
( ) Rubber ( ) Leather
( ) Overboots:

Prot. Clothing: ( ) Not needed
( ) Encapsulated Suit:
( ) Tyvek Coverall or
( ) Saranex Coverall
(X) Cloth Coverall:
( ) Other:

Gloves: ( ) Not needed
( ) Undergloves:
(X) Gloves: nitrile
( ) Overgloves:

Other: specify below
( ) Tick Spray
( ) Flotation Device If Over Water
(X) Hearing Protection
(X) Sun Screen

BLOCK B

Exit

Area

TASKS: 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10
LEVEL: A - B - C - D - Modified

Respiratory: (X) Not needed
( ) SCBA, Airline:
[illegible]k:
[illegible]er:
[illegible]eed[illegible]
( ) Safety Glasses:
( ) Face Shield:
( ) Goggles:
( ) Hard Hat:
[illegible]er:

[illegible]oo[illegible] Not[illegible]
[illegible]e [illegible] Steel
( ) Ru[illegible] Leather
( ) Overboots: Latex

Prot. Clothing: ( ) Not needed
( ) Encapsulated Suit:
([illegible]e[illegible]or
([illegible]anex[illegible]erall
([illegible]th C[illegible]ll:
([illegible]er: W[illegible]thes-
Long Sleeves

Gloves: ( ) Not needed
( ) Undergloves:
( ) Gloves: nitrile
( ) Overgloves:

O[illegible]pecify[illegible]
( ) Tick[illegible]
[illegible]oat[illegible] Water
( ) Hearing Protection
( ) Sun Screen

BLOCK C

TASKS: 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10
LEVEL: A - B - C - D - Modified
( ) Primary (X) Contingency

Respiratory: ( ) Not needed
( ) SCBA, Airline:
( ) APR:
( ) Cartridge:
( ) Escape Mask:
( ) Other:

Head and Eye: ( ) Not needed
( ) Safety Glasses:
( ) Face Shield:
( ) Goggles:
( ) Hard Hat:
( ) Other:

Boots: ( ) Not needed
( ) Steel-Toe ( ) Steel Shank
( ) Rubber ( ) Leather
( ) Overboots:

Prot. Clothing: ( ) Not needed
( ) Encapsulated Suit:
( ) Splash Suit
( ) Apron:
( ) Tyvek Coverall
( ) Saranex Coverall
( ) Cloth Coverall:
( ) Other: Work Clothes- Long Sleeves

Gloves: ( ) Not needed
( ) Undergloves:
( ) Gloves: nitrile
( ) Overgloves:

Other: specify below
( ) Tick Spray
( ) Flotation Device
( ) Hearing Protection
( ) Sun Screen

BLOCK D

TASKS: 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10
LEVEL: A - B - C - D - Modified

Respiratory: ( ) Not needed
( ) SCBA, Airline:
( ) APR:
( ) Cartridge:
( ) Escape Mask:
( ) Other:

Head and Eye: ( ) Not needed
( ) Safety Glasses:
( ) Face Shield:
( ) Goggles:
( ) Hard Hat:
( ) Other:

Boots: ( ) Not needed
( ) Steel-Toe ( ) Steel Shank
( ) Rubber ( ) Leather
( ) Overboots:

Prot. Clothing: ( ) Not needed
( ) Encapsulated Suit:
( ) Splash Suit
( ) Apron:
( ) Tyvek Coverall
( ) Saranex Coverall
( ) Cloth Coverall:
( ) Other:

Gloves: ( ) Not needed
( ) Undergloves:
( ) Gloves:
( ) Overgloves:

Other: specify below
( ) Tick Spray
( ) Flotation Device
( ) Hearing Protection
( ) Sun Screen

This health and safety plan form constitutes hazard analysis per 29 CFR 1910.132

HEALTH AND SAFETY PLAN FORM *This document is for the exclusive* **CDM Smith**
CDM Smith Health and Safety Program *use of CDM Smith and its subcontractors* **PROJECT DOCUMENT #:**

MONITORING EQUIPMENT: *Specify by task. Indicate type as necessary. Attach additional sheets if needed.*

INSTRUMENT	**TASK**	**ACTION GUIDELINES**		**COMMENTS**
Combustible **Gas Indicator**	1-2-3-4-5-6-7-8	0-10% LEL 10-25% LEL >25% LEL 21.0% O2 <21.0% O2 <19.5% O2	*No explosion hazard* *Potential explosion hazard; notify SHSC* *Explosion hazard; interrupt task/evacuate* *Oxygen normal* *Oxygen deficient; notify SHSC* *Interrupt task/evacuate*	(X) Not Needed
Radiation **Survey Meter**	1-2-3-4-5-6-7-8	3 x Background: >2mR/hr:	*Notify HSM* *Establish REZ*	(X) Not Needed
Photoionization **Detector** _____eV Lamp Type ____	1-2-3-4-5-6-7-8	*Specify:*		(X) Not Needed
Flame Ionization **Detector** Type____________	1-2-3-4-5-6-7-8	*Specify:*		(X) Not Needed
Single Gas Type____________ Type____________	1-2-3-4-5-6-7-8	*Specify:*		(X) Not Needed
Respirable **Dust Monitor** Type____________ Type____________	1-2	*Specify:*	***Zero dust policy during all drilling/test pit operations. All visible dust must be controlled. If visible dust, stop drilling, implement engineering controls (e.g., use of water spray) or modify work practices. Resume activities only when no visible dust.***	
Other *Specify:* **X-ray Fluorescense (XRF) Meter** Type____________ Type____________	2-Jan	*Specify:*		( ) Not Needed XRF will be used to field monitor arsenic concentrations during drilling and text pit explorations.
Other *Specify:* Type____________ Type____________	1-2-3-4-5-6-7-8	*Specify:*		( ) Not Needed

HEALTH AND SAFETY PLAN FORM
CDM Smith Health and Safety Program

This document is for the exclusive use of CDM Smith and its subcontractors

CDM Smith
PROJECT DOCUMENT #:

DECONTAMINATION PROCEDURES

ATTACH SITE MAP INDICATING EXCLUSION, DECONTAMINATION, & SUPPORT ZONES AS PAGE TWO

Personnel Decontamination *Summarize below or attach diagram;* A personal decontamination station will be established just outside of the exclusion zone in the contaminant reduction zone. Wash hands and face with soap and water after taking PPE on and off. Workers will remove protective equipment in this order: 1.) equipment drop; 2.) hard hat; 3.)gloves; 4.) face and hand wash. WASH HANDS AND FACE BEFORE EATING OR DRINKING. ( ) Not Needed	**Sampling Equipment Decontamination** *Summarize below or attach diagram;* All non-disposable sampling equipment such as spoons will be thoroughly decontaminated between samples with soap, water, and rinsing with distilled water. The four steps of equipment decontamination are: 1.) Scrub with mild solution of Alconox; 2.) rinse with potable water; 3.)spray rinse with distilled water; 4.) air-dry. ( ) Not Needed	**Heavy Equipment Decontamination** *Summarize below or attach diagram;* All down-hole/excavation equipment and tool parts that contact soil are constructed of heavy gauge steel and have no natural or synthetic components that could absorb and retain most soil-borne organic contaminants. The drill tooling shall be decontaminated in between borings (X) Not Needed
Containment and Disposal Method PPE waste generated during soil and groundwater sampling (nitrile gloves, paper towels, etc.) will be placed in plastic garbage bag(s) and sealed shut. The garbage bags will be placed in a County commercial waste collection container for ultimate disposal in accordance with 173-303 WAC and 173-340-820 WAC.	**Containment and Disposal Method** Decontamination water shall be contained, tested, and disposed of appropriately.	**Containment and Disposal Method** Drill cuttings, decontamination and purge water will be labeled and stored in 16-gallon drums, pending classification, and transported to a designated storage area at the end of each day.

HAZARDOUS MATERIALS TO BE BROUGHT ONSITE

Preservatives		*Decontamination*		*Calibration*	
( ) Hydrochloric Acid	( ) Zinc Acetate	(X) Alconox ™	( ) Hexane	( ) 100 ppm isobutylene	( ) Hydrogen Sulfide
( ) Nitric Acid	( ) Ascorbic Acid	( ) Liquinox ™	( ) Isopropanol	( ) Methane	( ) Carbon Monoxide
( ) Sulfuric Acid	( ) Acetic Acid	( ) Acetone	(X) Nitric Acid	( ) Pentane	(X) pH Standards
( ) Sodium Hydroxide	( ) Other:	( ) Methanol	( ) Other:	( ) Hyrogen	(X) Conductivity Std
		( ) Mineral Spirits		( ) Propane	( ) Other:

HEALTH AND SAFETY PLAN FORM *This document is for the exclusive use of CDM Smith and its subcontractors* **CDM Smith**

CDM Smith Health and Safety Program **PROJECT DOCUMENT #:**

EMERGENCY CONTACTS	
Water Supply	
Site Telephone	
24-Hr. First Aid/Non-Emergency Medical Services:	1-800-350-4511, Press 1
EPA Release Report #:	800 / 424 - 8802
Facility Management	N/A
Other (specify)	
CHEMTREC Emergency #:	800 / 424 - 9300

EMERGENCY CONTACT	**NAME**	**PHONE**
Health and Safety Manager	Paul Opem	303 / 383 - 2483
Project Manager	Pam Morrill	425 519 8303
Site Safety Coordinator	Haley Hutchins	518-867-7044
Client Contact	Jennifer Brennan	312 436 5385
Other *(specify)*		
Environmental Agency		
State Spill Number	Washington	(800) 258-5990
Fire Department		911
Police Department		911
State Police		911
Health Department		
Poison Control Center	Nationwide	800 / 222 - 1222
Occupational Physician	Dr. Fred Kohanna	800 / 350 - 4511

SAFETY NARRATIVE: *Summarize below*

Evacuate site if any unexpected hazardous conditions are encountered. The "buddy system" will be employed for all work being done. Site staff will discuss an evacuation area appropriate for each boring location prior to beginning work at each location. If a work team observes hazards for which they have not been prepared, they will withdraw from the area and call CDM Health and Safety. Without regard to monitoring instrument reading, CDM personnel will leave the site and evaluate upgrade their level of protection with HSM if they experience nausea or dizziness. All workers on the site will have "Stop Work Authority" to immediately stop work if he/she feels that a particular task is being performed unsafely. Stop Work Authority may be exercised by anyone working on the site at anytime without repercussions or retribution. Personnel must be familiar with attached COVID-19 safety protocol and adhere to guidelines.

For non-emergency medical services:

1. Call AllOne Health at 1.800.350.4511, PRESS 1, and tell them you are reporting an injury for CDM Smith. Supply requested information.
2. Follow AllOne Health instructions (e.g., first aid, go to clinic, etc.).
3. After care, follow-up with AllOne at the 1-800 #.

MEDICAL EMERGENCY		**PHONE**
Hospital Name:	Good Samaritan	253 697 4000
Hospital Address	407 14 Ave. SE, Puyallup, WA	

Name of Contact at Hospital:

Name of 24-Hour Ambulance:

Route to Hospital:

If unable to find an ambulance to respond after calling 911, then:
Go south on Pacific Hwy East/WA-99 toward 70th Ave E.
Turn left onto 70th Ave E.
Turn left onto Valley Ave E.
Turn right onto N Meridian/WA-161. Continue to follow N Meridian.
Take WA-167 N/WA-161 S.
Merge onto WA-512 W/WA-161 S toward Olympia/Eatonville.
Take the Meridian Street S exit amnd turn left onto S Meridian.
Turn left onto 15th Ave SE.
Turn left onto 5th St SE.
Turn left onto 14th Ave SE.

Distance to Hospital 7.16 miles

HEALTH AND SAFETY PLAN APPROVALS (H&S Mgr must sign each plan)

Prepared by Haley Hutchins Date 4/29/2020

HSC Signature Date 4/29/2020

HSM Signature Date May 13, 2020

HEALTH AND SAFETY PLAN SIGNATURE FORM

CDM Health and Safety Plan

All site personnel must sign this form indicating receipt of the H&SP. Keep this original on site. It becomes part of the permanent project files. Send a copy to the Health and Safety Manager (HSM).

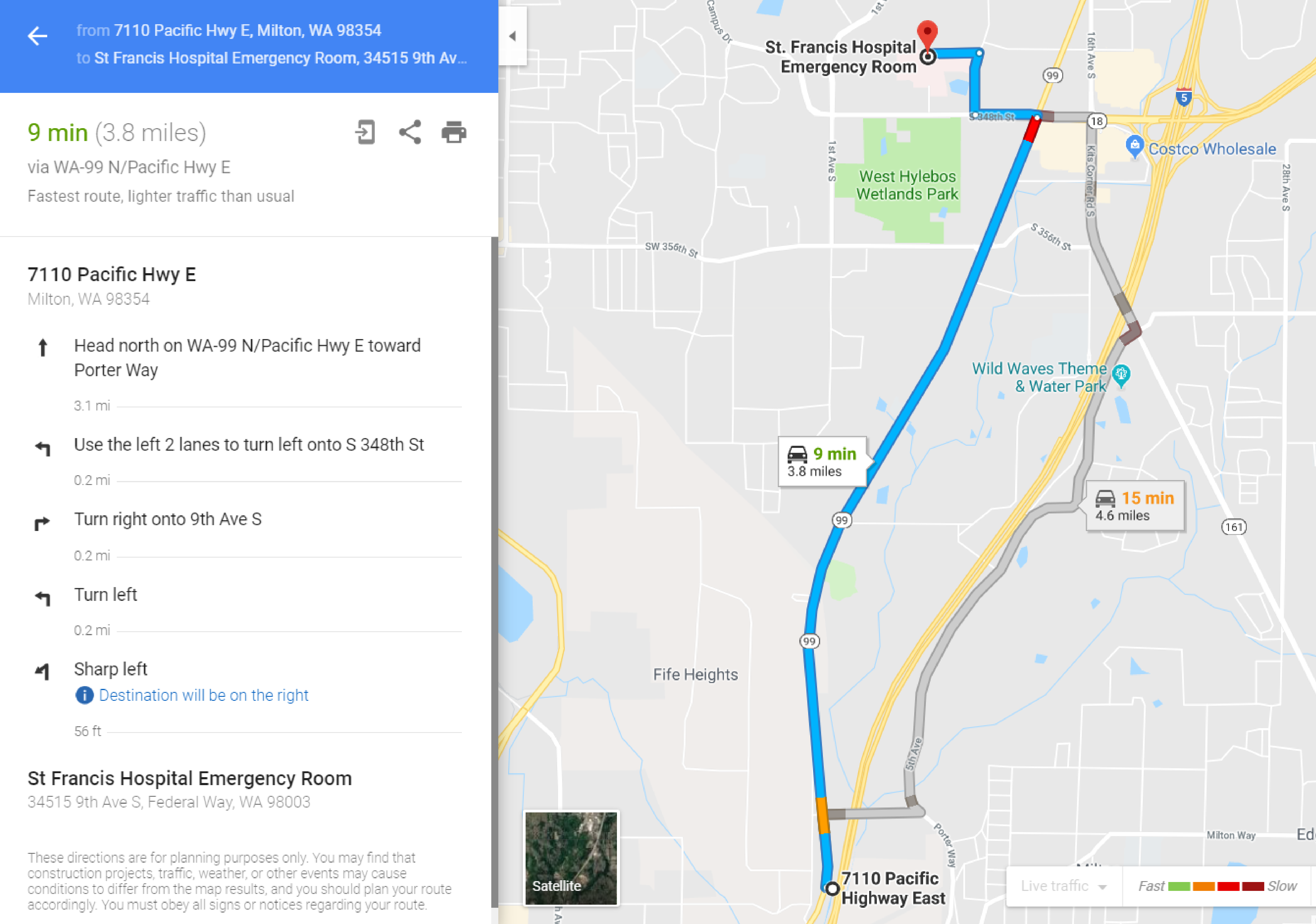
SITE NAME/NUMBER: USG - Hwy 99

DIVISION/LOCATION: CDM Bellevue Office

CERTIFICATION:

I understand, and agree to comply with, the provisions of the above referenced H&SP for work activities on this project. I agree to report any injuries, illnesses or exposure incidents to the site Health and Safety Coordinator (SHSC). I agree to inform the SHSC about any drugs (legal and illegal) that I take within three days of site work.

PRINTED NAME	SIGNATURE	DATE



from 7110 Pacific Hwy E, Milton, WA 98354
to St Francis Hospital Emergency Room, 34515 9th Av...

9 min (3.8 miles)

via WA-99 N/Pacific Hwy E

Fastest route, lighter traffic than usual

7110 Pacific Hwy E
Milton, WA 98354

- Head north on WA-99 N/Pacific Hwy E toward Porter Way

  3.1 mi

- Use the left 2 lanes to turn left onto S 348th St

  0.2 mi

- Turn right onto 9th Ave S

  0.2 mi

- Turn left

  0.2 mi

- Sharp left

  Destination will be on the right

  56 ft

St Francis Hospital Emergency Room
34515 9th Ave S, Federal Way, WA 98003

These directions are for planning purposes only. You may find that construction projects, traffic, weather, or other events may cause conditions to differ from the map results, and you should plan your route accordingly. You must obey all signs or notices regarding your route.

HEALTH AND SAFETY PLAN FORM

CDM Health and Safety Program

This document is for the exclusive use of CDM and its subcontractors

CDM Smith
PROJECT DOCUMENT #:

PROJECT NAME USG - Puyallup Geotechnical/Bench S
PROJECT# 19921 -246239
REGION WST

SITE ADDRESS 925 River RD
Puyallup, WA

CLIENT ORGANIZATION USG Interiors
CLIENT CONTACT Jennifer Brennan
CLIENT CONTACT PHONE # 312 436 5385

( ) AMENDMENT TO EXISTING APPROVED H&SP?
( ) H&SP AMENDMENT NUMBER? ______
( ) DATE OF PREVIOUS H&SP APPROVAL ______

OBJECTIVES OF FIELD WORK:
Conduct a field investigation in accordance with the Highway 99 and Puyallup Work Plan to characterize the soil and collect soil for Bench Scale Testing.

Fieldwork to meet this objective will consist of land clearing, advancing geotechnical borings, sonic borings, and test pits, and collecting soil and groundwater samples for analysis and bench scale testing.

SITE TYPE: *Check as many as applicable*

Active	( )	Landfill	( )	Unknown	( )
Inactive	(X)	Uncontrolled	( )	Military	( )
Secure	(X)	Industrial	( )	Other (specify)	
Unsecure	(X)	Recovery	( )		
Enclosed space	( )	Well Field	( )		

All requirements described in the **CDM Health and Safety Manual** are incorporated in this health and safety plan by reference.

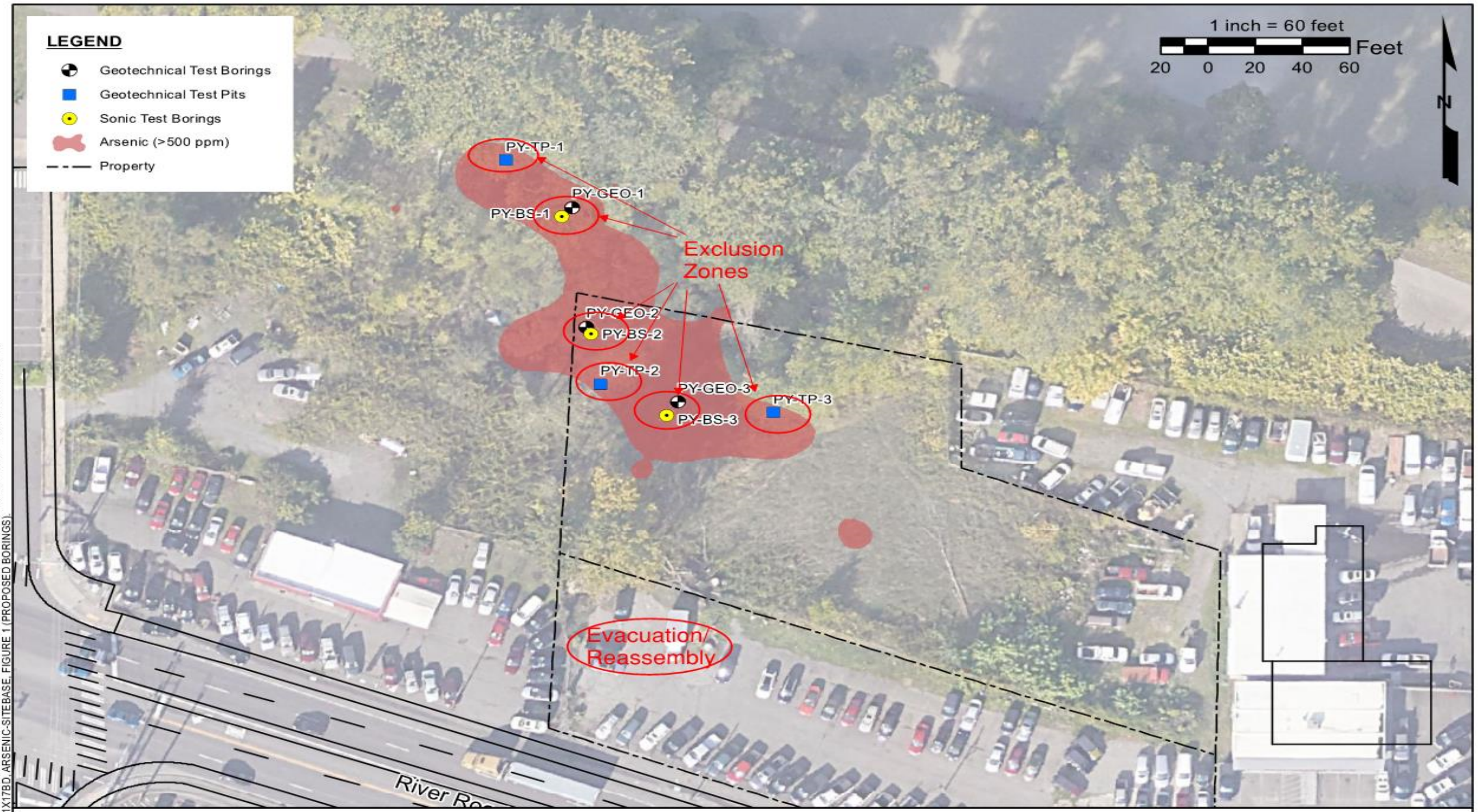
PERSONNEL AND RESPONSIBILITIES

NAMES OF WORK CREW MEMBERS	COMPANY or DIVISION	SUPERVISORY TRAINED?	PROJECT OR SITE RESPONSIBILITIES	Tasks On Site?
Pam Morrill	TSU	Yes	Project Manager	
Pam Morrill	TSU	Yes	Site Health & Safety Coordinator	
Meredith Passaro	TSU		Geotechnical Engineer	
Haley Hutchins	TSU		Geotechnical Engineer	1-2-3
Morgan Simon	TSU	Yes	Environmental Scientist	4-5
Land clearing			Subcontractor	1
Driller - TPD			Subcontractor	2
Excavator - TPD			Subcontractor	3

BACKGROUND REVIEW: (X) Complete ( ) Incomplete

HEALTH AND SAFETY PLAN FORM	*This document is for the exclusive*	**CDM Smith**
CDM Health and Safety Program	*use of CDM and its subcontractors*	**PROJECT DOCUMENT #:**

SITE MAP: *Show Exclusion, Contamination Reduction, and Support Zones. Indicate Evacuation and Reassembly Points*



SOURCE: GOOGLE EARTH PRO, 2018

CDM Smith

USG INTERIORS/PUYALLUP SITE
PUYALLUP, WASHINGTON

Boring and Test Pit Locations

DOCUMENT PATH: E:_Projects\USG Interiors - Puyallup\GIS\MXD\Figure-X_Puyallup-Boring-Locations.mxd; 4/28/2020 10:19:33 PM;
CAD XREFS: ARSENIC-11X17BD, ARSENIC-SITEBASE, FIGURE 1 (PROPOSED BORINGS).

HEALTH AND SAFETY PLAN FORM	*This document is for the exclusive*	**CDM Smith**
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HISTORY: *Summarize conditions that relate to hazard. Include citizen complaints, spills, previous investigations or agency actions, known injuries, etc.*

The site was used to dispose of industrial waste from USG Interior's former mineral fiber manufacturing facility in Tacoma, Washington. In the early 1980s, USG excavated and removed industrial waste material and soil contaminated by industrial waste. The excavation was backfilled. With the exception of the site cleanup, termed the source removal action and environmental monitoring, no activity has occurred on the site. It is presently an overgrown vacant lot that is partially fenced.

WASTE TYPES: ( ) Liquid ( ) Solid ( ) Sludge ( ) Gas ( ) Unknown ( ) Other, specify:

WASTE CHARACTERISTICS: *Check as many as applicable.*

( ) Corrosive	( ) Flammable	( ) Radioactive
(X) Toxic	( ) Volatile	( ) Reactive
( ) Inert Gas	( ) Unknown	
( ) Other: ______________		

WORK ZONES:

Exclusion: Within 1.5x the drill rig mast height for drilling and for test pits. 5 feet around wells for GW sampling. The contamination reduction zone will be outside the exclusion zone radius. The support zone will be placed in a manner that allow for safe operations

HAZARDS OF CONCERN: *Check as many as applicable.*

( ) Heat Stress	CDM Guideline	(X) Noise	CDM Guideline
( ) Cold Stress	CDM Guideline	(X) Inorganic Chemicals	
( ) Explosive/Flammable		( ) Organic Chemicals	
( ) Oxygen Deficient		( ) Motorized Traffic	
( ) Radiological		(X) Heavy Machinery	
( ) Biological		(X) Slips & Falls	CDM Guideline
(X) Other: COVID-19			
( ) Other: ______________			

FACILITY'S PAST AND PRESENT DISPOSAL METHODS AND PRACTICES:

See history

This plan incorporates CDM's procedure for: *(Click on the relevant topics to download the hazard guideline. Delete irrelevant topics.)*

Housekeeping

Manual Material Handling

Traffic and Work Zone Safety

Tools and Power Equipment

Working Around Heavy Equipment

Hazardous Waste Site Decontamination

Hazardous Waste Site Controls

Working Safely Around Drill Rigs

HEALTH AND SAFETY PLAN FORM **CDM Health and Safety Program**	*This document is for the exclusive use of CDM and its subcontractors*	**CDM Smith** **PROJECT DOCUMENT #:**

DESCRIPTION AND FEATURES: *Include principal operations and unusual features (containers, buildings, dikes, power lines, hillslopes, rivers, etc.)*

The USG Puyallup property is vacant land located adjacent to the Puyallup River in Puyallup, Washington. The northern portion of the property is unpaved and prone to seasonal overbank flooding of the Puyallup River. The property is presently overgrown with alder, cottonwood, blackberries and other misc. vegetation.

SURROUNDING POPULATION: ( ) Residential ( ) Industrial (X) Commercial ( ) Rural ( ) Urban OTHER:

HAZARDOUS MATERIAL SUMMARY: ***Highlight or bold waste types and estimate amounts by category.***

CHEMICALS: *Amount/Units:*	**SOLIDS:** *Amount/Units:*	**SLUDGES:** *Amount/Units:*	**SOLVENTS:** *Amount/Units:*	**OILS:** *Amount/Units:*	**OTHER:** *Amount/Units:*
Acids	Flyash	Paints	Ketones	Oily Wastes	Laboratory
Pickling Liquors	Mill or Mine Tailings	Pigments	Aromatics	Gasoline	Pharmaceutical
Caustics	Asbestos	Metals Sludges	Hydrocarbons	Diesel Oil	Hospital
Pesticides	Ferrous Smelter	POTW Sludge	Alcohols	Lubricants	Radiological
Dyes or Inks	Non-Ferrous Smelter	Distillation Bottoms	Halogenated (chloro, bromo)	Polynuclear Aromatics	Municipal
Cyanides	**Metals : Arsenic**	Aluminum	Esters	PCBs	Construction
Phenols	Dioxins		Ethers	Heating Oil	Munitions
Halogens					
Other - *specify*	Other - *specify*	Other - *specify*	Other - *specify*	Other - *specify*	Other - *specify*

HEALTH AND SAFETY PLAN FORM **CDM Health and Safety Program**		*This document is for the exclusive* *use of CDM and its subcontractors*		**CDM Smith** **PROJECT DOCUMENT #:**		
KNOWN CONTAMINANTS	**HIGHEST OBSERVED CONCENTRATION**	**PEL/TLV** *ppm or mg/m3 (specify)*	**IDLH** *ppm or mg/m3 (specify)*	**Warning Concentration** *(in ppm)*	**SYMPTOMS & EFFECTS OF ACUTE EXPOSURE**	**PHOTO IONIZATION POTENTIAL**
Arsenic, inorganic	**2,540 mg/kg (S)** **2,000 ug/L (GW)**	10 µg/m3	5 mg/m3	Dust	Nasal ulcers, fever, bronchitis, melanosis, peripheral neuropathy	Dust

NA = Not Available **NE = None Established** **U = Unknown**

Verify your access to an MSDS for each chemical you will use at the site.

S = Soil	SW = Surface Water	T = Tailings	W = Waste	TK = Tanks	SD = Sediment
A = Air	GW = Ground Water	SL = Sludge	D = Drums	L = Lagoons	OFF = Off-Site

HEALTH AND SAFETY PLAN FORM *This document is for the exclusive* **CDM (Camp Dresser & McKee)**
CDM Health and Safety Program *use of CDM and its subcontractors* **PROJECT DOCUMENT #:**

SPECIFIC TASK DESCRIPTIONS	Disturbing the Waste?	TASK - SPECIFIC HAZARDS	HAZARD & SCHEDULE
1 Land clearing	***Intrusive***	Mechanical hazards from excavator, chain saws. Risks posed by falling trees, blackberries, Slips, trips, falls. Potentially vagrants and needles associated with drug use. Complying with social distancing and personal hygiene measures as part of overall COVID-19 field safety protocol.	Moderate Hazard Jul-20
2 Soil Sampling using drilling methods (auger drilling and sonic drilling)	***Intrusive***	Mechanical hazards from drill rigs and excavators. Slips, trips, falls. Chemical hazardous from contact with arsenic contaminated soils. Complying with social distancing and personal hygiene measures as part of overall COVID-19 field safety protocol.	Moderate Hazard Jul-20
3 Monitor and collect soil samples from excavator bucket during test pit excavation	***Intrusive***	Mechanical hazards from drill rigs and excavators. Slips, trips, falls. Chemical hazardous from contact with arsenic contaminated soils. Complying with social distancing and personal hygiene measures as part of overall COVID-19 field safety protocol.	Moderate Hazard Jul-20
4 Groundwater Sampling using low flow methods	***Intrusive***	Contact with arsenic contaminated groundwater. Slips, trips, falls. Complying with social distancing and personal hygiene measures as part of overall COVID-19 field safety protocol.	Moderate Hazard Jul-20
5 Disposal of IDW	***Non-intrusive***	Contact with arsenic contaminated soils and purge water. Slips, trips, falls. Strains if moving drums. Complying with social distancing and personal hygiene measures as part of overall COVID-19 field safety protocol.	Moderate Hazard Sep-20
6	Intrusive Non-intrusive		

SPECIALIZED TRAINING REQUIRED:

HAZWOPER

SPECIAL MEDICAL SURVEILLANCE REQUIREMENTS:

None apart from the standard annual medical monitoring required under HAZWOPER

OVERALL HAZARD EVALUATION: ( ) High (x) Medium () Low ( ) Unknowr *(Where tasks have different hazards, evaluate each.)*

JUSTIFICATION: Field staff does not operate the equipment. Field Staff to keep distance from operating equipment and maintain eye contact with operators. Potential exposure to contaminants can be mitigated with good hygeine and PPE. Contact local police if vagrants need to be moved. Do not pick up any trash left by vagrants. Drums will be staged by the drillers in a location that will not require moving until the vendor comes to pick them up.

FIRE/EXPLOSION POTENTIAL: ( ) High ( ) Medium (X) Low ( ) Unknown

HEALTH AND SAFETY PLAN FORM *This document is for the exclusive use of CDM and its subcontractors* **CDM Smith**

CDM Health and Safety Program **PROJECT DOCUMENT #:**

PROTECTIVE EQUIPMENT: *Specify by task. Indicate type and/or material, as necessary. Group tasks if possible. Use copies of this sheet if needed.*

BLOCK A

TASKS: **1 - 2 - 3 - 4** - 5 - 6 - 7 - 8 - 9 - 10
LEVEL: A - B - C - **D - Modified**
(X) Primary ( ) Contingency

Respiratory: (X) Not needed	Prot. Clothing: ( ) Not needed
( ) SCBA, Airline:	( ) Encapsulated Suit:
( ) Escape Mask:	( ) Tyvek Coverall or
( ) Other:	( ) Saranex Coverall
	(X) Cloth Coverall:
Head and Eye: ( ) Not needed	( ) Other:
(X) Safety Glasses: All Tasks	
( ) Face Shield:	Gloves: ( ) Not needed
( ) Goggles:	() Undergloves:
(X) Hard Hat: During soil boring and sai	(X) Gloves: Nitrile
(X) Other: Face masks encouraged if not required by project	( ) Overgloves:
Boots: ( ) Not needed	Other: specify below
(X) Steel-Toe: All ( ) Steel Shank	( ) Tick Spray
( ) Rubber ( ) Leather	( ) Flotation Device If Over Water
( ) Overboots:	(X) Hearing Protection
	(X) Sun Screen

BLOCK B

TASKS: **1 - 2 - 3** - 4 - 5 - 6 - 7 - 8 - 9 - 10
LEVEL: A - B - C - D - Modified
( ) Primary (X) Contingency

Exit Area

Respiratory: ( ) Not needed	Prot. Clothing: ( ) Not needed
( ) SCBA, Airline:	( ) Encapsulated Suit:
( ) Esc	yvek al
( ) Oth	Sarane eral
	oth all:
Head and Eye: ( ) Not needed	( ) Other:
( ) Safety Glasses:	
( ) Face Shield:	Gloves: ( ) Not needed
( ) Goggles:	( ) Undergloves:
( ) Hard Hat:	( ) Gloves:
( ) O	( ) Overgloves:
B led	elo
(S hank	(
( ) Rubber ( ) Leather	( ) Float. Device If Over Water
( ) Overboots: Latex	( ) Hearing Protection
	( ) Sun Screen

BLOCK C

TASKS: 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10
LEVEL: A - B - C - D - Modified
( ) Primary ( ) Contingency

Respiratory: ( ) Not needed	Prot. Clothing: ( ) Not needed
( ) SCBA, Airline:	( ) Encapsulated Suit:
( ) APR:	( ) Splash Suit
( ) Cartridge:	( ) Apron:
( ) Escape Mask:	( ) Tyvek Coverall
( ) Other:	( ) Saranex Coverall
	( ) Cloth Coverall:
Head and Eye: ( ) Not needed	( ) Other:
( ) Safety Glasses:	
( ) Face Shield:	Gloves: ( ) Not needed
( ) Goggles:	( ) Undergloves:
( ) Hard Hat:	( ) Gloves:
( ) Other:	( ) Overgloves:
Boots: ( ) Not needed	Other: specify below
( ) Steel-Toe ( ) Steel Shank	( ) Tick Spray
( ) Rubber ( ) Leather	( ) Flotation Device
( ) Overboots:	( ) Hearing Protection
	( ) Sun Screen

BLOCK D

TASKS: 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10
LEVEL: A - B - C - D - Modified
( ) Primary ( ) Contingency

Respiratory: ( ) Not needed	Prot. Clothing: ( ) Not needed
( ) SCBA, Airline:	( ) Encapsulated Suit:
( ) APR:	( ) Splash Suit
( ) Cartridge:	( ) Apron:
( ) Escape Mask:	( ) Tyvek Coverall
( ) Other:	( ) Saranex Coverall
	( ) Cloth Coverall:
Head and Eye: ( ) Not needed	( ) Other:
( ) Safety Glasses:	
( ) Face Shield:	Gloves: ( ) Not needed
( ) Goggles:	( ) Undergloves:
( ) Hard Hat:	( ) Gloves:
( ) Other:	( ) Overgloves:
Boots: ( ) Not needed	Other: specify below
( ) Steel-Toe ( ) Steel Shank	( ) Tick Spray
( ) Rubber ( ) Leather	( ) Flotation Device
( ) Overboots:	( ) Hearing Protection
	( ) Sun Screen

This health and safety plan form constitutes hazard analysis per 29 CFR 1910.132

HEALTH AND SAFETY PLAN FORM **CDM Health and Safety Program**	*This document is for the exclusive use of CDM and its subcontractors*	**CDM Smith** **PROJECT DOCUMENT #:**

MONITORING EQUIPMENT: *Specify by task. Indicate type as necessary. Attach additional sheets if needed.*

INSTRUMENT	**TASK**	**ACTION GUIDELINES**		**COMMENTS**
Combustible Gas Indicator	1-2-3-4-5-6-7-8	0-10% LEL 10-25% LEL >25% LEL 21.0% O2 <21.0% O2 <19.5% O2	*No explosion hazard* *Potential explosion hazard; notify SHSC* *Explosion hazard; interrupt task/evacuate* *Oxygen normal* *Oxygen deficient; notify SHSC* *Interrupt task/evacuate*	(X) Not Needed
Radiation Survey Meter	1-2-3-4-5-6-7-8	3 x Background: >2mR/hr:	*Notify HSM* *Establish REZ*	(X) Not Needed
Photoionization Detector _____eV Lamp Type ____	1-2-3-4-5-6-7-8	*Specify:*		(X) Not Needed
Flame Ionization Detector Type____________	1-2-3-4-5-6-7-8	*Specify:*		(X) Not Needed
Single Gas Type____________ Type____________	1-2-3-4-5-6-7-8	*Specify:*		(X) Not Needed
Respirable Dust Monitor Type____________ Type____________	1-2;3	*Specify:*	Zero dust policy during all drilling/test pit/land clearing operations. All visible dust must be controlled (water if necessary). If visible dust, stop drilling, implement engineering controls (e.g., use of water spray) or modify work practices. Resume activities only when no visible dust.	
Other *Specify:* **X-ray Fluorescnese (XRF) Meter** Type____________ Type____________	2-3	*Specify:*		( ) Not Needed
Other *Specify:* Type____________ Type____________	1-2-3-4-5-6-7-8	*Specify:*		( ) Not Needed

HEALTH AND SAFETY PLAN FORM
CDM Health and Safety Program

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CDM Smith
PROJECT DOCUMENT #:

DECONTAMINATION PROCEDURES

ATTACH SITE MAP INDICATING EXCLUSION, DECONTAMINATION, & SUPPORT ZONES AS PAGE TWO

Personnel Decontamination *Summarize below or attach diagram;* A personal decontamination station will be established just outside of the exclusion zone in the contaminant reduction zone. Wash hands and face with soap and water after taking PPE on and off. Workers will remove protective equipment in this order: 1.) equipment drop; 2.) hard hat; 3.)gloves; 4.) face and hand wash. WASH HANDS AND FACE BEFORE EATING OR DRINKING. ( ) Not Needed	**Sampling Equipment Decontamination** *Summarize below or attach diagram;* All non-disposable sampling equipment such as spoons will be thoroughly decontaminated between samples with soap, water, and rinsing with distilled water. The four steps of equipment decontamination are: 1.) Scrub with mild solution of Alconox; 2.) rinse with potable water; 3.)spray rinse with distilled water; 4.) air-dry. ( ) Not Needed	**Heavy Equipment Decontamination** *Summarize below or attach diagram;* All down-hole/excavation equipment and tool parts that contact soil are constructed of heavy gauge steel and have no natural or synthetic components that could absorb and retain most soil-borne organic contaminants. The drill tooling shall be decontaminated in between borings (X) Not Needed
Containment and Disposal Method PPE waste generated during soil, groundwater, and sediment sampling (rubber gloves, paper towels, etc.) will be placed in plastic garbage bag(s) and sealed shut. The garbage bags will be placed in a County commercial waste collection container for ultimate disposal in accordance with 173-303 WAC and 173-340-820 WAC.	**Containment and Disposal Method** Decontamination water shall be contained, tested, and disposed of appropriately.	**Containment and Disposal Method** Drill cuttings, decontamination and purge water will be labeled and stored in 16-gallon drums, pending classification, and transported to a designated storage area at the end of each day.

HAZARDOUS MATERIALS TO BE BROUGHT ONSITE

Preservatives		*Decontamination*		*Calibration*	
( ) Hydrochloric Acid	( ) Zinc Acetate	(X) Alconox ™	( ) Hexane	( ) 100 ppm isobutylene	( ) Hydrogen Sulfide
( ) Nitric Acid	( ) Ascorbic Acid	( ) Liquinox ™	( ) Isopropanol	( ) Methane	( ) Carbon Monoxide
( ) Sulfuric Acid	( ) Acetic Acid	( ) Acetone	(X) Nitric Acid	( ) Pentane	(X) pH Standards
( ) Sodium Hydroxide	( ) Other:	( ) Methanol	( ) Other:	( ) Hyrogen	( ) Conductivity Std
		( ) Mineral Spirits		( ) Propane	( ) Other:

HEALTH AND SAFETY PLAN FORM

CDM Health and Safety Program

This document is for the exclusive use of CDM and its subcontractors

CDM Smith

PROJECT DOCUMENT #:

EMERGENCY CONTACTS

Water Supply	
Site Telephone	
EPA Release Report #:	800 / 424 - 8802
24-Hr. First Aid/Non-Emergency Medical Services:	1-800-350-4511, Press 1
Facility Management	
Other (specify)	
CHEMTREC Emergency #:	800 / 424 - 9300

SAFETY NARRATIVE:

Summarize below

Evacuate site if any unexpected hazardous conditions are encountered. The "buddy system" will be employed for all work being done. Site staff will discuss an evacuation area appropriate for each boring location prior to beginning work at each location. If a work team observes hazards for which they have not been prepared, they will withdraw from the area and call CDM Health and Safety. Without regard to monitoring instrument reading, CDM personnel will leave the site and upgrade their level of protection if they experience nausea or dizziness. All workers on the site will have "Stop Work Authority" to immediately stop work if he/she feels that a particular task is being performed unsafely. Stop Work Authority may be exercised by anyone working on the site at anytime without repercussions or retribution. Personnel must be familiar with attached CDM Smith COVID-19 field guidance and comply with protocol.

HEALTH AND SAFETY PLAN APPROVALS (H&S Mgr must sign each plan)

Prepared by	Haley Hutchins	Date	4/29/2029
HSC Signature	Pam Morrill	Date	4/29/2029
HSM Signature		Date	May 13, 2020

EMERGENCY CONTACT	NAME	PHONE
Health and Safety Manager	Paul Opem	303 / 383 - 2483
Project Manager	Pam Morrill	425 453 8303
Site Safety Coordinator	Haley Hutchins	518-867-7044
Client Contact	Jennifer Brennan	312 436 5385
Other *(specify)*		
Environmental Agency		
State Spill Number	Washington	(800) 258-5990
Fire Department		911
Police Department		911
State Police		911
Health Department		
Poison Control Center	Nationwide	800 / 222 - 1222
Occupational Physician	Kenneth Chase	800 / 777 - WOHA

MEDICAL EMERGENCY

		PHONE
Hospital Name:	Good Samaritan	253 697 4000
Hospital Address	407 14 Ave. SE, Puyallup, WA	

Name of Contact at Hospital:

Name of 24-Hour Ambulance:

Route to Hospital:

Head east on River Rd toward 9th St NW 0.6 mi ; Turn right at N Meridian 1.4 mi ; Turn left at 14th Ave SE 0.2 mi ; arrive at 407 14 Ave SE -Good Samaritan Hospital

Distance to Hospital 2.5 miles

HEALTH AND SAFETY PLAN SIGNATURE FORM

CDM Health and Safety Plan

All site personnel must sign this form indicating receipt of the H&SP. Keep this original on site. It becomes part of the permanent project files. Send a copy to the Health and Safety Manager (HSM).

SITE NAME/NUMBER: USG - Puyallup

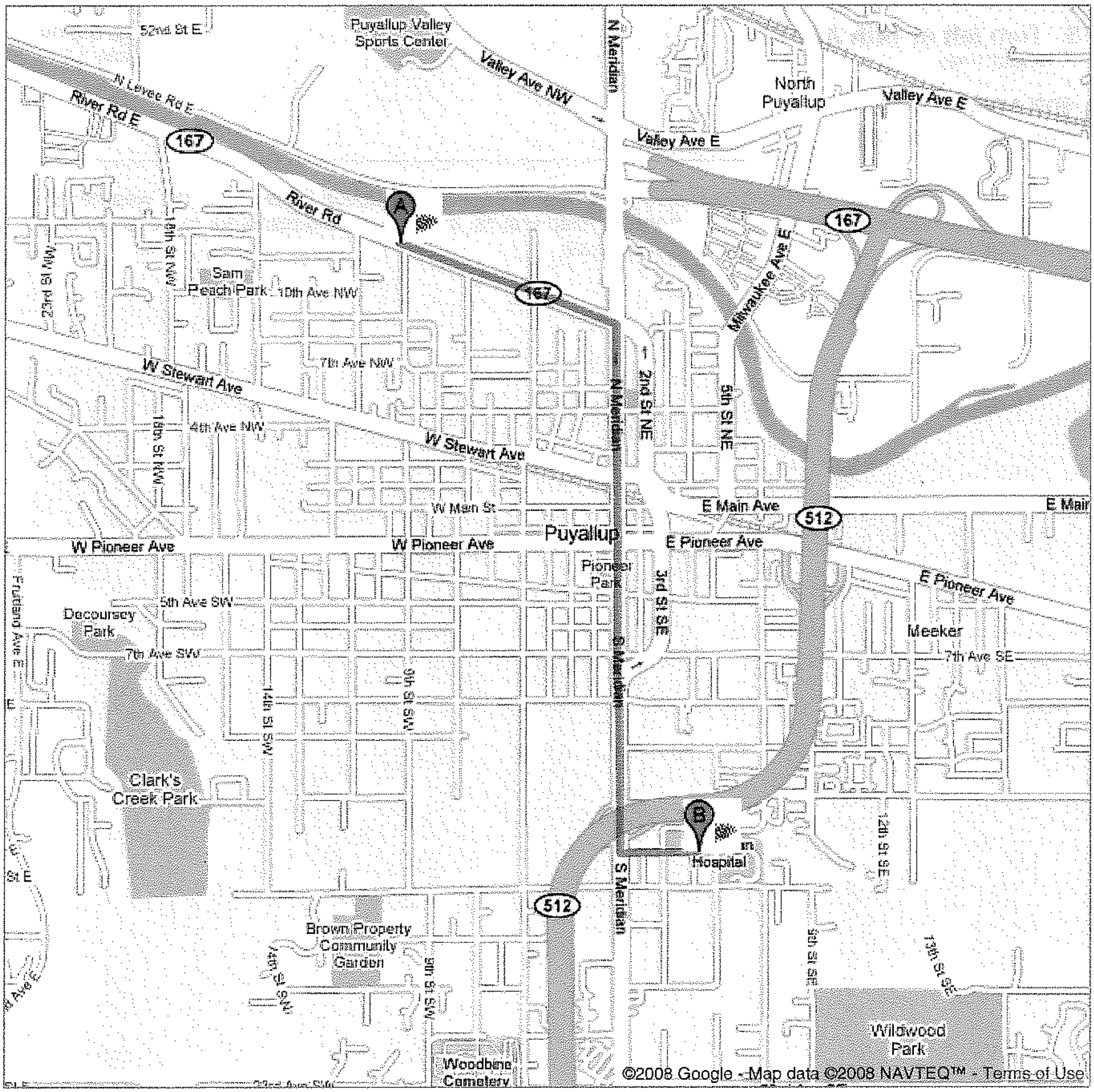
DIVISION/LOCATION: CDM Bellevue Office

CERTIFICATION:

I understand, and agree to comply with, the provisions of the above referenced H&SP for work activities on this project. I agree to report any injuries, illnesses or exposure incidents to the site Health and Safety Coordinator (SHSC). I agree to inform the SHSC about any drugs (legal and illegal) that I take within three days of site work.

PRINTED NAME	SIGNATURE	DATE

Directions to 407 14th Ave SE, Puyallup, WA 98372
2.2 mi – about **7 mins**



COVID-19 Prevention Guidance for Field Activities

Per Tim Wall's memorandum on 3/16/20, *Working Safely during the Coronavirus (COVID-19) Outbreak Update*, we have new firm-wide policies for how to best respond to this outbreak, establish continuity of operations, and protect personnel.

This document is intended to provide basic guidance to field and project teams that have operations outside of a CDM Smith office other than CCI construction sites. Included are measures on how to best protect employees and minimize potential exposure to COVID-19.

Planning

All projects involving field work should have an H&S plan to address specific hazards associated with that project. Since potential exposure to this virus is a new hazard, those H&S plans will need to be modified at the project level to address their specific COVID-19 exposures. These modifications will need to be communicated to personnel ASAP. The practices below must be evaluated and included in any greater planning activities and project-specific H&S plans. For non-routine exposure scenarios contact your H&S Manager for assistance in working out appropriate precautions.

COVID-19 Practices to Minimize Exposure

COVID-19 exposure is most directly associated with close contact with an infected individual. There are also less direct means of contact that are not as fully understood such as contact with contaminated surfaces. To minimize exposure, it is imperative that field staff exercise the same precautions that have been given to the general public. To the extent feasible:

- Maintain social distancing. Stay a minimum of 6 feet away from other people. **This is probably the most important action to limit exposure.**
- Minimize contact with others. Do not shake hands (use non-contact greetings).
- Wash your hands frequently and thoroughly with soap and water, for a minimum of 20 seconds. If you can find it, carry a bottle of hand sanitizer (containing at least 60% alcohol) and use after contacting common surfaces – this will be effective when soap and water are not available.
- Do not use common coffee pots or water coolers. Bring your own and use individual water bottles.
- Minimize time in shared office spaces, trailers etc. Maximize social distancing from other people as much as possible.
- Avoid touching your face, in particular your mouth, eyes, and nose.
- Common surfaces that are encountered should be wiped down frequently with disinfectant wipes. If not available, the surface can be cleaned with soap and water or a diluted solution of bleach.
- Plan work at the jobsite to reduce the density of people in one area.
- Stay home if you are sick and/or have symptoms of COVID-19 or a cold/flu.

- Organize virtual meetings as opposed to in-person meetings where possible, even if between field offices (for example, with major subconsultants or suppliers).
- Postpone or change the format of already planned in-person meetings, especially those where there is likely to be a higher density of people in the room, to accommodate remote attendance.
- At the beginning of your work day, discuss with any CDM Smith or Client team members the precautions that are to be taken to minimize exposure, this will help to inform them and might even raise their awareness of similar precautions they should be taking.

The social distancing and personal hygiene actions described above are the most effective means to minimize exposures to COVID-19.

The equipment center has an inventory of N95 masks for activities that present a potential airborne hazard. The equipment center also has an inventory of nitrile protective gloves for hazards that involve frequent contact with potentially contaminated surfaces. However, frequent handwashing, wiping of common surfaces, and the social distancing/personal hygiene actions described are considered sufficient protection in most cases.

If you have encountered a potentially infected individual or are starting to notice symptoms of COVID-19, please notify your field team leader and direct manager. Self-quarantine measures may be required in accordance with the most recent Corporate guidance.

Appendix B

Standard Operating Procedures (SOPs)

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Standard Operation Procedure #1: Geotechnical Field Investigations

The protocol set forth in this Standard Operating Procedure (SOP) outlines the required field procedures for the collection of subsurface data and soil samples by geotechnical drilling.

Details regarding the sampling objectives, design, and quality assurance (QA) requirements are provided in the work plan; the procedures outlined here will be performed in compliance with the work plan.

Geotechnical Drilling and Sampling

The procedures to be followed for collection of subsurface data and soil samples are presented below.

A. Materials:

The following materials will be available, as required, during geotechnical drilling and sampling:

- GeoExplorer Trimble unit or equivalent for use in identifying boring locations in the field.
- CME 45/55 or equivalent drill rig equipped with a 63-kilogram (kg) (140-lb) automatic hammer, with capabilities of conducting either Hollow Stem Auger or Mud Rotary Drilling Methodologies.
- 4-inch I.D. hollow stem augers, drill rods, pipe clamps/hangers and slip rings to advance borings to the depths required by the site-specific work and sampling plans.
- Sufficient numbers of split-barrel samplers so that at least one sampler is always clean and available for sampling. Three split-barrel samplers are generally the minimum necessary.
- Shelby tubes.
- Glass Sample Jars and Plastic zip-top bags.
- Field logbook.
- Indelible black ink pens and markers.
- Clear, waterproof tape.
- Appropriate sample containers.
- Stainless steel and/or Teflon-lined spatulas and pans, trays, bowls, trowels, or spoons.
- Labels and appropriate forms/documentation for sample shipment.
- Cleaning supplies including materials to perform decontamination of drilling materials and equipment
- Sample chain-of-custody forms.
- Nitrile or appropriate gloves.
- Kimwipes or paper towels.
- Small hand tools including wrenches, hammers, and screw driver.
- 6 foot field tape.
- Backfill materials (e.g., portland cement, potable water, and bentonite powder and/or chips).

Standard Operation Procedure #1: Geotechnical Field Investigations

B. Procedures

Sediment, subsurface data and soil samples will be collected using standard geotechnical drilling methods. Information will be collected at designated locations. The procedures for geotechnical drilling and sampling are provided below.

B-1. Preparation

1. Review the Work Plan, HASP, and project plans before initiating sampling activity.
2. Don the appropriate personal protective equipment (PPE) as indicated in HASP.
3. Prepare an area to perform sample collection activities. Sample collection should be performed at a safe distance from all heavy equipment, or as determined by the heavy equipment operator(s) and/or the CDM Smith field representative.
4. Use GPS device to record the sampling location(s). When possible, reference locations to existing site features such as structures, bridges, etc. Locations of proposed geotechnical borings may be modified in the field based on conditions encountered at the time of drilling, including, but not limited to equipment access limitations, to avoid obstructions such as rocks/boulders, overhanging trees, and/or for other specific reasons identified in the field. The as-drilled locations will be located as close as practicable to the proposed locations. Should geotechnical borings need to be relocated, the reason(s) will be documented in field notes and updates provided as necessary.

B-2. Sample Collection

The following general steps are to be followed when collecting all subsurface soil samples.

1. All sampling information, including geotechnical soil characterization, sample depth, sample volume, and requisite geotechnical analyses shall be recorded in the field logbook and on any associated forms as specified in the site-specific sampling/work plans. Sample lithology shall be described in accordance with the Modified Burmister Soil Classification System and the Unified Soil Classification System (ASTM D2487).
2. Specific sampling devices to be used shall be identified in the site-specific work/sampling plans and shall be recorded in the field logbook.
3. Care must be taken to prevent cross-contamination and misidentification of samples.
4. Drilling observations, such as “rig chattering”, “drilling fluid loss”, etc., must be recorded with the approximate start and end depths.
5. Groundwater level must be read to at least one decimal place. Reading date, time, and weather (temperature and conditions), must be noted.
6. Photos must be taken of site, boring locations (before and after drilling), and samples. Close-up photos must include size references (such as folding field tape).

B-3. Split-Barrel Sampling

The general drilling activities are to be performed by a licensed drilling contractor, not by CDM Smith personnel. The CDM Smith personnel are responsible for making sure that the licensed drilling contractor is adhering to the ASTM standards for the drilling procedure specified in the project specific work plan. The ASTM standards for auger drilling is provided below and is included in Attachment A:

Standard Operation Procedure #1: Geotechnical Field Investigations

1. ASTM D6151/D6151M: Standard Practice for Using Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling

In addition to making sure that the drilling contractor is adhering to ASTM standards, the CDM Smith personnel is responsible for recording the following data:

1. Record the number of blows required to drive the sampler through each 15-cm (6-inch) increment.

2. Record the length that the spoon is advanced and the length of the sample that is recovered in the spoon. For instances where refusal is encountered, stop driving the split-barrel sampler. Refusal occurs when little or no progress is made for 50 blows of the hammer. ASTM D1586 § 7.2.1 and 7.2.2 defines "refusal" as >50 blows per 6-inches advanced or a total of 100 blows.

3. If less than 4 inches of a sample is recovered after the 2-inch spoon is advanced its full length, a second attempt to collect a soil sample must be made with a 3-inch spoon. Blow counts and recovery should be recorded separately for the 3 inch spoon.

4. Large volumes of sample material may be collected for additional sample retention. If this is decided upon, then a 3-inch spoon may be used to collect additional sample volume at the selected depths.

5. Label sample containers with appropriate information. Record the sample identification number, depth from which the sample was taken, sample recovery and the analyses to be performed on the samples in the field logbook and on the appropriate forms.

6. In the field logbook and on the boring log describe sample lithology. The sample lithology should adhere to the CDM Smith Soil Classification Guidelines and any additional client specific standards presented in the project specific work plan.

7. Place the sample in the labeled container (e.g., zip-top type bags or glass jars).

8. Complete the field logbook entry and other forms, being sure to record all relevant information before leaving the site.

9. Properly package all samples for shipment to laboratories and complete all necessary sample shipment documentation.

10. Remand custody of the samples to appropriate personnel.

B-4. Shelby Tube Sampling

Note: Steps 1 through 5 describe activities to be performed by a licensed drilling contractor, not by CDM Smith personnel. ASTM D1587 provides additional details pertaining to this sampling methodology.

The following steps are to be followed when collecting geotechnical samples using Shelby tubes:

1. Attach a head assembly to a new, clean Shelby tube sampler assembly. Attach the Shelby tube assembly to the drill rods.

2. Lower the Shelby tube and drill rods into the casing and seat it at the bottom. Be sure to leave 30 inches or more of drill rod above the lowest point to the hydraulic piston's extension.

3. Use the rig's hydraulic drive to push the Shelby tube into undisturbed soil. The tube shall be pushed with a slow, steady force. The pressure used by the driller to push the Shelby tube shall be noted in the field logbook.

4. When the Shelby tube has been advanced to its full length or to refusal, back off the hydraulic pistons. Attach a hoisting plug to the upper end of the drill rod. Wait 20 to 30 minutes then slowly rotate the tube one revolution to shear the material at the end of the Shelby tube and to relieve water or suction pressures. Retrieve the Shelby tube to ground surface, detach it from the drill rod, and remove the head assembly.

5. Since the typical intent of Shelby tube sampling is for engineering purposes and an undisturbed sample is required, the tube ends shall be sealed immediately. Sealing is accomplished by filling any void space in the tube with melted paraffin wax, then placing caps on the ends of the tube and taping caps into place. Caps should then be taped. The top and bottom ends of the tube shall be marked and the tube transported to the laboratory in an upright position. ***It is extremely important that the Shelby tube samples are not disturbed in any way (dropped, rolled, subjected to extreme temperatures, etc.).***

6. Wipe sealed tubes clean with a clean Kimwipe or paper towel.

7. Indicate boring number and depth on outside of the tube.

8. Complete the field logbook entry, being sure to record all relevant information before leaving the site.

C. Borehole Decommissioning

The actual methods of decommissioning boreholes at a site vary depending on site conditions and the construction materials and methods used during the original installation. The method to be used at a site shall be stated in the site-specific plans. Deviations from the methods prescribed in this SOP may be required based on site-specific considerations.

C-1. Boring Decommissioning Using Bentonite Chips or Cement-Bentonite Grout

Boreholes shall be plugged using either bentonite chips or cement-bentonite grouting methods. Bentonite based grout shall be mixed to the manufacturer's specifications and then pumped into place using minimum pump pressure. All additives to grouts shall be evaluated for their effects on the subsurface.

C-2. Management of Drill Cuttings and Decontamination Water

Drill cuttings/spoils will be managed as specified in the project specific work plan.

Attachment A
ASTM Standard Practice for Using Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling

Designation: D6151/D6151M – 15

Standard Practice for Using Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling[1]

This standard is issued under the fixed designation D6151/D6151M; 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.

1. Scope

1.1 This practice covers how to obtain soil samples using Hollow-Stem Auger (HSA) sampling systems and use of hollow-stem auger drilling methods for geotechnical exploration. This practice addresses how to obtain soil samples suitable for engineering properties testing.

1.2 In most geotechnical explorations, Hollow-Stem Auger (HSA) drilling is combined with other sampling methods. Split barrel penetration tests (Test Method D1586) are often performed to provide estimates of engineering properties of soils. Thin-wall tube (Practice D1587) and ring-lined barrel samples (Practice D3550) are also frequently taken. This practice discusses hole preparation for these sampling events. For information on the sampling process, consult the related standards. Other in situ tests, such as the vane shear Test Method D2573, can be performed below the base of the boring by access through the drill string. Other drilling methods are summarized in Guide D6286. Practice D1452 describes solid stem augers.

1.3 This practice does not include considerations for geoenvironmental site characterizations and installation of monitoring wells which are addressed in Guide D5784.

1.4 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 practice means only that the document has been approved through the ASTM consensus process.

1.5 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026, unless superseded by this standard.

1.6 The values stated in either inch-pound units or SI units [presented in brackets] are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.7 Hollow-stem auger drilling for geotechnical exploration often involves safety planning, administration, and documentation. This standard does not purport to specifically address exploration and site safety. 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 its use. *Performance of the test usually involves use of a drill rig, therefore, safety requirements as outlined in applicable safety standards, for example OSHA (Occupational Health and Safety Administration) regulations, DCDMA safety manual (***1***)*,[2] drilling safety manuals, and other applicable state and local regulations must be observed.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D420 Guide to Site Characterization for Engineering Design and Construction Purposes (Withdrawn 2011)[4]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

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[1] This practice is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Evaluations.

Current edition approved July 1, 2015, Published July 2015. Originally approved in 1997. Last previous edition approved in 2008 as D6151 – 08. DOI: 10.1520/D6151_D6151M-15.

[2] The boldface numbers in parentheses refer to the references at the end of this practice.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] The last approved version of this historical standard is referenced on www.astm.org.

D5434 Guide for Field Logging of Subsurface Explorations of Soil and Rock

D6026 Practice for Using Significant Digits in Geotechnical Data

2.2 *Standards for Sampling of Soil and Rock:*

D1452 Practice for Soil Exploration and Sampling by Auger Borings

D1586 Test Method for Penetration Test (SPT) and Split-Barrel Sampling of Soils

D1587 Practice for Thin-Walled Tube Sampling of Fine-Grained Soils for Geotechnical Purposes

D2113 Practice for Rock Core Drilling and Sampling of Rock for Site Exploration

D3550 Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils (Withdrawn 2016)[4]

D4220 Practices for Preserving and Transporting Soil Samples

2.3 *In situ Testing:*

D2573 Test Method for Field Vane Shear Test in Saturated Fine-Grained Soils

D3441 Test Method for Mechanical Cone Penetration Tests of Soil (Withdrawn 2014)[4]

D4719 Test Methods for Prebored Pressuremeter Testing in Soils (Withdrawn 2016)[4]

2.4 *Instrument Installation and Monitoring:*

D4428/D4428M Test Methods for Crosshole Seismic Testing

D5092 Practice for Design and Installation of Groundwater Monitoring Wells

2.5 *Drilling Methods:*

D5784 Guide for Use of Hollow-Stem Augers for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices

D6286 Guide for Selection of Drilling Methods for Environmental Site Characterization

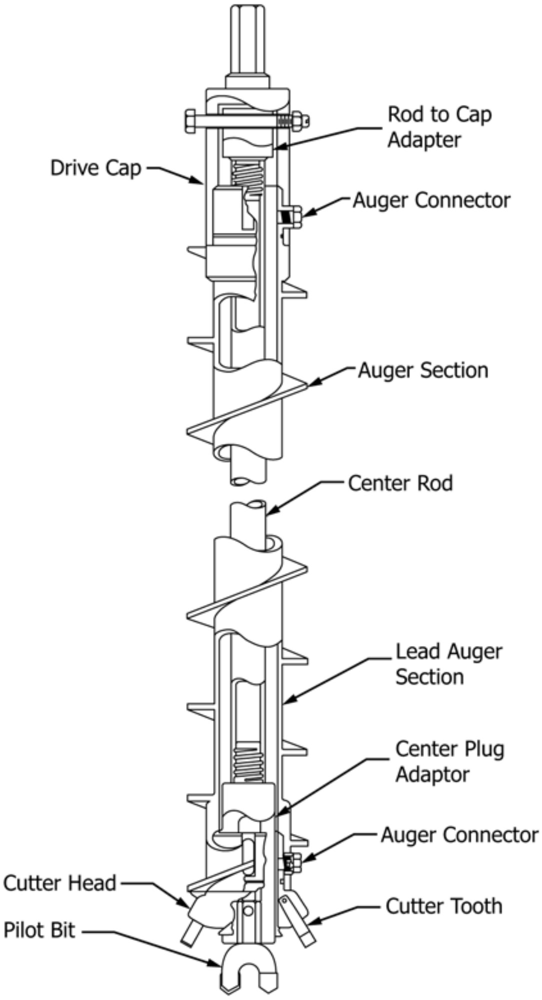

FIG. 1 Rod-Type Auger System With Pilot Bit

3. Terminology

3.1 *Definitions:*

3.1.1 For common definitions of terms in this standard, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:* (see Figs. 1-5 for typical system components):

3.2.1 *auger cutter head*—the terminal section of the lead auger equipped with a hollow cutting head for cutting soil.

3.2.1.1 *Discussion*—The cutter head is connected to the lead auger. The cutter head is equipped with abrasion-resistant cutting devices, normally with carbide surfaces. The cutter can be teeth (usually square or conical), or blades (rectangular or spade design). Cutter head designs may utilize one style cutter or a combination of cutters.

3.2.2 *bit clearance ratio*—a ratio, expressed as a percentage of the difference between the inside diameter of the sampling tube and the inside diameter of the cutting bit divided by the inside diameter of the sampling tube.

3.2.3 *blow-in*—(Practice D5092)—the inflow of groundwater and unconsolidated material into the borehole or casing caused by differential hydraulic heads; that is, caused by the presence of a greater hydraulic head outside the borehole/casing than inside. Also known as *sanding in* or *soil heave*.

3.2.4 *clean out depth*—the depth to which the end of the drill string (bit or core barrel cutting end) has reached after an interval of drilling.

3.2.4.1 *Discussion*—The clean out depth (or drilled depth as it is referred to after cleaning out of any sloughed material or cuttings in the bottom of the drill hole) is normally recorded to the nearest 0.1 ft. [0.03 m].

3.2.5 *continuous sampling devices*—sampling systems which continuously sample as the drilling progresses.

3.2.5.1 *Discussion*—Hollow-stem sampling systems are often referred to as continuous samplers because they can be operated in that mode. Hollow-stem sampling systems are double-tube augers where barrel-type samplers fit within the lead auger of the hollow auger column. The double-tube auger operates as a soil coring system in certain subsurface conditions where the sampler barrel fills with material as the augers advance. The barrel can be removed and replaced during pauses in drilling for continuous coring.

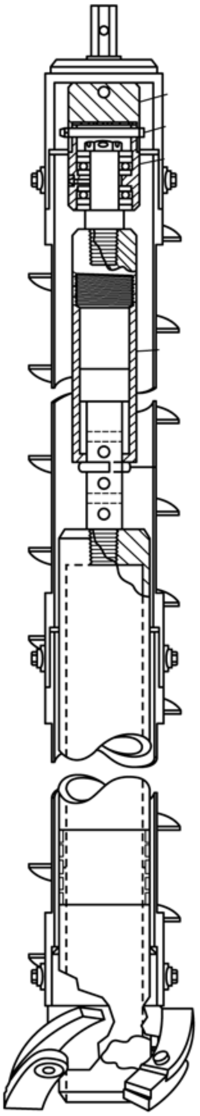

FIG. 2 Example of Rod-Type Sampling System

3.2.6 *double-tube auger*—an auger equipped with an inner barrel for soil sampling (soil coring); if equipped with an inner barrel and liner, the auger system can be described as a triple-tube auger.

3.2.7 *drill hole*—a cylindrical hole advanced into the subsurface by mechanical means. Also known as borehole or boring.

3.2.8 *drill string*—the complete drilling assembly under rotation including augers, core barrel or pilot bit, drill rods, and connector subassemblies.

3.2.8.1 *Discussion*—Drilling depth is determined by knowledge of the total length of the drill string, and by subtracting the string length above a ground surface datum.

3.2.9 *fluid injection devices*—pumps, fittings, hose and pipe components, or drill rig attachments that may be used to inject a fluid within a hollow auger column during drilling.

3.2.10 *hollow stem auger (HSA)*—a cylindrical hollow tube with a continuous helical fluting/fighting on the outside, which acts as a screw conveyor to lift cuttings produced by an auger drill head or cutter head bit to the surface.

3.2.11 *in-hole-hammer*—a drop hammer for driving a soil sampling device.

3.2.11.1 *Discussion*—The in-hole hammer is designed to run down-hole within the HSA column. It is usually operated with a free-fall wireline hoist capable of lifting and dropping the hammer weight to drive the sampler below the HSA column and retrieve the hammer and sampler to the surface. See Fig. 6[5]

3.2.12 *in situ testing devices*—sensors or probes, used for obtaining test data for estimation of engineering properties, that are typically pushed, rotated, or driven in advance of the hollow auger column assembly at a designated depth or advanced simultaneously with advancement of the auger column (see 2.3).

3.2.13 *intermittent sampling devices*—barrel-type samplers that may be rotated, driven, or pushed below the auger head at a designated depth prior to advancement of the auger column (see 2.2).

3.2.14 *lead auger assembly*—the first hollow stem auger to be advanced into the subsurface.

3.2.14.1 *Discussion*—The end of the lead auger assembly is equipped with a cutter head for cutting. The lead auger may also contain a pilot bit assembly or sample barrel assembly housed within the hollow portion of the auger. If a wireline system is used, the lead auger assembly will have an adapter housing on top of the first auger containing a latching device for locking the pilot bit assembly or sampling core barrel into the lead auger assembly.

3.2.15 *lead distance*—the mechanically adjusted length or distance that the inner core barrel cutting shoe is set to extend beyond the lead auger assembly cutting head.

3.2.16 *overshot*—a latching mechanism located at the end of the hoisting line (wireline) specially designed to latch onto or release the pilot bit or core barrel assemblies serving as a lifting device for removing the pilot bit or sampler assembly.

3.2.17 *O-ring*—a rubber ring for preventing leakage between joining metal connections, such as hollow-stem auger sections.

3.2.18 *percent recovery*—percentage which indicates the success of sample retrieval, calculated by dividing the length of sample recovered by the length of sampler advancement.

3.2.19 *pilot bit assembly*—an assembly designed to attach to a drill rod or lock into the lead auger assembly for drilling without sampling.

3.2.19.1 *Discussion*—The pilot bit can have various configurations (drag bit, roller cone, tooth bit, or combination of designs) to aid in more efficient or rapid hole advancement.

3.2.20 *recovery length*—the length of sample actually retrieved during the sampling operation.

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[5] Foremost Mobile, Mobile Drilling Company Inc., 3807 Madison Avenue, Indianapolis, IN.

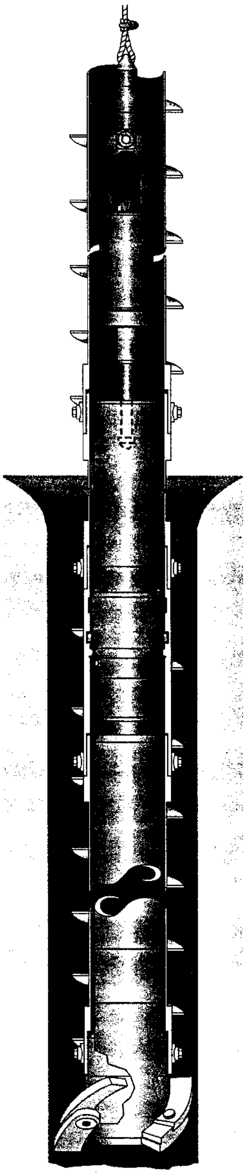

FIG. 3 Example of Wireline Sampling System

3.2.21 *sanding in*—a condition that occurs when sand or silt enters the auger after removal of the pilot bit or sampling barrel. See *blow-in*.

3.2.21.1 *Discussion*—Sanding in can occur from hydrostatic imbalance or by suction forces caused by removal of the pilot bit or sampling barrel.

3.2.22 *slough*—the disturbed material left in the bottom of the borehole, usually from falling off the side of the borehole, or falling out of the sampler, or off of the auger.

3.2.23 *soil coring, hollow-stem*—The drilling process of using a double-tube HSA system to intermittently or continuously sample the subsurface material (soil).

3.2.24 *wireline drilling, hollow-stem*—a rotary drilling process using a lead auger which holds a pilot bit or sampling barrel delivered and removed by wireline hoisting.

3.2.24.1 *Discussion*—Latching assemblies are used to lock or unlock the pilot bit or sampler barrel. The pilot bit or core barrel is raised or lowered on a wireline cable with an overshot latching device.

3.3 *Acronyms:*

3.3.1 *HSA, n*—Hollow Stem Auger(s). See 3.2.10.

4. Significance and Use

4.1 Hollow-stem augers are frequently used for geotechnical exploration. One reason they are used is that the method is considered a “dry” drilling method where drill fluids are not needed to advance the borehole in unstable formations. Often, hollow-stem augers are used with other sampling systems, such as split barrel penetration resistance testing, Test Method D1586, or thin-wall tube sampling, Practice D1587 (see 2.5).

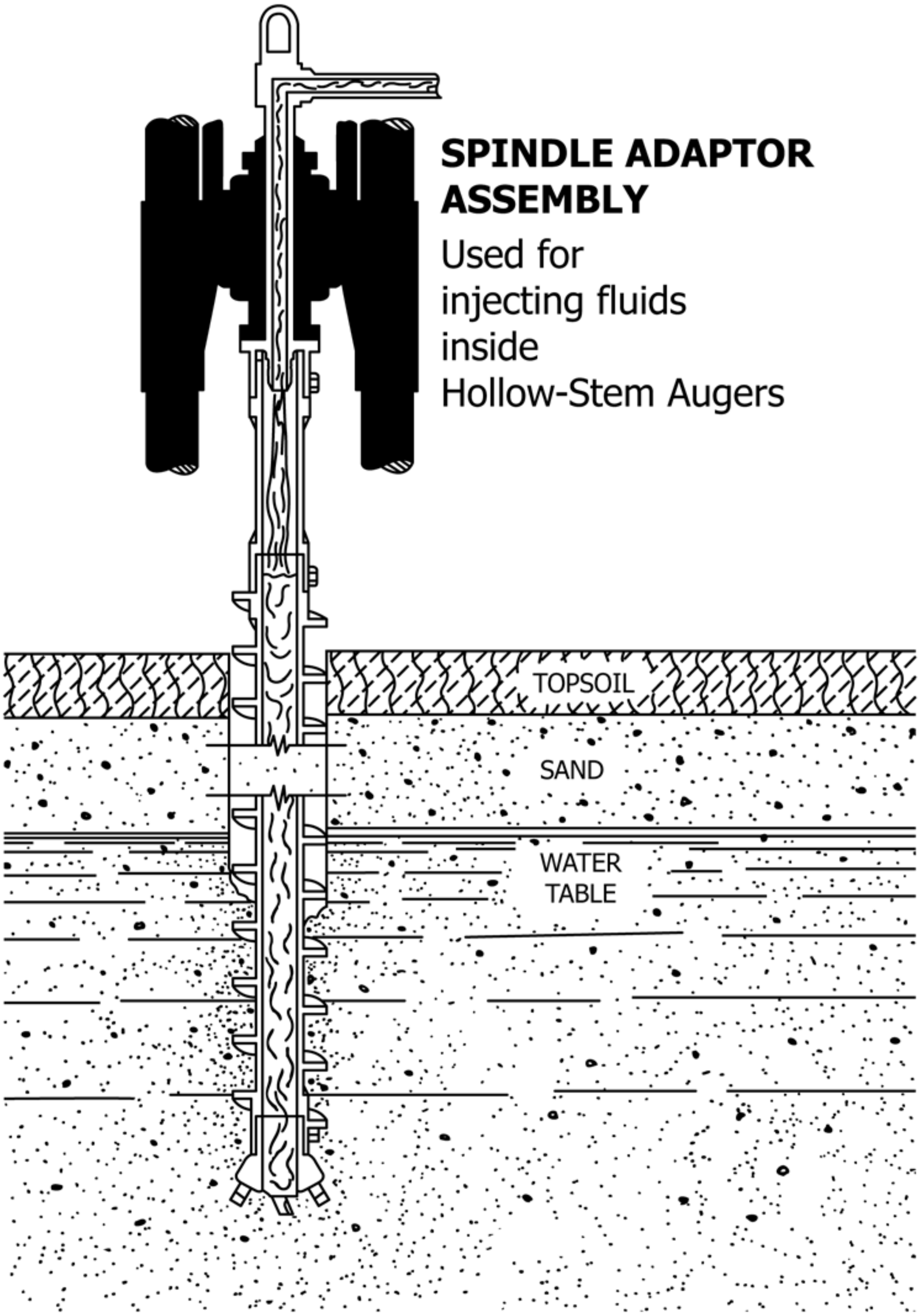

FIG. 4 Spindle Adaptor Assembly

HSA may be used to advance a drill hole without sampling using a pilot bit assembly, or they may be equipped with a sampling system for obtaining soil cores. In some subsurface conditions that contain cohesive soils, the drillhole can be successfully advanced without the use of a pilot bit assembly. Intermittent drilling (advancing of the HSA column with or without a pilot bit) and sampling can be performed depending on the intervals to be sampled, or continuous sampling can be performed. During pauses in the drilling and sampling process, in situ testing or other soil sampling methods can be performed through the hollow auger column below the lead auger assembly. At completion of the boring to the depth of interest, the hole may be abandoned or testing or monitoring devices can be installed. Hollow-stem auger drilling allows for drilling and casing the hole simultaneously, thereby eliminating hole caving problems and contamination of soil samples (**2**). The hollow-stem auger drilling and sampling method can be a satisfactory means for collecting samples of shallow unconsolidated subsurface materials (**2**). Additional guidance on use can be found in Refs. **2**, **3**, **4**, **5**, **6**.

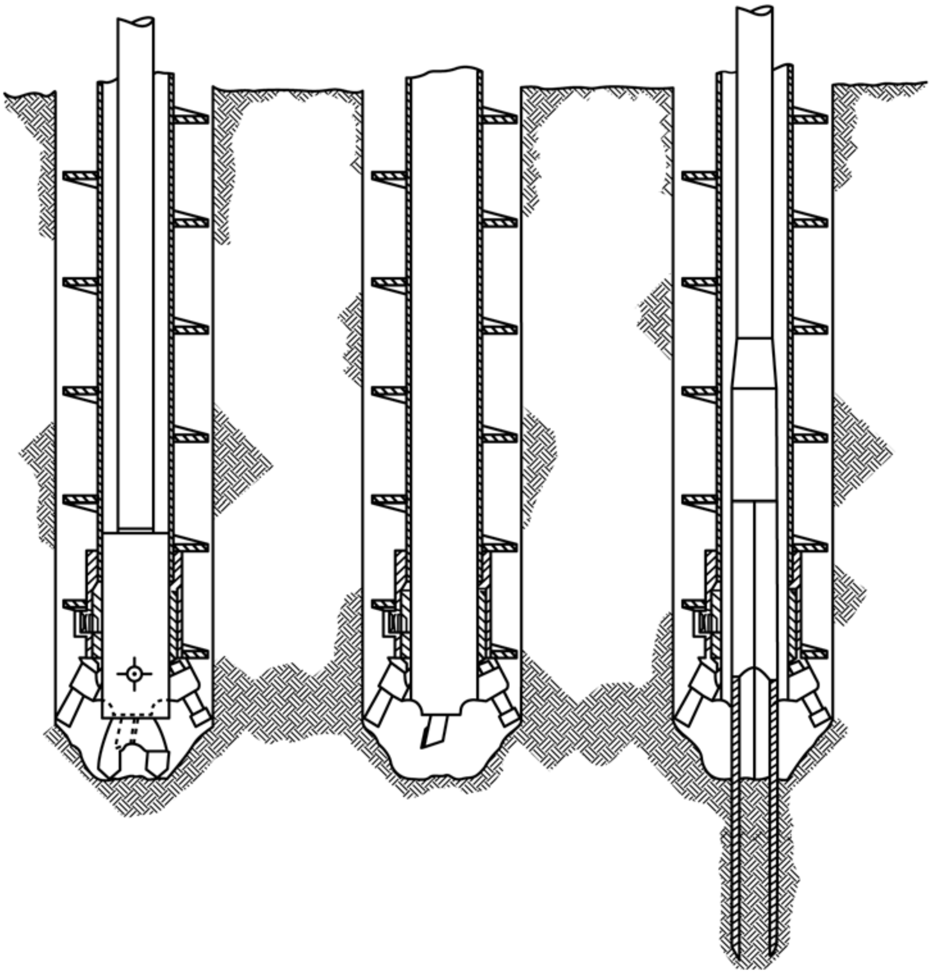

FIG. 5 Example of Drive Case Sampling Through HSA

4.2 Soil sampling with a double-tube hollow-stem sampling system provides a method for obtaining continuous or intermittent samples of soils for accurate logging of subsurface materials to support geotechnical testing and exploration. A wide variety of soils from clays to sands can be sampled. The sampling systems can be particularly effective in dry soft to stiff clayey or silty deposits but also can work well under saturated conditions. Saturated cohesionless soils such as clean sands may flow and cave during drilling (see Note 1). In many cases, the HSA soil core sampling system can produce very little disturbance to the sample and can provide samples for laboratory tests for measurement of selected engineering properties. Large-diameter soil cores, if taken carefully, can provide Class C and D samples as described in Practice D4220. The HSA systems can also provide disturbed samples of unsaturated sands and gravels with some structure preserved. Full 5-ft [1.5-m] long cores usually cannot be obtained in unsaturated sands due to increasing side wall friction between the dry sands and inside surface of the sample core barrel. Sample length of 2 to 2.5 ft. [0.60 to 0.75 m] is generally the limit of amount of sample that can be recovered in unsaturated sands before the friction between the sampler and the sand becomes too high and causes blocking or plugging of the sampler. Shorter large diameter core runs of 2.5 ft [0.75-m] with the 5-ft [1.5-m] sample barrel system, or with a 2.5-ft [0.75-m] sample barrel system, have generally proven to result in the best samples.

NOTE 1—Research on thin-wall piston sampling in clean sands indicates that in general it is impossible to obtain truly undisturbed samples of saturated clean sands. These soils can dilate or collapse upon insertion of a sampling tube. The hollow-stem auger double-tube system can only obtain partially disturbed samples of sands below the water table.

4.3 Hollow-stem auger drilling is considered a shallow drilling method with maximum depth of drilling of 200 to 300 ft (60 to 90 m) depending on torque and pull down/retract capacity of the drilling equipment and subsurface conditions of the formation(s) encountered. Saturated loose unconsolidated deposits further limit maximum depth that can be attained. HSA can act as casings set through unconsolidated surficial soils and drilling can be converted to other methods (see 2.5) for deeper drilling.

4.4 Drilling and soil sampling can be accomplished with a variety of HSA systems. Types of systems can be chosen depending on the advantages of handling, sampling requirements, and subsurface conditions. There are two basic types of systems. One type of system uses inner drill rods or hex rods connecting the sampler or pilot bit assembly to the surface for advancing and retrieving the sampler barrel or pilot

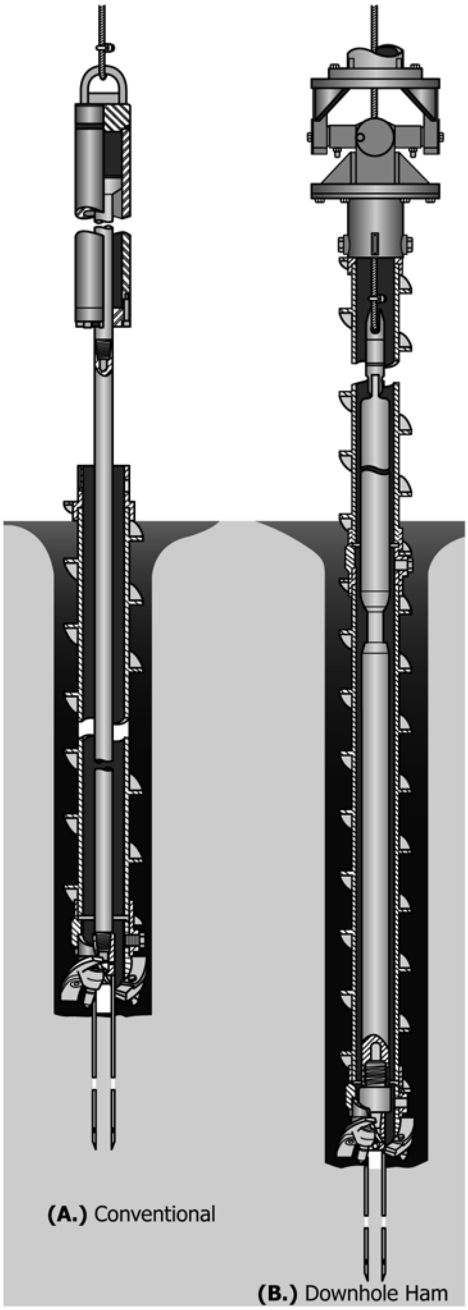

FIG. 6 In-Hole-Hammer and Conventional Drive Hammer

bit assembly (Fig. 1[6] and Fig. 2[5]). Another system uses a wireline latching system in the HSA column to lower, latch, and retrieve a core barrel or pilot bit assembly (Fig. 3[5]).

4.5 Double tube HSA sampling systems can be particularly advantageous for sampling water-sensitive soils, such as collapsible soils, since fluid is not used in the drilling process. Since no pressurized circulation medium is used during the drilling process, the possibility for hydraulic fracturing of formation materials and core contamination from drill fluids is reduced.

4.6 Difficulties in drilling may occur if cohesionless soils are drilled below the water table. Possibilities for sand lock or wedging of cuttings may occur (2). In cases where sands enter the HSA, water or drilling fluid may be added to the HSA column to provide hydrostatic balance or special pilot bit assemblies can be used (see 5.6). Problems may occur in getting the soil core barrel or pilot bit assembly back to the

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[6] Modified from Central Mine Equipment Company, 4215 Rider Trail North, Earth City, MO.

bottom of the HSA column. Highly saturated sands or liquefiable material may be drawn into the HSA by vacuum created when the sampler barrel or pilot bit assembly is initially pulled back through the cutter head of the lead auger assembly from the bottom of the borehole.

4.7 Consideration should be given to proper decontamination and cleaning of drilling equipment, hollow-stem augers, samplers, and soil coring components.

NOTE 2—The quality of the result produced by this standard 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 D3740 are generally considered capable of competent and objective sampling. Users of this practice are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

Practice D 3740 was developed for agencies engaged in the laboratory testing and/or inspection of soil and rock. As such, it is not totally applicable to agencies performing this practice. However, user of this practice should recognize that the framework of practice D 3740 is appropriate for evaluating the quality of an agency performing this practice. Currently there is no known qualifying national authority that inspects agencies that perform this practice.

5. Apparatus

5.1 Fig. 1 illustrates the components of a HSA used with a pilot bit for hole advancement using a center-inner rod system. Figs. 2 and 3 illustrate HSA equipped for soil sampling in either a rod-type or wireline system. Hollow-stem auger systems consist of rotating outer HSA and a cutter head assembly, with either a center pilot bit or a nonrotating inner sample barrel with a smooth cutting shoe.

5.2 *Hollow-stem Augers*—Each auger section of the HSA assembly consists of a cylindrical steel tube with continuous helical steel flights rigidly attached to the outer surface of the tube (see Fig. 1). Each hollow auger section has a coupling at each end for attaching additional auger sections at the top end to make up the articulated hollow-stem auger column. The bottom of the lead auger has a coupling attachment for the cutter head. Typical HSA inside diameters are 2¼, 3¼, 3⅜, 4¼, 4⅝, 6¼, 6⅝ in., and range up to 12¼ in. [50, 80, 85, 105, 115, 160, 170, and 300 mm]. Outside diameters of the auger flights range from 5 to 18 in. [125 to 450 mm]. Typical HSA double-tube sample inside diameters range from 2.25 to 6.85 [50 to 175 mm]. HSA are normally supplied in 5-ft [1.5-m] lengths. The helical auger flights are often hard surfaced for better wearing characteristics.

5.2.1 *Diameter Requirements*—The inside diameter of the HSA system is selected by considering sample size requirements, intermittent sampling and in situ testing tool size, and completion requirements. For intact sampling, larger-diameter systems generally produce less disturbance (**6**). For logging purposes, where a disturbed sample is sufficient, smaller diameters are selected. The inside diameter of the hollow stem must be large enough to insert intermittent sampling or in situ testing devices if used (sec 2.2 and 2.3). When using sampling methods such as split barrel, Method D1586, or thin-wall tube Test Method D1587, the inside diameter of the hollow-stem should be at least 0.25 in. [5 mm] larger than the sampler outside diameter or rod diameter, whichever is largest. If other drilling methods (see 2.5) are to be used, the inside diameter of the HSA drill string should be selected to accommodate those tools. If special completion is required, such as piezometer or well casing installation, the diameter should be large enough for placing completion materials. For example, if a 2-in. [50-mm] riser pipe is to be completed for shear wave velocity testing in accordance with Test Methods D4428/D4428M, consideration of clearance for tremie pipes may also increase diameter requirements. If the lead auger section contains a stabilizer ring, this clearance may govern available diameter for sampling, testing, or completion (see 5.4.1).

5.2.2 *Auger Connections*—Augers are connected using either locking bolts, drive pins, locking collars, or threaded connections. In some cases when drilling saturated soils, water entering the augers may cause difficulty with drilling or sampling. HSA may be used with O-ring seals or other sealing designs at the HSA connections to prevent leakage. Some HSA connection designs have compression seals and bolt caps to facilitate sealing between auger connections. This can prevent soil or water ingress through the auger connecting joints (in certain drilling conditions) and the accumulation of a high solids slurry in the bottom of the HSA column that may interfere with the latching system for retrieval and placement of sample barrel assembly by means of the wireline/overshot system

5.3 *Drive Cap*—The drive cap assembly (see Fig. 1) attaches to the uppermost HSA section and transfers rotary power and axial force from the drill rig to the auger drill string assembly.

5.4 *Lead Auger Section*—The lead auger has a hollow cutter head. The cutter head is attached to the lead auger of the hollow auger column and usually contains replaceable, abrasion-resistant cutters or teeth (see Fig. 1). As the hollow auger head is rotated, it cuts and directs the cuttings to the auger flights which convey the cuttings to the surface. The cutters can be made of hardened steel or carbide and in several designs. Cutter head types should be selected to effectively remove cuttings and minimize soil disturbance when sampling. The cutter head or cutter teeth, or both, should be replaced if worn or damaged.

5.4.1 If a wireline system is used, there can be an adapter coupling on top of the lead auger and may contain inside barrel grooves or recesses for latching systems for wireline tooling.

5.4.2 A stabilizer ring may be used (usually made of brass) in the end of the HSA cutter head opening. The stabilizer ring is machined to a close tolerance to be slightly larger than the outside diameter of the sample barrel or pilot bit. The actual opening of the end of the HSA column at the cutter head is smaller with this stabilizer ring than the normal designated inside diameter of the HSA being used. The stabilizer ring keeps the sample barrel centered in the middle of the HSA cutter head and prevents material that may interfere with the sample barrel remaining stationary from lodging around the barrel and shoe and between the full opening of the HSA cutter head. In some cases, in unstable soils the vacuum created during removal of the pilot bit through a stabilizer ring may produce sanding in. In these cases, provisions for venting may be required.

5.5 *Sampler or bit retrieval system:*

5.5.1 *Rod-type System* (Fig. 1 and Fig. 2)—The sampler or pilot bit can be inserted into the lead auger using a system of inner rods. The inner rods are typically AW, or NW size (**7**) or hex rods. Rods are supplied in the same lengths as the hollow-stem augers.

5.5.2 *Wireline system, In-hole-hammer* —The sampler or pilot bit can be inserted into the lead auger by using a free-fall wireline cable hoist capable of lifting and dropping the hammer weight down the hole within the HSA column to drive the sampler below the HSA column. This wireline method can also be used in conjunction with a drilling rig with an open spindle rotary head to allow the wireline and in-hole-hammer with the proper bit to act as a pilot bit assembly while advancing the HSA column. The weight of the hammer and pilot bit is allowed to float within the HSA column and advance with the cutter head and lead auger section to deter material from entering the HSA column.

5.5.3 *Wireline System, Double-tube HSA* (Fig. 3)—The sampler or pilot bit is raised and lowered using a wireline and latching mechanism. A wireline system may consist of a latching lead auger section, a locking or latching head assembly above the sample barrel or pilot bit, and an overshot (retrieving tool) that locks into the locking head assembly to hoist and lower the sample barrel or pilot bit assembly through the HSA column.

5.6 *Pilot Bit Assembly*—The pilot bit assembly can be a machined plug with a bit attached to the bottom to enhance cutting when used with the cutter head of the HSA and to keep material from entering the hollow-stem auger. Another version is a center auger with left-handed flighting to provide a downward spiral rotation in the middle of the HSA drill string. This left hand flighting keeps material from entering the HSA drill string forcing the parent material down and to the outside of the main auger. While the HSA drill string is rotating and drilling, the material displaced by the left hand flighting is conveying up along the outer flighting away from the cutter head to the surface.

5.7 *Hollow-stem Double-tube Auger Sample Barrel Systems*—The sampler is suspended in the HSA column and is retained in a stationary position. The head may be made with connections to a latching assembly including a bearing assembly. A bearing assembly helps prevent rotation of the sampler barrel and is especially important for intact sampling. In the wireline system the barrel is connected to a latching and hanger bearing assembly that locks into the HSA column (Fig. 3). In the rod-type system (Fig. 2) the bearing is located either down hole or at the top of the auger column and is connected to drill rods or hex rods extending to the top of the HSA column. The drill rod or hex rod string is connected through the auger drive adapter to the drill rig to provide a means of controlling rotation of the sampler.

5.7.1 The sample barrel may be of various sizes and lengths. The barrel may be used with or without liners. A split barrel without a liner is most often used for easy examination of disturbed soil cores while a barrel with a liner is most often used for preserving specimens for laboratory testing. The liners fit in the inside of the barrel to facilitate sample collection. The sample barrel and HSA are matched with respect to size. The actual sample diameter varies with different manufacturers. The sample diameter is controlled by the inside diameter of the cutting shoe. With some manufacturer's designs, the inside diameter of the cutting shoe varies depending upon the liners used in the sample barrel. To obtain samples with minimal disturbance, care must be taken to ensure a smooth transition from the insider diameter of the cutting shoe to the barrel or liners. There should be no gaps or upset surfaces in the inside clearance. A smaller inside diameter shoe can be used when coring swelling materials, such as stiff clays, to allow for the sample to swell inside the barrel without blocking. Core swelling may affect engineering properties determinations.

5.7.2 Sample barrels may be 5-ft [1.5-m] long, solid or split, or two 30-in. [0.75-m] barrels (solid or split), with a coupling to make a 5-ft [1.5-m] barrel. The 5-ft [1.5-m] barrel length matches the length of the lead HSA section. The shorter 2.5-ft [0.75-m] barrel may be used in place of the 5-ft [1.5-m] barrel for shorter sampling runs to reduce disturbance and to facilitate handling.

5.7.3 *Retainers*—Basket retainers are used, if necessary, to prevent the sample from falling out of the barrel during retrieval. They are generally used when sampling some wet clays and wet or dry sands and gravels. The retainers may affect the sample quality.

5.7.4 *Cutting Shoe and Lead Distance*—The sample barrel with cutting shoe is extended beyond the cutter head in varying increments. The shoe is set at or beyond the bottom of the cutter bits, or teeth. The extent of the distance the shoe is set beyond the cutter head is dictated by the stiffness of the material to be sampled (cored). When the sampler cutting shoe is extended beyond the cutter head, the cutting edge of the shoe is being forced down in front of the cutter head before the HSA cutter head cuts the soil away. The HSA column and cutter head is rotating around the double-tube HSA soil coring barrel as the drill rig applies down force and rotation to the HSA soil coring column. The softer the material, the greater the lead distance. The harder the soil, the shorter the lead distance. Adjusting the lead distance for the sample barrel shoe may be done by various methods. Some systems require adjusting the lead distance directly above the sample barrel assembly, some can be adjusted at the top of the HSA column. Examples of adjusting methods include the following: rod subs, adjustable hex extension with U-pins, threaded adjustment with locking nut, special HSA drive adapter with adjusting slots, or different shoe lengths. The length of extension may vary from the shoe being flush (even) with the cutter bits to as much as 6 in. [150 mm] or more.

5.7.5 *Liners*—The sample barrel may be fitted with liners. Liners are nomially one 5-ft [1.5-m] length or two 2½-ft [0.75-m] sections. The liners can be metal, stainless steel, or acrylic. Acrylic tubing provides for visual inspection of the material sampled. Clear liners can sometimes show detailed soil layering, but, in many cases, the core could be smeared or masked by the disturbance. If the purpose of the exploration program is detailed, logging the complete core should be inspected. Liners should be checked for roundness and wall thickness. Acrylic tubing is reusable but should be checked for cracks before reuse.

5.8 Auxiliary components of a HSA system are various devices such as auger connector wrenches, auger forks, hoisting hooks, hoisting assemblies, pipe vices, strap wrenches or chain wrenches, and fluid injection swivels or adapters (Fig. 4).

5.9 A drill rig is used to rotate and advance the auger column. The drill rig must be capable of producing controlled rotation, feed pressure, and feed rate. The drill rig should be capable of applying sufficient power and torque at a rotary velocity of 50 to 100 rev/min. The drill rig should have a feed stroke of at least the effective length of the auger sections plus the effective length of the auger couplings plus about 4 in. [100 mm]. As the HSA soil coring systems diameters increase, more torque and pulldown/retract capacities of the drill rig will be required. The subsurface conditions to be explored will also affect the torque and pulldown/retract capabilities required of the drill rig. Conditions such as depth to groundwater, cemented or very dense formations, loose sands and gravels, cobbles, cohesiveness of soil, and potential for saturated flowing conditions and heaving sands will affect the depth that can be explored with a drill of any given torque and pulldown/retract capability.

6. Drilling and Sampling Procedures

6.1 *General*—Several drilling approaches are discussed in the following sections. Hollow-stem auger drilling can be performed with a pilot bit to advance a boring. During pauses in drilling, sampling and field testing can be performed at the base of the augers. A section is also devoted to taking continuous or intermittent cores with the double tube auger soil coring method. Any combination of these drilling and sampling methods may be performed in a single boring.

6.2 *General Drilling and Sampling Considerations:*

6.2.1 *Site Setup*—Stabilize the drill rig, erect the drill rig mast, and attach an initial assembly of HSA components (Fig. 1) to the rotary drive of the drill rig. When erecting the mast, check above the drilling rig for overhead obstructions or hazards, such as power lines, prior to lifting the mast. Perform a survey of underground and all other utilities prior to drilling to evaluate possible hazards. Establish and document a datum for measuring hole depth. This datum normally consists of the ground surface, or a stake driven into stable ground surface, or a drilling deck if used. If the hole is to be surveyed later for elevation, record and report the height of the datum to the ground surface.

6.2.2 *Hole Starting*—Push the auger column assembly below the ground surface and initiate rotation at a low velocity. Good practice for starting a straight hole normally requires minimum rotation speed while maintaining firm downward pressure to avoid whipping and widening of the top of the hole (**1**). An auger guide or solid stem augers may be used (if available) to aid in starting the first auger to maintain a straight hole.

6.2.3 *Hole Advancement and Cuttings Return*—As the augers are rotating, apply down feed pressure to the HSA column to clean the hole and bring cuttings to the surface. Use rotation and penetration rates compatible with efficient cuttings returns. The use of excessive penetration rates faster than cuttings can be returned to the surface may result in the following: (1) cuttings which are packed into the auger flights, prohibiting newly penetrated materials from moving up the auger or, (2) forcing materials into the hole wall and increasing the chances of locking or binding of the HSA drill string. After advance of the auger string to the desired incremental depth in a hole advancement mode with pilot bits, rotation is normally continued without penetration for a time period long enough to ensure circulation of the cuttings up the flights.

6.2.4 *Pauses in Drilling*—Sampling or in situ testing can be performed at any depth by interrupting the advance of the augers and stopping rotation. During pauses in drilling the HSA drill string can be held in place with an auger fork inserted at the surface. The fork will suspend the augers and prevent settling.

6.2.5 *Drill Hole Advancement*—Drilling at greater depths is accomplished by attaching additional hollow-stem auger sections to the top of the previously advanced HSA column assembly. If drilling with the pilot bit assembly in the HSA column using a wireline/overshot system; HSA sections can be added to the top of the HSA column without pulling the pilot bit assembly or adding any drill rods to advance the hole to a predetermined depth. When using the rod-type system, add a new inner rod along with an additional hollow-stem section.

6.2.6 *Cuttings Removal and Classification*—Periodically remove cuttings from around the top of the auger column, typically with a shovel. Soil cuttings above the groundwater may be representative of deposits being penetrated if proper conveyance up the auger flight is maintained. Cuttings from below the groundwater surface are likely to be mixed from varying formations in the hole and are usually not representative of deposits at the end of the auger. If cuttings are sampled for classification (Practice D2488) and relation to lithology, report and document the intervals sampled.

6.2.7 *Recording of Drilling Information*—Record depths, progress, and location of samples or testing as drilling progresses. Monitor down feed pressures, rotation rates, and cuttings return during drilling. Note any indications of binding or locking of the augers during drilling. Observe the ease or difficulty of advancing the HSA drill string during drilling as it relates to the geologic strata being penetrated. Document occurrences of any significant abrupt changes and anomalies, which occur during drilling. As drilling progresses, note and document drilling procedures such as water or drilling fluid added and losses, and intervals where equipment is changed or drilling method is changed.

6.3 *Hole Advancement with Pilot Bit:*

6.3.1 *General Considerations*—Following an increment of drilling, removal of the pilot bit assembly should be performed slowly so that the entrance of material into the bottom of the HSA column is minimized prior to sampling or installation of testing devices. The success of pilot assembly removal without disturbance will depend upon the following several principal factors: (1) the character of the soil at the auger head, (2) the water levels inside and outside the HSA column prior to removal of the pilot assembly, (3) the type of pilot assembly used, and (4) the speed of removal. As drilling progresses in saturated, granular materials, it usually becomes progressively more difficult to maintain the stability of the material below the auger column because of unbalanced hydraulic heads between outside groundwater and inside the hollow stem. The stability of the material below the auger head may be enhanced by using special pilot assemblies, or maintaining fluid level in the HSA column during auger advancement and during retrieval of the pilot bit assembly (Fig. 4). Under some circumstances it may be effective to drill without using a pilot assembly. If a pilot assembly is not used, however, and water or drilling fluid is not injected into the auger column simultaneously with advancement, material often will enter the hollow stem of the auger column. In some cases when drilling in saturated granular materials, a screened lead auger section may be used to help deter blow-in. The screened auger allows formation water to flow into the HSA column to help prevent water level differences and maintain a hydrostatic balance.

6.3.2 *Knock Out Plugs*—If sampling or in situ testing is not required during drilling for installation of an instrumentation device, the boring can be advanced (for some geologic conditions) using an expendable, knock-out plate or plug, or flexible center plug instead of a pilot assembly. Knock-out plates or plugs usually remain in the ground close to the instrumentation device. It may be necessary to fill or partially fill the auger stem with water or drilling fluid to prevent blow-in, or sanding in at the time of plate or plug removal. An auger head with an integral, hinged aperture cover or flexible center plug can be used to deter entrance of materials into the auger stem.

6.3.2.1 *Flexible Plug*—The flexible center plug system uses a plastic basket with flexible finger, inverted in the HSA column at the cutter head. The flexible center plug allows split spoon sampling through the flexible fingers and helps prevent water-bearing sands from entering the HSA column while advancing the augers.

6.3.3 *Locking Problems, Blow-in*—There may be instances, during insertion of the pilot bit, when difficulties are encountered in locking of the bit and getting it back to the bottom of the HSA column. If material is present in the HSA, it may be necessary to lift the HSA column to engage the locking mechanism. The action of lifting the hollow-stem augers can cause subsurface disturbance. Blow-in can be minimized by venting or the use of fluids in the hollow-stem auger.

6.4 *Intermittent Sampling or Field Testing*—Sampling or field testing can be performed at any depth by interrupting the advance of the augers and stopping rotation. Soil sampling is usually accomplished by either of the following two methods: (1) drive, push, or core sampling or (2) soil coring using HSA (see 6.5)

6.4.1 Soil sampling and in situ testing methods, some of which are listed in 2.2 and 2.3, are often used to obtain samples or perform tests at the base of the boring. Slowly remove the pilot assembly, if being used, and insert a sampler or testing device through the hollow stem of the auger column. The sampled or tested depth should be compared to the clean-out depth if the sampler is attached to the rods. This comparison is accomplished by resting the sampler or testing device at the bottom of the hole and comparing the apparent depth with the clean-out depth. If cuttings, cave in material, or sanding in is apparent, these conditions should be noted. Sampler barrels which drop past the cutting teeth of the augers may indicate excessive disturbance at the base of the drill hole. If there is material in the HSA column that does not allow for the sampler to rest at the augured depth below the end of the HSA bit, it may be necessary to allow the material to fall out of the HSA column. Actual depth of the sampler in relation to the bottom of the hole should be considered, not where the bottom of HSA string is setting. If in situ testing is performed below the base of the borehole, check for disturbance below the base of the borehole, and advance the testing instrument well in advance of any disturbance at the base of the boring.

6.5 *Continuous or Intermittent Soil Sampling with the Double-Tube HSA Soil Coring System:*

6.5.1 *Intermittent Sampling*—The pilot bit can be replaced at any time with the double-tube HSA core barrel assembly and samples taken at desired depths. Samples can be taken at selected intervals of concern and based on change of soils encountered.

6.5.2 *Continuous Sampling*—In the continuous soil sampling process a sampler barrel is used during hole advancement. Remove and replace barrels as drilling progresses. Detailed stratigraphic logging and sampling for geotechnical exploration may be obtained.

6.5.3 *Hole Advancement and Cuttings Return*—When using the double-tube HSA soil coring system, typically perform drilling at a rotary velocity of about 50 to 100 rev/min. Advance the system to a depth equal to the length of the sample barrel, or where intermittent sampling or in situ testing is required, or until the cutter head assembly is advanced to the desired depth. When using the HSA double-tube soil sampling system, rotational speeds and rate of down feed may vary with the degree of resistance of the material being sampled. As the augers are rotating, apply down feed pressure to the HSA column. Cut away the material from around the inner barrel by the cutter head. The rotating action of the cutter head around the sampler barrel cutting shoe allows the inner sample barrel to push/core down over the column of material filling the inner barrel. Cuttings are directed to the HSA flights and conveyed to the surface by the rotating HSA column. Rotation to clean cuttings from the hole should be limited in the HSA double-tube soil sampling mode to prevent sample from being vibrated (loosen) out of the sample barrel. Rotation for borehole cleaning can be accomplished after removal of the HSA sample barrel prior to the beginning of the next sampling increment.

6.5.4 *Selection of HSA Sampling Barrel*—Depending on the exploration needs, different types of sample barrels may be used. Split barrels are often used for lithologic logging and soil classification. Split barrel samples are often taken in 5-ft [1.5-m] lengths. Sample length can be reduced to reduce disturbance. Intact samples consistent with Practice D4220, Groups C and D are often taken in liners. For intact sampling, it is important to adjust the clearance ratio and the lead distance to reduce disturbance. In general, satisfactory intact samples are usually at least 3 in. [75 mm] in diameter and larger and sampling length is reduced to 2.5 ft [0.75 m].

6.5.4.1 *Considerations for Intact Sampling:*

(1) Intact Sampling—If the goal of the exploration program is to obtain samples with minimal disturbance, lead distance and cutting shoe clearance ratio must be adjusted for optimum sample recovery. This will be a trial-and-error process. The ultimate goal in intact sampling is to achieve core recovery as close to 100 % as possible with a sample that just fills the liner.

(2) Lead Distance Optimization—The lead distance of the core barrel cutting shoe should be adjusted to obtain optimum sample recovery (see 5.7.4). With wireline systems, the lead distance can be checked by vertically suspending the entire lead auger so that the inner barrel assembly can hang freely and then latch inside the lead auger.

(3) Clearance Ratio Optimization—The clearance ratio of the cutting shoe should be optimized for the soil formations to be sampled (see 5.7.4). For intact sampling, hold the liners in place in the sample barrel assembly by the cutting shoe which threads onto the end of the barrel. Cutting shoes are machined with different bit clearance ratios (see 3.2.2). Cutting shoe bit clearance ratios should be checked prior to use. Guidelines for bit clearance ratios for different soil types are as follows:

Bit clearance ratio %	Material
0 to ½	sands with little or no fines
½ to 1	silty sand, clay, silt
1 to 1½	expansive clay, shales, claystones

6.5.5 *General HSA Sampling Considerations*—When the bit or sample barrel assembly is removed and replaced, check the depth to the base of the boring where the end of the string rests and compare to the clean-out depth to evaluate hole quality. Hole depth is recorded by knowing the length of the auger assemblies and the actual amount of extension of the end of the sample barrel beyond the end of the HSA cutter head. This will facilitate accurate depth calculation of the sample taken and comparison of its position relative to the established surface datum. Excessive slough or cuttings within the hollow stem are undesirable and should be corrected by changes in technique, changes in equipment, or repair of equipment. Carefully record the start and stop depths of the sampling interval. Calculate the recovery. Sample recovery is the most important indicator of sample quality. To enhance sample recovery, the rate of penetration should be no greater than the speed at which the HSA cutter head is able to cut; that is, the downward force on the sampler barrel assembly should be a minimum. Using excessive down feed rate and pressure can disturb the core. The speed of rotation should be limited to that which will not tear or break the soil during sampling (generally this varies from 40 to 125 rev/min). Important considerations for optimum sampling are lead distance and clearance ratio or head space of the cutting shoe and prevention of inner barrel rotation (**5**). Extension of the sample barrel shoe beyond the HSA cutter head depends on the soil type and should be the least amount which will result in a fully filled sample barrel (see 5.7.4).

6.5.6 *Sample Barrel Recovery and Reinsertion*

6.5.6.1 *Rod Systems*—After drilling the length of the sample barrel, stop, secure, and disconnect the HSA column from the drill rig drive connector. Disconnect the connecting rods inside the HSA column that may be attached to or extend through the rotary spindle of the drill rig. Remove the drill rotary head off the hole and hoist the rods connecting the sample barrel out of the HSA column. Replace the barrel by attachment of a new barrel to inner rods which are lowered back into the hollow-stem column and secured through the drive cap or rotary spindle attachment.

6.5.6.2 *Wireline Systems*—If a wireline/overshot system is used, after disconnecting the drill rig rotary drive connector from the top of the HSA column and removing the rotary head, lower the overshot retrieval tool down the HSA column to latch into the latching head on top of the sample barrel assembly. After the overshot is locked into the latching head assembly, hoist the sample barrel out of the HSA drill string on a wire cable attached to a hydraulic winch on the drill rig. Remove the sample barrel and connect another sample barrel assembly to the latching head and hoist and lower down the HSA column by means of the overshot and wireline assembly until the latching head locks into the latching connector box (part of the HSA column above the lead HSA and cutter head). Release the overshot from the locking head above the sample barrel and hoist to the surface.

6.5.6.3 *Reinsertion*—Add the next HSA section to the top of the HSA column and connect to the drill rig rotary spindle. Connect inner connecting rods (if not the wireline system) to or through the rotary spindle before the auger drive adapter is connected to the top of the HSA column. In special cases, such as in loose sand, lift the HSA drill string by the drill rig to remove the auger holding fork, and then lower to the bottom of the hole where the previous sample stopped. Rotate and push the HSA column to begin the soil coring procedure again.

6.5.6.4 There may be instances, during insertion of the sample barrel, when difficulties are encountered in locking of the barrel and returning it back to the bottom of the HSA column. If material is present in the hollow-stem auger it may be necessary to lift the HSA column to engage the locking mechanism. This will allow the sample barrel assembly to fall to the bottom of the HSA column, forcing out the slough and reach the locking position. When the sample barrel assembly is connected to drill rods or hex rods to the top of the HSA column, the rods may have to be pushed with the hydraulics of the drill rig to the bottom of the HSA column to reach the proper depth to begin the next soil coring interval. When drilling in 5-ft [1.5-m] intervals, a shorter HSA coring interval may have to be run to allow for slough material. If 2.5-ft [0.75-m] sample intervals are being used, use of a 5-ft [1.5-m] barrel will allow for accommodation of slough. Note and record sample intervals, recovery, and any slough, cuttings, fluid exposure, or evidence of rotation contained in the samples recovered.

6.5.7 *Sample Testing and Handling*—First measure samples for recovery upon retrieval. Handle and transport samples in accordance with Practice D4220. Classify soil samples in accordance with Practice D2488. Samples from split liners can be classified and stored in jars or bags. Report the locations of specimens removed for testing. Collect material for classification of samples in liners to be stored for laboratory testing from the ends of the sample. Trim and seal the sample ends for preservation. The average soil in-place unit weight can be determined (**6**). Moisture specimens can be obtained from the cutting shoe or liner trimmings. Report results and locations of any tests performed on cores such as Torvane or pocket penetrometer.

7. Drill Hole Monitoring and Completion

7.1 *Monitoring*—It is advisable to monitor groundwater levels, if present, in the drill hole during and after drilling. Groundwater elevations should be measured and documented during drilling. If groundwater is not encountered or if the level is of doubtful reliability, such information should also be documented.

7.2 *Installation of Instrumentation Devices:*

7.2.1 Instrumentation devices, such as piezometers or inclinometers (see 2.4) are installed using HSA following a three-step procedure: (1) drilling, with or without sampling, (2) removal of the pilot assembly, if being used, and insertion of the instrumentation device, and (3) incremental removal of the hollow auger column as completion materials such as backfill or grout is installed as required.

7.2.1.1 If materials enter the bottom of the auger hollow stem during removal of the pilot assembly, they can be removed with a bailer, other device, or fluid rotary drilling (see 2.4) .

7.2.1.2 Completion materials such as bentonite pellets, granules and chips, and grouts should be selected and installed to specific subsurface instrumentation requirements.

7.3 *Other Completion Methods*—Depending on requirements of the exploration it may be necessary to perform special installations with protective casings or to the backfilling. An example of special completion is for the seismic crosshole test (Test Methods D4428/D4428M) which requires grouted PVC casings. These installations are also performed using the three-step method in 7.2.1. Several methods are available for grouting of casings. It is desirable to use injection grouting where injection is performed at the base of the boring, and grouts are pumped up the annulus until they reach the surface indicating a continuous seal.

7.4 *Drill hole Abandonment*—If there are no needs for special completion or instrument installations for the drill hole, it should be backfilled for completion. The method of backfilling for abandonment depends on the requirements of the exploration program and should be specified as part of the program. Certain state and local regulations may apply. At a minimum, the surface of the hole should be backfilled to reduce potential hazard to those at the surface. In cases where the hole is to be backfilled completely, the condition of the hole should be evaluated and documented. Any zones of caving or blocking which preclude complete backfilling should be documented. Backfilling can be performed by addition of backfill materials from the surface or through injection by tremie pipes. When backfilling from the surface, either cuttings spoil, (only if suitable for replacement) bentonite pellets or granules, or select materials may be added. If complete backfilling is desired using surface methods, use of uniform backfill materials such as bentonite pellets or granules will reduce the possibility of bridging. The hole can be probed to test for bridging. The tremie methods ensure the best backfilling and should be performed when exploration plans require assurance of complete backfilling. Tremie methods consist of placing a small-diameter grout pipe near the base of the drill hole and pumping either cement or bentonite grouts to the surface while displacing any drill hole fluid. The tremie pipe is withdrawn in increments, but the tip is maintained below the grout surface. Typical grout consistencies depend on equipment and the needs of the exploration program. Typical grout mixtures are given in Practice D5092 and Test Methods D4428/D4428M.

8. Report

8.1 Report general information in accordance with Guide D5434 of "Subsurface Explorations of Soil" and identified as necessary and pertinent to the needs of the exploration program. Information is normally required for the project, exploration type and execution, personnel performing the drilling and preparing the drill log, drilling equipment and methods, subsurface conditions encountered, groundwater conditions, sampling events, and installations.

8.2 Other information in addition to that mentioned in Guide D5434 should be considered if deemed appropriate and necessary to the requirements of the exploration program. Additional information should be considered as follows:

8.2.1 *Drilling Methods:*

8.2.1.1 Report description of the hollow-stem auger system including the head, drive, and pilot assemblies. Provide information on drill hole and sample sizes. Note intervals of equipment change or drilling method changes and reasons for change.

8.2.1.2 Report type, quantities, and locations of use of additives such as water added to the hole. If changes to the circulating medium are made, such as addition of water, the depth(s) or interval(s) of these changes should be documented.

8.2.1.3 Report descriptions of down-feed pressures, rotation rates, and cuttings returns over intervals drilled. Note locations of loss of cuttings return and probable cause. Note any indications of binding or locking of the augers during drilling. Observe the ease of drilling during advancement as it relates to the geologic strata being penetrated. Document occurrences of any significant abrupt changes and anomalies in drilling conditions which occur during drilling.

8.2.1.4 If blow-in or sanding-in is evident in the HSA column, note occurrences and the amount. As the drilling progresses, note and document drilling procedures such as cuttings return, water added and losses, and intervals where equipment is changed or drilling method is changed.

8.2.2 *General Sampling Information:*

8.2.2.1 When core sampling or intact sampling at the base of the boring, report any unusual condition of the base of the boring prior to sampling when inserting the sampler and report any slough or cuttings present in the recovered sample.

8.2.2.2 If cuttings are sampled for classification and relation to lithology, report and document the intervals sampled.

8.2.2.3 During insertion of the continuous sample barrel note any difficulties in locking of the barrel. Note any disturbances or evidence of rotation observed in the samples recovered.

8.2.3 *General In-situ Testing Information:*

8.2.3.1 For devices testing or seating at the drill hole wall, report any unusual conditions of the drill hole wall when installing testing devices such as inability to seat pressure packers.

8.2.4 *General—Completion and Installations*—A description of completion materials and methods of placement, approximate volumes placed, intervals of placement, methods of confirming placement, and areas of difficulty or unusual occurrences.

8.3 Record as a minimum the following sampling data as follows:

8.3.1 Record all depths and elevations to the nearest 0.1 ft [0.03 m] or better. Record sample lengths to the nearest 1 in. [25 mm] or better.

8.3.2 *Sampling:*

8.3.2.1 Report depth interval sampled, sample recovery length and percent, classification, and any other tests performed, such as moisture or soil in-place unit weight determinations.

8.3.3 *In situ Testing:*

8.3.3.1 For devices which were inserted below the base of the drill hole, report the depths below the base of the hole and any unusual conditions during testing.

9. Keywords

9.1 continuous sampling; double-tube auger; drilling; hollow-stem augers; soil coring; soil sampling; subsurface exploration

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Sonic Sampling with

SingleWall and DualWall CoreBarrel

Feel the sonic vibe!

SonicSampDrill

a Royal Eijkelkamp Company

SingleWall and DualWall CoreBarrel

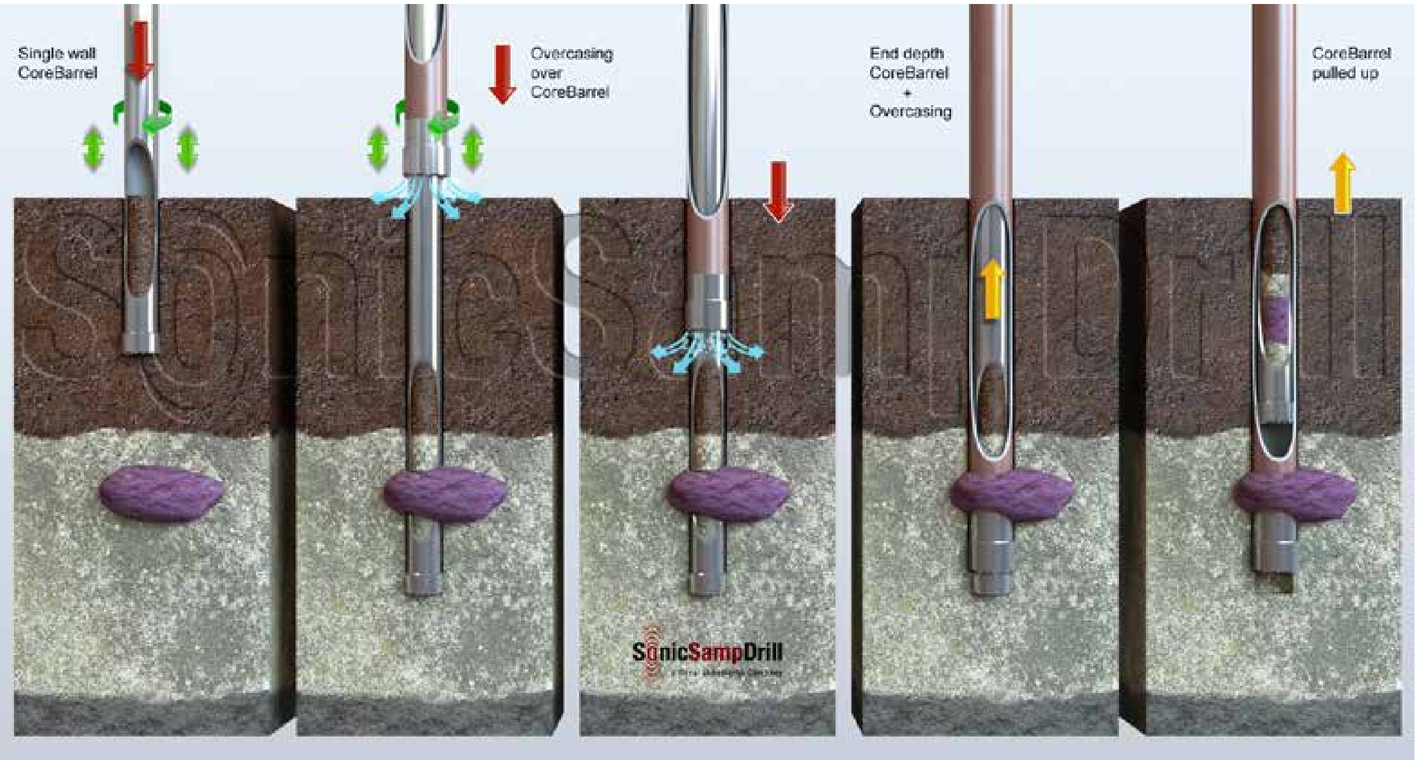
Do you need:

- high recovery rates with long and large samples?
- high speed sample production?
- high quality samples of mixed geology?
- long samples with low disturbance, even from coarse sand?
- samples taken from difficult types of rock?

Sampling hard formations

With other formations than sand, loam, peat or clay, our CoreBarrel is the right choice in combination with our sonic rigs. You combine vibration with rotation to allow the tungsten carbide-buttoned coring shoes to cut through the harder formations.

How does it work:

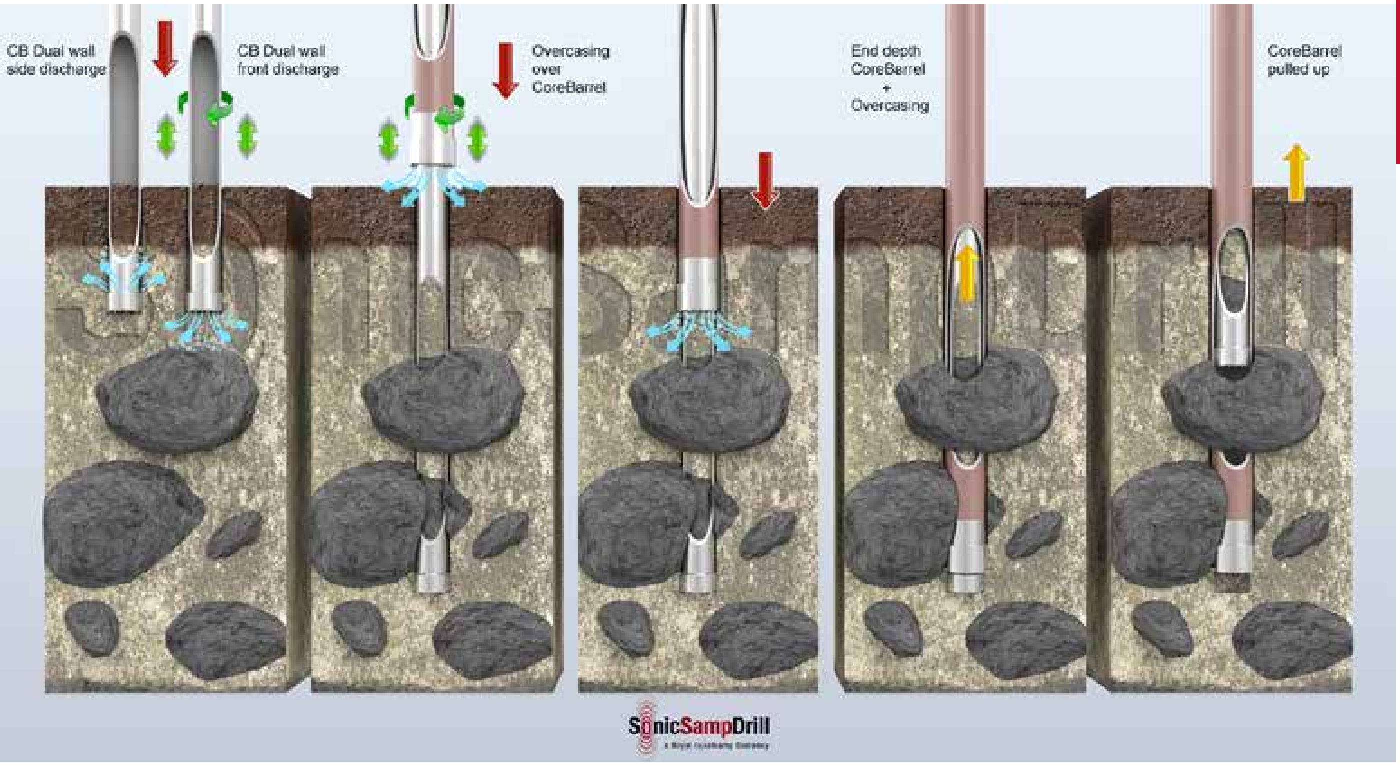


You can use the SingleWall and DualWall CoreBarrel for:

- **Environmental sampling:** You can accurately and rapidly locate impermeable layers, describe an undisturbed soil profile and take sub-samples for physical and chemical analysis.
- **Foundation research:** You can take cost-effcient and accurate samples with A3/B3 (ISO 22475-1:2006) quality to large depths.
- **Remediation drilling, well installations and cold-heat exchanging systems:** In one run you can take a sample for profile description and if required, install a well.
- **Archaeological sampling:** You can rapidly take samples of a large area in a dense grid on archaeological remains.
- **Off-shore sampling of water bottoms:** In highly mixed geology, you can take long, practically undisturbed cores.
- **Pre-investigation of dewatering projects:** You can do very rapid soil profiling, followed by the installation of a well if required.
- **Mineral sampling:** Highly productive soil sampling in mixed geology with accurate layer thickness analysis and sample composition.

Sampling rock

The DualWall CoreBarrel is designed to take cores from rock and very hard layers. This type of CoreBarrel allows you to core and flush at the same time. The flushing medium does not damage or flush the sample itself, because the medium is led through the annular space between the two barrels. The CoreBarrel is available with side and front discharge bits. It has proven to provide excellent samples in hard overburden, mixed rock layers and bedrock.



Extremely straight boreholes

The sonic drilling method creates an extremely straight borehole, making it an optimal technology for the installation of instrumentation and monitoring equipment. Drilling contractors use sonic technology to install inclinometers that monitor the formation and help mining operators to know whether the ground is subsiding or moving, so they can predict dam failure before it occurs.

Feel the

sonic vibe!

SonicSampDrill
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Core Barrel specifications

	SingleWall	SingleWall	DualWall	DualWall
Core Barrel	**3”**	**4”**	**68**	**89**
Sample diameter	76,2 mm	101 mm	65 mm	89 mm
Sample length	2 m	2 m	2 m	2 m
Core Catcher	yes	yes	yes	yes
Casing size	5,5”	6,5/8”	5,5”	6,5/8”

What do others say about the SingleWall and DualWall CoreBarrel?

Theo Berkhout, Boskalis, Surinam:

“We were searching for a supplier of sonic rigs. SonicSampDrill stood out because of the innovative approach of this drilling technique. We purchased the CompactRotoSonic crawler, AquaLock system and Dualwall CoreBarrel. In combination with sonic drilling, the DualWall CoreBarrel offers us the possibility to sample in harder foundations like weathered rock.

With a minimum of flushing agents, we get maximum recoveries at an unsurpassed drilling speed! SonicSampDrill people make sure you get the very best solution for your specific drilling challenges. Their technique is very progressive and we are happy with the results of our rig.”

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Let us carry out your pilot projects!

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Royal Eijkelkamp
Earth Sampling Group

Standard Operation Procedure #25:
Subsurface Exploration: Test Pit Excavation and Sampling

The protocol set forth in this Standard Operating Procedure (SOP) outlines the required field procedures for the collection of subsurface data and soil samples by excavating test pits.

Details regarding the sampling objectives, design, and quality assurance (QA) requirements are provided in the Work Plan; the procedures outlined here will be performed in compliance with the Work Plan.

Geotechnical Drilling and Sampling

The procedures to be followed for collection of subsurface data and soil samples are presented below.

A. Materials:

The following materials will be available, as required, during test pit excavation and sampling:

- Backhoe/excavation equipment;
- Personal protective equipment as required by the Health and Safety Plan (HASP);
- Real-Time Kinematic (RTK) GPS survey equipment;
- Field logbook and test pit logs;
- Indelible black ink pens and markers;
- Clear, waterproof tape;
- Appropriate sample containers (sample jars, plastic zip-top bags, 5-gallon buckets with lids, etc.);
- Stainless steel and/or Teflon-lined spatulas and pans, trays, bowls, trowels, or spoons;
- Labels and appropriate forms/documentation for sample shipment;
- Cleaning supplies;
- Insulated cooler(s) and waterproof sealing tape;
- Sample chain-of-custody forms;
- Bags of ice or “blue ice” packs;
- Nitrile or appropriate gloves;
- Paper towels;
- Small hand tools including wrenches, hammers, and screw driver; and
- 6 foot field tape.

B. Procedures

Subsurface data and soil samples will be collected using standard test pit excavation methods. Information will be collected at designated locations. The procedures for test pit excavation and sampling are provided below:

B-1. Preparation

1. Review Work Plan, HASP, and project plans before initiating test pit excavation and sampling activities.

2. Don the appropriate personal protective equipment (PPE) as indicated in HASP.

3. Use RTK surveying techniques to navigate excavation equipment to the test pit location(s).

4. Locate test pit location(s) in accordance with project documents and document pertinent information in the appropriate field logbook. When possible, reference locations to existing site features such as structures, bridges, docks, etc. Locations of proposed test pits may be modified in the field based on conditions encountered at the time of excavation, including, but not limited to equipment access limitations, to avoid obstructions such as existing underground or overhead utility lines, rocks/boulders, overhanging trees, and/or for other specific reasons identified in the field. The as-excavated locations will be located as close as practicable to the proposed locations. Should test pits need to be relocated, the reason(s) will be documented in field notes and updates provided to office staff as necessary.

5. Prepare area to perform sample collection activities. Sample collection will be performed at a safe distance from all heavy equipment, or as determined by the heavy equipment operator(s) and/or the CDM Smith field representative.

6. Prepare all drums for collection of waste material if determined necessary.

B-2. Test Pit Excavation

The following general steps will be followed when excavating test pits. Extreme care must be taken when working around open excavations. Maintain safe distances from test pit sidewalls to avoid injury should a sidewall slough back into the excavation. **Unless otherwise stated in the HASP, no personnel will enter the test pit.**

1. At the direction of the CDM Smith field representative, the backhoe will excavate the test pit in increments.

2. Backhoe operator will take care to separate distinctly different materials when stockpiling excavated material.

3. Test pit excavations will cease for closer observation if any of the following occurs:

    a. Distinct changes in stratigraphy or materials;

    b. Odors;

    c. Groundwater fluid phase contaminants; or

    d. Buried materials, especially containers.

4. Test pit excavations will cease at the direction of the CDM Smith field representative for sample collection or closer observation of test pit and excavated materials.

B-3. Sample Collection

The following general steps will be followed when collecting all subsurface soil samples:

1. Use a clean stainless steel or Teflon-lined trowel or spoon to collect sufficient material to fill sample containers.

2. Fill the sample containers directly from the sampling device, removing sticks, grass, etc., from the sample. Additional sample containers may be required to obtain enough material.

3. Immediately secure caps/seal the sample container(s).
4. Label container with appropriate identifying information.
5. Record samples in the field logbook.

B-4. Test Pit Decommissioning

The following general steps will be followed when decommissioning and backfilling a test pit:

1. Backfilling will occur in increments. The backhoe operator will take care to backfill distinctly different materials to conform to the soil layers observed during excavation.
    a. Backfilling will occur in approximately 12-inch lifts and material will be compacted after each subsequent lift is completed and before continuing with the next 12-inch lift.
    b. If soils are not suitable for use as backfill, soils will be drummed as indicated in the SOP#21 Drilling Spoils Handling and Disposal Protocol.
2. Decontaminate excavation and sampling equipment after decommissioning each test pit location to minimize cross contamination.

C. Other Requirements

C-1. Field Data

The CDM Smith field representative will record activities and test pit data in a field logbook and test pit log. Representative photographs will be taken of test pits and soils encountered. The following are requirements for recorded data in the field logbook and test pit log, at a minimum:

- Plan and profile sketches of the test pit showing materials encountered, the depth of material, and sample locations.
- Sketch of the test pit and distance and direction from permanent, identifiable location marks as appropriate.
- A description of the material removed from the excavation. Soil shall be described in accordance with the Modified Burmister Soil Classification System and the Unified Soil Classification System (ASTM D2487).
- A record of the samples collected.
- The presence or absence of water in the test pit and the depth encountered.
- Photographs depicting the before and after excavation of each proposed test pit area.
- Other readings or measurements taken during the excavation.

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METHOD 6200

FIELD PORTABLE X-RAY FLUORESCENCE SPECTROMETRY FOR THE DETERMINATION OF ELEMENTAL CONCENTRATIONS IN SOIL AND SEDIMENT

SW-846 is not intended to be an analytical training manual. Therefore, method procedures are written based on the assumption that they will be performed by analysts who are formally trained in at least the basic principles of chemical analysis and in the use of the subject technology.

In addition, SW-846 methods, with the exception of required method use for the analysis of method-defined parameters, are intended to be guidance methods which contain general information on how to perform an analytical procedure or technique which a laboratory can use as a basic starting point for generating its own detailed Standard Operating Procedure (SOP), either for its own general use or for a specific project application. The performance data included in this method are for guidance purposes only, and are not intended to be and must not be used as absolute QC acceptance criteria for purposes of laboratory accreditation.

1.0 SCOPE AND APPLICATION

1.1 This method is applicable to the in situ and intrusive analysis of the 26 analytes listed below for soil and sediment samples. Some common elements are not listed in this method because they are considered "light" elements that cannot be detected by field portable x-ray fluorescence (FPXRF). These light elements are: lithium, beryllium, sodium, magnesium, aluminum, silicon, and phosphorus. Most of the analytes listed below are of environmental concern, while a few others have interference effects or change the elemental composition of the matrix, affecting quantitation of the analytes of interest. Generally elements of atomic number 16 or greater can be detected and quantitated by FPXRF. The following RCRA analytes have been determined by this method:

Analytes	CAS Registry No.
Antimony (Sb)	7440-36-0
Arsenic (As)	7440-38-0
Barium (Ba)	7440-39-3
Cadmium (Cd)	7440-43-9
Chromium (Cr)	7440-47-3
Cobalt (Co)	7440-48-4
Copper (Cu)	7440-50-8
Lead (Pb)	7439-92-1
Mercury (Hg)	7439-97-6
Nickel (Ni)	7440-02-0
Selenium (Se)	7782-49-2
Silver (Ag)	7440-22-4
Thallium (Tl)	7440-28-0
Tin (Sn)	7440-31-5

Analytes	CAS Registry No.
Vanadium (V)	7440-62-2
Zinc (Zn)	7440-66-6

In addition, the following non-RCRA analytes have been determined by this method:

Analytes	CAS Registry No.
Calcium (Ca)	7440-70-2
Iron (Fe)	7439-89-6
Manganese (Mn)	7439-96-5
Molybdenum (Mo)	7439-93-7
Potassium (K)	7440-09-7
Rubidium (Rb)	7440-17-7
Strontium (Sr)	7440-24-6
Thorium (Th)	7440-29-1
Titanium (Ti)	7440-32-6
Zirconium (Zr)	7440-67-7

1.2 This method is a screening method to be used with confirmatory analysis using other techniques (e.g., flame atomic absorption spectrometry (FLAA), graphite furnance atomic absorption spectrometry (GFAA), inductively coupled plasma-atomic emission spectrometry, (ICP-AES), or inductively coupled plasma-mass spectrometry, (ICP-MS)). This method's main strength is that it is a rapid field screening procedure. The method's lower limits of detection are typically above the toxicity characteristic regulatory level for most RCRA analytes. However, when the obtainable values for precision, accuracy, and laboratory-established sensitivity of this method meet project-specific data quality objectives (DQOs), FPXRF is a fast, powerful, cost effective technology for site characterization.

1.3 The method sensitivity or lower limit of detection depends on several factors, including the analyte of interest, the type of detector used, the type of excitation source, the strength of the excitation source, count times used to irradiate the sample, physical matrix effects, chemical matrix effects, and interelement spectral interferences. Example lower limits of detection for analytes of interest in environmental applications are shown in Table 1. These limits apply to a clean spiked matrix of quartz sand (silicon dioxide) free of interelement spectral interferences using long (100 -600 second) count times. These sensitivity values are given for guidance only and may not always be achievable, since they will vary depending on the sample matrix, which instrument is used, and operating conditions. A discussion of performance-based sensitivity is presented in Sec. 9.6.

1.4 Analysts should consult the disclaimer statement at the front of the manual and the information in Chapter Two for guidance on the intended flexibility in the choice of methods, apparatus, materials, reagents, and supplies, and on the responsibilities of the analyst for demonstrating that the techniques employed are appropriate for the analytes of interest, in the matrix of interest, and at the levels of concern.

In addition, analysts and data users are advised that, except where explicitly specified in a regulation, the use of SW-846 methods is *not* mandatory in response to Federal testing requirements. The information contained in this method is provided by EPA as guidance to be used by the analyst and the regulated community in making judgments necessary to generate results that meet the data quality objectives for the intended application.

1.5 Use of this method is restricted to use by, or under supervision of, personnel appropriately experienced and trained in the use and operation of an XRF instrument. Each analyst must demonstrate the ability to generate acceptable results with this method.

2.0 SUMMARY OF METHOD

2.1 The FPXRF technologies described in this method use either sealed radioisotope sources or x-ray tubes to irradiate samples with x-rays. When a sample is irradiated with x-rays, the source x-rays may undergo either scattering or absorption by sample atoms. This latter process is known as the photoelectric effect. When an atom absorbs the source x-rays, the incident radiation dislodges electrons from the innermost shells of the atom, creating vacancies. The electron vacancies are filled by electrons cascading in from outer electron shells. Electrons in outer shells have higher energy states than inner shell electrons, and the outer shell electrons give off energy as they cascade down into the inner shell vacancies. This rearrangement of electrons results in emission of x-rays characteristic of the given atom. The emission of x-rays, in this manner, is termed x-ray fluorescence.

Three electron shells are generally involved in emission of x-rays during FPXRF analysis of environmental samples. The three electron shells include the K, L, and M shells. A typical emission pattern, also called an emission spectrum, for a given metal has multiple intensity peaks generated from the emission of K, L, or M shell electrons. The most commonly measured x-ray emissions are from the K and L shells; only metals with an atomic number greater than 57 have measurable M shell emissions.

Each characteristic x-ray line is defined with the letter K, L, or M, which signifies which shell had the original vacancy and by a subscript alpha (α), beta (β), or gamma (γ) etc., which indicates the higher shell from which electrons fell to fill the vacancy and produce the x-ray. For example, a K_α line is produced by a vacancy in the K shell filled by an L shell electron, whereas a K_β line is produced by a vacancy in the K shell filled by an M shell electron. The K_α transition is on average 6 to 7 times more probable than the K_β transition; therefore, the K_α line is approximately 7 times more intense than the K_β line for a given element, making the K_α line the choice for quantitation purposes.

The K lines for a given element are the most energetic lines and are the preferred lines for analysis. For a given atom, the x-rays emitted from L transitions are always less energetic than those emitted from K transitions. Unlike the K lines, the main L emission lines (L_α and L_β) for an element are of nearly equal intensity. The choice of one or the other depends on what interfering element lines might be present. The L emission lines are useful for analyses involving elements of atomic number (Z) 58 (cerium) through 92 (uranium).

An x-ray source can excite characteristic x-rays from an element only if the source energy is greater than the absorption edge energy for the particular line group of the element, that is, the K absorption edge, L absorption edge, or M absorption edge energy. The absorption edge energy is somewhat greater than the corresponding line energy. Actually, the K absorption edge energy is approximately the sum of the K, L, and M line energies of the particular element, and the L absorption edge energy is approximately the sum of the L and M line energies. FPXRF is more sensitive to an element with an absorption edge energy close to but less than the excitation energy of the source. For example, when using a cadmium-109 source, which has an excitation energy of 22.1 kiloelectron volts (keV), FPXRF would exhibit better sensitivity for zirconium which has a K line energy of 15.77 keV than to chromium, which has a K line energy of 5.41 keV.

2.2 Under this method, inorganic analytes of interest are identified and quantitated using a field portable energy-dispersive x-ray fluorescence spectrometer. Radiation from one or more radioisotope sources or an electrically excited x-ray tube is used to generate characteristic x-ray emissions from elements in a sample. Up to three sources may be used to irradiate a sample. Each source emits a specific set of primary x-rays that excite a corresponding range of elements in a sample. When more than one source can excite the element of interest, the source is selected according to its excitation efficiency for the element of interest.

For measurement, the sample is positioned in front of the probe window. This can be done in two manners using FPXRF instruments, specifically, in situ or intrusive. If operated in the in situ mode, the probe window is placed in direct contact with the soil surface to be analyzed. When an FPXRF instrument is operated in the intrusive mode, a soil or sediment sample must be collected, prepared, and placed in a sample cup. The sample cup is then placed on top of the window inside a protective cover for analysis.

Sample analysis is then initiated by exposing the sample to primary radiation from the source. Fluorescent and backscattered x-rays from the sample enter through the detector window and are converted into electric pulses in the detector. The detector in FPXRF instruments is usually either a solid-state detector or a gas-filled proportional counter. Within the detector, energies of the characteristic x-rays are converted into a train of electric pulses, the amplitudes of which are linearly proportional to the energy of the x-rays. An electronic multichannel analyzer (MCA) measures the pulse amplitudes, which is the basis of qualitative x-ray analysis. The number of counts at a given energy per unit of time is representative of the element concentration in a sample and is the basis for quantitative analysis. Most FPXRF instruments are menu-driven from software built into the units or from personal computers (PC).

The measurement time of each source is user-selectable. Shorter source measurement times (30 seconds) are generally used for initial screening and hot spot delineation, and longer measurement times (up to 300 seconds) are typically used to meet higher precision and accuracy requirements.

FPXRF instruments can be calibrated using the following methods: internally using fundamental parameters determined by the manufacturer, empirically based on site-specific calibration standards (SSCS), or based on Compton peak ratios. The Compton peak is produced by backscattering of the source radiation. Some FPXRF instruments can be calibrated using multiple methods.

3.0 DEFINITIONS

3.1 FPXRF -- Field portable x-ray fluorescence.

3.2 MCA -- Multichannel analyzer for measuring pulse amplitude.

3.3 SSCS -- Site-specific calibration standards.

3.4 FP -- Fundamental parameter.

3.5 ROI -- Region of interest.

3.6 SRM -- Standard reference material; a standard containing certified amounts of metals in soil or sediment.

3.7 eV -- Electron volt; a unit of energy equivalent to the amount of energy gained by an electron passing through a potential difference of one volt.

3.8 Refer to Chapter One, Chapter Three, and the manufacturer's instructions for other definitions that may be relevant to this procedure.

4.0 INTERFERENCES

4.1 The total method error for FPXRF analysis is defined as the square root of the sum of squares of both instrument precision and user- or application-related error. Generally, instrument precision is the least significant source of error in FPXRF analysis. User- or application-related error is generally more significant and varies with each site and method used. Some sources of interference can be minimized or controlled by the instrument operator, but others cannot. Common sources of user- or application-related error are discussed below.

4.2 Physical matrix effects result from variations in the physical character of the sample. These variations may include such parameters as particle size, uniformity, homogeneity, and surface condition. For example, if any analyte exists in the form of very fine particles in a coarser-grained matrix, the analyte’s concentration measured by the FPXRF will vary depending on how fine particles are distributed within the coarser-grained matrix. If the fine particles "settle" to the bottom of the sample cup (i.e., against the cup window), the analyte concentration measurement will be higher than if the fine particles are not mixed in well and stay on top of the coarser-grained particles in the sample cup. One way to reduce such error is to grind and sieve all soil samples to a uniform particle size thus reducing sample-to-sample particle size variability. Homogeneity is always a concern when dealing with soil samples. Every effort should be made to thoroughly mix and homogenize soil samples before analysis. Field studies have shown heterogeneity of the sample generally has the largest impact on comparability with confirmatory samples.

4.3 Moisture content may affect the accuracy of analysis of soil and sediment sample analyses. When the moisture content is between 5 and 20 percent, the overall error from moisture may be minimal. However, moisture content may be a major source of error when analyzing samples of surface soil or sediment that are saturated with water. This error can be minimized by drying the samples in a convection or toaster oven. Microwave drying is not recommended because field studies have shown that microwave drying can increase variability between FPXRF data and confirmatory analysis and because metal fragments in the sample can cause arcing to occur in a microwave.

4.4 Inconsistent positioning of samples in front of the probe window is a potential source of error because the x-ray signal decreases as the distance from the radioactive source increases. This error is minimized by maintaining the same distance between the window and each sample. For the best results, the window of the probe should be in direct contact with the sample, which means that the sample should be flat and smooth to provide a good contact surface.

4.5 Chemical matrix effects result from differences in the concentrations of interfering elements. These effects occur as either spectral interferences (peak overlaps) or as x-ray absorption and enhancement phenomena. Both effects are common in soils contaminated with heavy metals. As examples of absorption and enhancement effects; iron (Fe) tends to absorb copper (Cu) x-rays, reducing the intensity of the Cu measured by the detector, while chromium (Cr) will be enhanced at the expense of Fe because the absorption edge of Cr is slightly lower in energy than the fluorescent peak of iron. The effects can be corrected mathematically through the use of fundamental parameter (FP) coefficients. The effects also can be compensated for using SSCS, which contain all the elements present on site that can interfere with one another.

4.6 When present in a sample, certain x-ray lines from different elements can be very close in energy and, therefore, can cause interference by producing a severely overlapped spectrum. The degree to which a detector can resolve the two different peaks depends on the energy resolution of the detector. If the energy difference between the two peaks in electron volts is less than the resolution of the detector in electron volts, then the detector will not be able to fully resolve the peaks.

The most common spectrum overlaps involve the K_β line of element Z-1 with the K_α line of element Z. This is called the K_α/K_β interference. Because the $K_\alpha:K_\beta$ intensity ratio for a given element usually is about 7:1, the interfering element, Z-1, must be present at large concentrations to cause a problem. Two examples of this type of spectral interference involve the presence of large concentrations of vanadium (V) when attempting to measure Cr or the presence of large concentrations of Fe when attempting to measure cobalt (Co). The V K_α and K_β energies are 4.95 and 5.43 keV, respectively, and the Cr K_α energy is 5.41 keV. The Fe K_α and K_β energies are 6.40 and 7.06 keV, respectively, and the Co K_α energy is 6.92 keV. The difference between the V K_β and Cr K_α energies is 20 eV, and the difference between the Fe K_β and the Co K_α energies is 140 eV. The resolution of the highest-resolution detectors in FPXRF instruments is 170 eV. Therefore, large amounts of V and Fe will interfere with quantitation of Cr or Co, respectively. The presence of Fe is a frequent problem because it is often found in soils at tens of thousands of parts per million (ppm).

4.7 Other interferences can arise from K/L, K/M, and L/M line overlaps, although these overlaps are less common. Examples of such overlap involve arsenic (As) K_α/lead (Pb) L_α and sulfur (S) K_α/Pb M_α. In the As/Pb case, Pb can be measured from the Pb L_β line, and As can be measured from either the As K_α or the As K_β line; in this way the interference can be corrected. If the As K_β line is used, sensitivity will be decreased by a factor of two to five times because it is a less intense line than the As K_α line. If the As K_α line is used in the presence of Pb, mathematical corrections within the instrument software can be used to subtract out the Pb interference. However, because of the limits of mathematical corrections, As concentrations cannot be efficiently calculated for samples with Pb:As ratios of 10:1 or more. This high ratio of Pb to As may result in reporting of a "nondetect" or a "less than" value (e.g., <300 ppm) for As, regardless of the actual concentration present.

No instrument can fully compensate for this interference. It is important for an operator to understand this limitation of FPXRF instruments and consult with the manufacturer of the FPXRF instrument to evaluate options to minimize this limitation. The operator’s decision will be based on action levels for metals in soil established for the site, matrix effects, capabilities of the instrument, data quality objectives, and the ratio of lead to arsenic known to be present at the site. If a site is encountered that contains lead at concentrations greater than ten times the concentration of arsenic it is advisable that all critical soil samples be sent off site for confirmatory analysis using other techniques (e.g., flame atomic absorption spectrometry (FLAA), graphite furnance atomic absorption spectrometry (GFAA), inductively coupled plasma-atomic emission spectrometry, (ICP-AES), or inductively coupled plasma-mass spectrometry, (ICP-MS)).

4.8 If SSCS are used to calibrate an FPXRF instrument, the samples collected must be representative of the site under investigation. Representative soil sampling ensures that a sample or group of samples accurately reflects the concentrations of the contaminants of concern at a given time and location. Analytical results for representative samples reflect variations in the presence and concentration ranges of contaminants throughout a site. Variables affecting sample representativeness include differences in soil type, contaminant concentration variability, sample collection and preparation variability, and analytical variability, all of which should be minimized as much as possible.

4.9 Soil physical and chemical effects may be corrected using SSCS that have been analyzed by inductively coupled plasma (ICP) or atomic absorption (AA) methods. However, a major source of error can be introduced if these samples are not representative of the site or if the analytical error is large. Another concern is the type of digestion procedure used to prepare the soil samples for the reference analysis. Analytical results for the confirmatory method will vary depending on whether a partial digestion procedure, such as Method 3050, or a total digestion procedure, such as Method 3052, is used. It is known that depending on the nature of the soil or sediment, Method 3050 will achieve differing extraction efficiencies for different analytes of interest. The confirmatory method should meet the project-specific data quality objectives (DQOs).

XRF measures the total concentration of an element; therefore, to achieve the greatest comparability of this method with the reference method (reduced bias), a total digestion procedure should be used for sample preparation. However, in the study used to generate the performance data for this method (see Table 8), the confirmatory method used was Method 3050, and the FPXRF data compared very well with regression correlation coefficients (r often exceeding 0.95, except for barium and chromium). The critical factor is that the digestion procedure and analytical reference method used should meet the DQOs of the project and match the method used for confirmation analysis.

4.10 Ambient temperature changes can affect the gain of the amplifiers producing instrument drift. Gain or drift is primarily a function of the electronics (amplifier or preamplifier) and not the detector as most instrument detectors are cooled to a constant temperature. Most FPXRF instruments have a built-in automatic gain control. If the automatic gain control is allowed to make periodic adjustments, the instrument will compensate for the influence of temperature changes on its energy scale. If the FPXRF instrument has an automatic gain control function, the operator will not have to adjust the instrument's gain unless an error message appears. If an error message appears, the operator should follow the manufacturer's procedures for troubleshooting the problem. Often, this involves performing a new energy calibration. The performance of an energy calibration check to assess drift is a quality control measure discussed in Sec. 9.2.

If the operator is instructed by the manufacturer to manually conduct a gain check because of increasing or decreasing ambient temperature, it is standard to perform a gain check after every 10 to 20 sample measurements or once an hour whichever is more frequent. It is also suggested that a gain check be performed if the temperature fluctuates more than 10° F. The operator should follow the manufacturer's recommendations for gain check frequency.

5.0 SAFETY

5.1 This method does not address all safety issues associated with its use. The user is responsible for maintaining a safe work environment and a current awareness file of OSHA regulations regarding the safe handling of the chemicals listed in this method. A reference file of material safety data sheets (MSDSs) should be available to all personnel involved in these analyses.

NOTE: No MSDS applies directly to the radiation-producing instrument because that is covered under the Nuclear Regulatory Commission (NRC) or applicable state regulations.

5.2 Proper training for the safe operation of the instrument and radiation training should be completed by the analyst prior to analysis. Radiation safety for each specific instrument can be found in the operator's manual. Protective shielding should never be removed by the analyst or any personnel other than the manufacturer. The analyst should be aware of the local state and national regulations that pertain to the use of radiation-producing equipment and radioactive materials with which compliance is required. There should be a person appointed within the organization that is solely responsible for properly instructing all personnel, maintaining inspection records, and monitoring x-ray equipment at regular intervals.

Licenses for radioactive materials are of two types, specifically: (1) a general license which is usually initiated by the manufacturer for receiving, acquiring, owning, possessing, using, and transferring radioactive material incorporated in a device or equipment, and (2) a specific license which is issued to named persons for the operation of radioactive instruments as required by local, state, or federal agencies. A copy of the radioactive material license (for specific licenses only) and leak tests should be present with the instrument at all times and available to local and national authorities upon request.

X-ray tubes do not require radioactive material licenses or leak tests, but do require approvals and licenses which vary from state to state. In addition, fail-safe x-ray warning lights should be illuminated whenever an x-ray tube is energized. Provisions listed above concerning radiation safety regulations, shielding, training, and responsible personnel apply to x-ray tubes just as to radioactive sources. In addition, a log of the times and operating conditions should be kept whenever an x-ray tube is energized. An additional hazard present with x-ray tubes is the danger of electric shock from the high voltage supply, however, if the tube is properly positioned within the instrument, this is only a negligible risk. Any instrument (x-ray tube or radioisotope based) is capable of delivering an electric shock from the basic circuitry when the system is inappropriately opened.

5.3 Radiation monitoring equipment should be used with the handling and operation of the instrument. The operator and the surrounding environment should be monitored continually for analyst exposure to radiation. Thermal luminescent detectors (TLD) in the form of badges and rings are used to monitor operator radiation exposure. The TLDs or badges should be worn in the area of maximum exposure. The maximum permissible whole-body dose from occupational exposure is 5 Roentgen Equivalent Man (REM) per year. Possible exposure pathways for radiation to enter the body are ingestion, inhaling, and absorption. The best precaution to prevent radiation exposure is distance and shielding.

6.0 EQUIPMENT AND SUPPLIES

The mention of trade names or commercial products in this manual is for illustrative purposes only, and does not constitute an EPA endorsement or exclusive recommendation for use. The products and instrument settings cited in SW-846 methods represent those products and settings used during method development or subsequently evaluated by the Agency. Glassware, reagents, supplies, equipment, and settings other than those listed in this manual may be employed provided that method performance appropriate for the intended application has been demonstrated and documented.

6.1 FPXRF spectrometer -- An FPXRF spectrometer consists of four major components: (1) a source that provides x-rays; (2) a sample presentation device; (3) a detector that converts x-ray-generated photons emitted from the sample into measurable electronic signals; and (4) a data processing unit that contains an emission or fluorescence energy analyzer, such as an MCA, that processes the signals into an x-ray energy spectrum from which elemental concentrations in the sample may be calculated, and a data display and storage system. These components and additional, optional items, are discussed below.

6.1.1 Excitation sources -- FPXRF instruments use either a sealed radioisotope source or an x-ray tube to provide the excitation source. Many FPXRF instruments use sealed radioisotope sources to produce x-rays in order to irradiate samples. The FPXRF instrument may contain between one and three radioisotope sources. Common radioisotope sources used for analysis for metals in soils are iron Fe-55 (^{55}Fe), cadmium Cd-109 (^{109}Cd), americium Am-241 (^{241}Am), and curium Cm-244 (^{244}Cm). These sources may be contained in a probe along with a window and the detector; the probe may be connected to a data reduction and handling system by means of a flexible cable. Alternatively, the sources, window, and detector may be included in the same unit as the data reduction and handling system.

The relative strength of the radioisotope sources is measured in units of millicuries (mCi). All other components of the FPXRF system being equal, the stronger the source, the greater the sensitivity and precision of a given instrument. Radioisotope sources undergo constant decay. In fact, it is this decay process that emits the primary x-rays used to excite samples for FPXRF analysis. The decay of radioisotopes is measured in "half-lives." The half-life of a radioisotope is defined as the length of time required to reduce the radioisotopes strength or activity by half. Developers of FPXRF technologies recommend source replacement at regular intervals based on the source's half-life. This is due to the ever increasing time required for the analysis rather than a decrease in instrument performance. The characteristic x-rays emitted from each of the different sources have energies capable of exciting a certain range of analytes in a sample. Table 2 summarizes the characteristics of four common radioisotope sources.

X-ray tubes have higher radiation output, no intrinsic lifetime limit, produce constant output over their lifetime, and do not have the disposal problems of radioactive sources but are just now appearing in FPXRF instruments. An electrically-excited x-ray tube operates by bombarding an anode with electrons accelerated by a high voltage. The electrons gain an energy in electron volts equal to the accelerating voltage and can excite atomic transitions in the anode, which then produces characteristic x-rays. These characteristic x-rays are emitted through a window which contains the vacuum necessary for the electron acceleration. An important difference between x-ray tubes and radioactive sources is that the electrons which bombard the anode also produce a continuum of x-rays across a broad range of energies in addition to the characteristic x-rays. This continuum is weak compared to the characteristic x-rays but can provide substantial excitation since it covers a broad energy range. It has the undesired property of producing background in the spectrum near the analyte x-ray lines when it is scattered by the sample. For this reason a filter is often used between the x-ray tube and the sample to suppress the continuum radiation while passing the characteristic x-rays from the anode. This filter is sometimes incorporated into the window of the x-ray tube. The choice of accelerating voltage is governed both by the anode material, since the electrons must have sufficient energy to excite the anode, which requires a voltage greater than the absorption edge of the anode material and by the instrument's ability to cool the x-ray tube. The anode is most efficiently excited by voltages 2 to 2.5 times the edge energy (most x-rays per unit power to the tube), although voltages as low as 1.5 times the absorption edge energy will work. The characteristic x-rays emitted by the anode are capable of exciting a range of elements in the sample just as with a radioactive source. Table 3 gives the recommended operating voltages and the sample elements excited for some common anodes.

6.1.2 Sample presentation device -- FPXRF instruments can be operated in two modes: in situ and intrusive. If operated in the in situ mode, the probe window is placed in direct contact with the soil surface to be analyzed. When an FPXRF instrument is operated in the intrusive mode, a soil or sediment sample must be collected, prepared, and placed in a sample cup. For FPXRF instruments operated in the intrusive mode, the probe may be rotated so that the window faces either upward or downward. A protective sample cover is placed over the window, and the sample cup is placed on top of the window inside the protective sample cover for analysis.

6.1.3 Detectors -- The detectors in the FPXRF instruments can be either solid-state detectors or gas-filled, proportional counter detectors. Common solid-state detectors include mercuric iodide (HgI_2), silicon pin diode and lithium-drifted silicon Si(Li). The HgI_2 detector is operated at a moderately subambient temperature controlled by a low power thermoelectric cooler. The silicon pin diode detector also is cooled via the thermoelectric Peltier effect. The Si(Li) detector must be cooled to at least -90 °C either with liquid nitrogen or by thermoelectric cooling via the Peltier effect. Instruments with a Si(Li) detector have an internal liquid nitrogen dewar with a capacity of 0.5 to 1.0 L. Proportional counter detectors are rugged and lightweight, which are important features of a field portable detector. However, the resolution of a proportional counter detector is not as good as that of a solid-state detector. The energy resolution of a detector for characteristic x-rays is usually expressed in terms of full width at half-maximum (FWHM) height of the manganese K_α peak at 5.89 keV. The typical resolutions of the above mentioned detectors are as follows: HgI_2-270 eV; silicon pin diode-250 eV; Si(Li)–170 eV; and gas-filled, proportional counter-750 eV.

During operation of a solid-state detector, an x-ray photon strikes a biased, solid-state crystal and loses energy in the crystal by producing electron-hole pairs. The electric charge produced is collected and provides a current pulse that is directly proportional to the energy of the x-ray photon absorbed by the crystal of the detector. A gas-filled, proportional counter detector is an ionization chamber filled with a mixture of noble and other gases. An x-ray photon entering the chamber ionizes the gas atoms. The electric charge produced is collected and provides an electric signal that is directly proportional to the energy of the x-ray photon absorbed by the gas in the detector.

6.1.4 Data processing units -- The key component in the data processing unit of an FPXRF instrument is the MCA. The MCA receives pulses from the detector and sorts them by their amplitudes (energy level). The MCA counts pulses per second to determine the height of the peak in a spectrum, which is indicative of the target analyte's concentration. The spectrum of element peaks are built on the MCA. The MCAs in FPXRF instruments have from 256 to 2,048 channels. The concentrations of target analytes are usually shown in ppm on a liquid crystal display (LCD) in the instrument. FPXRF instruments can store both spectra and from 3,000 to 5,000 sets of numerical analytical results. Most FPXRF instruments are menu-driven from software built into the units or from PCs. Once the data–storage memory of an FPXRF unit is full or at any other time, data can be downloaded by means of an RS-232 port and cable to a PC.

6.2 Spare battery and battery charger.

6.3 Polyethylene sample cups -- 31 to 40 mm in diameter with collar, or equivalent (appropriate for FPXRF instrument).

6.4 X-ray window film -- Mylar^{TM}, Kapton^{TM}, Spectrolene^{TM}, polypropylene, or equivalent; 2.5 to 6.0 µm thick.

6.5 Mortar and pestle -- Glass, agate, or aluminum oxide; for grinding soil and sediment samples.

6.6 Containers -- Glass or plastic to store samples.

6.7 Sieves -- 60-mesh (0.25 mm), stainless-steel, Nylon, or equivalent for preparing soil and sediment samples.

6.8 Trowels -- For smoothing soil surfaces and collecting soil samples.

6.9 Plastic bags -- Used for collection and homogenization of soil samples.

6.10 Drying oven -- Standard convection or toaster oven, for soil and sediment samples that require drying.

7.0 REAGENTS AND STANDARDS

7.1 Reagent grade chemicals must be used in all tests. Unless otherwise indicated, it is intended that all reagents conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

7.2 Pure element standards -- Each pure, single-element standard is intended to produce strong characteristic x-ray peaks of the element of interest only. Other elements present must not contribute to the fluorescence spectrum. A set of pure element standards for commonly sought analytes is supplied by the instrument manufacturer, if designated for the instrument; not all instruments require the pure element standards. The standards are used to set the region of interest (ROI) for each element. They also can be used as energy calibration and resolution check samples.

7.3 Site-specific calibration standards -- Instruments that employ fundamental parameters (FP) or similar mathematical models in minimizing matrix effects may not require SSCS. If the FP calibration model is to be optimized or if empirical calibration is necessary, then SSCSs must be collected, prepared, and analyzed.

7.3.1 The SSCS must be representative of the matrix to be analyzed by FPXRF. These samples must be well homogenized. A minimum of 10 samples spanning the concentration ranges of the analytes of interest and of the interfering elements must be obtained from the site. A sample size of 4 to 8 ounces is recommended, and standard glass sampling jars should be used.

7.3.2 Each sample should be oven-dried for 2 to 4 hr at a temperature of less than 150 °C. If mercury is to be analyzed, a separate sample portion should be dried at ambient temperature as heating may volatilize the mercury. When the sample is dry, all large, organic debris and nonrepresentative material, such as twigs, leaves, roots, insects, asphalt, and rock should be removed. The sample should be homogenized (see Sec. 7.3.3) and then a representative portion ground with a mortar and pestle or other mechanical means, prior to passing through a 60-mesh sieve. Only the coarse rock fraction should remain on the screen.

7.3.3 The sample should be homogenized by using a riffle splitter or by placing 150 to 200 g of the dried, sieved sample on a piece of kraft or butcher paper about 1.5 by 1.5 feet in size. Each corner of the paper should be lifted alternately, rolling the soil over on itself and toward the opposite corner. The soil should be rolled on itself 20 times. Approximately 5 g of the sample should then be removed and placed in a sample cup for FPXRF analysis. The rest of the prepared sample should be sent off site for ICP or AA analysis. The method use for confirmatory analysis should meet the data quality objectives of the project.

7.4 Blank samples -- The blank samples should be from a "clean" quartz or silicon dioxide matrix that is free of any analytes at concentrations above the established lower limit of detection. These samples are used to monitor for cross-contamination and laboratory-induced contaminants or interferences.

7.5 Standard reference materials -- Standard reference materials (SRMs) are standards containing certified amounts of metals in soil or sediment. These standards are used for accuracy and performance checks of FPXRF analyses. SRMs can be obtained from the National Institute of Standards and Technology (NIST), the U.S. Geological Survey (USGS), the Canadian National Research Council, and the national bureau of standards in foreign nations. Pertinent NIST SRMs for FPXRF analysis include 2704, Buffalo River Sediment; 2709, San Joaquin Soil; and 2710 and 2711, Montana Soil. These SRMs contain soil or sediment from actual sites that has been analyzed using independent inorganic analytical methods by many different laboratories. When these SRMs are unavailable, alternate standards may be used (e.g., NIST 2702).

8.0 SAMPLE COLLECTION, PRESERVATION, AND STORAGE

Sample handling and preservation procedures used in FPXRF analyses should follow the guidelines in Chapter Three, "Inorganic Analytes."

9.0 QUALITY CONTROL

9.1 Follow the manufacturer’s instructions for the quality control procedures specific to use of the testing product. Refer to Chapter One for additional guidance on quality assurance (QA) and quality control (QC) protocols. Any effort involving the collection of analytical data should include development of a structured and systematic planning document, such as a Quality Assurance Project Plan (QAPP) or a Sampling and Analysis Plan (SAP), which translates project objectives and specifications into directions for those that will implement the project and assess the results.

9.2 Energy calibration check -- To determine whether an FPXRF instrument is operating within resolution and stability tolerances, an energy calibration check should be run. The energy calibration check determines whether the characteristic x-ray lines are shifting, which would indicate drift within the instrument. As discussed in Sec. 4.10, this check also serves as a gain check in the event that ambient temperatures are fluctuating greatly (more than 10 °F).

9.2.1 The energy calibration check should be run at a frequency consistent with manufacturer's recommendations. Generally, this would be at the beginning of each working day, after the batteries are changed or the instrument is shut off, at the end of each working day, and at any other time when the instrument operator believes that drift is occurring during analysis. A pure element such as iron, manganese, copper, or lead is often used for the energy calibration check. A manufacturer-recommended count time per source should be used for the check.

9.2.2 The instrument manufacturer's manual specifies the channel or kiloelectron volt level at which a pure element peak should appear and the expected intensity of the peak. The intensity and channel number of the pure element as measured using the source should be checked and compared to the manufacturer's recommendation. If the energy calibration check does not meet the manufacturer's criteria, then the pure element sample should be repositioned and reanalyzed. If the criteria are still not met, then an energy calibration should be performed as described in the manufacturer's manual. With some FPXRF instruments, once a spectrum is acquired from the energy calibration check, the peak can be optimized and realigned to the manufacturer's specifications using their software.

9.3 Blank samples -- Two types of blank samples should be analyzed for FPXRF analysis, specifically, instrument blanks and method blanks.

9.3.1 An instrument blank is used to verify that no contamination exists in the spectrometer or on the probe window. The instrument blank can be silicon dioxide, a polytetraflurorethylene (PTFE) block, a quartz block, "clean" sand, or lithium carbonate. This instrument blank should be analyzed on each working day before and after analyses are conducted and once per every twenty samples. An instrument blank should also be analyzed whenever contamination is suspected by the analyst. The frequency of analysis will vary with the data quality objectives of the project. A manufacturer-recommended count time per source should be used for the blank analysis. No element concentrations above the established lower limit of detection should be found in the instrument blank. If concentrations exceed these limits, then the probe window and the check sample should be checked for contamination. If contamination is not a problem, then the instrument must be "zeroed" by following the manufacturer's instructions.

9.3.2 A method blank is used to monitor for laboratory-induced contaminants or interferences. The method blank can be "clean" silica sand or lithium carbonate that undergoes the same preparation procedure as the samples. A method blank must be analyzed at least daily. The frequency of analysis will depend on the data quality objectives of the project. If the method blank does not contain the target analyte at a level that interferes with the project-specific data quality objectives then the method blank would be considered acceptable. In the absence of project-specific data quality objectives, if the blank is less than the lowest level of detection or less than 10% of the lowest sample concentration for the analyte, whichever is greater, then the method blank would be considered acceptable. If the method blank cannot be considered acceptable, the cause of the problem must be identified, and all samples analyzed with the method blank must be reanalyzed.

9.4 Calibration verification checks -- A calibration verification check sample is used to check the accuracy of the instrument and to assess the stability and consistency of the analysis for the analytes of interest. A check sample should be analyzed at the beginning of each working day, during active sample analyses, and at the end of each working day. The frequency of calibration checks during active analysis will depend on the data quality objectives of the project. The check sample should be a well characterized soil sample from the site that is representative of site samples in terms of particle size and degree of homogeneity and that contains contaminants at concentrations near the action levels. If a site-specific sample is not available, then an NIST or other SRM that contains the analytes of interest can be used to verify the accuracy of the instrument. The measured value for each target analyte should be within ±20 percent (%D) of the true value for the calibration verification check to be acceptable. If a measured value falls outside this range, then the check sample should be reanalyzed. If the value continues to fall outside the acceptance range, the instrument should be recalibrated, and the batch of samples analyzed before the unacceptable calibration verification check must be reanalyzed.

9.5 Precision measurements -- The precision of the method is monitored by analyzing a sample with low, moderate, or high concentrations of target analytes. The frequency of precision measurements will depend on the data quality objectives for the data. A minimum of one precision sample should be run per day. Each precision sample should be analyzed 7 times in replicate. It is recommended that precision measurements be obtained for samples with varying concentration ranges to assess the effect of concentration on method precision. Determining method precision for analytes at concentrations near the site action levels can be extremely important if the FPXRF results are to be used in an enforcement action; therefore, selection of at least one sample with target analyte concentrations at or near the site action levels or levels of concern is recommended. A precision sample is analyzed by the instrument for the same field analysis time as used for other project samples. The relative standard deviation (RSD) of the sample mean is used to assess method precision. For FPXRF data to be considered adequately precise, the RSD should not be greater than 20 percent with the exception of chromium. RSD values for chromium should not be greater than 30 percent. If both in situ and intrusive analytical techniques are used during the course of one day, it is recommended that separate precision calculations be performed for each analysis type.

The equation for calculating RSD is as follows:

$$RSD = (SD/\text{Mean Concentration}) \times 100$$

where:

RSD = Relative standard deviation for the precision measurement for the analyte
SD = Standard deviation of the concentration for the analyte
Mean concentration = Mean concentration for the analyte

The precision or reproducibility of a measurement will improve with increasing count time, however, increasing the count time by a factor of 4 will provide only 2 times better precision, so there is a point of diminishing return. Increasing the count time also improves the sensitivity, but decreases sample throughput.

9.6 The lower limits of detection should be established from actual measured performance based on spike recoveries in the matrix of concern or from acceptable method performance on a certified reference material of the appropriate matrix and within the appropriate calibration range for the application. This is considered the best estimate of the true method sensitivity as opposed to a statistical determination based on the standard deviation of replicate analyses of a low-concentration sample. While the statistical approach demonstrates the potential data variability for a given sample matrix at one point in time, it does not represent what can be detected or most importantly the lowest concentration that can be calibrated. For this reason the sensitivity should be established as the lowest point of detection based on acceptable target analyte recovery in the desired sample matrix.

9.7 Confirmatory samples -- The comparability of the FPXRF analysis is determined by submitting FPXRF-analyzed samples for analysis at a laboratory. The method of confirmatory analysis must meet the project and XRF measurement data quality objectives. The confirmatory samples must be splits of the well homogenized sample material. In some cases the prepared sample cups can be submitted. A minimum of 1 sample for each 20 FPXRF-analyzed samples should be submitted for confirmatory analysis. This frequency will depend on project-specific data quality objectives. The confirmatory analyses can also be used to verify the quality of the FPXRF data. The confirmatory samples should be selected from the lower, middle, and upper range of concentrations measured by the FPXRF. They should also include samples with analyte concentrations at or near the site action levels. The results of the confirmatory analysis and FPXRF analyses should be evaluated with a least squares linear regression analysis. If the measured concentrations span more than one order of magnitude, the data should be log-transformed to standardize variance which is proportional to the magnitude of measurement. The correlation coefficient (r) for the results should be 0.7 or greater for the FPXRF data to be considered screening level data. If the r is 0.9 or greater and inferential statistics indicate the FPXRF data and the confirmatory data are statistically equivalent at a 99 percent confidence level, the data could potentially meet definitive level data criteria.

10.0 CALIBRATION AND STANDARDIZATION

10.1 Instrument calibration -- Instrument calibration procedures vary among FPXRF instruments. Users of this method should follow the calibration procedures outlined in the operator's manual for each specific FPXRF instrument. Generally, however, three types of calibration procedures exist for FPXRF instruments, namely: FP calibration, empirical calibration, and the Compton peak ratio or normalization method. These three types of calibration are discussed below.

10.2 Fundamental parameters calibration -- FP calibration procedures are extremely variable. An FP calibration provides the analyst with a "standardless" calibration. The advantages of FP calibrations over empirical calibrations include the following:

- No previously collected site-specific samples are necessary, although site-specific samples with confirmed and validated analytical results for all elements present could be used.

- Cost is reduced because fewer confirmatory laboratory results or calibration standards are necessary.

However, the analyst should be aware of the limitations imposed on FP calibration by particle size and matrix effects. These limitations can be minimized by adhering to the preparation procedure described in Sec. 7.3. The two FP calibration processes discussed below are based on an effective energy FP routine and a back scatter with FP (BFP) routine. Each FPXRF FP calibration process is based on a different iterative algorithmic method. The calibration procedure for each routine is explained in detail in the manufacturer's user manual for each FPXRF instrument; in addition, training courses are offered for each instrument.

10.2.1 Effective energy FP calibration -- The effective energy FP calibration is performed by the manufacturer before an instrument is sent to the analyst. Although SSCS can be used, the calibration relies on pure element standards or SRMs such as those obtained from NIST for the FP calibration. The effective energy routine relies on the spectrometer response to pure elements and FP iterative algorithms to compensate for various matrix effects.

Alpha coefficients are calculated using a variation of the Sherman equation, which calculates theoretical intensities from the measurement of pure element samples. These coefficients indicate the quantitative effect of each matrix element on an analyte's measured x-ray intensity. Next, the Lachance Traill algorithm is solved as a set of simultaneous equations based on the theoretical intensities. The alpha coefficients are then downloaded into the specific instrument.

The working effective energy FP calibration curve must be verified before sample analysis begins on each working day, after every 20 samples are analyzed, and at the end of sampling. This verification is performed by analyzing either an NIST SRM or an SSCS that is representative of the site-specific samples. This SRM or SSCS serves as a calibration check. A manufacturer-recommended count time per source should be used for the calibration check. The analyst must then adjust the y-intercept and slope of the calibration curve to best fit the known concentrations of target analytes in the SRM or SSCS.

A percent difference (%D) is then calculated for each target analyte. The %D should be within ±20 percent of the certified value for each analyte. If the %D falls outside this acceptance range, then the calibration curve should be adjusted by varying the slope of the line or the y-intercept value for the analyte. The SRM or SSCS is reanalyzed until the %D falls within ±20 percent. The group of 20 samples analyzed before an out-of-control calibration check should be reanalyzed.

The equation to calibrate %D is as follows:

$$\%D = ((C_s - C_k) / C_k) \times 100$$

where:

%D = Percent difference
C_k = Certified concentration of standard sample
C_s = Measured concentration of standard sample

10.2.2 BFP calibration -- BFP calibration relies on the ability of the liquid nitrogen-cooled, Si(Li) solid-state detector to separate the coherent (Compton) and incoherent (Rayleigh) backscatter peaks of primary radiation. These peak intensities are known to be a function of sample composition, and the ratio of the Compton to Rayleigh peak is a function of the mass absorption of the sample. The calibration procedure is explained in detail in the instrument manufacturer's manual. Following is a general description of the BFP calibration procedure.

The concentrations of all detected and quantified elements are entered into the computer software system. Certified element results for an NIST SRM or confirmed and validated results for an SSCS can be used. In addition, the concentrations of oxygen and silicon must be entered; these two concentrations are not found in standard metals analyses. The manufacturer provides silicon and oxygen concentrations for typical soil types. Pure element standards are then analyzed using a manufacturer-recommended count time per source. The results are used to calculate correction factors in order to adjust for spectrum overlap of elements.

The working BFP calibration curve must be verified before sample analysis begins on each working day, after every 20 samples are analyzed, and at the end of the analysis. This verification is performed by analyzing either an NIST SRM or an SSCS that is representative of the site-specific samples. This SRM or SSCS serves as a calibration check. The standard sample is analyzed using a manufacturer-recommended count time per source to check the calibration curve. The analyst must then adjust the y-intercept and slope of the calibration curve to best fit the known concentrations of target analytes in the SRM or SSCS.

A %D is then calculated for each target analyte. The %D should fall within ±20 percent of the certified value for each analyte. If the %D falls outside this acceptance range, then the calibration curve should be adjusted by varying the slope of the line the y-intercept value for the analyte. The standard sample is reanalyzed until the %D falls within ±20 percent. The group of 20 samples analyzed before an out-of-control calibration check should be reanalyzed.

10.3 Empirical calibration -- An empirical calibration can be performed with SSCS, site-typical standards, or standards prepared from metal oxides. A discussion of SSCS is included in Sec. 7.3; if no previously characterized samples exist for a specific site, site-typical standards can be used. Site-typical standards may be selected from commercially available characterized soils or from SSCS prepared for another site. The site-typical standards should closely approximate the site's soil matrix with respect to particle size distribution, mineralogy, and contaminant analytes. If neither SSCS nor site-typical standards are available, it is possible to make gravimetric standards by adding metal oxides to a "clean" sand or silicon dioxide matrix that simulates soil. Metal oxides can be purchased from various chemical vendors. If standards are made on site, a balance capable of weighing items to at least two decimal places is necessary. Concentrated ICP or AA standard solutions can also be used to make standards. These solutions are available in concentrations of 10,000 parts per million, thus only small volumes have to be added to the soil.

An empirical calibration using SSCS involves analysis of SSCS by the FPXRF instrument and by a conventional analytical method such as ICP or AA. A total acid digestion procedure should be used by the laboratory for sample preparation. Generally, a minimum of 10 and a maximum of 30 well characterized SSCS, site-typical standards, or prepared metal oxide standards are necessary to perform an adequate empirical calibration. The exact number of standards depends on the number of analytes of interest and interfering elements. Theoretically, an empirical calibration with SSCS should provide the most accurate data for a site because the calibration compensates for site-specific matrix effects.

The first step in an empirical calibration is to analyze the pure element standards for the elements of interest. This enables the instrument to set channel limits for each element for spectral deconvolution. Next the SSCS, site-typical standards, or prepared metal oxide standards are analyzed using a count time of 200 seconds per source or a count time recommended by the manufacturer. This will produce a spectrum and net intensity of each analyte in each standard. The analyte concentrations for each standard are then entered into the instrument software; these concentrations are those obtained from the laboratory, the certified results, or the gravimetrically determined concentrations of the prepared standards. This gives the instrument analyte values to regress against corresponding intensities during the modeling stage. The regression equation correlates the concentrations of an analyte with its net intensity.

The calibration equation is developed using a least squares fit regression analysis. After the regression terms to be used in the equation are defined, a mathematical equation can be developed to calculate the analyte concentration in an unknown sample. In some FPXRF instruments, the software of the instrument calculates the regression equation. The software uses calculated intercept and slope values to form a multiterm equation. In conjunction with the software in the instrument, the operator can adjust the multiterm equation to minimize interelement interferences and optimize the intensity calibration curve.

It is possible to define up to six linear or nonlinear terms in the regression equation. Terms can be added and deleted to optimize the equation. The goal is to produce an equation with the smallest regression error and the highest correlation coefficient. These values are automatically computed by the software as the regression terms are added, deleted, or modified. It is also possible to delete data points from the regression line if these points are significant outliers or if they are heavily weighing the data. Once the regression equation has been selected for an analyte, the equation can be entered into the software for quantitation of analytes in subsequent samples. For an empirical calibration to be acceptable, the regression equation for a specific analyte should have a correlation coefficient of 0.98 or greater or meet the DQOs of the project.

In an empirical calibration, one must apply the DQOs of the project and ascertain critical or action levels for the analytes of interest. It is within these concentration ranges or around these action levels that the FPXRF instrument should be calibrated most accurately. It may not be possible to develop a good regression equation over several orders of analyte concentration.

10.4 Compton normalization method -- The Compton normalization method is based on analysis of a single, certified standard and normalization for the Compton peak. The Compton peak is produced from incoherent backscattering of x-ray radiation from the excitation source and is present in the spectrum of every sample. The Compton peak intensity changes with differing matrices. Generally, matrices dominated by lighter elements produce a larger Compton peak, and those dominated by heavier elements produce a smaller Compton peak. Normalizing to the Compton peak can reduce problems with varying matrix effects among samples. Compton normalization is similar to the use of internal standards in organics analysis. The Compton normalization method may not be effective when analyte concentrations exceed a few percent.

The certified standard used for this type of calibration could be an NIST SRM such as 2710 or 2711. The SRM must be a matrix similar to the samples and must contain the analytes of interests at concentrations near those expected in the samples. First, a response factor has to be determined for each analyte. This factor is calculated by dividing the net peak intensity by the analyte concentration. The net peak intensity is gross intensity corrected for baseline reading. Concentrations of analytes in samples are then determined by multiplying the baseline corrected analyte signal intensity by the normalization factor and by the response factor. The normalization factor is the quotient of the baseline corrected Compton K_α peak intensity of the SRM divided by that of the samples. Depending on the FPXRF instrument used, these calculations may be done manually or by the instrument software.

11.0 PROCEDURE

11.1 Operation of the various FPXRF instruments will vary according to the manufacturers' protocols. Before operating any FPXRF instrument, one should consult the manufacturer's manual. Most manufacturers recommend that their instruments be allowed to warm up for 15 to 30 minutes before analysis of samples. This will help alleviate drift or energy calibration problems later during analysis.

11.2 Each FPXRF instrument should be operated according to the manufacturer's recommendations. There are two modes in which FPXRF instruments can be operated: in situ and intrusive. The in situ mode involves analysis of an undisturbed soil sediment or sample. Intrusive analysis involves collection and preparation of a soil or sediment sample before analysis. Some FPXRF instruments can operate in both modes of analysis, while others are designed to operate in only one mode. The two modes of analysis are discussed below.

11.3 For in situ analysis, remove any large or nonrepresentative debris from the soil surface before analysis. This debris includes rocks, pebbles, leaves, vegetation, roots, and concrete. Also, the soil surface must be as smooth as possible so that the probe window will have good contact with the surface. This may require some leveling of the surface with a stainless-steel trowel. During the study conducted to provide example performance data for this method, this modest amount of sample preparation was found to take less than 5 min per sample location. The last requirement is that the soil or sediment not be saturated with water. Manufacturers state that their FPXRF instruments will perform adequately for soils with moisture contents of 5 to 20 percent but will not perform well for saturated soils, especially if ponded water exists on the surface. Another recommended technique for in situ analysis is to tamp the soil to increase soil density and compactness for better repeatability and representativeness. This condition is especially important for heavy element analysis, such as barium. Source count times for in situ analysis usually range from 30 to 120 seconds, but source count times will vary among instruments and depending on the desired method sensitivity. Due to the heterogeneous nature of the soil sample, in situ analysis can provide only “screening” type data.

11.4 For intrusive analysis of surface or sediment, it is recommended that a sample be collected from a 4- by 4-inch square that is 1 inch deep. This will produce a soil sample of approximately 375 g or 250 cm^3, which is enough soil to fill an 8-ounce jar. However, the exact dimensions and sample depth should take into consideration the heterogeneous deposition of contaminants and will ultimately depend on the desired project-specific data quality objectives. The sample should be homogenized, dried, and ground before analysis. The sample can be homogenized before or after drying. The homogenization technique to be used after drying is discussed in Sec. 4.2. If the sample is homogenized before drying, it should be thoroughly mixed in a beaker or similar container, or if the sample is moist and has a high clay content, it can be kneaded in a plastic bag. One way to monitor homogenization when the sample is kneaded in a plastic bag is to add sodium fluorescein dye to the sample. After the moist sample has been homogenized, it is examined under an ultraviolet light to assess the distribution of sodium fluorescein throughout the sample. If the fluorescent dye is evenly distributed in the sample, homogenization is considered complete; if the dye is not evenly distributed, mixing should continue until the sample has been thoroughly homogenized. During the study conducted to provide data for this method, the time necessary for homogenization procedure using the fluorescein dye ranged from 3 to 5 min per sample. As demonstrated in Secs. 13.5 and 13.7, homogenization has the greatest impact on the reduction of sampling variability. It produces little or no contamination. Often, the direct analysis through the plastic bag is possible without the more labor intensive steps of drying, grinding, and sieving given in Secs. 11.5 and 11.6. Of course, to achieve the best data quality possible all four steps should be followed.

11.5 Once the soil or sediment sample has been homogenized, it should be dried. This can be accomplished with a toaster oven or convection oven. A small aliquot of the sample (20 to 50 g) is placed in a suitable container for drying. The sample should be dried for 2 to 4 hr in the convection or toaster oven at a temperature not greater than 150 °C. Samples may also be air dried under ambient temperature conditions using a 10- to 20-g portion. Regardless of what drying mechanism is used, the drying process is considered complete when a constant sample weight can be obtained. Care should be taken to avoid sample cross-contamination and these measures can be evaluated by including an appropriate method blank sample along with any sample preparation process.

CAUTION: Microwave drying is not a recommended procedure. Field studies have shown that microwave drying can increase variability between the FPXRF data and confirmatory analysis. High levels of metals in a sample can cause arcing in the microwave oven, and sometimes slag forms in the sample. Microwave oven drying can also melt plastic containers used to hold the sample.

11.6 The homogenized dried sample material should be ground with a mortar and pestle and passed through a 60-mesh sieve to achieve a uniform particle size. Sample grinding should continue until at least 90 percent of the original sample passes through the sieve. The grinding step normally takes an average of 10 min per sample. An aliquot of the sieved sample should then be placed in a 31.0-mm polyethylene sample cup (or equivalent) for analysis. The sample cup should be one-half to three-quarters full at a minimum. The sample cup should be covered with a 2.5 µm Mylar (or equivalent) film for analysis. The rest of the soil sample should be placed in a jar, labeled, and archived for possible confirmation analysis. All equipment including the mortar, pestle, and sieves must be thoroughly cleaned so that any cross-contamination is below the established lower limit of detection of the procedure or DQOs of the analysis. If all recommended sample preparation steps are followed, there is a high probability the desired laboratory data quality may be obtained.

12.0 DATA ANALYSIS AND CALCULATIONS

Most FPXRF instruments have software capable of storing all analytical results and spectra. The results are displayed in ppm and can be downloaded to a personal computer, which can be used to provide a hard copy printout. Individual measurements that are smaller than three times their associated SD should not be used for quantitation. See the manufacturer's instructions regarding data analysis and calculations.

13.0 METHOD PERFORMANCE

13.1 Performance data and related information are provided in SW-846 methods only as examples and guidance. The data do not represent required performance criteria for users of the methods. Instead, performance criteria should be developed on a project-specific basis, and the laboratory should establish in-house QC performance criteria for the application of this method. These performance data are not intended to be and must not be used as absolute QC acceptance criteria for purposes of laboratory accreditation.

13.2 The sections to follow discuss three performance evaluation factors; namely, precision, accuracy, and comparability. The example data presented in Tables 4 through 8 were generated from results obtained from six FPXRF instruments (see Sec. 13.3). The soil samples analyzed by the six FPXRF instruments were collected from two sites in the United States. The soil samples contained several of the target analytes at concentrations ranging from "nondetect" to tens of thousands of mg/kg. These data are provided for guidance purposes only.

13.3 The six FPXRF instruments included the TN 9000 and TN Lead Analyzer manufactured by TN Spectrace; the X-MET 920 with a SiLi detector and X-MET 920 with a gas-filled proportional detector manufactured by Metorex, Inc.; the XL Spectrum Analyzer manufactured by Niton; and the MAP Spectrum Analyzer manufactured by Scitec. The TN 9000 and TN Lead Analyzer both have a HgI_2 detector. The TN 9000 utilized an Fe-55, Cd-109, and Am-241 source. The TN Lead Analyzer had only a Cd-109 source. The X-Met 920 with the SiLi detector had a Cd-109 and Am-241 source. The X-MET 920 with the gas-filled proportional detector had only a Cd-109 source. The XL Spectrum Analyzer utilized a silicon pin-diode detector and a Cd-109 source. The MAP Spectrum Analyzer utilized a solid-state silicon detector and a Cd-109 source.

13.4 All example data presented in Tables 4 through 8 were generated using the following calibrations and source count times. The TN 9000 and TN Lead Analyzer were calibrated using fundamental parameters using NIST SRM 2710 as a calibration check sample. The TN 9000 was operated using 100, 60, and 60 second count times for the Cd-109, Fe-55, and Am-241 sources, respectively. The TN Lead analyzer was operated using a 60 second count time for the Cd-109 source. The X-MET 920 with the Si(Li) detector was calibrated using fundamental parameters and one well characterized site-specific soil standard as a calibration check. It used 140 and 100 second count times for the Cd-109 and Am-241 sources, respectively. The X-MET 920 with the gas-filled proportional detector was calibrated empirically using between 10 and 20 well characterized site-specific soil standards. It used 120 second times for the Cd-109 source. The XL Spectrum Analyzer utilized NIST SRM 2710 for calibration and the Compton peak normalization procedure for quantitation based on 60 second count times for the Cd-109 source. The MAP Spectrum Analyzer was internally calibrated by the manufacturer. The calibration was checked using a well-characterized site-specific soil standard. It used 240 second times for the Cd-109 source.

13.5 Precision measurements -- The example precision data are presented in Table 4. These data are provided for guidance purposes only. Each of the six FPXRF instruments performed 10 replicate measurements on 12 soil samples that had analyte concentrations ranging from "nondetects" to thousands of mg/kg. Each of the 12 soil samples underwent 4 different preparation techniques from in situ (no preparation) to dried and ground in a sample cup. Therefore, there were 48 precision data points for five of the instruments and 24 precision points for the MAP Spectrum Analyzer. The replicate measurements were taken using the source count times discussed at the beginning of this section.

For each detectable analyte in each precision sample a mean concentration, standard deviation, and RSD was calculated for each analyte. The data presented in Table 4 is an average RSD for the precision samples that had analyte concentrations at 5 to 10 times the lower limit of detection for that analyte for each instrument. Some analytes such as mercury, selenium, silver, and thorium were not detected in any of the precision samples so these analytes are not listed in Table 4. Some analytes such as cadmium, nickel, and tin were only detected at concentrations near the lower limit of detection so that an RSD value calculated at 5 to 10 times this limit was not possible.

One FPXRF instrument collected replicate measurements on an additional nine soil samples to provide a better assessment of the effect of sample preparation on precision. Table 5 shows these results. These data are provided for guidance purposes only. The additional nine soil samples were comprised of three from each texture and had analyte concentrations ranging from near the lower limit of detection for the FPXRF analyzer to thousands of mg/kg. The FPXRF analyzer only collected replicate measurements from three of the preparation methods; no measurements were collected from the in situ homogenized samples. The FPXRF analyzer conducted five replicate measurements of the in situ field samples by taking measurements at five different points within the 4-inch by 4-inch sample square. Ten replicate measurements were collected for both the intrusive undried and unground and intrusive dried and ground samples contained in cups. The cups were shaken between each replicate measurement.

Table 5 shows that the precision dramatically improved from the in situ to the intrusive measurements. In general there was a slight improvement in precision when the sample was dried and ground. Two factors caused the precision for the in situ measurements to be poorer. The major factor is soil heterogeneity. By moving the probe within the 4-inch by 4-inch square, measurements of different soil samples were actually taking place within the square. Table 5 illustrates the dominant effect of soil heterogeneity. It overwhelmed instrument precision when the FPXRF analyzer was used in this mode. The second factor that caused the RSD values to be higher for the in situ measurements is the fact that only five instead of ten replicates were taken. A lesser number of measurements caused the standard deviation to be larger which in turn elevated the RSD values.

13.6 Accuracy measurements -- Five of the FPXRF instruments (not including the MAP Spectrum Analyzer) analyzed 18 SRMs using the source count times and calibration methods given at the beginning of this section. The 18 SRMs included 9 soil SRMs, 4 stream or river sediment SRMs, 2 sludge SRMs, and 3 ash SRMs. Each of the SRMs contained known concentrations of certain target analytes. A percent recovery was calculated for each analyte in each SRM for each FPXRF instrument. Table 6 presents a summary of this data. With the exception of cadmium, chromium, and nickel, the values presented in Table 6 were generated from the 13 soil and sediment SRMs only. The 2 sludge and 3 ash SRMs were included for cadmium, chromium, and nickel because of the low or nondetectable concentrations of these three analytes in the soil and sediment SRMs.

Only 12 analytes are presented in Table 6. These are the analytes that are of environmental concern and provided a significant number of detections in the SRMs for an accuracy assessment. No data is presented for the X-MET 920 with the gas-filled proportional detector. This FPXRF instrument was calibrated empirically using site-specific soil samples. The percent recovery values from this instrument were very sporadic and the data did not lend itself to presentation in Table 6.

Table 7 provides a more detailed summary of accuracy data for one particular FPXRF instrument (TN 9000) for the 9 soil SRMs and 4 sediment SRMs. These data are provided for guidance purposes only. Table 7 shows the certified value, measured value, and percent recovery for five analytes. These analytes were chosen because they are of environmental concern and were most prevalently certified for in the SRM and detected by the FPXRF instrument. The first nine SRMs are soil and the last 4 SRMs are sediment. Percent recoveries for the four NIST SRMs were often between 90 and 110 percent for all analytes.

13.7 Comparability -- Comparability refers to the confidence with which one data set can be compared to another. In this case, FPXRF data generated from a large study of six FPXRF instruments was compared to SW-846 Methods 3050 and 6010 which are the standard soil extraction for metals and analysis by inductively coupled plasma. An evaluation of comparability was conducted by using linear regression analysis. Three factors were determined using the linear regression. These factors were the y-intercept, the slope of the line, and the coefficient of determination (r^2).

As part of the comparability assessment, the effects of soil type and preparation methods were studied. Three soil types (textures) and four preparation methods were examined during the study. The preparation methods evaluated the cumulative effect of particle size, moisture, and homogenization on comparability. Due to the large volume of data produced during this study, linear regression data for six analytes from only one FPXRF instrument is presented in Table 8. Similar trends in the data were seen for all instruments. These data are provided for guidance purposes only.

Table 8 shows the regression parameters for the whole data set, broken out by soil type, and by preparation method. These data are provided for guidance purposes only. The soil types are as follows: soil 1--sand; soil 2--loam; and soil 3--silty clay. The preparation methods are as follows: preparation 1--in situ in the field; preparation 2--intrusive, sample collected and homogenized; preparation 3--intrusive, with sample in a sample cup but sample still wet and not ground; and preparation 4–intrusive, with sample dried, ground, passed through a 40-mesh sieve, and placed in sample cup.

For arsenic, copper, lead, and zinc, the comparability to the confirmatory laboratory was excellent with r^2 values ranging from 0.80 to 0.99 for all six FPXRF instruments. The slopes of the regression lines for arsenic, copper, lead, and zinc, were generally between 0.90 and 1.00 indicating the data would need to be corrected very little or not at all to match the confirmatory laboratory data. The r^2 values and slopes of the regression lines for barium and chromium were not as good as for the other for analytes, indicating the data would have to be corrected to match the confirmatory laboratory.

Table 8 demonstrates that there was little effect of soil type on the regression parameters for any of the six analytes. The only exceptions were for barium in soil 1 and copper in soil 3. In both of these cases, however, it is actually a concentration effect and not a soil effect causing the poorer comparability. All barium and copper concentrations in soil 1 and 3, respectively, were less than 350 mg/kg.

Table 8 shows there was a preparation effect on the regression parameters for all six analytes. With the exception of chromium, the regression parameters were primarily improved going from preparation 1 to preparation 2. In this step, the sample was removed from the soil surface, all large debris was removed, and the sample was thoroughly homogenized. The additional two preparation methods did little to improve the regression parameters. This data indicates that homogenization is the most critical factor when comparing the results. It is essential that the sample sent to the confirmatory laboratory match the FPXRF sample as closely as possible.

Sec. 11.0 of this method discusses the time necessary for each of the sample preparation techniques. Based on the data quality objectives for the project, an analyst must decide if it is worth the extra time necessary to dry and grind the sample for small improvements in comparability. Homogenization requires 3 to 5 min. Drying the sample requires one to two hours. Grinding and sieving requires another 10 to 15 min per sample. Lastly, when grinding and sieving is conducted, time has to be allotted to decontaminate the mortars, pestles, and sieves. Drying and grinding the samples and decontamination procedures will often dictate that an extra person be on site so that the analyst can keep up with the sample collection crew. The cost of requiring an extra person on site to prepare samples must be balanced with the gain in data quality and sample throughput.

13.8 The following documents may provide additional guidance and insight on this method and technique:

13.8.1 A. D. Hewitt, "Screening for Metals by X-ray Fluorescence Spectrometry/Response Factor/Compton K_α Peak Normalization Analysis," American Environmental Laboratory, pp 24-32, 1994.

13.8.2 S. Piorek and J. R. Pasmore, "Standardless, In Situ Analysis of Metallic Contaminants in the Natural Environment With a PC-Based, High Resolution Portable X-Ray Analyzer," Third International Symposium on Field Screening Methods for Hazardous Waste and Toxic Chemicals, Las Vegas, Nevada, February 24-26, 1993, Vol 2, pp 1135-1151, 1993.

13.8.3 S. Shefsky, "Sample Handling Strategies for Accurate Lead-in-soil Measurements in the Field and Laboratory," *International Symposium of Field Screening Methods for Hazardous Waste and Toxic Chemicals*, Las Vegas, NV, January 29-31, 1997.

14.0 POLLUTION PREVENTION

14.1 Pollution prevention encompasses any technique that reduces or eliminates the quantity and/or toxicity of waste at the point of generation. Numerous opportunities for pollution prevention exist in laboratory operation. The EPA has established a preferred hierarchy of environmental management techniques that places pollution prevention as the management option of first choice. Whenever feasible, laboratory personnel should use pollution prevention techniques to address their waste generation. When wastes cannot be feasibly reduced at the source, the Agency recommends recycling as the next best option.

14.2 For information about pollution prevention that may be applicable to laboratories and research institutions consult *Less is Better: Laboratory Chemical Management for Waste Reduction* available from the American Chemical Society's Department of Government Relations and Science Policy, 1155 16th St., N.W. Washington, D.C. 20036, http://www.acs.org.

15.0 WASTE MANAGEMENT

The Environmental Protection Agency requires that laboratory waste management practices be conducted consistent with all applicable rules and regulations. The Agency urges laboratories to protect the air, water, and land by minimizing and controlling all releases from hoods and bench operations, complying with the letter and spirit of any sewer discharge permits and regulations, and by complying with all solid and hazardous waste regulations, particularly the hazardous waste identification rules and land disposal restrictions. For further information on waste management, consult *The Waste Management Manual for Laboratory Personnel* available from the American Chemical Society at the address listed in Sec. 14.2.

16.0 REFERENCES

1. Metorex, X-MET 920 User's Manual.

2. Spectrace Instruments, "Energy Dispersive X-ray Fluorescence Spectrometry: An Introduction," 1994.

3. TN Spectrace, Spectrace 9000 Field Portable/Benchtop XRF Training and Applications Manual.

4. Unpublished SITE data, received from PRC Environment Management, Inc.

17.0 TABLES, DIAGRAMS, FLOWCHARTS, AND VALIDATION DATA

The following pages contain the tables referenced by this method. A flow diagram of the procedure follows the tables.

TABLE 1

EXAMPLE INTERFERENCE FREE LOWER LIMITS OF DETECTION

Analyte	Chemical Abstract Series Number	Lower Limit of Detection in Quartz Sand (milligrams per kilogram)
Antimony (Sb)	7440-36-0	40
Arsenic (As)	7440-38-0	40
Barium (Ba)	7440-39-3	20
Cadmium (Cd)	7440-43-9	100
Calcium (Ca)	7440-70-2	70
Chromium (Cr)	7440-47-3	150
Cobalt (Co)	7440-48-4	60
Copper (Cu)	7440-50-8	50
Iron (Fe)	7439-89-6	60
Lead (Pb)	7439-92-1	20
Manganese (Mn)	7439-96-5	70
Mercury (Hg)	7439-97-6	30
Molybdenum (Mo)	7439-93-7	10
Nickel (Ni)	7440-02-0	50
Potassium (K)	7440-09-7	200
Rubidium (Rb)	7440-17-7	10
Selenium (Se)	7782-49-2	40
Silver (Ag)	7440-22-4	70
Strontium (Sr)	7440-24-6	10
Thallium (Tl)	7440-28-0	20
Thorium (Th)	7440-29-1	10
Tin (Sn)	7440-31-5	60
Titanium (Ti)	7440-32-6	50
Vanadium (V)	7440-62-2	50
Zinc (Zn)	7440-66-6	50
Zirconium (Zr)	7440-67-7	10

Source: Refs. 1, 2, and 3
These data are provided for guidance purposes only.

TABLE 2

SUMMARY OF RADIOISOTOPE SOURCE CHARACTERISTICS

Source	Activity (mCi)	Half-Life (Years)	Excitation Energy (keV)	Elemental Analysis Range	
Fe-55	20-50	2.7	5.9	Sulfur to Chromium	K Lines
				Molybdenum to Barium	L Lines
Cd-109	5-30	1.3	22.1 and 87.9	Calcium to Rhodium	K Lines
				Tantalum to Lead	K Lines
				Barium to Uranium	L Lines
Am-241	5-30	432	26.4 and 59.6	Copper to Thulium	K Lines
				Tungsten to Uranium	L Lines
Cm-244	60-100	17.8	14.2	Titanium to Selenium	K Lines
				Lanthanum to Lead	L Lines

Source: Refs. 1, 2, and 3

TABLE 3

SUMMARY OF X-RAY TUBE SOURCE CHARACTERISTICS

Anode Material	Recommended Voltage Range (kV)	K-alpha Emission (keV)	Elemental Analysis Range	
Cu	18-22	8.04	Potassium to Cobalt	K Lines
			Silver to Gadolinium	L Lines
Mo	40-50	17.4	Cobalt to Yttrium	K Lines
			Europium to Radon	L Lines
Ag	50-65	22.1	Zinc to Technicium	K Lines
			Ytterbium to Neptunium	L Lines

Source: Ref. 4

Notes: The sample elements excited are chosen by taking as the lower limit the same ratio of excitation line energy to element absorption edge as in Table 2 (approximately 0.45) and the requirement that the excitation line energy be above the element absorption edge as the upper limit (L2 edges used for L lines). K-beta excitation lines were ignored.

TABLE 4

EXAMPLE PRECISION VALUES

Analyte	Average Relative Standard Deviation for Each Instrument at 5 to 10 Times the Lower Limit of Detection					
	TN 9000	TN Lead Analyzer	X-MET 920 (SiLi Detector)	X-MET 920 (Gas-Filled Detector)	XL Spectrum Analyzer	MAP Spectrum Analyzer
Antimony	6.54	NR	NR	NR	NR	NR
Arsenic	5.33	4.11	3.23	1.91	12.47	6.68
Barium	4.02	NR	3.31	5.91	NR	NR
Cadmium	29.84[a]	NR	24.80[a]	NR	NR	NR
Calcium	2.16	NR	NR	NR	NR	NR
Chromium	22.25	25.78	22.72	3.91	30.25	NR
Cobalt	33.90	NR	NR	NR	NR	NR
Copper	7.03	9.11	8.49	9.12	12.77	14.86
Iron	1.78	1.67	1.55	NR	2.30	NR
Lead	6.45	5.93	5.05	7.56	6.97	12.16
Manganese	27.04	24.75	NR	NR	NR	NR
Molybdenum	6.95	NR	NR	NR	12.60	NR
Nickel	30.85[a]	NR	24.92[a]	20.92[a]	NA	NR
Potassium	3.90	NR	NR	NR	NR	NR
Rubidium	13.06	NR	NR	NR	32.69[a]	NR
Strontium	4.28	NR	NR	NR	8.86	NR
Tin	24.32[a]	NR	NR	NR	NR	NR
Titanium	4.87	NR	NR	NR	NR	NR
Zinc	7.27	7.48	4.26	2.28	10.95	0.83
Zirconium	3.58	NR	NR	NR	6.49	NR

These data are provided for guidance purposes only.
Source: Ref. 4

[a] These values are biased high because the concentration of these analytes in the soil samples was near the lower limit of detection for that particular FPXRF instrument.

NR Not reported.

NA Not applicable; analyte was reported but was below the established lower limit detection.

TABLE 5

EXAMPLES OF PRECISION AS AFFECTED BY SAMPLE PREPARATION

Analyte	Average Relative Standard Deviation for Each Preparation Method		
	In Situ-Field	Intrusive- Undried and Unground	Intrusive- Dried and Ground
Antimony	30.1	15.0	14.4
Arsenic	22.5	5.36	3.76
Barium	17.3	3.38	2.90
Cadmium[a]	41.2	30.8	28.3
Calcium	17.5	1.68	1.24
Chromium	17.6	28.5	21.9
Cobalt	28.4	31.1	28.4
Copper	26.4	10.2	7.90
Iron	10.3	1.67	1.57
Lead	25.1	8.55	6.03
Manganese	40.5	12.3	13.0
Mercury	ND	ND	ND
Molybdenum	21.6	20.1	19.2
Nickel[a]	29.8	20.4	18.2
Potassium	18.6	3.04	2.57
Rubidium	29.8	16.2	18.9
Selenium	ND	20.2	19.5
Silver[a]	31.9	31.0	29.2
Strontium	15.2	3.38	3.98
Thallium	39.0	16.0	19.5
Thorium	NR	NR	NR
Tin	ND	14.1	15.3
Titanium	13.3	4.15	3.74
Vanadium	NR	NR	NR
Zinc	26.6	13.3	11.1
Zirconium	20.2	5.63	5.18

These data are provided for guidance purposes only.
Source: Ref. 4

[a] These values may be biased high because the concentration of these analytes in the soil samples was near the lower limit of detection.

ND Not detected.
NR Not reported.

TABLE 6

EXAMPLE ACCURACY VALUES

Analyte	Instrument															
	TN 9000				TN Lead Analyzer				X-MET 920 (SiLi Detector)				XL Spectrum Analyzer			
	n	Range of % Rec.	Mean % Rec.	SD	n	Range of % Rec.	Mean % Rec.	SD	n	Range of % Rec.	Mean % Rec	SD	n	Range of % Rec.	Mean % Rec.	SD
Sb	2	100-149	124.3	NA	--	--	--	--	--	--	--	--	--	--	--	--
As	5	68-115	92.8	17.3	5	44-105	83.4	23.2	4	9.7-91	47.7	39.7	5	38-535	189.8	206
Ba	9	98-198	135.3	36.9	--	--	--	--	9	18-848	168.2	262	--	--	--	--
Cd	2	99-129	114.3	NA	--	--	--	--	6	81-202	110.5	45.7	--	--	--	--
Cr	2	99-178	138.4	NA	--	--	--	--	7	22-273	143.1	93.8	3	98-625	279.2	300
Cu	8	61-140	95.0	28.8	6	38-107	79.1	27.0	11	10-210	111.8	72.1	8	95-480	203.0	147
Fe	6	78-155	103.7	26.1	6	89-159	102.3	28.6	6	48-94	80.4	16.2	6	26-187	108.6	52.9
Pb	11	66-138	98.9	19.2	11	68-131	97.4	18.4	12	23-94	72.7	20.9	13	80-234	107.3	39.9
Mn	4	81-104	93.1	9.70	3	92-152	113.1	33.8	--	--	--	--	--	--	--	--
Ni	3	99-122	109.8	12.0	--	--	--	--	--	--	--	--	3	57-123	87.5	33.5
Sr	8	110-178	132.6	23.8	--	--	--	--	--	--	--	--	7	86-209	125.1	39.5
Zn	11	41-130	94.3	24.0	10	81-133	100.0	19.7	12	46-181	106.6	34.7	11	31-199	94.6	42.5

Source: Ref. 4. These data are provided for guidance purposes only.

n: Number of samples that contained a certified value for the analyte and produced a detectable concentration from the FPXRF instrument.

SD: Standard deviation; NA: Not applicable; only two data points, therefore, a SD was not calculated.

%Rec.: Percent recovery.

-- No data.

TABLE 7

EXAMPLE ACCURACY FOR TN 9000[a]

Standard Reference Material	Arsenic			Barium			Copper			Lead			Zinc		
	Cert. Conc.	Meas. Conc.	%Rec.	Cert. Conc.	Meas. Conc.	%Rec.	Cert. Conc.	Meas. Conc.	%Rec.	Cert. Conc.	Meas. Conc.	%Rec.	Cert. Conc.	Meas. Conc.	%Rec.
RTC CRM-021	24.8	ND	NA	586	1135	193.5	4792	2908	60.7	144742	149947	103.6	546	224	40.9
RTC CRM-020	397	429	92.5	22.3	ND	NA	753	583	77.4	5195	3444	66.3	3022	3916	129.6
BCR CRM 143R	--	--	--	--	--	--	131	105	80.5	180	206	114.8	1055	1043	99.0
BCR CRM 141	--	--	--	--	--	--	32.6	ND	NA	29.4	ND	NA	81.3	ND	NA
USGS GXR-2	25.0	ND	NA	2240	2946	131.5	76.0	106	140.2	690	742	107.6	530	596	112.4
USGS GXR-6	330	294	88.9	1300	2581	198.5	66.0	ND	NA	101	80.9	80.1	118	ND	NA
NIST 2711	105	104	99.3	726	801	110.3	114	ND	NA	1162	1172	100.9	350	333	94.9
NIST 2710	626	722	115.4	707	782	110.6	2950	2834	96.1	5532	5420	98.0	6952	6476	93.2
NIST 2709	17.7	ND	NA	968	950	98.1	34.6	ND	NA	18.9	ND	NA	106	98.5	93.0
NIST 2704	23.4	ND	NA	414	443	107.0	98.6	105	106.2	161	167	103.5	438	427	97.4
CNRC PACS-1	211	143	67.7	--	772	NA	452	302	66.9	404	332	82.3	824	611	74.2
SARM-51	--	--	--	335	466	139.1	268	373	139.2	5200	7199	138.4	2200	2676	121.6
SARM-52	--	--	--	410	527	128.5	219	193	88.1	1200	1107	92.2	264	215	81.4

Source: Ref. 4. These data are provided for guidance purposes only.

[a] All concentrations in milligrams per kilogram.

%Rec.: Percent recovery; ND: Not detected; NA: Not applicable.

-- No data.

TABLE 8

EXAMPLE REGRESSION PARAMETERS FOR COMPARABILITY[1]

	Arsenic				**Barium**				**Copper**			
	n	r^2	Int.	Slope	n	r^2	Int.	Slope	n	r^2	Int.	Slope
All Data	824	0.94	1.62	0.94	1255	0.71	60.3	0.54	984	0.93	2.19	0.93
Soil 1	368	0.96	1.41	0.95	393	0.05	42.6	0.11	385	0.94	1.26	0.99
Soil 2	453	0.94	1.51	0.96	462	0.56	30.2	0.66	463	0.92	2.09	0.95
Soil 3	—	—	—	—	400	0.85	44.7	0.59	136	0.46	16.60	0.57
Prep 1	207	0.87	2.69	0.85	312	0.64	53.7	0.55	256	0.87	3.89	0.87
Prep 2	208	0.97	1.38	0.95	315	0.67	64.6	0.52	246	0.96	2.04	0.93
Prep 3	204	0.96	1.20	0.99	315	0.78	64.6	0.53	236	0.97	1.45	0.99
Prep 4	205	0.96	1.45	0.98	313	0.81	58.9	0.55	246	0.96	1.99	0.96

	Lead				**Zinc**				**Chromium**			
	n	r^2	Int.	Slope	n	r^2	Int.	Slope	n	r^2	Int.	Slope
All Data	1205	0.92	1.66	0.95	1103	0.89	1.86	0.95	280	0.70	64.6	0.42
Soil 1	357	0.94	1.41	0.96	329	0.93	1.78	0.93	—	—	—	—
Soil 2	451	0.93	1.62	0.97	423	0.85	2.57	0.90	—	—	—	—
Soil 3	397	0.90	2.40	0.90	351	0.90	1.70	0.98	186	0.66	38.9	0.50
Prep 1	305	0.80	2.88	0.86	286	0.79	3.16	0.87	105	0.80	66.1	0.43
Prep 2	298	0.97	1.41	0.96	272	0.95	1.86	0.93	77	0.51	81.3	0.36
Prep 3	302	0.98	1.26	0.99	274	0.93	1.32	1.00	49	0.73	53.7	0.45
Prep 4	300	0.96	1.38	1.00	271	0.94	1.41	1.01	49	0.75	31.6	0.56

Source: Ref. 4. These data are provided for guidance purposes only.

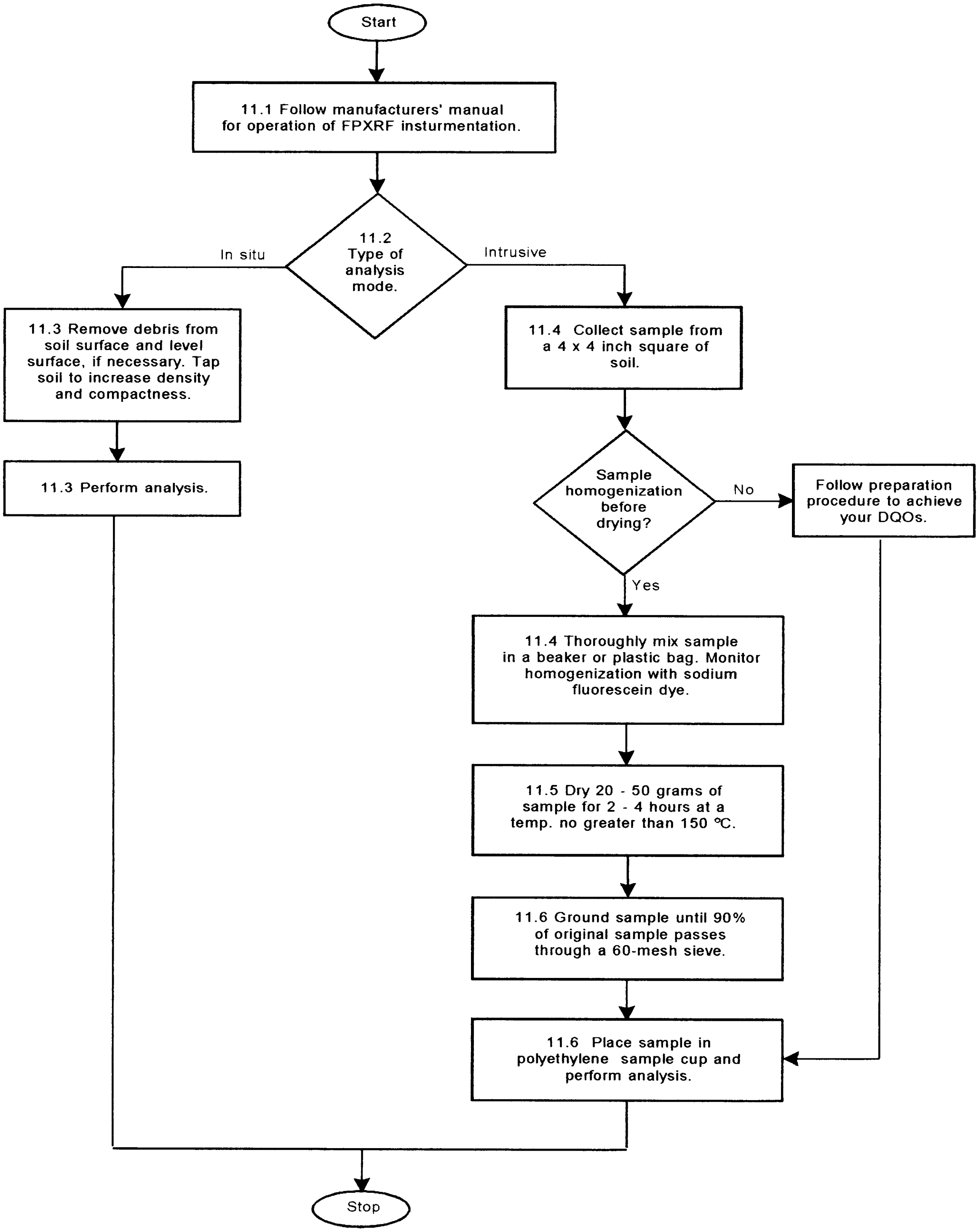
[1] Log-transformed data

n: Number of data points; r^2: Coefficient of determination; Int.: Y-intercept

— No applicable data

METHOD 6200

FIELD PORTABLE X-RAY FLUORESCENCE SPECTROMETRY FOR THE DETERMINATION OF ELEMENTAL CONCENTRATIONS IN SOIL AND SEDIMENT



Field Standard Operation Procedure No.21
Drilling Spoils Handling and Disposal Protocol

Sampling Handling and Disposal Procedures

The following procedure is for the handling and disposal of test pit cuttings, geotechnical boring spoils, bench scale test boring spoils, and PPE from the Highway 99 and Puyallup sites.

A. Materials:
- Personal protective equipment as required by Health and Safety Plan (HASP)
- Solid Hazardous Waste drums
- Poly sheeting

B. Procedure:

1. All soils extracted at the test pit locations will be used as backfill for the test pits only. The operator will take the following precautions for test pits in these areas:

    a. When removing soils from the test pit, the operator will keep soils separated in the order of removal. Soils will be backfilled in in the same order they were removed.

    b. When backfilling the test pit soils will be placed in a minimum of 12-inch lifts, the operator will use the backhoe to compact material before each subsequent lift.

2. All soils extracted from the geotechnical test borings, decontamination water, and bench scale test boring material not collected for sampling will be separated and placed in 55-gallon drums for disposal off-site.

Low- Stress (Low-Flow) Groundwater Sampling

SOP 1-12
Revision: 2
Date: February 2015

Approved: JoNell Mullins

Technical Review: Lynne France

1.0 Objective

The purpose of this technical standard operating procedure (SOP) is to define the procedural requirements for low-flow (minimal drawdown) groundwater sampling.

2.0 Background

Low-flow groundwater sampling is a method of collecting samples from a well that, unlike traditional purging methods, does not require the removal of large volumes of water from the well. The objective of low-flow groundwater sampling is to collect samples with minimal alterations to water chemistry through pumping the well at a rate low enough to minimize drawdown and to avoid disturbance in the well. Low-flow groundwater sampling refers to the velocity with which water enters the pump intake, and that which is imparted to the formation pore water in the immediate vicinity of the well screen. It does not necessarily refer to the flow rate of water discharged at the surface of the well which can be affected by flow regulators or restrictions.

Water level drawdown provides the best indication of the stress imparted by a given flow-rate for a given hydrological situation. The objective of low-flow groundwater sampling is to pump the well in a manner that minimizes stress (drawdown) to the system. Minimal drawdown must be stabilized such that the water to be sampled is representative of the formation surrounding the screened interval, and is not from the stagnant water column above the screened interval. Minimal drawdown is achieved to the extent practical taking site sampling objectives into account. Typically flow rates on the order of 0.1 to 0.5 liter per minute (L/min) are used. However, achieving flow rates of 0.1 to 0.5 L/min can be dependent on site-specific hydrogeology. Some very coarse-textured formations have successfully been sampled via low-flow techniques at flow rates up to 1 L/min. The effectiveness of using low-flow purging is intimately linked with proper well screen location, well screen length, and well construction and development techniques.

Low-flow groundwater sampling can be used to collect samples for all categories of aqueous-phase contaminants and naturally occurring analytes, including volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), and other organic compounds; metals and other inorganics; pesticides; polychlorinated biphenyls (PCBs); radionuclides; and microbiological constituents. Low-flow groundwater sampling techniques are particularly well-suited in applications where it is desirable to sample aqueous-phase constituents that may sorb or partition to particulate matter. It is not applicable to sampling wells that contain either light or dense non-aqueous-phase liquids (LNAPLs or DNAPLs).

A variety of sampling devices are available for low-flow groundwater sampling, including peristaltic pumps, bladder pumps, electrical submersible pumps, and gas-driven pumps. Pump type should be selected based on known site conditions, including well depth, well diameter, water level, and anticipated well volume, as well as sampling objectives. Note that peristaltic pumps (suction pumps) cannot be used under conditions in which the water table is greater than 25 feet below ground surface. Additionally, in most instances, peristaltic pumps may not be used for collecting VOC samples because they create a vacuum that potentially contributes bias to sampling for VOC's via low flow technicques. Bailers, too, are generally inappropriate devices for low-flow sampling. Gas-driven pumps are generally not advisable for VOC or SVOC sample collection due to the potential for sample contamination.

Dedicated pumps (those which are permanently installed in the well –e.g., bladder pumps) are preferred over portable pumps because they eliminate disturbance to the water column in the well during pump insertion, thus providing lower turbidity values, shorter purge times, and lower purge volumes to achieve stabilized indicator parameter measurements. However, portable pumps can be used if care is taken to minimize disturbance to the water column during pump insertion, and if adequate time is allowed following pump insertion and prior to pump operation for any particulates agitated in the water column to settle. Both dedicated and portable pumps should be easily adjustable, and should operate reliably at lower flow rates. All pumps typically have some limitations which should be evaluated with respect to site-specific considerations and data quality objectives on a case-by-case basis.

Water quality indicator parameters should be continuously monitored during low-flow purging using a flow-through cell, or in-line parameter monitoring techniques. Continuous indicator parameter monitoring is a critical component to low-flow groundwater sampling. Water quality indicator parameters include temperature, pH, oxidation-reduction potential (ORP), specific conductivity, dissolved oxygen (DO), and turbidity. The flow-through cell enables continuous collection of real-time parameters during low-flow purging. Stabilization is achieved after all parameters fall within established limits for three successive readings as discussed in Section 5. Stabilization of low-flow parameters is further discussed in Section 5.0 (Procedure) of this SOP.

Advantages of low-flow groundwater sampling are:

- Improved sample quality (e.g., less turbid and more representative of the aquifer)
- Potentially reduced purging and sampling times
- Reduced purge water volume

2.1 Associated Procedures

- SOP 1-6, *Water Level Measurement*
- SOP 4-5, *Field Equipment Decontamination at Nonradioactive Sites*
- SOP 2-2, *Guide to Handing of Investigation Derived Waste*

3.0 General Responsibilities

Site Manager - The site manager is responsible for ensuring that field personnel are trained in the use of this procedure and for verifying that well development and purging are carried out in accordance with this procedure.

Field Team Leader - The field team leader is responsible for complying with this procedure.

Note: Responsibilities may vary from site to site. Therefore, all field team member responsibilities shall be defined in the field plan or site-/project-specific quality assurance plan.

4.0 Required Equipment

- Pump (including peristaltic pumps, bladder pumps, electrical submersible pumps, and gas-driven pumps as discussed in Section 2.0 of this SOP)
- Appropriate controller for selected pump type
- For bladder pumps: Compressor and controller for the system (compressed non-reactive gas may also be used in lieu of a compressor)
- Power source (e.g., battery or generator), as required
- Pump tubing (typically polyethylene with Teflon® lining).Note that portable bladder pumps require combination tubing (for air and water); therefore the correct tubing sizes for the portable bladder pump should be verified. Additionally, peristaltic pumps require flexible tubing (silicone or Tygon) tubing for the pump head.
- Electronic water level meter or oil-water interface probe (according to SOP 1-6)
- Water quality meter(e.g., YSI 600 Series) with a closed flow-through cell for continuous in-line measurement of temperature, pH, conductivity, ORP, and DO prior to sample collection
- Turbidity meter (Reporting in nephelometric turbidity units [NTUs])
- Standards for calibration and field check, as needed, of water quality and turbidity meters (as determined by anticipated field conditions)
- Volume measuring device to determine flow (e.g., graduated cylinder)
- Stop watch
- Tape measure
- Personal protective equipment as specified in the site-specific health and safety plan
- Polyethylene sheeting

- Sample containers, including packaging supplies and all associated paperwork (e.g., chain of custody forms) as required in the sampling plan and/pr SOP 2-1, Packaging and Shipping Environmental Samples
- Decontamination supplies, as required, according to SOP 4-5
- Disposal drums (e.g., 55-gallon Department of Transportation-approved) or other purge water storage container, if required by the site-specific sampling plan
- Photoionization detector (PID)/organic vapor monitor (OVM) or equivalent as specified in site-specific health and safety plan

Note: All sampling devices (bladders, pumps, and tubing) should be constructed of stainless steel, polyethylene, Teflon®, glass, or similar non-reactive materials.

5.0 Procedure

The following steps must be followed for low-flow groundwater sampling activities:

1. Review site-specific health and safety plan, and site-specific project and sampling plans before initiating sampling activities.

2. Review available existing data for site to evaluate approach to sampling site wells: prepare to sample site wells in the order of least contaminated to most contaminated. Additionally, existing site data should be reviewed to determine anticipated hydrogeologic conditions and well completion details.

3. Prior to sampling, all sampling devices and monitoring equipment shall be calibrated according to manufacturer's recommendations and the site-specific sampling plan. Calibration of pH should be performed with at least two buffers which bracket the expected pH range. DO calibrations should be corrected for local barometric pressure readings and altitude.

4. Put on personal protective clothing and equipment as specified in the site-specific health and safety plan.

5. Open the well cover and check condition of the wellhead, including the condition of the surveyed reference mark, if any. If no reference mark exists, create a reference mark on the north side of the well riser using a permanent marker or equivalent. Record the location of the reference mark in the field notes.

6. Monitor the air space at the wellhead for VOCs using a PID/OVM or equivalent immediately upon removal of the well plug and as according to health and safety requirements.

7. Determine the depth to static water level in accordance with SOP 1-6, taking precautions to minimize disturbance of the stagnant water column above the screened interval during water level measurement. Well depth should be obtained from review of the well completion logs or from previous work. Insertion of a water level measuring device to the bottom of the well casing will result in resuspension of settled solids from the formation surrounding the screened interval, thus requiring longer purging times for turbidity and other field parameter equilibration.

8. Dedicated sampling devices (those permanently installed in the well) capable of pumping and sampling are preferred over any other type of device. Any portable sampling device should be slowly and carefully lowered to the middle of the screened interval or slightly above the middle to minimize excessive mixing of the stagnant water in the casing above the screen with the screened interval zone water, and to minimize resuspension of solids collected at the bottom of the well or in the surrounding formation within the screened interval.

9. New polyethylene tubing shall be used for each sample when using non-dedicated sampling equipment. Prepare the pump and tubing for insertion into the well. Lower the pump intake down into the well casing. Connect the flow-though cell in-line with the pump effluent tubing.

10. Generally, the pump intake should be placed in the mid-point of the screened interval. This provides consistency between sampling rounds. However, if the geology of the screened interval consists of heterogeneous materials with layers of contrasting hydraulic conductivity, the pump intake should be positioned adjacent to the zone of highest hydraulic conductivity (as determined via review of the existing site hydrogeologic conditions/well completion logs). Also, the sampling plan should be consulted to determine if particular zones (e.g., known zones of contamination) are targeted for sampling per DQOs).

11. To achieve low-flow purging conditions, the purge rate should generally not exceed 0.5 L/min. Adjust the pump control to stabilize the flow rate, and therefore minimize drawdown (less than 0.3 foot during purging activities). The water level in the well should be measured throughout the purging process to monitor drawdown. Flow rate can be measured from the discharge tube using a volumetric measuring device (e.g., a graduated cylinder) and a stop watch (Note: determine flow rate by measuring volume in 0.5-minute or 1-minute increments.)

12. Record water level measurements, and field parameters including pH, temperature, specific conductivity, oxidation reduction potential (ORP), DO, turbidity, and flow rate every three to five minutes during the purging process. Record all measurements and observations in the log book or on a Groundwater Purging and Sampling Form (Attachment 1). Purging shall continue until the field parameters have stabilized. Parameters are considered stable when three consecutive readings are within the limits of the criteria defined in Table 5.1 and/or in accordance with the site-specific sampling plan. Turbidity ideally should stabilize below 10 NTU prior to sample collection, particularly if groundwater samples are to be collected for metals or PCB analyses.

TABLE 5.1 Stabilization of Water Quality Indicator Parameters

Parameter	Units	Stabilization Criteria
Water Level	Feet/meters	< 0.3 foot (< 0.1 meter)
Temperature	°F/°C	± 3 percent, or ±1.8 degrees Fahrenheit (°F) /±1 degree Celsius (°C)
pH	(n/a)	± 10 percent, or ±0.1 standards units (SU)
Specific Conductivity	µm/cm	±3 percent (microsiemens per centimeter, or µm/cm)
ORP	mV	±10 millivolts (mV)
Dissolved Oxygen	mg/L	±10 percent, or 0.2 milligram per liter (mg/L) - whichever is greater
Turbidity	NTU	± 1 Nephelometric Turbidity Unit (NTU) (±10 percent for turbidity if greater than 10 NTU)
Flow Rate	L/min	0.1 to 0.5 Liters per minute (L/min) (< 1 L/min), Specific flow rates and sampling rates to be identified in the sampling plan if project/contract required.

13. In low recharge aquifers, the following steps shall be followed:
    (1) If the initial water level is less than 10 feet above the top of the well screen, then purge the well until dry and allow sufficient recharge to collect samples.
    (2) If the initial water level in the well is greater than 10 feet above the top of the screen, then care shall be taken to prevent the dewatering of the screened interval during purging of the well.
        (2a) Continue purging until the water level is between 1 foot (0.3 meter) and 5 feet (1.5 meters) above the top of the screened interval.
        (2b) Allow the well to recharge, then continue purging until at least one full initial well volume has been purged.
    (3) Record all data, measurements, and observations in the log book.

14. After field parameters have stabilized, disconnect the flow through cell, and collect groundwater samples directly from the discharge tubing into an appropriate sample container. If using a peristaltic pump to collect VOC samples, refer to item 16 of this SOP for the correct procedure for sampling VOCs with a peristaltic pump. If an in-line, flow-through cell is used to continuously monitor indicator parameters, it should be disconnected or bypassed during sample collection. During sample collection, maintain the pump rate at the same rate used during purging (unless specified in the sampling plan). The pump rate used during sample collection may need to be lowered to minimize aeration, bubble formation, or turbulent flow of water into sample bottles, or to prevent sample preservatives from being washed out of the sample container.

15. Groundwater sampling (including the collection of all required quality assurance/quality control samples specified in the sampling plan) shall be performed immediately upon completion of purging (unless time for recharge is required for low-recharge wells) using the same equipment used for purging. Sampling should occur in a progression from the least to the most contaminated well, if this is known. Generally, volatile (e.g., solvents and fuel constituents) and gas sensitive (e.g., Fe^{2+}, CH_4, H_2S/HS^-, and alkalinity) analytes should be sampled first. The sequence in which samples for most inorganic parameters are collected is immaterial unless filtered (dissolved) samples are required. Filtered samples should be collected last and in-line filters should be used. After all unfiltered samples have been collected, a 0.45 micron (µm) in-line filter shall be inserted in the discharge line for collection of filtered samples, as required.

16. VOC samples should not be collected directly from the discharge end of a peristaltic pump. After field parameters have stabilized, and all other samples have been collected as required, stop the pump and simultaneously pinch the discharge end of the tubing shut. Disconnect the flow-through cell. Remove the tubing from the well and fill the VOC sample containers from the influent end of the sample tubing, (the end of the tubing that was located down-well during purging activities). The flow rate when filling sample vials may be controlled by setting the peristaltic pump in reverse.

17. Place all samples in a cooler with ice or ice packs to comply with project, laboratory, and/or regulatory requirements.

18. After sampling activities have been completed, remove the portable pump assembly from the well, if used, and decontaminate all non-disposable components. Replace the well plug. Secure the well plug and well cover. Clean up the work area: containerize and/or dispose of purge water as required by the site-specific sampling plan, and dispose of tubing and all other disposable sampling equipment as investigation derived waste (IDW) after each use as described in the site-specific sampling plan.

6.0 Restrictions/Limitations

Only grounded electrical devices should be used for low-flow sampling activities. If a gasoline-powered electrical source is used, place portable power sources (e.g., generators) 50 feet (15 meters) or farther from the wellhead to prevent potential contamination of samples. Additionally, it should be clearly noted in the field notes or on the Groundwater Sampling Log (Attachment 1) if a well has been pumped dry and allowed to recharge prior to sample collection, as low-flow sampling data is no longer applicable.

7.0 References

ASTM D6452-99(2012)e1, Standard Guide for Purging Methods for Wells Used for Groundwater Quality Investigations, ASTM International, West Conshohocken, PA, 2012.

ASTM D4448-01(2013), Standard Guide for Sampling Ground-Water Monitoring Wells, ASTM International, West Conshohocken, PA, 2013.
Puls, R.W. and M.J. Barcelona. April 1996. *Low-Flow (Minimal Drawdown) Ground Water Sampling Procedures*. U.S. EPA, Ground Water Issue, Publication Number EPA/540/S-95/504.

U. S. Environmental Protection Agency. May 2002. *Groundwater Sampling Guidelines for Superfund and RCRA Project Managers.* Ground Water Forum Issue Paper, EPA 542-S-02-001, OSWER, Technology Innovative Office, Washington, D.C.

Attachment 1

EXAMPLE LOW-FLOW GROUNDWATER SAMPLING PURGING DATA SHEET

Site Name: ______________________________ **Date:** _________________________

OVM: **FID** ☐ **PID** ☐ **In Casing (ppm): (Initial)** _______________ **(Vented to)** ____________________

Well ID: ____

Purging/Sampling Device: ____

Initial Static Water Level (feet btoc): ____

Analytical Parameters: ____

Final Water Level (feet btoc): ____

QC Samples Collected: ____

Purge Start Time: ____

Sample Number: ____

Sample Time: ____

Samplers' Signatures: ____

Time	Water Level (ft btoc)	Temperature (ºC)	pH (SU)	Conductivity (µs/cm)	Dissolved Oxygen (mg/L)	ORP (mV)	Turbidity (NTU)	Flow Rate (mL/min)	Comments (e.g., depth of pump intake, screened interval)

Parameter	Units	Stabilization Criterion
Water Level	Feet/meters	< 0.3 foot (< 0.1 meter)
Temperature	°F/°C	± 3 percent, or ±1.8 degrees Fahrenheit (°F) /±1 degree Celsius (°C)
pH	(n/a)	± 10 percent, or ±0.1 standards units (SU)
Specific Conductivity	µm/cm	±3 percent (microsiemens per centimeter, or µm/cm)
ORP	mV	±10 millivolts (mV)
Dissolved Oxygen	mg/L	±10 percent, or 0.2 milligram per liter (mg/L) - whichever is greater
Turbidity	NTU	± 1 Nephelometric Turbidity Unit (NTU) (±10 percent for turbidity if greater than 10 NTU)
Flow Rate	L/min	0.1 to 0.5 Liters per minute (L/min) (< 1 L/min)

Field Standard Operation Procedure #6:
Bench Scale Treatability Testing

The protocol set forth in this Standard Operating Procedure (SOP) outlines the procedures to be used for evaluating the in-situ solidification and stabilization (ISS) mix design from the Highway 99 and Puyallup sites using various reagents. Sampling details and quality assurance (QA) requirements are provided in the Work Plan; the procedures outlined here will be performed in compliance with the Work Plan.

Required Equipment for Solidification and Stabilization (S/S) Bench Scale Testing

1. 5-gallon plastic buckets
2. Plastic cups
3. Two 1000 milliliter (ml) clear beakers
4. 100 ml graduated cylinder
5. 1000 ml graduated cylinder
6. Metal bowls
7. Metal spoons
8. Small metal spatulas
9. Syringes
10. Paddle mixing equipment (optional)
11. 5/8” rebar or tamping rod
12. 2”x4” plastic molds with lids
13. Electrical tape
14. Groundwater sample from Highway 99 site
15. Groundwater sample from Puyallup site

Procedure

1. Don health and safety equipment per the health and safety plan.
2. Collect samples of soil for the bench scale treatability study in 5-gallon buckets. Prior to placement in 5-gallon buckets, soil samples shall be logged and classified in accordance with the unified soil classification system (USCS) and screened with a hand-held X-ray fluorescence (XRF) spectrometer to determine arsenic concentrations. Samples shall be placed in separate buckets based on USCS classification and arsenic concentration as follows:
    a. Fine-grained soils – CH, CL, CL-ML, ML, MH
    b. Coarse-grained soils – SP, SM, SC, GM, GC
    c. Soils with significant organic content – OH, OL
    d. XRF readings as follows:
        i. Less than 500 parts per million (ppm)

        ii. 500 to 1,000 ppm
        iii. Greater than 1,000 ppm

3. Transport to CDM Smith Geotechnical Laboratory in Bellevue Washington.
4. At the laboratory develop composite soil mixes for each site based on the USCS classifications of each soil. Collect required geotechnical and analytical samples from the composite soils and submit for analytical testing.
5. After physical and analytical characterization testing is complete and results are received, begin preparation of the bench scale treatability testing in accordance with the work plan.
6. To a bowl (or paddle mixing bowl) add required weight of composite soil.
7. Prepare required amount of reagent(s) and stabilization components to add to the composite soil 1000 ml beaker(s). Document weight of reagent(s) and stabilization components. The ratios of the reagent(s) and stabilization components will be calculated based on the unit weight of the composite soil.
    a. If reagent is to be added as a grout mixture, make grout mixture with site groundwater to obtain required reagent/water ratio by mixing reagent(s) in metal bowls until uniform mixture is obtained.
8. Add reagent(s) and stabilization components to composite soil and mix (by hand or with paddle mixer) to obtain uniform mixture. Make notes regarding test observations.
9. Allow mixture set for 5 minutes and draw off free water prior to casting samples into molds.
10. Weigh each mold on scale before filling and document.
11. Cast required number of cylinders, as per the work plan, into 2”x4” cylinders. Place the material in the molds in three layers. Tamp each layer 25 times with a tamping rod or piece of 5/8” rebar to provide a homogeneous sample and remove any entrapped air bubbles.
12. Weigh each completed cylinder on scale and document.
13. Cover with plastic caps and electrical tape to prevent evaporation of moisture and label the plastic molds.
14. Place completed cylinders upright in coolers and store at room temperature and not in direct sun light.

Synthetic Precipitation Leaching Procedure and Semi-Dynamic Leaching Procedure on Amended Soils

Laboratory-Specific SOP: DTL 1-10
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Prepared:	Todd Burgesser	**Technical Review:**	Roger Olsen
Lab Manager:	Todd Burgesser	**Editorial Review:**	Traci Mordell
Laboratory Name:	CDM Smith Denver Treatability Laboratory (DTL)		

1.0 Overview and Application

This technical standard operating procedure (SOP) describes the laboratory procedures that will be followed to prepare and leach composite soil and stabilized and solidified soils for leaching by the synthetic precipitation leaching procedure (SPLP) by modified EPA SW-846 1312 and the semi-dynamic leaching procedure (SDL) by modified EPA 1315 and ASTM 1308. All procedures will be performed in the CDM Smith Denver Treatability Laboratory (DTL). The SPLP and SDL procedures have the options of using extraction fluid #1 at a pH of 4.2 (site location east of the Mississippi River), extraction fluid #2 at a pH of 5.0 (site location east of the Mississippi River), site groundwater, or synthetic water formulated to replicate a specific process water. The SPLP procedure will be modified to use a 2:1 liquid to solid ratio. The SDL procedure will be modified to incorporate nine sampling intervals at times contained in both ASTM 1308 and EPA 1315. These sampling intervals will be 2 hours, 24 hours, 48 hours, 72 hours, 7 days, 14 days, 21 days, 28 days, and 42 days. The solidified cylinders or stabilized soils will be leached using the selected SPLP water (discussed above). The liquid to surface area ratio will be maintained at approximately 10:1 milliliter per square centimeters. All leaching procedures will be performed in the CDM Smith DTL.

2.0 Associated Procedures

- SOP 1-2 Sample Custody
- SOP 4-1 Logbook Documentation

3.0 General Responsibilities

Laboratory Manager – The laboratory manager is responsible for ensuring that laboratory personnel are trained in the use of this procedure, the required equipment, and health and safety procedures and that soil samples are prepared in accordance with this procedure and any other SOPs pertaining to laboratory procedures. The laboratory manager must also ensure that the quantity and type of quality assurance samples collected meet the requirements of the work plans.

4.0 Project Planning

This section provides a list of general equipment used for sample preparation operations and health and safety considerations.

4.1 General Equipment

- Site-specific plans (e.g., sampling, work, health and safety)
- Laboratory logbook
- Indelible black ink pens and markers
- Appropriate sample containers
- Labels and appropriate forms/documentation for sample shipment
- Nitrile or appropriate gloves
- Sample containers
- Ice/Refrigerators
- Plastic cylinders with endcaps (2- x 6-inch)
- Disposal spatulas, spoons, and other miscellaneous equipment.
- Twelve-inch 2-millimeter stainless steel sieve
- Extraction fluid
- Peristaltic pump
- Plastic zip-top bags
- Personal protective clothing and equipment
- Stainless steel and/or Teflon®-lined spatulas and pans and knives, trays, bowls, trowels, or spoons
- Decontamination supplies
- Sample chain-of-custody forms
- Laboratory grade oven capable of 160˚C +/- 2˚C
- Riffle splitter with catch pans (1/2- or 3/4-inch)
- Stainless steel bowls
- Rotary tumbler
- Analytical balance (0.01 gram [g] accuracy)
- Polytetrafluoroethylene (PTFE) bottles – 500 to 1000 milliliters (mL)

- pH meter with pH electrode and oxidation reduction potential (ORP) electrode
- Borosilicate glass beakers (various sizes)
- Silicon tubing
- Conductivity meter

5.0 Modified SPLP Procedure

After preparation of the soils samples, the following steps should be taken to leach the desired materials by SPLP:

1. Label the appropriate-sized PTFE bottles with the relevant sample identifications of samples to be leached.
2. Transfer the appropriate mass of the soil to the tared PTFE bottles and weigh to the nearest 0.1 g. Record the mass.
3. Quantitatively add the selected extraction fluid to each bottle (general ratio is 1:2, g/mL). Record the exact volume added.
4. Securely cap each bottle and invert the bottle to mix the soil and extraction fluid.
5. Uncap the bottles and measure the solution pH, ORP, and conductivity and record the measurements.
6. Cap the bottles and secure the cap with electrical tape.
7. Place each bottle in the rotary tumbler drum and pack the drum with bubble wrap to secure the bottles. Place the lid on the drum.
8. Rotate the bottles for 24 hours at 30 revolutions per minute.
9. After the 24 hours tumbling time, remove the sample bottles from the tumbler and allow them to sit for 30 minutes to settle the solids.
10. Remove the caps from the bottles and measure the pH, ORP, and conductivity and record the measurements.
11. Decant the solution into a labeled preserved sample bottle for analysis of total mercury.
12. Submit the samples to the contracted laboratory for total mercury analysis.

6.0 Modified SDL Procedure

The SDL procedure can be performed on either solidified solid materials (a monolith generally molded in a 2- x 6-inch cylinder) or on loose chemically stabilized soil (compacted granular material).

1. Label the selected leaching vessels (hermetic glass jar with lid and a rubber gasket, preventing contact with the leaching fluid or PTFE bottles).
2. For loose chemically stabilized material, compact the soil in a mold that matches the inside diameter of the leaching vessel. This vessel should have an opening that is equivalent or slightly larger than the bottom of the vessel (1-liter [L] beaker). Granular samples are compacted into the sample holder using a variation on the modified Proctor compaction (see Ref. 5) to include the use of 6-centimeter (cm) high-test molds. Shorter or taller molds (or packing depths) may be used as long as the compaction effort of 56,000 ft-lbf/ft^{3}is achievable. The number of packing layers should be five layers. Compaction can be performed in the leaching vessel if the vessel is sturdy enough to withstand the compaction efforts.
3. For solidified monolith samples, measure the mass and dimensions of each unmolded cylinder. Each 2- x 3-inch cylinder should have an approximate surface area of 200 square centimeters. Record the measurements and calculate the surface area. For compacted granular materials, measure the surface area of the surface that will be in the direction of mass transfer (directly in contact with the leaching fluid).
4. For monolith molded samples, suspend each cylinder (mold removed) in the leaching vessel by constructing a sling out of Teflon disks (top and bottom) and Teflon string. Place the cylinder between the disks and secure with the Teflon string. Attach the Teflon string to the outside of the vessel with packaging tape. The Teflon disks are designed in a way to contact the cylinder or core minimally at the very edges of the top and bottom of the cylinder. Suspend the cylinder at a minimum of 1 cm from the bottom and walls of the leaching vessel (glass jar). The Teflon string should not come into contact with the cylinder.
5. For compacted granular materials, place the molded compacted material directly in the bottom of the vessel.
6. Quantitatively transfer the appropriate volume of extraction fluid to the vessels. The volume of extraction fluid will equal the surface area of the cylinder times 10.

7. At the specified sampling intervals (2 hours, 24 hours, 48 hours, 72 hours, 7 days, 14 days, 21 days, 28 days, and 42 days), open the leaching vessel and transfer the leachate to a 2-L glass beaker with a peristaltic pump and clean silicon tubing. Every attempt should be made not to touch or disturb the cylinder.
8. Measure the pH, ORP, and conductivity of the leachate contained in the 2-L beakers and record the measurements.
9. Transfer the leachate to the appropriate preserved sample bottles and submit to the contracted laboratory for analysis.
10. Repeat steps 4 through 7 for each sampling interval.

7.0 Equipment Cleaning Procedures

To ensure that samples are not contaminated by equipment or containers, it is necessary to follow certain procedures for cleaning or decontaminating equipment. All equipment in direct contact with the sample must be cleaned between each sample. Decontamination procedures for this equipment are discussed below:

1. Rinse all surfaces of the glassware with deionized or distilled water.
2. Using a spray bottle, apply a layer of phosphate-free detergent to all surfaces.
3. Vigorously scrub all surfaces of glassware.
4. Rinse all surfaces again with deionized or distilled water until all detergent has been removed. Perform in triplicate.
5. Place the equipment in the drying rack. To accelerate drying, the equipment can be place in the oven at 60°C until dry.

8.0 Quality Control

Two types of quality control samples (laboratory duplicates and equipment blanks) will be prepared as described below:

8.1 Laboratory Duplicates

When adequate sample volumes are available, a laboratory duplicate sample will be prepared following the preparation of the original sample at a rate of 1 per 20 samples. The laboratory duplicate sample will be treated in the same manner as the original sample. The relative percent difference (RPD) between the original and the laboratory duplicate will be calculated as described below. Corrective action for the initial calibration is to investigate the outlying level and reanalyze that level. If the problem is not corrected, it may be necessary to remake the standard or correct the problem with the instrument and reanalyze all levels.

$$\mathbf{RPD = (D^1 - D^2)/([D^1 + D^2]/2)x100}$$

Where: RPD = relative percent difference
D^1 = first sample value
D^2 = second sample value (laboratory duplicate)

8.2 Equipment Blanks

Equipment blanks are collected after equipment decontamination. Place a suitable-sized aliquot (50 g) of sand into a drying pan and follow the procedure outlined in Sections 5 and 6. Equipment blank samples are prepared at a rate of 1 per 20 samples.

9.0 Documentation

Bound laboratory logbooks shall be used for the maintenance of laboratory records. All aspects of sample preparation and visual observations shall be documented in the laboratory logbooks. The soil drying and splitting logs, documenting the sequence and results for each day's activities, shall be filled out during preparation of all samples. All entries in laboratory logbooks should be legibly recorded and contain accurate and inclusive documentation of an individual's activities. Corrections to logbook and run log entries will be accomplished by a single cross out with the date and initials of the person making the entry. Correction fluid or correction tape is not permitted. Logbooks will be maintained in accordance with SOP DTL 4-1.