Bridgeton Landfill, LLC, Cotter Corporation (N.S.L.), and the United States Department of Energy ("OU-3 Respondents")

Field Sampling Plan

West Lake OU-3 Remedial Investigation/Feasibility Study

Volume 2a

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Field Sampling Plan

West Lake OU-3 Remedial Investigation/Feasibility Study

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Acronyms and Abbreviations

Name	Description
AI	Indoor air
AO	Outdoor air
ASAOC	Administrative Settlement Agreement and Order on Consent
bgs	below ground surface
CDFM	Corehole dynamic flow meter
CHS	Cased hold sampler
CoC	chain of custody
COPC	constituent of potential concern
CSM	Conceptual Site model
CSR	Code of State Regulations
DQO	Data quality objective
DUP	Blind field duplicate
EB	Equipment blank
EQuIS	Environmental Quality Information System
ERM	ERM Consulting & Engineering, Inc.
ESRI	Environmental Systems Research Institute
FB	Field blank
FILTB	Filter blank
FSP	Field Sampling Plan
GB	Sub-slab soil gas
GS	Exterior soil gas
HASP	Health and Safety Plan
HVAC	Heating, ventilation, and air conditioning
IDW	Investigation-derived waste
LCS	Leachate Collection Sump
MDNR	Missouri Department of Natural Resources
MET	Meteorological station
mL/min	milliliter per minute
MoDOT	Missouri Department of Transportation
MS/MSD	Matrix spike/matrix spike duplicate
NAVD 88	North American Vertical Datum of 1988
NMR	Nuclear magnetic resonance
OU	Operable Unit
OU-3 Respondents	Bridgeton Landfill, LLC, Cotter Corporation (N.S.L.), and the United States Department of Energy
P	Sampling port
PDF	portable document format
PID	Photoionization detector
PPE	Personal Protective Equipment
PSQ	Principal Study Question
PVC	Polyvinyl chloride
PZ	Piezometer
QA	Quality Assurance
QAM	Quality Assurance Manager
QAPP	Quality Assurance Project Plan
QC	Quality Control
RI/FS	Remedial Investigation/Feasibility Study

RIM	radiologically impacted materials
ROW	right-of-way
Site	West Lake Landfill
SO	Solid
SOP	Standard Operating Procedure
SOW	Scope of Work
SOW	Statement of Work
TB	Trip blank
U.S.	United States
U.S.C.	United States Code
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
USGS	United States Geological Survey
VI	Vapor intrusion
VISL	Vapor intrusion screening levels
VOC	Volatile organic compound
WG	Groundwater
WL	Leachate water
WQ	Water quality

1. INTRODUCTION

This Remedial Investigation/Feasibility Study (RI/FS) Field Sampling Plan (FSP) has been prepared by ERM Consulting & Engineering, Inc. (ERM) on behalf of Bridgeton Landfill, LLC, Cotter Corporation (N.S.L.), and the United States (U.S.) Department of Energy (collectively, "OU-3 Respondents"), for Site-wide groundwater (Operable Unit 3 [OU-3]), at the West Lake Landfill (Site). The Site is located at 13570 St. Charles Rock Road, Bridgeton, Missouri (Figure 1-1, Site Location).

The FSP was prepared at the request of the U.S. Environmental Protection Agency (USEPA) in accordance with requirements outlined in the Final RI/FS OU-3 Statement of Work (SOW), dated 21 September 2018, included as Appendix B in the Administrative Settlement Agreement and Order on Consent (ASAOC), dated 6 February 2019 (USEPA 2019).

This FSP is being submitted as Volume 2a of the RI/FS Work Plan; the Quality Assurance Project Plan (QAPP) are being submitted as the Sampling and Analysis Plan, included as Volume 2 of the RI/FS Work Plan. The Health and Safety Plan is Volume 3 of the RI/FS Work Plan.

The Site was added to the Superfund National Priorities List in 1990 and consists of three OUs:

- OU-1 includes former waste disposal areas Radiological Area 1 (Area 1) and Radiological Area 2 (Area 2) where radiologically impacted materials (RIM) have been identified (USEPA ID#MOD079900932). OU-1 also includes radionuclides on neighboring Buffer Zone and Crossroad Lot 2A2 parcels attributed to historical erosion of impacted soil from Area 2 (EMSI 2018A).
- OU-2 has no known areas identified as having been impacted with RIM and includes the Closed Demolition Landfill, Inactive Sanitary Landfill, and the North and South Quarry portions of the Bridgeton Landfill (also referred to as the Former Active Sanitary Landfill). The Missouri Department of Natural Resources (MDNR) is responsible for overseeing activities at the Bridgeton Landfill and the Closed Demolition Landfill portions of OU-2, in contrast to the remedial actions for the Inactive Sanitary Landfill, which are being addressed under USEPA's Superfund authority.
- OU-3 includes the groundwater beneath, and associated with the entire approximately 200-acre Site and off-Site areas, and is the focus of this RI/FS.

1.1 Site Background and Setting

The 212-acre Site was originally used for agriculture until a limestone quarrying and crushing operation began in 1939. Quarrying continued until 1988 and resulted in two excavation areas and two quarry pits excavated to a maximum depth of approximately 240 feet below ground surface (bgs) (H&A 2005; Golder 1996).

The Site includes six historical waste disposal areas (units), including Area 1 and Area 2 of OU-1, and the Closed Demolition Landfill, the Inactive Sanitary Landfill, and the North Quarry and South Quarry portions of the Bridgeton Landfill. A brief history and description of the Site areas is presented in Table 1, Site History, and additional details are provided in Work Plan Appendix A (Site History). The Site layout is shown on Figure 1-2, Site Layout.

The date that landfilling activities started at the West Lake Landfill is not known with certainty and has been variously cited as beginning in or around the early 1950s (EMSI 2000), or as starting in 1952 or possibly 1962 (H&A 2005). Due in part to the fact that the disposal of solid and liquid waste at the Site predated state and federal regulations for landfills, there is uncertainty regarding the specific Site activities and disposal practices. The landfill was authorized by the county to accept sanitary waste in 1952. USEPA reported that "from 1941 through 1953 it appeared that limestone extraction was the prime activity at the facility; however, as time passed, the focus of the activity appeared to shift from mining to waste disposal" (USEPA 1989).

Table 1: Site History

Area	Approximate Dates of Operation	Description of Historical Operations
West Lake Landfill Radiological Area 1	c. 1952–1974	Historical landfilling operations including disposal of RIM. There is an abandoned underground diesel tank in this area. The southwestern part of Area 1 was covered by the above-grade portion of the North Quarry of the Bridgeton Landfill in approximately 2002–2003.
West Lake Landfill Radiological Area 2	c. 1962–1974	Historical landfilling operations including disposal of RIM.
Closed Demolition Landfill	Sanitary landfilling: c. 1966–1976 Demolition landfilling: 1976–1996	Historical landfilling operations prior to permitting; municipal solid waste landfill and demolition debris landfilling operations after permitting implemented.
Inactive Sanitary Landfill	c. 1952–early 1980s	Municipal solid waste landfill
South Quarry of the Bridgeton Landfill	1985–2004	Municipal solid waste landfill
North Quarry of the Bridgeton Landfill	1979–2004	

RIM = radiologically impacted material

Source: EMSI 2018

Radionuclides on neighboring Buffer Zone and Crossroad Lot 2A2 parcels[1] (Figure 1-2, Site Layout) are attributed to historical erosion of impacted soil from Area 2 (EMSI 2018). Surrounding land use is commercial/industrial (Figure 1-3, Land Use Restrictions and Surrounding Land Use).

The nearest residential area to the Site is the Terrisan Reste mobile home park, to the southeast approximately 0.7 miles from Area 1 and 1.1 miles from Area 2. The Spanish Village residential subdivision is south of the Site near the intersection of St. Charles Rock Road and I-270, approximately 1 mile from Area 1 and 1.25 miles from Area 2 (Figure 1-2, Site Layout).

The Site is approximately 1.75 miles east-southeast of the Missouri River, with portions of the Site ranging from 1.4 to 2.0 miles from the river (Figure 1-1, Site Location). There are a series of storm water detention ponds near the Site, including one along the west side of the landfill property. This pond is part of the storm water management system operated and maintained by the Earth City Flood Control and Levee District.

1.2 Alignment with OU-3 RI/FS Work Plan and Data Quality Objectives

Table 2 below provides a list of key topics and where the topics are addressed in the OU-3 RI/FS Work Plan.

[1] These parcels were formerly owned by Ford Motor Credit, Inc. and are sometimes referred to as the "Ford Property."

Table 2: Alignment with OU-3 RI/FS Work Plan

Key Topic	Section Addressed in Work Plan
Initial conceptual Site model	Section 3
Identified data gaps	Section 4
Problem description, including list of principal study questions	Section 5.1
Site characterization approach	Section 5.2
Proposed investigation tools	Section 5.3
Reporting process	Section 6

The QAPP outlines the data quality objectives (DQOs) for the project that will be used to demonstrate that the data collected during the RI/FS program are of acceptable quality. Data from the OU-3 RI/FS will be used to refine the conceptual Site model (CSM), address principal study questions (PSQs) associated with the DQOs in QAPP Section 3, and inform decision making for the Feasibility Study.

This FSP outlines how the data will be collected, including detailed field methodology descriptions.

1.3 Remedial Investigation Field Activities

ERM will perform the field activities described in this FSP on behalf of the OU-3 Respondents as part of the OU-3 RI/FS to refine the CSM, address the PSQs, and inform decision making for the Feasibility Study. Each of these field activities and their purpose is described in Section 3 of this FSP. The FSP will be revised to include any additional activities proposed as part of the OU-3 RI/FS.

1.4 Project Organization and Field Team Responsibilities

The OU-3 Respondents will direct this project. The OU-3 Project Coordinator has the responsibility for overall project completion and communication between the regulators and OU-3 Respondents. The OU-3 Technical Advisor will coordinate communication between the OU-3 Respondents and contractors. ERM will function as the primary contractor and has the responsibility for subcontractor coordination, field work, and reporting. Key roles and team members are presented below. Section 2.0 of the QAPP contains detailed descriptions of the complete roles listed below.

Table 3: Key Roles and Team Members

Key Roles	Team Members
Project Coordinator	Paul Rosasco, Engineering Management Support, Inc.
OU-3 Technical Advisor	Ralph Golia, P.G., AMO Environmental Decisions, Inc.
Partner-in-Charge	Joe Fiacco, P.G.
Project Manager	Alice Sandzén, P.G.
Field Team Leader	Clementine Dulieu
Quality Assurance Manager	Andrea Brazell
Field Safety Officer	Role may be fulfilled by various ERM field team members
Geospatial Coordinator	Brett Shaver
Radiation Safety Officer	Tim Pratt, Ameriphysics
Radiation Control Supervisor	Role may be fulfilled by various staff from Ameriphysics

P.G. = Professional Geologist

1.5 Health and Safety Plan

A Health and Safety Plan (HASP), which includes the most current OU-1 Radiation Safety Plan and OU-1 Emergency Response Plan for work conducted within the boundaries of OU-1 Areas 1 and 2, is included as Volume 3 of the RI/FS Work Plan. The HASP provides a summary of personnel responsibilities, protective equipment, health and safety procedures and protocols, personnel training, and type and extent of medical surveillance. The plan identifies problems or hazards that may be encountered during performance of the RI and how these are to be addressed. Additionally, procedures for protecting third parties, such as Site visitors, vehicular or pedestrian traffic near drilling locations or sampling crews, and for the surrounding community, in general, are described in the HASP.

2. SAMPLING PLAN DESIGN AND RATIONALE

ERM will implement the OU-3 RI using a dynamic investigation approach that will rely on high-resolution screening data to develop a three-dimensional understanding of Site geologic and hydrogeologic conditions and constituent of potential concern (COPC) distribution, as discussed in Section 5.2 of the Work Plan. ERM has developed a preliminary CSM, which is presented in Section 3 of the Work Plan, and will update it in real time as data is generated. ERM will use the refined CSM to support design of an efficient monitoring well network that will be installed, gauged, sampled, and tested to refine ERM's CSM.

Field activities will be prioritized and sequenced based on the PSQs they are intended to answer as described in Work Plan. Data will be continuously evaluated as they are collected and presented to the USEPA, so work can continue in accordance with the Work Plan, QAPP, and FSP without unnecessary pauses.

As described in Section 6.2 of the Work Plan, addenda to the Work Plan will be submitted to the USEPA for its review and approval to allow for a flexible, iterative, and collaborative approach to the OU-3 RI/FS. Data collected and evaluated during Site characterization activities will be presented to the USEPA on a regular basis and used to inform decisions on how to proceed to adequately answer the PSQs.

The FSP for the OU-3 RI/FS has been designed to obtain the additional data required to adequately characterize subsurface conditions including, but not limited to, geologic conditions, the groundwater flow regime, nature and extent of COPCs, and background levels of naturally occurring constituents. The additional data will support the OU-3 Baseline Risk Assessment and evaluation of remedial technologies and alternatives.

2.1 Sampling Rationale and Laboratory Analyses

The media to be sampled and associated laboratory analyses were selected to meet the objectives of the OU-3 RI/FS PSQs and the DQOs outlined in QAPP Section 3. Groundwater/leachate, alluvial aquifer matrix, bedrock aquifer matrix, vapor, and groundwater screening samples will be collected for analysis of the parameters listed in attached Table 2-1a-f. Information on parameters, analytical methods, preservation requirements, and container requirements is provided in attached Table 2-2a-e. A detailed discussion of the analytical test methods and the detection limits are included in the QAPP.

2.2 Sample Collection Order

The recommended collection order for the water samples is presented in attached Table 2-3. The collection order protocol is designed to prevent cross contamination and sample agitation, with the most volatile analyses collected first. When collecting groundwater samples for volatile organic compound (VOC) analysis at CHS locations, samples will be collected during steady laminar flow to avoid aeration within the sample bottles or overfilling and preservative loss. If limited sample volume is available from a particular groundwater monitoring well, parameters determined to be the most crucial to understanding groundwater quality will be collected first, in agreement with USEPA.

2.3 Sample Handling and Custody

Sample handling field activities include: sample collection, preservation of the samples, packing, transportation, and handling of the samples prior to receipt by the laboratory. The following sections outline the sample naming conventions by sample type, and protocols for sample collection documentation, container labeling, and packing and shipping. Field quality assurance (QA)/quality control (QC) procedures are summarized in Section 2.4, and in Section 5.1 of the QAPP. Appendix A includes the standard operating procedures (SOPs) for field documentation, chain of custody (CoC), and shipping procedures.

2.3.1 Sample Naming Conventions

All field measurement locations, sample locations, and samples, including those collected for QA/QC purposes, will be assigned a unique identification number. The unique identification number will be used to track field-screening data and laboratory analytical results in the project database, as well as presentation of the data in reports. During field work, the unique identification numbers will be recorded in the field book, on field forms, on the sample containers, and/or on the CoC. The naming conventions used for each type of sample are described below.

2.3.1.1 Solid Samples

- Location: Monitoring well (MW) series (proposed new drilling locations only).
- Sample Depth Interval (feet bgs): 0–10, 10–20, 20–30, etc.
- Sample Matrix: SO (solid—i.e., alluvium and bedrock matrices).
- Sample Date: YYYYMMDD (year, month, day).
- Example: MW-500-25-26-SO-20210102 (solid sample collected on 2 January 2021 from MW-500 drilling location at a depth of 25 to 26 feet bgs).

2.3.1.2 Groundwater Samples

- Location: MW and Piezometer (PZ) series.
- Sampling Port (P) Number (for multi-level wells): P1, P2, P3, etc.
- Sample Matrix: WG (groundwater).
- Sample Date: YYYYMMDD (year, month, day).
- Example: PZ-111-SD-WG-20210102 (groundwater sample collected from PZ-111-SD on 2 January 2021), MW-500-P1-WG-20210302 (groundwater sample collected from Port 1 of MW-500 on 2 March 2021).

2.3.1.3 Groundwater Screening Samples

- Location: WATERLOO APS, numbered sequentially in order of collection (001, 002, 003, etc.), or MW series name (for groundwater screening samples collected during drilling activities).
- Sample Depth (feet bgs): 10, 20, 30, etc.
- Sample Matrix: WG (groundwater).
- Sample Date: YYYYMMDD (year, month, day).
- Example: APS-001-15-WG-20210102 (groundwater screening sample collected on 2 January 2021 from first APS location at a depth of 15 feet bgs), MW-400-80-WG-20210102 (groundwater screening sample collected on 2 January 2021 while drilling MW-400 at 80 feet bgs).

2.3.1.4 Leachate Samples

- Location: Leachate Collection Sump (LCS) series.
- Sample Matrix: WL (leachate water).

- Sample Date: YYYYMMDD (year, month, day).
- Example: LCS-1D-WL-20210102 (leachate sample collected from LCS-1D on 2 January 2021).

2.3.1.5 Indoor and Outdoor Air Samples

- Location: Indoor Air (AI) or Outdoor Air (AO), numbered sequentially in order of collection (001, 002, 003, etc.)
- Sample Date: YYYYMMDD (year, month, day)
- Example: AI-001-20210102 (first indoor air sample of sampling event, collected on 2 January 2021) and AO-001-20210102 (first outdoor air sample of sampling event, collected on 2 January 2021)

During each sampling event, the location of indoor and outdoor air samples will be noted in relation to on-Site buildings on the associated field sampling form. Indoor air sample locations will be replicated in subsequent sampling events, where applicable. Outdoor air locations will be dependent on wind direction and unique to each sampling round.

2.3.1.6 Soil Gas Samples (if warranted)

- Location: Sub-Slab Soil Gas (GB) or Exterior Soil Gas (GS), numbered sequentially in order of installation (001, 002, 003, etc.)
- Sample Date: YYYYMMDD (year, month, day)
- Example: GB-001-20210102 (first sub-slab soil gas sample, collected on 2 January 2021)

During each sampling event, the location of soil gas samples will be noted on the associated field sampling form (i.e., inside or outside buildings, on- or off-Site, etc.). Soil gas sample locations will be replicated in subsequent sampling events, where applicable.

2.3.2 Field QA/QC Sample Naming Convention

Field QA/QC samples will include blind duplicates, equipment blanks, filter blanks, field blanks, trip blanks, and matrix spike/matrix spike duplicates, as described in Section 5.1.3.1 of the QAPP. Naming conventions for field QA/QC samples are described below.

2.3.2.1 Blind Field Duplicates

- Sample Type: Blind Field Duplicate (DUP).
- Sample Number: 001, 002, 003, etc.
- Sample Matrix: SO, WG, WL, AI, AO, GB, GS, etc.
- Sample Date: YYYYMMDD (year, month, day).
- Example: DUP-001-SO-20210102 (first solid matrix blind field duplicate of sampling event collected on 2 January 2021).

Blind field duplicate samples will be numbered sequentially in order of collection per sample matrix and per sampling event. Blind field duplicate sample names will be recorded on the associated sampling field form for the parent sample and in the field book.

2.3.2.2 Equipment Blanks

- Sample Type: Equipment Blank (EB).

- Sample Number: 001, 002, 003, etc.
- Sample Matrix: WQ (water quality).
- Sample Date: YYYYMMDD (year, month, day).
- Example: EB-001-WQ-20210102 (first equipment blank of sampling event, collected on 2 January 2021).

Equipment blank samples will be numbered sequentially in order of collection per sampling event. The equipment brand, model, and serial number from which each equipment blank was collected will be noted in the field book.

2.3.2.3 Filter Blanks

- Sample Type: Filter Blank (FILTB).
- Sample Number: 001, 002 003, etc.
- Sample Matrix: WQ (water quality).
- Sample Date: YYYYMMDD (year, month, day).
- Example: FILTB-001-WQ-20210102 (first filter blank of sampling event, collected on 2 January 2021).

Filter blank samples will be numbered sequentially in order of collection per sampling event. The lot of filters from which the filter blank was collected will be noted in the field book.

2.3.2.4 Field Blanks

- Sample Type: Field Blank (FB).
- Field Blank Number: 001, 002, 003, etc.
- Sample Matrix: WQ (water quality).
- Sample Date: YYYYMMDD (year, month, day).
- Example: FB-001-WQ-20210102 (first field blank of sampling event, collected on 2 January 2021).

Field blank samples will be numbered sequentially in order of collection per sampling event.

2.3.2.5 Trip Blanks

- Sample Type: Trip Blank (TB).
- Trip Blank Number: 001, 002, 003, etc.
- Sample Matrix: WQ (water quality).
- Sample Date: YYYYMMDD (year, month, day).
- Example: TB-001-WQ-20210102 (first trip blank of sampling event, submitted with samples collected on 2 January 2021).

Trip blank samples will be numbered sequentially in order of submittal per sampling event.

2.3.2.6 Matrix Spike/Matrix Spike Duplicates

For matrix spike/matrix spike duplicate (MS/MSD) analysis, the same sample nomenclature will be used as regular primary samples. Additional volume will be collected as required by the laboratory, and samples will be indicated as MS/MSD on the laboratory CoC.

2.3.3 Sample Documentation

During sampling activities, pertinent sampling information will be recorded on the applicable field sampling form and field book, as described in the SOP for Field Documentation (SOP #01, Appendix A). Copies of field forms for the activities described in this Field Sampling Plan are included in Appendix B. Pertinent sampling information will include sample location, date and time of sample collection, sampler name, requested analysis, and container counts and preservation information for each sample. QA/QC samples such as duplicates and MS/MSDs will also be noted. QA/QC samples that are not associated with a specific sampling location, such as trip blanks, equipment blanks, and filter blanks, will be noted in the field book.

All samples collected for laboratory analysis will be documented on a CoC, as described below.

2.3.4 Sample Containers and Labeling

For sample collection, each sample container will be identified with a label. The labels will be pre-printed, where possible, or handwritten using indelible ink. Sample container labels will include sample name, date and time of sample collection, sampler name, requested analysis, and preservative.

For vapor and air sampling, Summa® canisters will be identified with a laboratory-provided sample tag. The sample tag should include the sample name and date of collection recorded on the CoC. Other information on the tag may include the canister start and stop vacuum reading and sample collection time. Electret samplers used for collection of vapor samples for radon analysis will be placed in double-zip, labeled bags, which will contain sample name, date and time of sample collection, sampler name, and requested analysis.

2.3.5 Sample Preservation, Packaging, and Shipping

The type of sample containers, volumes, and preservatives are listed in Table 2-2. The containers will either be new or will be pre-cleaned by the laboratory. Sample containers requiring preservatives will be provided by the analytical laboratories. Sample containers will be placed on ice, if required, in coolers and picked up at the Site by a laboratory courier or shipped to the laboratory per the details outlined in the SOP for Sample Packing and Shipping (SOP #03, Appendix A).

2.3.6 Sample Chain of Custody Forms and Custody Seals

The CoC provides documentation to trace sample possession continuously from the time of collection until the time of receipt in the laboratory. Samples will be delivered or shipped to the analytical laboratory in accordance with the SOP for CoC (SOP #02, Appendix A). If multiple coolers are sent to a single laboratory during a single day, CoCs will be completed and sent with the samples for each cooler. A copy of the CoC will be kept in the project files.

When the samples leave the custody of the sampling team, the shipping container/cooler will be sealed with a custody seal to determine if the samples have been disturbed during transportation to the laboratory. The laboratory personnel receiving the coolers will note the condition of the seal and the sample containers within the cooler on the CoC. The laboratory will notify the ERM Quality Assurance Manager (QAM) of any deficiencies. If samples are transferred directly from sampling personnel to laboratory personnel, custody seals are not required, but CoCs must be completed to document the transfer. In the event of an incomplete CoC form (with regard to the receipt signature), a signed affidavit will be required from the laboratory documenting that the samples were received. The ERM QAM will be contacted should any uncertainty arise regarding the identification of the samples. In the event sample tampering is indicated, the ERM QAM will be contacted immediately.

2.4 Quality Assurance/Quality Control Samples

The QA/QC objectives provide quantitative and qualitative measures of the ability to produce high quality results through a properly designed sampling and analysis program. The objectives of the overall QA/QC program are to:

- Document procedures, including any changes from the RI/FS Work Plan, FSP, or QAPP requirements;
- Conduct sampling and analytical procedures according to sound scientific principles;
- Monitor the performance of the field sampling team and laboratory with a systematic audit program and provide for corrective action necessary to assure sample quality;
- Evaluate the quality of the analytical data through a system of quantitative and qualitative criteria; and
- Record and archive data and observations, as specified in Section 3.12 of the QAPP.

A description of the proposed field quality control samples and laboratory quality control samples is included below.

2.4.1 Field Quality Control Samples

Accuracy in the field will be assessed through the use of trip, equipment, and field blanks and through the adherence to protocols and requirements regarding sample handling, preservation, and holding times. Accuracy for field measurements will be maintained through adherence to the calibration procedures for the field instruments as outlined in their respective SOPs and Section 4.0.

Trip blanks are collected to identify and measure contamination from transit between the field and the laboratory. Equipment blanks are collected to identify and measure cross-contamination between monitoring points from field equipment that is not properly decontaminated. Filter blanks are collected to identify and measure contamination from field filtering equipment. Field blanks are collected to identify and measure contamination from ambient sources. The number/frequency for each QC sample type is summarized in Table 2-1 and outlined in Section 5.1.4.1 of the QAPP.

To minimize the chance of cross contamination, samples expected to have high concentrations of COPCs based on past analytical results or location will be segregated and shipped separately from those samples expected to have lower levels of contamination.

2.4.2 Laboratory Quality Control Samples

Analytical accuracy is expressed as the percent recovery of a spiked constituent, such as a surrogate standard, laboratory control sample/laboratory control sample duplicate, or MS/MSD. Surrogate percent recoveries measure system performance and efficiency during organic analyses. Comparisons of results from laboratory control sample/laboratory control sample duplicate pairs in conjunction with the MS/MSD pairs can be used to provide evidence that the laboratory methods resulted in data that is within acceptance criteria and, if applicable, the extent of matrix interference. Quality control recovery limits are calculated by the laboratory and are established based on statistical evaluation of previous laboratory analytical results for organic and inorganic analyses. Laboratory QC checks are detailed in Section 5.1.3.2 of the QAPP.

3. FIELD METHODS AND PROCEDURES

This section describes the Site characterization rationale and the associated field methods and procedures for sample collection that were developed in accordance with industry standard practices. These procedures are intended to provide for the collection of consistent, comprehensive, and representative samples.

SOPs are included in Appendix A, and field forms are included in Appendix B of this FSP. Subcontractor SOPs and user manuals for specialized equipment are included in Appendix C. Calibration procedures for field equipment are outlined in Section 4.0. Decontamination procedures for field equipment are outlined in Section 5.0. Investigation-derived waste (IDW) management, handling, sampling, and documentation are outlined in Section 6.0.

3.1 Site Characterization Rationale

The OU-3 Site characterization activities have been designed to supplement the existing data set with additional data to sufficiently characterize the nature and extent of hazardous substance impacts to groundwater and their potential risk posed to human health and the environment. The resulting data will be used to answer the PSQs outlined in Section 5.1 of the Work Plan. This FSP includes the Site characterization activities currently planned, and the work will proceed in an iterative manner until the PSQs have been adequately answered.

Using the data collected from current planned activities, the scope of subsequent work to address data gaps will be promptly presented to the USEPA in the Work Plan addenda for consideration and approval prior to implementation.

The following Site characterization tasks have been initiated and/or will be completed to address the data gaps outlined in Section 4.0 of the Work Plan and meet the objectives of the RI/FS process:

- Compile quantitative data and information pertaining to existing surface water features, geology, hydrogeology, geochemistry, property access conditions, and the proximity of potential receptors to known or potential contaminants.
- Determine adequacy, usability and status of existing monitoring wells and their associated data, and the usability of data from on-Site/near-Site abandoned monitoring wells. Install additional monitoring wells/piezometers, as needed.
- Collect continuous cores at select new locations for matrix parameter analyses.
- Apply borehole geophysical methods within the Site interior, Site perimeter areas, and other areas sufficiently far from the Site to provide a more complete characterization of the alluvial aquifer and bedrock formations, and collect high-resolution hydrogeologic parameter data in existing and new monitoring wells.
- Install data loggers in a selected set of existing and new monitoring wells, piezometers, and stilling wells to continuously measure groundwater and surface water levels.
- Collect and analyze field data to assist in the evaluation of potential groundwater remedies.
- Evaluate sources of radionuclides and other COPC in aquifers located beneath, and near, the Site.
- Prepare a geologic modeling database and perform groundwater modeling.
- Complete a detailed well survey and gather any additional data needed to complete the human health and ecological risk assessments for OU-3.Site characterization will be conducted in

accordance with the Work Plan. Samples will be collected and analyzed in accordance with this FSP and the QAPP.

3.1.1 Proposed Monitoring Well Network

Existing and new on-Site and off-Site groundwater data will be used to support this OU-3 RI/ FS. A preliminary well inventory has been conducted to confirm the status of existing monitoring wells. Well information was used to evaluate the distribution of existing data within the current CSM, identify data gaps, and propose on-Site, near-Site, off-Site, and background monitoring well locations.

3.1.1.1 *Existing Monitoring Well Network*

A preliminary monitoring well inventory was conducted on several of the inactive monitoring wells not included in the active Bridgeton Landfill groundwater monitoring well network during a Site walkover on 17 April 2018. The purpose of the preliminary monitoring well inventory was to update the monitoring well status and to understand the available, existing monitoring well network. Inactive monitoring wells visited were photographed, and depth to water, well construction, and total depth were recorded. The existing well network is shown on Figure 3-1 and a summary of the existing well construction details and survey data is provided in attached Table 3-1a and Table 3-1b.

A total of 80 existing wells will be included in the OU-3 monitoring well network, which includes 78 wells associated with the Site and two wells installed by the MDNR near the Site. Attached Table 3-1c provides a summary of the existing wells that will be included in the OU-3 monitoring well network. The existing wells include 50 wells in the current Bridgeton Landfill monitoring program and 30 wells not routinely sampled. The complete monitoring well inventory (preliminary and proposed inventories) will be documented in a Well Inventory Summary Report.

3.1.1.2 *Proposed New Monitoring Wells*

The installation of new monitoring wells and collection of high-resolution aquifer characterization data will address the PSQs presented in Section 5.1 of the Work Plan and the data gaps outlined in the OU-3 ASAOC SOW (USEPA 2019). Well designations are based on location and the number of proposed screened intervals. In general, the proposed well network embodies a more regional evaluation of groundwater near the Site. Historical investigations focused almost entirely on areas within the Site boundary but have not defined the potential horizontal and vertical extent of impacts on groundwater quality. Additionally, the existing network did not provide adequate data to make a clear determination of background groundwater conditions upgradient or laterally away from the Site. A total of 81 new monitoring locations (either single well or cased hole sampler [CHS] well sampling ports) at 31 well sites are currently proposed. Additional step in/out locations will be determined based on the high resolution and matrix/groundwater sampling data obtained from the new wells. Locations and rationale for each location are summarized in attached Table 3-2 and discussed in the following sections.

Monitoring Well Designations

Monitoring well nomenclature is generally consistent with that used in the past and consists of reference to a well series and a monitoring zone. New monitoring wells will be identified using the “MW” prefix. Series will be designated based on proximity to Site features as described below:

- 100 Series—Adjacent to the Bridgeton Landfill
- 200 Series—Within 500 feet of the Bridgeton Landfill
- 300 Series—Adjacent to the Inactive Sanitary Landfill

- 400 Series—Within 350 feet of Area 2
- 500 Series—Off-Site and potentially downgradient
- 600 Series—Background

New water level piezometers will be identified using the “PZ” prefix. The 700 Series piezometers represent supplemental groundwater level measurement points at locations distant from the Site, which are not anticipated to be impacted by COPCs.

Groundwater monitoring zones will be based on the results of high-resolution characterization data collected during the RI/FS investigation that identifies hydrogeologic characteristics of the alluvium or bedrock that exhibits one of the following characteristics:

- Mass Flux Intervals—alluvium or bedrock that has characteristically high groundwater flux (high hydraulic conductivity) and evidence of leachate impacts or elevations of select COPCs. These intervals will be used to define the vertical and lateral extent of contamination and the mass distribution within one or more contaminant plumes to assist with the feasibility study (if warranted based on the findings of the RI).
- Groundwater Flux Intervals—alluvium or bedrock that has characteristically high groundwater flux but lacks evidence of leachate impacts or elevations of select COPCs. These intervals will be used to define the downgradient extent of contamination, and background conditions of groundwater in the Site vicinity.
- Mass Storage Intervals—alluvium or bedrock that has characteristically moderate to low groundwater flux with evidence of leachate impacts or elevations of select COPCs. These intervals will be used to identify and define potential secondary sources of COPC within the Site boundaries to refine the CSM and further facilitate development of the feasibility study (if warranted based on the findings of the RI).

The hydrogeologic characteristics will be prioritized for well selection in the order listed above in the event that more than one is demonstrated within a general aquifer zone. If no mass flux, no groundwater flux, and no mass storage is identified, within a general aquifer zone, then no well screen will be set within that zone.

The alluvium is considered a single aquifer with a high degree of heterogeneity that will require the proposed high-resolution data collection methods for adequate characterization. Bedrock formations include the St. Louis, Salem, and Keokuk Formation. No additional Keokuk Formation monitoring wells are proposed during the Site characterization activities. Four Keokuk Formation monitoring wells surround the South Quarry, and are sampled as part of the Bridgeton Landfill groundwater monitoring program. Historical groundwater quality data from these wells show that impacts do not appear to have migrated through the Warsaw Formation aquitard into the Keokuk Formation. Sustained monitoring of the Keokuk Formation with existing groundwater monitoring wells will be conducted to verify the continued presence of an upward hydraulic gradient with no downward migration of Site-related contamination across the Warsaw Formation aquitard, and geophysical logging will be conducted to confirm the integrity of the Warsaw Formation. Groundwater monitoring of the Warsaw Formation aquitard is not proposed because it is not a significant water bearing unit.

Proposed Off-Site Monitoring Well Locations and Rationale

There are currently no off-Site monitoring wells beyond 350 feet of the property boundary. To characterize off-Site groundwater quality, six new off-Site CHS wells with a total of 22 sampling ports will be installed to the west and north and east (500 series wells) as shown on Figure 3-2.

An evaluation of existing potentiometric data suggests the proposed locations are appropriate to evaluate the nature and extent of COPC impacts. In addition to defining downgradient extent of impacts, off-Site monitoring wells are proposed to evaluate off-Site (a) aquifer properties; (b) localized hydraulic gradients and flow directions within and between the alluvial aquifer and bedrock aquifer system; (c) groundwater geochemistry; (d) potential effects of the Bridgeton Landfill-related infrastructure on groundwater; (e) temporal variability in groundwater levels and flow direction; and (f) effects of nearby surface water features and storm events.

The proposed monitoring well series will be comprised of four alluvial CHS wells with a minimum of three sampling intervals and two combined alluvial and bedrock CHS wells with a minimum of three alluvial and two bedrock sampling ports. Hydrogeologic and groundwater quality data from these wells will be used to inform decisions on placement of additional (step-in/step-out) 500-series wells.

Proposed On-Site/Near Site Monitoring Well Locations and Rationale

A total of 15 new on-Site/near-Site well locations are proposed to be installed as part of the OU-3 RI as shown on Figure 3-2. These include 12 perimeter wells along the east, north, and west property boundary, and three interior wells to fill in data gaps associated with OU-1 and OU-2 that have been identified. The perimeter wells include 200-series, 300-series, and 400-series wells spaced approximately 500 feet apart in the assumed downgradient and cross-gradient groundwater flow directions. The wells will be used to assess the potential for off-Site migration of COPC. Four of the locations will be completed with combined alluvial and bedrock CHS wells (MW-304, MW-400, MW-404, and MW-406), seven will be completed with alluvial only CHS wells (MW-213, MW-303, MW-306, MW-401, MW-402, MW-403, and MW-405), and one will be a single well completion in alluvium (MW-302) to address a data gap in existing monitoring wells at that location. There will generally be a minimum of three sampling ports in the alluvial intervals and two sampling ports in the bedrock intervals unless a neighboring existing monitoring well is available to monitor an interval identified by high-resolution methods that meets the well screen selection criteria.

The three additional on-Site infill wells proposed to fill data gaps in the OU-1 and OU-2 groundwater monitoring program include MW-111, MW-113, and MW-205. MW-111 will be completed as an alluvial CHS well with a minimum of three sampling ports. MW-111 and MW-205 will be completed as single completion bedrock wells installed in the Salem Formation.

Proposed Background Monitoring Well Locations and Rationale

An understanding of natural background groundwater quality is an important and necessary component of this OU-3 groundwater study. Background monitoring wells will be installed to help determine if the COPCs are Site-related. The U.S Geological Survey (USGS) attempted to establish natural background groundwater quality, but concluded that the existing data set was not sufficient (USGS 2015). Regional potentiometric data for both the alluvium and the bedrock at the Site suggest a down-valley component of groundwater flow direction. Therefore, newly installed background wells will be installed to the southwest, south, southeast, and east of the Site.

Establishing natural background groundwater quality requires the collection of “near-Site” data that are representative of the aquifer. The locations of wells used by the USGS, along with regional groundwater flow in the alluvial and bedrock aquifers, were evaluated to select locations for additional background monitoring wells. Six locations (600-series) are proposed for new background monitoring wells as shown on Figure 3-3. A statistical evaluation will be completed on the current and new data sets after the first year of monitoring to evaluate whether the number of background samples and/or background well locations is sufficient to adequately characterize natural background water quality.

Three of the background wells will be installed where bedrock occurs at or near the surface (east of the Edge of Alluvium line on Figure 3-3), and will be completed as bedrock CHS wells with a minimum of two sample ports (MW-603, MW-604, and MW-605). Two of the background monitoring wells will be installed as alluvial only CHS wells with a minimum of three sampling ports (MW-600 and MW-601). The remaining well will be installed as a combined alluvial and bedrock CHS well with a minimum of three alluvial sampling ports and two bedrock sampling ports (MW-601).

The 600-series wells will be used to calculate natural background groundwater conditions, as described in the QAPP Section 4.2.7. It is acknowledged that due to the regional presence of anthropogenic groundwater impacts, groundwater quality in some of the 600-series monitoring wells could be affected by off-Site sources. Information obtained from MDNR regarding registered environmental Sites in the area will be reviewed as part of the background evaluation. Groundwater geochemistry, COPC concentrations, and statistics will be used on an ongoing basis to evaluate whether COPC data from 600-series monitoring wells are appropriately representative to be used to establish natural background groundwater quality in accordance with Section 4.2.7 of the QAPP. Additional 600-series monitoring wells will be proposed in an addendum if the data quality objectives for determination of natural background cannot be met with the proposed network.

Step-In and Step-Out Monitoring Wells

Step-in wells will be used to reduce the horizontal spacing between wells to about 200 feet in areas where evidence of leachate-impacted groundwater is observed, following interpretation of the initial results from the initial set of wells. Step-out wells will be located beyond an outermost well in a transect. Groundwater monitoring zones at step-in and step-out locations will be based on the results of high-resolution characterization data. The focus of the step-in/step-out borings is to delineate or further characterize solute plumes emanating from the Site (i.e., if the solute plume is present in shallow alluvium at two adjacent locations, then the step-in/step-out boring will target this interval). If necessary, one or more additional monitoring well transects will be installed further downgradient to complete plume delineation.

The need for additional step-in/step-out drilling locations will be evaluated throughout the high-resolution characterization program. As the need for step-in/step-out drilling locations is identified, ERM will submit an email describing the proposed activities with a map showing the proposed locations(s) to USEPA for review and approval prior to proceeding with the proposed additional wells.

Proposed Piezometers

In addition to 81 new single well or CHS monitoring locations, five shallow alluvial piezometers will be installed to support the groundwater modeling. Proposed piezometer locations are shown on Figure 3-3. These piezometers will be installed during the initial WATERLOO APS™ drilling program. The piezometers will be constructed using the same procedures as shallow alluvial wells and used for water level gauging to calibrate the groundwater model. They will be identified using the “PZ” prefix and will be designated a part of the 700-series.

Proposed Stilling Wells (Staff Gauges)

Nine stilling wells (staff gauges) will be installed to evaluate the temporal and spatial variability in groundwater levels and flow direction in response to potential influences of the Missouri River, impounded water, and other nearby surface water bodies. The proposed stilling wells are shown on Figure 3-3. The stilling wells will be installed and continuously monitored. Missouri River stage data will be downloaded from the USGS. Installation of the stilling wells will be subject to securing access agreements with off-Site property owners.

Two staff gauges equipped with transducers and telemetry already exist in the Earth City ponds and are used to operate pumps that maintain a constant elevation in the ponds. These will be evaluated as alternatives to the installing the stilling wells proposed in the Earth City ponds if access to the data is granted and they meet the requirements in the QAPP.

3.1.2 Adequacy of Monitoring Well Network

A total of 80 existing monitoring wells were identified for inclusion in the proposed OU-3 monitoring well network, in addition to the 31 new monitoring wells equipped with 81 sampling ports or screen intervals. The five new piezometers are not included as part of the monitoring well network, since they are not included in routine sampling. It should be noted that some interior Site monitoring wells were given “PZ” designations under formerly used naming conventions, but are not piezometers and will be monitored for water quality. The proposed monitoring well network includes the wells described in attached Tables 3-1c and 3-2. The network will be used to monitor Site groundwater conditions for a minimum of eight consecutive quarters. Further monitoring of the well network will be conducted as warranted, based on analytical results, until a remedy is selected and implemented at the Site.

The proposed monitoring program is preliminary and subject to access agreements. It is likely that additional monitoring wells will be installed to fill the data gaps listed in the OU-3 ASAOC SOW and answer the PSQs. It is also possible that several existing monitoring wells can be removed from the monitoring network in the future. Thus, the monitoring network will be modified in collaboration with the USEPA and with USEPA approval as Site characterization activities continue over time.

Additional monitoring wells may be added if OU-1 Remedial Action activities result in the need for well replacement. However, the proposed well list was created in coordination with OU-1 to provide sufficient monitoring well network coverage, and reflects both wells that are currently expected to be abandoned and wells that are expected to remain in place following OU-1 remedial activities. Wells within the OU-1 footprint that are likely to be abandoned as part of the OU-1 remedy will be sampled for eight quarters prior to abandonment, and new wells to be installed will be located outside of the OU-1 footprint.

3.2 Preparatory Activities

Off-Site activities proposed for the OU-3 RI/FS will require access agreements to private properties, notifications to the USEPA, utility clearance activities, and permits. A description of the procedures for each preparatory activity is included below.

3.2.1 Site Access

Access agreement requests will be prepared for the OU-3 RI/FS off-Site activities. For the OU-3 RI/FS, access will be requested from property owners of proposed off-Site monitoring well and stilling well locations. ERM will attempt to locate all off-Site monitoring well locations in public rights-of-ways (ROWs), if possible. If a location requires private property access, ERM will use best efforts, as described in Section XI, paragraph 64 of the ASAOC (CERCLA-07-2018-0259), to obtain access agreements. If best efforts have been completed in accordance with the ASAOC and an agreement is not obtained in a timely manner for a property, ERM will proved USEPA with thorough and detailed documentation regarding the steps taken to comply with the requirements. If USEPA deems it appropriate, it may assist with obtaining access. The ability to drill will be based not only on access agreements, but also on the presence or absence of subsurface and overhead utilities. Should additional private well locations be identified during the radius search for off-Site wells (discussed in Section 3.3), access agreement requests will also be prepared.

3.2.2 Notifications

Required notifications to the USEPA during implementation of the OU-3 RI/FS will be completed as outlined in the ASAOC:

- Contractor Selection—the USEPA will be notified within 21 days prior to commencement of any work by additional contractors or subcontractors. Notification will include the names, titles, addresses, telephone numbers, email addresses, and qualifications of personnel.
- Unanticipated Site Changes—the USEPA will be notified within 24 hours of discovery of any unanticipated or changed circumstances at the Site.
- Sample Collection Activity—the USEPA and the MDNR will be notified no less than seven days prior to any sample collection activity to allow for the coordination of the collection of split duplicate samples.

The following notifications will be made as outlined in the ASAOC related to emergency response and release reporting:

- Emergency Response—the USEPA will be notified should any event occur during performance of the work that causes or threatens to cause a release of waste material on, at, or from the Site that either constitutes an emergency situation or that may present an immediate threat to public health, welfare, or the environment. OU-3 Respondents will take all appropriate action to prevent, abate, or minimize such release or threat of release. The OU-3 Respondents will immediately notify the USEPA's Remedial Project Manager of the incident, or in the event of his/her unavailability, the Regional Duty Officer at (913) 281-0991.
- Release Reporting—the USEPA will be notified of any release requiring reporting pursuant to Section 103 of Comprehensive Environmental Response, Compensation, and Liability Act, 42 United States Code (U.S.C.) 9603, or Section 304 of the Emergency Planning and Community Right-to-Know Act, 42 U.S.C. 11004. The OU-3 Respondents will immediately orally notify the USEPA's Remedial Project Manager or the Regional Duty Officer.
- Written Report—a written report will be submitted to the USEPA within seven days of any Emergency Response or Release Reporting event describing the event, measures taken to mitigate any release or threat of release, and measures taken to prevent the reoccurrence of a release.

3.2.3 Utility Clearance

The proposed drilling locations include on-Site areas, developed properties, and areas within public ROWs, which may have considerable buried or overhead utilities present. As part of the Site preparatory activities, public utility locate requests will be submitted to refine drilling locations prior to mobilization. The public utility clearance process will be repeated prior to commencement of drilling activities. Public utility clearances will be coordinated with the drilling subcontractor (to be determined). The Missouri One Call System will be contacted at least 3, but not more than 30 working days prior to beginning subsurface activities.

Additionally, a private utility locator will be used to evaluate the potential presence of buried utilities at each proposed drilling location. The SOP for Subsurface Clearance (SOP #04, Appendix A) and Subsurface Clearance Project Plan (Appendix B) will be used for each well cluster, piezometer, stilling well, and any other location where intrusive field activities occur.[2] Utility clearance activities will be

[2] The SOP for Subsurface Clearance and the Project Plan will also account for overhead utilities.

conducted throughout the subsurface investigation program prior to conducting subsurface investigation activities at any given location.

3.2.4 Permits and Licenses

Prior to any monitoring well or vapor well installation activities (if required), ERM, or its subcontractor, will obtain the necessary permits required to perform the work scope. Permit requirements will depend on the investigation location. ERM will confirm the ownership information and appropriate regulating entity to determine the permitting requirements prior to any field work. Anticipated permits include the following:

1. St. Louis County—St. Louis County requires a Special Use Permit for work proposed within public ROWs designated as part of the St. Louis County Arterial Road System, dedicated public ROWs in unincorporated St. Louis County, and certain easements for sidewalk and drainage projects. St. Louis County requires at least 48 hours advanced notification. Procedures for obtaining the Special Use Permit include:
    - Submittal of a Special Use Permit application(s) and required fee(s) of $208 per application and $43 each for Core Drilling and Extraction. The application can be found on the County's website https://www.stlouisco.com/Portals/8/docs/document%20library/highways/sup/SUP_Application_and_Conditions.pdf;
    - Submittal of proof of liability insurance as outlined in the Special Use Permit; and
    - Confirmation that work will be conducted in accordance with the Manual of Uniform Traffic Control Devices.
2. City of Bridgeton—The City of Bridgeton will require an Excavation Permit for drilling activities. Procedures for obtaining the City of Bridgeton Excavation Permit include:
    - Submittal of an Excavation Permit application(s) and required fee(s) of $100 per application. The application can be found on the City's website www.bridgetonmo.com under Public Works/Engineering Department;
    - Submittal of three sets of detailed construction drawings for each application showing the location of the work and what it will entail;
    - Submittal of proof of liability insurance that meets Section 530.060 of the City's Excavation Permit ordinances ($100,000 for bodily injury to each person, $300,000 for bodily injury to all persons in one occurrence, and $25,000 for all property damage in one occurrence); and
    - Submittal of a performance bond or escrow check in the amount of $2,000 to cover work in the ROW. If the work involves working in the street, the bond amount goes up to $4,000.
3. City of Maryland Heights—The City of Maryland Heights will require a ROW Use Permit for drilling activities. Procedures for obtaining the City of Maryland Heights Permit include:
    - Submittal of a ROW Use Permit application(s) and required fee(s) of $116.00 per unit. Permits will be charged on a unit basis and units applicable to the proposed permit activity will be determined by the Director of Public Works. The application can be found on the City's website http://www.marylandheights.com/ under Public Works;
    - Submittal of two sets of plans showing the extent of the proposed work. Applicants will receive one copy of the approved plans with the permit;
    - Submittal of either a cash deposit of not less than $100 or a surety bond of not less than $1,000. The type of deposit and amount will be determined by the Director of Public Works (or designee) based upon the nature and extent of the proposed work; and

- All work must be in accordance with Maryland Heights Municipal Code requirements or, where not defined, in accordance with the St. Louis County Department of Highways and Traffic and Metropolitan St. Louis Sewer District design criteria and standards.

4. Missouri Department of Transportation (MoDOT)—MoDOT requires a Permit for Work on ROWs for any excavations occurring on MoDOT-controlled ROWs or streets. The procedures for obtaining the ROW permit include the following steps subject to a determination by the MoDOT Local Traffic Specialist:
   - Submittal of an initial on-line permit application on MoDOT's website: https://www6.modot.mo.gov/Permitting/PermitRequest.aspx.
   - Submittal of engineering drawings or plans (to be determined by a MoDOT specialist).
   - Submittal of a traffic study, if required (to be determined by a MoDOT specialist).
   - Submittal of a traffic control plan, if required to be determined by a MoDOT specialist).
   - Submittal of a surety deposit.
   - Submittal of a performance bond.
5. MDNR—All monitoring wells and boreholes will be installed, constructed, and abandoned according to MDNR's Code of State Regulations (CSR) Title 10—Department of Natural Resources Division 23—Well Installation Regulations (Missouri 2019). For monitoring well and borehole installation, the following information will be submitted to MDNR:
   - A monitoring well contractor's permit to construct, repair, or properly plug a monitoring well.
   - A restricted monitoring well contractor's permit is required for environmental or engineering entities to contract these activities or to act as the primary contractor or on-Site supervisor.
   - Well certification and registration forms will be prepared as needed either prior to installation for items requiring a variance, such as nested wells, or following installation and abandonment:
   - MDNR Form 780-1415—Monitoring Well Certification Report
   - MDNR Form 780-2161—Monitoring Well/Test Hole/Soil and Geotechnical Boring Plugging Registration Report
   - MDNR Form 780-2169—Nested Monitoring Well Certification Report
   - MDNR Form 780-1422—Variance Request Form
   - Other forms will be prepared if applicable.

3.2.5 Mobilization and Temporary Facilities

Prior to drilling, ERM and the drilling subcontractor will coordinate mobilization of field crews and equipment to the Site. Temporary facilities will be designated for storage of field equipment, sample coolers, and well construction materials. A decontamination area will be established. Site control for access to the field equipment and sample coolers will be maintained with dedicated locks on the temporary facilities.

3.3 Well Inventory Activities

An off-Site well search will be completed to identify potential receptors within 2-miles of the Site. This will include records review of Environmental Data Resources database reports and historical local and regional studies on OU-1, OU-2, and groundwater and vapor by local, MDNR, federal, and private parties.

The MDNR will be contacted directly to obtain available information for older wells. Utility records will be reviewed for buildings without water connections. Visual assessments and drive-arounds will also be conducted to document potential receptors near the Site. ERM's project database (EQuIS^{TM}) and the USEPA-accessible database will be updated as new data become available. The off-Site well search will be expanded if data collected during the RI/FS process indicate the potential for exposures beyond this boundary.

The first field task to be completed as part of the OU-3 RI/FS will be the completion of a well inventory of the existing wells (as shown on Figure 3-1) included in the OU-3 proposed well network. During the well inventory, wells in need of repair, redevelopment, replacement, or abandonment will be identified, and the necessary activities will be completed prior to sampling. A description of the procedures to be used during implementation of the well inventory and repair task is provided in this section.

3.3.1 Monitoring Well Inventory

Field personnel and subcontractors will inspect and photo-document proposed and existing monitoring well locations and proposed stilling well locations. Existing off-Site wells, such as industrial wells, municipal wells, and water intake structures, may be identified during the off-Site well search, which may also be inventoried. This initial Site reconnaissance information will be recorded on the Well Inspection Form (Appendix B). A daily record of events for inventoried wells including the Site address, location name, and well identification (if available) will be kept in the field book. The records will be kept as outlined in the SOP for Field Documentation (SOP #01, Appendix A).

Total well depth will be measured from the surveyed top of casing by lowering the weighted probe to the bottom of the well. If pumps, tubing, or grab sampling devices are present and an obstacle to total well depth measurements, they will be removed prior to collecting total depth measurements. The well depth will be recorded to the nearest 0.1 foot.

The information gathered during the well inventory will be compared to the existing monitoring well survey and construction data summary (attached Tables 3-1a and 3-1b) to evaluate monitoring well integrity. For wells that appear to be damaged, a borehole camera will be used to evaluate, to the extent possible, if the well screen or riser pipe are compromised. The borehole camera images will be correlated to the top of casing elevation. The camera will be lowered from the top of casing, and the depths of findings will be noted in the field book. This will allow for comparison to the well construction logs. Video of the inspection will be recorded. Based on the findings of this survey, wells will be slated for redevelopment, repair, abandonment, and/or replacement.

3.3.2 Monitoring Well Repair, Redevelopment, Abandonment, and Replacement

All monitoring well repairs, replacement, or abandonment activities will be performed in accordance with the MDNR 10 CSR 23-4 (Missouri 2019).

Well parts (bolts, gaskets, lids, J-plugs) will be replaced in kind, if necessary. Cracked well pads will be filled (minor cracks) or replaced (major cracks). If a well casing has a constriction that limits pump deployment, the well will be evaluated to determine whether the casing can be repaired (for shallow casing issues) or will need to be replaced. For monitoring wells identified in need of major repairs, a scope of work will be prepared for a drilling subcontractor detailing the repairs required for each well.

Monitoring wells with more than 10 percent well screen occlusion will be redeveloped according to the procedures for monitoring well development in Section 3.10.

Well abandonment activities will be conducted according to 10 CSR 23-4. A Monitoring Well/Test Hole/Soil and Geotechnical Boring Plugging Registration Report (MDNR Form 780-2161) will be prepared for each location by the drilling subcontractor and reviewed by ERM.

For monitoring wells slated for replacement, the existing monitoring wells will first be abandoned. Monitoring well replacement activities will be performing following the same procedures in Sections 3.5 and 3.9, outlining drilling and monitoring well installation activities, respectively.

After monitoring well repairs are completed, pressure transducers will be deployed in existing wells noted in Table 3-1c to begin real-time groundwater level and temperature monitoring, as described in Section 3.16.2. Pressure transducers will remain for approximately 2 years during groundwater monitoring and will collect data every hour.

3.4 Ambient Air and Sample Field Screening

Ambient air and sample field screening will be performed using handheld instruments during specific OU-3 RI/FS field activities. Below is a summary of the proposed field screening instruments, a description of when readings will be collected, documentation, safety-related triggers, and field procedures for each device. Calibration procedures are outlined in Section 4.0.

3.4.1 Photoionization Detector

A photoionization detector (PID) equipped with a 10.6 electron volt (eV) lamp, such as a ppb RAE 3000 (or equivalent), will be used during field activities to monitor ambient air quality, and as a field screening tool for semiquantitative measurement of total VOC concentrations in ambient air and soil and bedrock samples. The PID uses an ultraviolet lamp to ionize organic vapors (USEPA 1997). The 10.6 eV lamp was selected due to its ability to detect a broad range of compounds, including aromatics, ketones and aldehydes, amines and amides, some chlorinated hydrocarbons, sulfur compounds, unsaturated hydrocarbons, alcohols, and saturated hydrocarbons. The known VOCs present in on-Site groundwater include benzene and chlorobenzene based on the ASAOC SOW. The ionization potential for these two compounds is 9.25 eV and 9.06 eV, respectively, as published by the manufacturer (RAE Systems, 2010). The PID will be fitted with a moisture filter to reduce moisture interference.

Safety ambient air measurements will be collected during field work where environmental exposure may occur. If ambient air PID readings are noted above levels defined in the HASP, work may be paused or stopped to evaluate the need for additional respiratory protection (see HASP for more details). Any elevated ambient air PID readings and responses taken will be noted in the field book.

During drilling, an aliquot of alluvial aquifer matrix from each 1-foot interval to the water table will be collected directly from the core and placed in a small resealable bag for headspace readings in accordance with the SOP for Field Screening Using a PID (SOP #05, Appendix A). The alluvial aquifer matrix will be field screened from the water table through the bedrock core by running the PID along each 10-foot core at a distance of 0.5-inch to 1-inch above the core. The highest PID results from the 10-foot interval, in parts per billion, will be recorded on field forms for each sample depth and location. Field screening readings from the PID will be recorded on the Vapor Sampling Field Forms and Drilling Log in Appendix B.

3.4.2 Multigas Meter

A four-gas or multigas meter, such as a BW Gas Alert Microclip (or equivalent), which measures combustible or toxic gases and vapors and oxygen, will be used when working inside or in close proximity (i.e., within about 100 meters) to the landfill property for ambient air monitoring, as outlined in the HASP. The meter will continuously measure hydrogen sulfide, methane, lower explosive limit, and oxygen values. The instrument will be set to sound an audible alarm when concentrations exceed preset limits as outlined in the HASP. Pursuant to the HASP, personnel will evacuate the area if alarm conditions are detected using the 4-gas meter. Any alarm conditions and responses taken will be noted in the field book.

3.4.3 Fixed Gas Meter

A fixed gas meter, such as the Landtec GEM™ 2000 (or equivalent), will be used as a field screening tool when conducting vapor sampling, in accordance with the SOP for Field Screening Using a Landfill Gas Meter (SOP #06, Appendix A). The fixed gas meter monitors methane, carbon dioxide, and oxygen concentrations. Field screening readings from the fixed gas meter will be recorded on the Vapor Sampling Field Forms in Appendix B.

3.5 Field Surveying and Mapping

Field surveying will be conducted for existing monitoring wells, leachate collection sumps, new monitoring wells, stilling wells, and vapor sampling locations. The surveying will be scheduled in phases based on the expected timeframes for the installation of new monitoring wells and stilling wells.

3.5.1 Land Survey

For the surveying of the monitoring wells and stilling wells, a State of Missouri registered professional land surveyor will complete the surveys in accordance with the following USGS guidelines from the USGS Techniques and Methods Book: The National Map Seamless Digital Elevation Model Specifications, U.S. Geological Survey Techniques and Methods (Archuleta 2017) and Methods of Practice and Guidelines for Using Survey-Grade Global Navigation Satellite Systems to establish Vertical Datum (Rydlund 2012) and in accordance with the Standards and Procedures for Referencing Project Elevation Grades to Nationwide Vertical Datums (USACE 2010).

Collected monitoring well and stilling well survey data will be input into ERM's project database (EarthSoft's Environmental Quality Information System [EQuIS™]) and exported into the USEPA-accessible database. Spatial information requirements for each surveyed location are as follows:

- Northing and Easting, reported to 0.5 foot, U.S. Survey Feet.
- Coordinates reported in decimal degrees, North American Datum of 1983.
- North-side top of well casing, reported to 0.01 foot, North American Vertical Datum of 1988 (NAVD 88). The north-side top of well casing will be notched for all later groundwater level measurements to reference.
- Ground surface elevation, reported to 0.01 foot, NAVD 88.
- All coordinates reported in North American Datum of 1983, Missouri East State Plane Zone.

Collected survey data will be submitted in Environmental Systems Research Institute (ESRI)-compatible format as either a shapefile or geodatabase. The survey will include installation of two permanent on-Site control points and horizontal and vertical control of the locations. The survey will be based on National Geodetic Survey monuments located near the Site.

3.6 Drilling

The RI will be conducted using a dynamic high-resolution characterization approach using a variety of tools to characterize geologic, hydrogeologic, and groundwater-quality conditions at and around the Site. The proposed tools and the type(s) of data collected using each tool is discussed in Section 5 of the RI/FS Work Plan. Proposed monitoring well and piezometer locations are shown on Figure 3-2 and Figure 3-3. In addition, step-in and step-out monitoring wells will be added during the investigation program to refine the monitoring well network within identified solute plumes and delineate the extent of these plumes. Drilling procedures are summarized below and in the SOP for Drilling Oversight (SOP #07, Appendix A). All alluvium classification and rock coring will be performed and logged in accordance with the SOP for Solid Matrix Logging and Sampling (SOP #08, Appendix A). Borehole advancement will be performed by an MDNR-certified well installation contractor and drilling company.

3.6.1 Direct Push Drilling and WATERLOO APS™

The upper 70 feet of alluvium will be characterized using the WATERLOO APS™. A total of 18 WATERLOO APS™ locations are proposed to be installed as part of the OU-3 RI, as shown on Figure 3-4. This tool generates a continuous index of hydraulic conductivity profile that will be reviewed in real time to determine groundwater sampling depths. Discrete-interval (i.e., about 4 inches long) groundwater samples and groundwater elevation measurements will be collected from zones exhibiting hydraulic conductivity values of approximately 10^{-4} centimeters per second or higher (i.e., fine sand or coarser). The tool is capable of collecting groundwater samples from multiple intervals without having to withdraw the tool for sample collection or decontamination. During advancement of the tool through relatively homogeneous geologic material exhibiting adequate hydraulic conductivity values, groundwater samples will be collected at approximately 5-foot intervals to identify the locations of solute plumes. In areas with heterogeneous geologic conditions, groundwater samples will be collected at the interface between relatively high and low permeability strata. It is anticipated that up to 12 discrete-interval groundwater samples will be collected from each borehole for analyses of VOCs and major anions and cations using a fixed laboratory. These data represent screening data and will be used to support the well screen selection process; these data will not be used for regulatory compliance purposes because of the extremely small vertical sampling interval, which is not reflective of an exposure-point concentration.

Groundwater samples will be collected via stainless steel tubing, under low flow conditions (generally 200 to 500 milliliters per minute [mL/min]) using a peristaltic pump or a gas drive system if the water table is too deep for the use of a peristaltic pump.[3] Geochemical parameters, including dissolved oxygen, oxidation-reduction potential, specific conductivity, pH, and temperature are measured during sample collection at each depth. Groundwater samples will be collected after water quality parameters have stabilized.[4] Samples collected for analysis of major cations and anions will be field filtered using a disposable 0.45-micrometer in-line filter. Groundwater purge times will not exceed 45 minutes; if it takes longer than 45 minutes to collect a representative groundwater sample from a particular depth, that sample interval may be skipped and the borehole continued.

Boreholes will be completed to the target depth, hard refusal, or push-rate refusal, as defined by the driller. After completion, the borehole will be pressure grouted from the bottom to ground surface to avoid cross contamination.

3.6.2 Sonic Drilling and Logging Procedures

The sonic drilling method is a type of rotary vibratory drilling that includes rotary motion and oscillation, which causes a high frequency force to be imposed on the drill string. The sonic drilling technique advances a core barrel and an override casing to prevent the borehole from collapsing when the core is retrieved. The technique uses the rotating and vibrating core barrel and override casing simultaneously to drill a clean borehole, minimizing the amount of drill cuttings and maximizing the amount of cored material retrieved for sampling. Key features of sonic drilling include:

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[3] The WATERLOO[APS] is set up to collect samples before the water passes through the pump head, which eliminates the issue of the flexible pump head tubing potentially sorbing contaminants or contributing organic compounds to the sample.

[4] In some cases, the field team leader may determine that it is appropriate to collect a sample prior to field-parameter stabilization if it is determined that stabilization is unlikely within the allotted time duration and that the sample clearly consists of aquifer water based on the total purge volume.

- Continuous casing of the borehole to prevent potential downward migration of constituents of concern;
- Continuous coring at 10-foot intervals;
- Ample core material for sampling; and
- Retention of minimally disturbed cores following sampling.

While there are concerns regarding the use of sonic drilling and short-term vaporization of VOCs in the immediate area of a well during installation, soil sampling for VOC analysis is not proposed. Screening-level groundwater grab samples will be collected ahead of the core barrel in undisturbed aquifer media. Subsequent groundwater sampling will be conducted following well development and then after a period of time to allow the aquifer system to equilibrate.

3.6.3 Alluvium

The alluvium monitoring wells included in the OU-3 RI/FS will be installed using sonic drilling techniques. Installation procedures for monitoring wells are described further in Section 3.10 and in the SOP for Monitoring Well Installation and Development (SOP #09, Appendix A).

Drilling and sampling procedures are as follows:

- The initial boring will be advanced using a 4-inch core barrel inside a 6-inch outer casing.
- The core barrel will be advanced at 10-foot intervals telescoping from below the outer casing.
- During boring advancement, the core barrel will be withdrawn from the subsurface at 10-foot intervals.
- The core barrel plastic sleeve containing the soil core will be removed from the barrel for field observation and logging.
- This process will be repeated until the entire depth of the alluvium aquifer has been sampled.
- The addition of potable water for advancing the drill casing will be kept to a minimum. The volume of potable water added during drilling will be recorded in the borehole log.
- Each cored interval will be inspected through the plastic sleeve before opening the plastic sleeve.
- Field team personnel wearing clean nitrile gloves will first sample and then log the soil core.
- One or more representative soil sample(s) from each 10-foot section of the sampler will be containerized for potential laboratory analysis, based on the observed lithology and heterogeneity of the sampling interval.
- A representative aliquot of the soil from each 1-foot section of the sampler in the unsaturated zone will be collected for the PID-headspace measurement.
- The alluvial aquifer matrix from the water table to the top of bedrock will be field screened by running the PID along each 10-foot core at a distance of 0.5-inch to 1-inch above the core. The highest PID results from the 10-foot interval, in parts per billion, will be recorded on field forms for each sample depth and location.
- Below the depth of the WATERLOO APS™ investigation (approximately 70 feet), the core barrel will be extracted at selected intervals to allow for discrete-interval groundwater sampling using the packer isolation method. At the selected interval, a stainless steel screen will be placed at the base of the boring, the outer casing will be extracted to expose the screen and the packer will be inflated to isolate the screen within a discrete portion of the alluvium for collection of a groundwater sample. The

discrete-interval groundwater samples will be collected for analyses of VOCs and major anions and cations using a fixed laboratory, consistent with the WATERLOO APS™ program. After each sample has been collected, the screen and packer assembly will be removed from the borehole, and the core barrel replaced to continue coring to the next sampling interval.

- Upon penetrating 5 feet into competent bedrock, the core barrel will be removed and a temporary 4-inch polyvinyl chloride (PVC) casing will be installed inside the outer casing to allow for borehole geophysical logging. Once the temporary casing has been installed, the outer casing will be removed and borehole geophysical logging will be conducted using nuclear magnetic resonance (NMR), gamma/spectral gamma, and induction methods.
- Upon completion of geophysical logging, the sonic drill rig will remobilize and drill over the temporary casing using an 8-inch outer casing to the base of alluvium, and the temporary casing will be removed. The 8-inch outer casing will provide adequate annular space for completion of the CHS multilevel well (a minimum of 4 inches greater than the diameter of the installed well completion diameter), as discussed in Section 3.10.

Alluvial descriptions will include the Unified Soil Classification System, color, grain size, stiffness or density, moisture content, sorting, angularity, and plasticity, as applicable. The alluvial descriptions will be logged according to the SOP for Solid Matrix Logging and Sampling (SOP #08, Appendix A) and recorded on the Drilling Log (Appendix B). Photos will be taken to document each drilling interval, including a scale (e.g., tape measure), location name, and depth of top and bottom of each interval (e.g., using a dry erase board). PID field screening readings will be taken according to the SOP for Field Screening Using a PID (SOP #06, Appendix A) and recorded on the Drilling Log. Soil samples will be bagged, maintained, labeled, and stored at a designated location for further testing, if required.

3.6.4 Bedrock

Borings at locations selected for installation of new bedrock monitoring wells will be advanced into rock only after characterization of the alluvium has been completed and in accordance with the SOP for Monitoring Well Installation and Development (SOP #09, Appendix A). For wells to be completed in both alluvium and bedrock, the outer casing used to over-drill the temporary alluvial casing will be 10 inches in diameter. Once the 10-inch casing is set approximately 5 feet into bedrock, an 8-inch diameter drill casing will then be used to advance through rock. Similar to the alluvium, the core barrel will be advanced in 10-foot increments to retrieve continuous 4-inch diameter sections of rock core. While portions of the core may exhibit increased disintegration from the vibratory drilling, it is anticipated that intact sections of core up to about 3 feet in length will be able to be recovered. Given that an extensive suite of geophysical logging tools will be used to identify the depth, orientation, and transmissivity of bedrock fractures, and that the recovered core will be more than adequate to log geologic characteristics and collect samples for laboratory analyses, the sonic drilling method is considered adequate to achieve the project objectives.

Recovered cores will be retained and inspected by a field geologist. To the extent possible, bedrock descriptions will include weathering, bedding, color, grain/crystal size, strength, lithologic description, and geologic formation, and borehole logs will record core recovery, fractures per foot, weathering index and strength index. The rock core will be field screened by running the PID along each 10-foot core at a distance of 0.5-inch to 1-inch above the core. The highest PID results from the 10-foot interval, in parts per billion, will be recorded on field forms for each sample depth and location. The bedrock cores will be logged according to the SOP for Solid Matrix Logging and Sampling (SOP #08, Appendix A) and recorded on the Rock Coring Log (Appendix B). Photos will be taken to document each drilling interval, including a scale (e.g., tape measure), location name, and depth of top and bottom of each interval (e.g., using a dry erase board). Samples from each 10-foot segment of bedrock core will be placed in sample containers, labeled, and stored at a designated location for further evaluation or testing, as needed. For boreholes designated for matrix sampling, one or more representative sample of core per 10-foot interval will be containerized for rock matrix analysis, based on the observed lithology and heterogeneity of the bedrock.

The borings will be advanced up to 10 feet into the Warsaw Formation (anticipated to be between 80 feet and 120 feet below the base of alluvium). Upon reaching the total depth of the boring, the core barrel will be extracted for geophysical logging of the bedrock interval, as described in Section 3.8.

3.7 Aquifer Matrix Sampling

Aquifer matrix sampling is best conducted in a targeted manner based on specific objectives, rather than at arbitrary depths using random interval sampling approaches. Sonic boring advancement will provide continuous cores of both alluvium and bedrock. The cores will be inspected, logged, screened for VOCs, and soil samples will be collected for possible laboratory analyses. Upon completion of coring, the boreholes will be logged using a variety of borehole geophysical tools that will provide geologic, hydrogeologic, and groundwater chemistry information. Based on the data collected, monitoring well screen intervals will then be selected in accordance with the prescribed selection criteria (Section 3.9). At that time, soil and bedrock matrix samples will be selected for laboratory analyses.

Borehole geophysical logging will generate a significant volume of data that will eliminate the need for typical soil physical property analyses. For example, NMR logging will provide robust estimates of total porosity, pore size distribution, and hydraulic conductivity (permeability); therefore, it isn’t necessary to collect soil samples for grain-size analyses. The list of aquifer matrix analyses is included in attached Table 2-1c.

Soil and bedrock samples will be collected from four alluvial/bedrock boring locations (i.e., perimeter wells MW-404 and MW-406, off-Site wells MW-500 and MW-502) and from one bedrock-only background well (i.e., MW-604) for aquifer matrix analyses.[5] ERM anticipates that 20 matrix samples will be analyzed from each of the four alluvial/bedrock borings and an additional 10 matrix samples will be collected from the background bedrock boring.[6] All soil and bedrock matrix samples collected for analytes that have specified holding times and preservation requirements will be appropriately handled and sent to the lab within the required holding timeframe in accordance with attached Table 2-2 (generally 180 days for metals, radiologic chemistry, and physical properties, and 14 to 28 days for geochemistry analytes). The resultant aquifer matrix physical property and chemistry data will be integrated with the high-resolution characterization data to enable characterization of the aquifer properties that may affect contaminant occurrence and transport. Procedures for aquifer matrix and bedrock matrix sampling are included in the SOP for Solid Matrix Logging and Sampling (SOP #08, Appendix A).

3.8 Geophysical Logging

Geophysical logging will be conducted in both the alluvium and bedrock using down-hole tooling to provide high-resolution vertical profiling of various geologic, hydrogeologic, and water quality parameters at each well location. The tools proposed for geophysical logging in alluvium and bedrock are discussed in Sections 5.3.2 and 5.3.3 of the RI/FS Work Plan, respectively. A summary of the proposed tools and

[5] Soil and rock samples will be retained from the other borings drilled during the RI program; in the event that additional laboratory analyses of the aquifer matrices are deemed necessary, then those samples can be submitted for analyses with extended or no holding times.

[6] One matrix sample will be collected from each representative type of soil and bedrock encountered, with an emphasis placed on vertical intervals where evidence of leachate-impacted groundwater is identified, and where induction logging results identify the presence of gamma-emitting radionuclides. If fewer than ten types of soil or bedrock are encountered, then more than one sample may be submitted from the thickest geologic units encountered. It is not likely that more than ten significantly different types of soil or bedrock will be encountered within a single borehole.

details relevant to OU-3 investigations regarding data acquisition, tool measurements, and derived hydrogeologic properties is provided in attached Table 3-3. Geophysical tools can be deployed in open boreholes or, with certain tools, in non-metallic cased wells. The order that geophysical logs will be acquired will be based on the geophysical service provider's specifications and may include stacked tools that collect data simultaneously.

For alluvium logging through temporary casing, the NMR tool will be run first, followed by induction and then natural gamma and spectral gamma (which are stacked and run in tandem). For bedrock borehole logging, the optical televiewer will be run first to assure good visual quality and assess the condition of the borehole. The remaining logs are typically run in the following order: temperature/conductivity, acoustic televiewer, NMR, gamma/spectral gamma (in tandem), induction, caliper, and finally corehole dynamic flow meter (CDFM; ambient followed by pumping). The CDFM tool will be run under both ambient and pumping conditions and is capable of detecting flows as small as 0.01 gallon per minute and up to 10 gallons per minute. This should be adequate to detect both vertical hydraulic gradients under ambient conditions and the anticipated range of flow in bedrock under pumping conditions.

Bedrock borehole logging will take up to 2 days to complete and bedrock boreholes will not be left open for more than 48 hours prior to logging. The sequence of logging tools may be adjusted based on schedule. For example, the temperature/conductivity log could be run first on the second day if there are concerns about well stabilization.

NMR can be used in existing wells through PVC casing. As such, ERM plans to conduct NMR logging in several existing deep alluvial (D-6, D-12, D-87, D-85, D-13, D-93, and D-83) and bedrock (PZ-109-SS, PZ-101-SS, PZ-100-KS, MW-1204, PZ-104SD, and PZ-106-SD) wells at the Site prior to initiating the drilling program. The initial NMR data collection program will be used to evaluate the efficacy of the Javelin tools for use in fractured bedrock. The Javelin 175D is the only tool that is small enough to fit within existing 2-inch diameter monitoring wells. Though the Javelin 175D will not be used to log newly installed borings, a larger-diameter tool manufactured by the same company (Javelin 350) may be used. Both Javelin tools log at a similar nominal vertical resolution, which may or may not be of adequate resolution to detect individual transmissive fractures within the bedrock beneath the site. The initial NMR results will be evaluated to determine if the Javelin 350 or the higher-resolution Qtec QL40-BMR-90 tool will be used to log the new bedrock borings.

The data collected will provide valuable background information prior to mobilization and drilling of new wells. The proposed wells were selected by first identifying those that meet the NMR tool specifications for original borehole diameter and well construction, and were installed in either deep alluvium or bedrock to provide the largest vertical profile possible. Based on that list, wells were selected that will be useful in providing adequate high resolution coverage across the Site, fill in potential data gaps between proposed new monitoring well sites to assist in developing transects, and further define areas where elevated CPOC have been detected. These data will augment the high-resolution data set that will be collected from the newly drilled boreholes.

Due to the presence of sands and gravels in the alluvium, an open borehole is anticipated to collapse. Therefore, proposed geophysical logging in the alluvium is limited to the instrumentation that can provide data through a temporarily installed PVC casing after the outer steel drill casing has been removed. The alluvial wells will be logged immediately following installation of the 4-inch temporary casing and removal of the 6-inch outer drill casing. As anticipated in this geologic setting, existing water level data indicate that upward vertical hydraulic gradients are observed between the bedrock and overlying alluvium. A temporary blank PVC well casing will be installed prior to logging alluvium to provide both borehole stability and minimize potential cross contamination between alluvial intervals. For bedrock wells, the temporary casing will be over-drilled and removed, and the outer drill casing will be advanced 5 feet into bedrock to seal the alluvium prior to coring the bedrock. Following bedrock geophysical logging, the well casing will be installed with annular seals between screened intervals, and a temporary blank casing liner will be installed across both the alluvium and bedrock zones.

When logging in casing, care must be taken to make sure the tool is measuring native formation materials and that the response is not overly muted by the casing material or the size of original borehole diameter. This can be compensated to some extent by controlling the rate of data acquisition (trolling speed) and taking longer-term, stationary measurements at various depths (repeat measurements) to compare with the actively-acquired geophysical data. For NMR data, the sensitive shell (distance from the tool where data is collected) is fixed based on the radio frequency used and must be greater than the original borehole diameter. For gamma and spectral gamma, the response will be proportional to the distance from the tool to the native formation. In either case, the smallest diameter borehole practical will be used.

In bedrock, the geophysical logs will be collected by lowering the tools through the 10-inch drill casing installed to the top of bedrock and then logging the open 8-inch bedrock borehole below that. The 10-inch outer drill casing will minimize the potential for cross flow between alluvium and bedrock during logging. If the open bedrock boreholes cannot be logged within 48 hours, a temporary borehole liner will be used to minimize the potential for cross contamination within the open bedrock borehole.

After drilling has been completed in bedrock, the 8-inch core barrel will be removed and the boreholes will be logged beginning with the caliper and optical/acoustic televiewer to confirm that the borehole hole is stable for the remaining tools to be used. Based on the proposed suite of logs, it should not be necessary to have a waiting period prior to conducting logging. NMR and dual-induction conductivity have multiple depths of investigation beyond potentially disturbed aquifer materials, and gamma will not be affected by drilling. Fluid temperature and resistivity collected in bedrock are used to detect changes in those properties across water-yielding intervals and do not depend on absolute values, but rather are interpreted to identify inflections in the data. The CDFM testing will extract water from the aquifer until equilibrium is established, thus removing groundwater that may have been disturbed during the drilling process. Borehole turbidity will affect the clarity of optical televiewer logs, but not acoustic televiewer logs. Therefore, there will be no need for an extended equilibration period following drilling, as such a period introduces potential risk for vertical contaminant migration within and out of the open borehole.

Geophysical logging will be performed at all new alluvial and bedrock well locations. With the exception of initial NMR logging of existing wells (which ERM is qualified to perform), ERM will use a qualified geophysical contractor for data acquisition processing. Data acquisition will be conducted in accordance with specifications and SOPs provided by the geophysical equipment manufacturers along with the contractor’s own SOPs. For the pilot NMR logging in existing wells, ERM will perform data acquisition and processing using the equipment manufacturer’s specifications and SOPs. For the initial NMR logging in existing wells, ERM will perform data acquisition and processing using the equipment manufacturer’s specifications and ERM’s SOP (SOP #19, Appendix A).Subcontractor SOPs and equipment manuals related to geophysical logging tools are included in Appendix C. Field logs will be generated and interpreted in real time. Following a technical review of the field results, final logs will be generated.

The field logs generated along with the various data files will be returned to the tool manufacturer with the field computer. Once received, the manufacturer will complete a technical review of the data files and generate final logs. Details regarding the manufacturer’s technical review process are included in ERM’s SOP for self-performed NMR logging (SOP #19, Appendix A).

The NMR data processing tools use industry-standard empirical formulas (SDR/SOE) to provide estimates of hydraulic conductivity. ERM will evaluate existing data and collect additional hydraulic conductivity measurements using one or more methods (e.g., slug test, pressure dissipation test, and flow meter data) within each major soil/rock type encountered to further calibrate the NMR estimates to other traditional methods available. Various parameters (constants and exponents) used in the empirical formulas can be adjusted to provide a best fit with the overall data collected, and the NMR field data can be post processed prior to final logs being generated. Several published studies that provide details of NMR post-processing are available and have been referenced in the SOP.

The borehole logs will be correlated to the ground surface elevation, which will be surveyed following monitoring well installation. This will allow for conversion of the logs to surveyed ground surface elevation points and comparison of elevations across the investigation area.

Additional geophysical logging may be conducted within those existing wells where NMR logging is conducted; however, any additional logging will be completed by a subcontractor during the high-resolution characterization program, not as part of the initial NMR data collection program.

3.9 Monitoring Well Design

The monitoring well network will be designed to target the COPC plumes identified during the high-resolution characterization program and the area vertically and horizontally around the COPC plumes to determine if the plumes are stable or transient. Monitoring wells located outside of COPC plumes (i.e., sentinel wells) will also be used to evaluate background groundwater quality. This will be achieved by selecting well-screen intervals that satisfy one of the following criteria:

- Zone exhibits both high groundwater flux and evidence of groundwater contamination (high mass flux for plume characterization).
- Zone exhibits high groundwater flux, but lacks evidence of groundwater contamination (plume extent).
- Zone exhibits lower groundwater flux, but evidence of groundwater contamination (mass storage/secondary sources).

Well screen intervals will be determined based on real-time interpretation of the collective high-resolution characterization data set collected from each borehole. The collective data set will be compiled into a draft log for each location and well screen intervals will be selected and depicted on the draft logs. Typically, three screens will be set in the alluvium and two will be set in the bedrock; some well locations require fewer well screens as monitoring wells already exist at some proposed drilling locations. ERM will share a copy of the draft log showing the collective high-resolution characterization data set and well screen intervals with USEPA's designated oversight representative prior to constructing the wells.

3.10 Monitoring Well Construction

The proposed OU-3 RI/FS monitoring well network is shown on Figures 3-2 and 3-3. The monitoring wells are grouped by location series as either perimeter wells (200-, 300-, and 400-series), off-Site/downgradient wells (500-series), off-Site background wells (600-series), interior fill-in wells (100-series), or piezometers (700-series). The monitoring wells at each location will be installed within a single borehole and completed as FLUTe™ CHS multi-interval wells or as traditional single-screen monitoring wells for locations requiring only one well screen. In addition, five shallow piezometers will be installed in the alluvial aquifer, as shown on Figure 3-3. Attached Table 3-2 shows the new monitoring wells, their location series, and the tentative number of screen intervals. The final well design and number of screen intervals will be determined based on a review of the high-resolution data collected at each well location using the process described below.

Figures 3-5 and 3-6 illustrate well construction types for multi-level wells and single screen well completions. Well installation will follow the MDNR Well Construction Code 10 CSR 23-4 (Missouri 2019) and the SOP for Monitoring Well Installation and Development (SOP #09, Appendix A). Well construction variance permits will be obtained as necessary from the MDNR. Well construction information will be recorded on the appropriate Monitoring Well Construction Logs, as included in Appendix B.

3.10.1 Cased Hole Samplers

The FLUTe™ CHS will be used in boreholes where more than one well screen will be installed (Figure 3-5). This is a multi-level well system that allows for sampling ports to be placed in both alluvium and bedrock using a single borehole. For this Site, the CHSs will be fitted with dedicated pressure transducers at each sampling interval. A positive displacement sampling system will be used for sample collection to minimize potential sample volatilization. Compressed nitrogen gas will be applied to the pump tubing to lift formation water from the sampling interval to the ground surface for collection.

At locations where a CHS well system will be installed in alluvium only, 8-inch drill casing will be advanced to the bedrock interface. A single 4-inch diameter, Schedule 40 PVC, flush-threaded monitoring well will be constructed with the appropriate number of 0.010-inch factory-slotted PVC well screens at the selected screen intervals with solid riser pipe in between. Once the PVC well material has been installed, a 16/35 or equivalent sand filter pack will be installed within the annulus between the PVC pipe and the drill casing for each well screen interval; the sand filter packs will extend two feet above and below each screen interval. Coated bentonite pellets will be installed within the annulus between the PVC pipe and the drill casing to create a hydraulic seal between each of the screened intervals, and if the first screen is set above the bottom of the borehole, bentonite pellets will be used to seal the bottom portion of the borehole up to two feet below the deepest screen. The drill casing will be slowly extracted from the borehole during well construction until it has been completely removed from the borehole.

At locations where CHS well screens will be placed in bedrock, the drilling procedure requires that a 10-inch drill casing be advanced to the alluvium-bedrock interface and an 8-inch drill casing be advanced through bedrock to the bottom of the borehole. The well installation will then be completed in the bedrock borehole using the same procedure as described for the alluvium, with the only difference being that the 8-inch drill casing will first be removed completely and the sand and bentonite intervals will be constructed in the annular space between the 4-inch CHS pipe and the 10-inch drill casing.

A blank liner will be installed within 48 hours to temporarily seal an open bedrock borehole or a CHS PVC casing after its completion. The liner will remain in place inside the PVC CHS casing until the CHS well system is ready for installation. Blank liners will be manufactured in advance and kept on Site for installation as needed. The borehole water will be pumped out from below the liner via a pump tube at a similar rate as the liner is displacing water while it is everting down the borehole. Consequently, displacement of borehole water into the formation will be minimized. Once the CHS PVC well has been installed, a FLUTe™ blank liner will be used to seal the well screens to avoid cross contamination within the open PVC pipe prior to deploying the CHS well system inside the casing. The FLUTe™ liners are designed to withstand installation in open bedrock boreholes and the same liner can be removed and installed multiple times in the same borehole, if necessary. The liners are made from a flexible urethane imbedded nylon fabric welded into tubular form. The liner will be attached to the top of the well casing and potable water will be added to the interior to create a driving pressure which propagates the liner down the inside of the well casing. By maintaining a positive pressure differential (i.e., keeping a higher water level inside the liner than that outside the liner), the liner creates a seal against the casing which prevents cross contamination between the well screens. To remove the temporary seal, the water inside the liner will be continuously pumped out of the liner and transferred to 55-gallon steel drums for disposal while the liner is winched out of the well by a tether attached to the bottom of the liner.

Surge blocks will be used to develop each screen interval starting at the shallowest screen and working downward in order to minimize buildup of sand on top of the surge block assembly. Due to the pressure differential that occurs immediately above and below the surge block, inflow and outflow will primarily occur at that specific well screen. Sediment will be removed from the bottom of the well using an air lift pump, or equivalent, following completion of the well surging. Up to five well volumes of water will be removed to conservatively account for water lost to the formation during surging. All water and sediment removed from the well will be containerized for disposal.

After the liner has been removed and the borehole has been developed, the sampling component of the CHS well system will be installed. A weight attached to the bottom allows for the well system to be lowered into the well. Once the weight has reached the bottom of the borehole, the liner will be filled with water using the same principle as the blank liner. The hydrostatic pressure inside the liner seals the interval between the well screens to avoid cross contamination. Similarly, water displaced by lowering the CHS system to the bottom of the PVC will be pumped out of the top of the borehole with a centrifugal pump. Water removed from the borehole during installation of the blank liners and the CHS system will be containerized for disposal.

3.10.2 Conventional Monitoring Wells and Piezometers

Boring locations that require only one well screen will be installed using conventional single-casing installation methods in accordance the SOP for Monitoring Well Installation and Development (SOP #09, Appendix A).

Single monitoring wells and piezometers will be installed in an approximately 7-inch borehole and constructed of 2-inch diameter, Schedule 40 PVC, flush-threaded riser pipe with 0.010-inch, factory-slotted, Schedule 40 PVC well screen. If the total well depth is greater than 100 feet, then Schedule 80 PVC pipe and screen will be used as per Missouri State Well Code. Screen lengths will be defined following interpretation of the high-resolution characterization data, but will be either 5 feet or 10 feet long. The annular space around the well screens for the shallow and intermediate alluvial wells will be filled with Morie #0 or equivalent sand and the annular space around the screened intervals for the deep alluvial wells will be filled with 10/20 or equivalent sand. The sand will be placed to a minimum of 2 feet above the top of the screen and, if the screen is not set at the bottom of the borehole, the sand will extend 2 feet below the bottom of the screen. Groundwater will be surged in each screened interval location prior to completing the filter pack placement to minimize future settlement of the filter pack.

The filter pack will be capped with at least 2 feet of bentonite (either chips or coated pellets, depending on how far the screen is below the water table) to form a hydraulic seal above the sand filter pack. Per 10 CSR 23-4, the chips will be hydrated after each 3-foot lift to help maintain proper hydration and a minimum of three times as much water as bentonite will be used. Alternatively, a bentonite-grout slurry will be installed using tremie pipes from the bottom to the top of the annular space. The grout will be allowed to settle overnight and additional grout will be emplaced to approximately 2 feet bgs. The remaining annular space beneath the concrete surface completion will be filled with sand to allow for surface water entering into a flush-mounted protective road box to infiltrate into the ground surface instead of potentially flooding the monitoring well.

3.10.3 Monitoring Well Completion

Following installation, the monitoring wells well be completed with either protective steel casing and bollards or flush-mounted road boxes, depending on their locations. Monitoring wells will be identified with the well number marked on the well cover, when possible, and metal labels will be included in the road box.

3.10.3.1 On-Site Monitoring Wells

The on-Site well completions will be constructed with a target riser height of approximately 3 feet. After well construction has been completed, a 4- or 6-inch diameter protective casing will be set in concrete at least 18 inches into the ground with the top of the protective casing located above the riser pipe. The steel casings will be equipped with a locking cap and rust resistant locks. All well locks will be keyed alike, to the extent practicable. Surface well pads will be constructed of concrete reinforced with steel mesh with a surface dimension of 2 feet by 2 feet. The concrete pads will be set about 2 inches above grade and sloped slightly away from the protective outer metal casing to the edge of the pad to shed precipitation away from the well. If vehicle traffic may be nearby, bollards will be used to help protect aboveground well casings. Bollards will be painted yellow and protective outer casings will be painted blue.

3.10.3.2 Off-Site Monitoring Wells

Off-Site monitoring wells will be completed with protective steel protective casings, where possible. Alternatively, a flush-mounted, sealed, traffic-rated road box will be installed; it will be fitted with specialized bolts to limit access. The road box will be emplaced slightly above the existing ground surface with the concrete apron sloping away from the road box to shed precipitation away from the well. The annular space inside the road box will be filled with sand inside and will extend a short distance below the base of the road box to allow any water entering the vault to seep out the bottom, rather than potentially entering the well. The road box for monitoring wells that may be installed in sidewalks, streets, or parking areas subject to snow removal will be flush with or no more than 0.5 inches below grade, depending on City of Bridgeton, City of Maryland Heights or Earth City requirements.

3.11 Monitoring Well Development

The objectives of monitoring well development are to:

- Allow groundwater to enter the well screen freely, thus yielding a representative groundwater sample and water level measurements;
- Remove water that may have been introduced or disturbed during drilling, or well installation activities;
- Remove fine-grained sediment in the filter pack to minimize the turbidity of the groundwater sample and decrease the likelihood of silt entering and settling in the well; and
- Maximize the efficiency of the filter pack.

The new monitoring wells will be developed no sooner than 48 hours after grouting has been completed. Well development will be completed as described in the SOP for Monitoring Well Development (SOP #09, Appendix A).

Casing volumes will be calculated based on total casing depth, standing water level, and casing diameter. One casing volume will be calculated as:

$$V = \pi r^2 h / 77.01$$

where: V is the volume of one well casing of water (1 cubic foot = 7.48 gallons);

r is the radius of the inner diameter of the well casing in inches (= diameter/2);

h is the total depth of water in the well (in feet).

The volume evacuated from each well and physical characteristics of the purge water (color, turbidity, odor, etc.) will be recorded at regular intervals during development activities. If natural recharge rates are adequate, development activities will continue until the extracted water is visibly free of sediment and turbidity has stabilized to below 10 nephelometric turbidity units, and at least three well casing volumes have been removed. If natural recharge rates are insufficient to attain the well development objectives, the rationale for discontinuing well development activities will be documented. Water levels and total depths will be measured before and after well development in accordance with the SOP for Fluid Level Gauging (SOP #10, Appendix A) and documented on the Monitoring Well Development Form

(Appendix B). Purge water and sediment will be containerized in 55-gallon drums for disposal as described in Section 6.6.

During the well inventory, should existing wells that are included in the proposed monitoring well network be found to require redevelopment due to sediment collection in the bottom of the well, these wells will be redeveloped following the same procedures.[7] If dedicated bladder pumps are in the wells, they will be removed and stored in a dedicated disposable plastic bag. Once the well has been redeveloped, the dedicated pump will be placed back in the well. If the well contains a Waterra valve and tubing, it will be removed and replaced with a new, dedicated bladder pump. The Waterra valve and tubing will be handled as IDW as described in Section 6.0.

3.12 Plugging and Abandoning Boreholes

Any borehole or monitoring well abandonment activities will be performed consistent with 10 CSR 23-4.080. The boreholes will be abandoned with a neat cement grout comprised of a mixture of 96 pounds of Portland cement to no more than 6 gallons of water. The boreholes will be pressure grouted from the bottom to the surface. Prior to abandonment, well construction, total depth, and depth to water will be confirmed, as appropriate. The field geologist will calculate the anticipated amount of grout required before plugging the borehole and record the amount of grout used during plugging in the field book.

3.13 Hydraulic Testing

Hydrogeologic properties of both the alluvial and bedrock aquifers will be measured using a variety of tools and methods. NMR geophysical logging will provide continuous vertical profiles of hydraulic conductivity and transmissivity in both alluvium and bedrock. Optical and acoustic televiewer logging will identify features in bedrock that may be water yielding (e.g., open fractures) and those features will be further characterized with CDFM logging under both ambient and stressed (pumping) conditions. For each CDFM test, the borehole will be pumped and drawdown recorded until it stabilizes. Following the test, a recovery curve will be recorded. This will serve as a short-term aquifer test in addition to characterizing fracture-specific permeability.

To address the issue of interconnectivity of fractures and flow within bedrock, ERM will conduct pneumatic slug testing (pulse-interference testing) in the open bedrock section of MW-113, immediately following geophysical logging. The boring for MW-113 will penetrate both the St. Louis Formation and the underlying Salem Formation. The slug tests will be conducted by isolating transmissive fractures identified using other tools using a straddle packer system and then conducting a slug test within each interval while monitoring responses in nearby bedrock piezometers and deep alluvial monitor wells.

The pneumatic slug test method uses air pressure to displace groundwater. Groundwater sampling will not be conducted in MW-113 within one month after the test to allow for re-equilibration of groundwater geochemical conditions in the vicinity of that well. Pneumatic slug testing will be conducted in accordance with the SOP for Pneumatic Slug Testing (SOP #11, Appendix A).

Prior to, during, and after testing, pressure transducers will collect real-time, high-resolution water levels and be analyzed, post-testing, to investigate water level changes in bedrock monitoring wells within 1,000 feet of MW-113. Additionally, transducers will be deployed in existing wells as noted in attached Table 3-1c; changes in water level during the testing at MW-113 will be evaluated in these additional

[7] Sedimentation will be evaluated by comparing the constructed total depth of the monitoring well to the measured total depth of the monitoring well.

locations. Transducer deployment is discussed further in Section 3.16.2 and in the SOP for Transducer Deployment (SOP #12, Appendix A).

3.14 Groundwater Sampling

Quarterly groundwater monitoring is proposed for eight consecutive quarters as part of the OU-3 RI/FS. An additional monitoring event will be conducted for each new well installed a minimum of two weeks following well completion to support decision making regarding the need for step-in or step-out wells. The proposed OU-3 monitoring well network is listed in attached Tables 3-1c (existing wells) and 3-2 (new wells) and shown on Figure 3-2. The groundwater samples will be submitted to the laboratory for analysis of the analytes presented in attached Table 2-1a.

Groundwater sampling will be performed in accordance with the SOP for Groundwater Sampling (SOP #13, Appendix A), which includes bladder pump procedures for traditional single screen monitoring wells, and positive displacement sampling procedures for sampling of the CHS multi-level wells. A high-level summary of the groundwater sampling methods is included below.

3.14.1 Bladder Pump Installation

A dedicated bladder pump will be installed in each of the new single-screen wells. Bladder pumps are currently installed in all of the active Bridgeton Landfill monitoring wells. New bladder pumps will be installed in existing wells identified for the OU-3 well network, as necessary, based on the condition of the existing pumps, which will be evaluated during the well inventory task. ERM anticipates installing QED Environmental Systems' Well Wizard® pumps Model Numbers P1101M and P1150 (or similar), which are currently used for other on-Site groundwater sampling programs.

Bladder pump intakes will be placed at the most transmissive zone or impacted zone identified during the high-resolution characterization program. If there are concerns with the well going dry, pumps will be placed 2 to 3 feet from the bottom of the well to permit reasonable drawdown without disturbing the bottom of the well. For most of the monitored groundwater zones, the pump will be set within the well's screened interval. The exception is within wells with very deep screened intervals that may require drop tubes to be set within the screened interval. Pumping rates will be regulated or controlled to minimize turbulent flow, prevent damage to the monitoring well components, and minimize the introduction of sediment into the well.

3.14.2 Monitoring Well Purging and Sampling

3.14.2.1 Traditional Single Screen Monitoring Wells

Groundwater samples will be collected from traditional single screen monitoring wells using low-flow sampling methods and dedicated bladder pumps. Pumping rates will generally range between 200 to 500 mL/min, and will be controlled to minimize turbulent flow, prevent damage to the monitoring well components, and minimize the introduction of sediment into the well. A flow cell will be used to collect water quality parameter measurements until stabilization is achieved in accordance with the stabilization criteria presented in the SOP for Groundwater Sampling (SOP #13, Appendix A). If a well is purged dry prior to the achieving water quality parameter equilibrium, the well will be purged to the lowest reasonable groundwater elevation, permitted to recover, and then sampled within 24 hours after completion of purging.

At the time of sample collection, the tubing will be disconnected from the flow cell, and sample bottles will be filled directly from the pump's discharge tube to minimize agitation and aeration. Groundwater sample information, including sample date and time, approximate flow rates, total volume of purged groundwater,

water quality parameters, and sample bottles collected will be recorded on the Groundwater Sampling Log (Appendix B). The final set of water quality parameters will be uploaded to the project database (EQuIS™).

3.14.2.2 CHS Monitoring Wells

Groundwater samples will be collected from CHS multi-level wells via positive displacement. The CHS well system draws water directly from the formation, minimizing well water storage to the sample tubing volume only (i.e., there is no standing water within the PVC well). Consistent with recommendations from the CHS manufacturer, the stagnant water will be purged using compressed nitrogen gas at a regulated pressure sufficient to lift the water to the ground surface.

For the CHS well systems, pressurized nitrogen gas will be distributed to the pump tubing via a manifold that allows for simultaneous purging and sampling of multiple ports. When the regulated gas pressure is applied, it passes through a one-way valve which prohibits backflow into the formation and instead lifts the water to the ground surface via the sample tube at a flow rate of approximately 500 to 1,000 mL/min. While this flow rate is higher than that of conventional low-flow sampling, it is important to note that the sample has already recharged into the sampling port and is not being pulled directly from the formation. Thus, the significance of controlling the flow rate of the effluent is limited to maintaining a controlled laminar flow to minimize any volatilization.

Each sample port will be purged simultaneously into its own bucket. Water quality parameter stabilization will not be monitored with a flow cell during purging due to the limited volume of each purge stroke. A total of 3 gallons of water will be purged prior to sampling to clear out filter pack drainage and stagnant water inside the tubing. The only source of recharge water will be groundwater within the adjacent geologic formation. Prior to sampling, one set of water quality parameters will be collected by collecting purge water from the sample port into a calibration cup and inserting a multi-meter probe into the cup. The probe will be tightened and allowed to adjust for several minutes before recording the water quality parameters. Due to the aeration that occurs during this process, the dissolved oxygen measurements are not considered representative and will be recorded for future reference only. Observations of any black iron sulfide flocculation and/or hydrogen sulfide odor will be recorded as lines of evidence in support of anaerobic conditions.

Pertinent groundwater sample information, including sample date and time, approximate flow rates, total volume of purged groundwater, water quality parameters, and sample bottles collected will be recorded on the Groundwater Sampling Log (Appendix B). The final set of water quality parameter values will be uploaded to the project database (EQuIS™).

3.14.2.3 Sample Collection for Laboratory Analysis

Individual sample containers will be filled as described in the SOP for Groundwater Sampling (SOP #13, Appendix A) for the laboratory analyses described in attached Table 2-2. Attached Table 2-3 details the order in which samples will be collected. In general, samples will be collected in order of decreasing volatility and samples for corresponding total and dissolved compounds are collected as concurrently as possible (without removing the filter) to maximize comparability. Sample containers for VOCs, dissolved gases, and TPH will be filled in a manner to eliminate head space within the container. At each sampling location, all bottles designated for a particular analysis (e.g., VOCs) will be filled sequentially before bottles designated for the next analysis are filled. If QA/QC samples (i.e., blind duplicates and MS/MSDs) are to be collected from a given well, samples should be collected in conjunction with the base sample (e.g., collect all VOC samples first, then all the semi-volatile organic compounds). When collecting groundwater samples for VOC analysis at CHS locations, the samples will be collected during a steady laminar flow to avoid aeration within the sample bottles or overfilling and preservative loss.

Samples collected for hexavalent chromium analysis will be collected after the sample for total metals and will be filtered in the field using a laboratory-provided syringe kit. Immediately following field filtering, the sampler will add the laboratory-provided preservative to the sample container and cap, prior to storing the sample in the cooler. Field preservation will be noted on the sampling form, on the sample label, and on the CoC.

Samples for dissolved metals, radiological analyses (excluding tritium), and organic carbon will be filtered in the field using a clean, unused 0.45-micron in-line filter. Each in-line filter will be pre-conditioned by running approximately 25 mL of sample water through the filter prior to collecting the sample. One filter will be used per well, unless the flow rate decreases to 10 percent or less of the initial sample flow rate due to the filter becoming clogged by elevated particulates.

For low-yield monitoring wells, attempts will be made to collect samples for all analyses during the initial sampling event. If recharge is insufficient to collect all samples, collection order may be modified, as described in the SOP for Groundwater Sampling (SOP #13, Appendix A). Based on the results of the initial sampling round, certain compounds may be prioritized on a well-by-well basis during future sampling events.

3.15 Leachate Collection System Sampling

The current leachate collection system is comprised of LCSs within the North Quarry (LCS-5A, LCS-5B, and LCS-6B) and South Quarry (LCS-1D, LCS-2D, LCS-3D, LCS-4B, LCS-4C) as documented in the March 2019 Operation, Maintenance and Monitoring Plan (CECI 2019). Each sump has been installed near the base of the quarry floor, approximately 270 feet bgs, with screens that range in length from 60 to 150 feet. Dedicated pumps were installed in each LCS point. Due to the subsurface reaction described in Work Plan Section 3.5, some of the South Quarry sump pumps are not currently operational. Leachate samples will be collected from LCS points with operational sampling ports which are safe to access, and produce fluid. Eight quarters of leachate sampling will be conducted. If the dedicated LCS pump is not operational, the LCS point will not be sampled. LCS samples will be collected for the same analytical suite of COPCs using the same sample order as groundwater samples. The sampling plan for LCS samples is included in Table 2-1b LCS sampling information, including sample name, date, time, and general physical observations of the purge water (i.e., color and odor), will be noted in the field book.

At the time of the OU-3 RI field activities, information will be obtained on operational status of the leachate collection and treatment system, including the presence of sampling port(s), whether the LCS point produces fluid, access issues, construction, operational history, frequency of use, pumping rates from each LCS point, pump configuration, and influent and effluent concentrations. ERM will monitor the weekly leachate levels and pumping rates on the MDNR website for the Bridgeton Landfill to determine when there is an adequate amount of leachate to collect LCS samples. LCS sampling will be coordinated with the quarterly groundwater monitoring, when possible. Ground temperature, vadose zone pressure, and gas extraction data from Bridgeton Landfill will also be compiled.

3.16 Monitoring Well Gauging

3.16.1 Water Level Measurements

Each month for a period of 24 consecutive months, the depth to static groundwater will be measured, within a 24-hour timeframe, at each groundwater monitoring well in the network, as well as prior to purging for groundwater sampling events, in accordance with the SOP for Fluid Level Gauging (SOP #10, Appendix A). Water level meters will be calibrated prior to first use, as described in Section 4.

In general, water levels will be measured first in wells which have the least amount of known contamination. Wells with known or suspected contamination will generally be measured last to reduce the potential for cross-contamination.

The need to collect total depth measurements will be determined at least annually based on multiple lines of evidence, including anomalous water quality parameter readings, analytical results, and turbidity readings. If it is determined that substantial sediment has accumulated in a well, the well will be redeveloped as described in Section 3.10.

3.16.2 Pressure Transducers

After completing a round of water level measurements, Solinst Model 3001 Levelogger absolute pressure transducers and a Barologger, both collectively termed data loggers, will be placed in select wells in accordance with the SOP for Transducer Deployment (SOP #12, Appendix A). Attached Table 3-2 lists proposed new wells and attached Table 3-1c identifies existing locations for deployment for a combined total of 88 data logger locations. The data loggers measure and record groundwater levels and temperature. Water levels are displayed as temperature-compensated pressure readings and are barometrically compensated with the aid of the Barologger. The Barologger uses algorithms based on measured atmospheric pressure to compensate water levels recorded by the data loggers.

The data loggers will be deployed with direct-read cables, hung from specialized well caps. Prior to use, pressure transducers will be allowed to equilibrate to groundwater temperature to alleviate potential erroneous readings. The data loggers will be placed approximately 10 feet below the static water level in each well and will remain for approximately 2 years, programmed to record data every hour. During quarterly groundwater monitoring events, transducer data will be downloaded from the wells and saved within the project files. The data logger deployment form is included in Appendix B.

3.17 Surface Water Gauge Installation and Monitoring

Surface water level monitoring will be conducted at nine locations as shown on Figure 3-3. In order to monitor surface water stage, stilling wells will be installed based on proposed designs as shown on Figure 3-7. The stilling well will extend to a minimum of 5 feet below the water surface and be instrumented with a data logger to record water levels every hour.

3.18 Vapor Intrusion Investigation

The OU-3 RI vapor intrusion (VI) investigation will include the following activities:

1. Collect indoor air samples from the four Site buildings shown on Figure 3-8.
2. Collect sub-slab soil gas (or crawlspace or near-slab soil gas samples if sub-slab is not accessible/possible) from the four Site buildings where indoor air samples will be collected.
3. Collect soil gas samples along the Site perimeter in areas that are not already being addressed by the OU-1, OU-2, or Bridgeton Landfill sampling activities (if warranted based on the perimeter landfill gas data from Bridgeton Landfill, OU-1, and OU-2 investigations).
4. Evaluate the potential for vapor-forming compounds, including organic compounds, radium (which decays to radon and radon decay products), and methane, to migrate from impacted groundwater into indoor air in current off-Site buildings.

The following sub-sections describe the field procedures for vapor-intrusion-related sampling activities.

3.18.1 Indoor and Outdoor Ambient Air Sampling

Indoor air sampling will be conducted at four on-Site buildings, as shown on Figure 3-8:

- Asphalt Plant Building (approximately 680 square feet)
- Pump House (approximately 660 square feet)
- Scale House (approximately 240 square feet)
- Engineering Office (approximately 5,240 square feet)

Four rounds of indoor air sampling will be conducted. One indoor air sample will be collected for every 2,000 square feet of building space, equating to one sample per building for all buildings except for the Engineering Office, where three samples will be collected. One outdoor ambient air sample will be collected per building per sampling round[8]. Prior to conducting any indoor air sampling, a Vapor Intrusion Interior Building Survey and Chemical Inventory will be completed and findings documented (Appendix B). Following completion of the building survey, the number of samples per building may be adjusted, based on information obtained regarding the room layout; heating, ventilation, and air conditioning (HVAC) configuration; and room use.

Mitigation/ventilations systems are currently operating in a small portion of the Engineering Office (i.e., the bathroom) and the Scale House. These systems were installed for odor/methane mitigation. During one of the four indoor air sampling events, two sets of indoor air samples will be collected in these two buildings. The first set will be collected while the systems are operating. The second set will be collected after the systems have been shut down for approximately 24 hours.

The indoor air/outdoor air sampling procedure is described in the SOP for Indoor and Outdoor Ambient Air Sampling (SOP #14, Appendix A).

3.18.1.1 Vapor Intrusion Interior Building Survey and Chemical Inventory

Prior to initiating indoor air monitoring and sampling, the following activities will occur:

1. The Vapor Intrusion Interior Building Survey and Chemical Inventory Form (Appendix B) will be completed by the building occupant to document VOC sources within the building and provide general building construction and operation (e.g., HVAC) information.
2. The questionnaire will be reviewed and a follow-up interview with the building occupant will be conducted to fill in data gaps.
3. An inspection of the premises will be completed by the sampling team to identify and document VOC sources (if any) not listed on the questionnaire. A detailed description of the chemical or material will be documented in field notes for that building. Inspection of the buildings construction and HVAC system operation will also be completed. The Site inspection will also include a building inventory to account for all current buildings and building uses on the Site (including buildings used for storage).

Identified VOC sources will be documented and removed from buildings, if possible, at least 24 hours prior to sample collection. Indoor and outdoor air will be monitored during the building survey and prior to sample placement for total organic vapor concentrations using a PID (ppbRae, or equivalent), as well as fixed gases including oxygen, methane, and carbon dioxide using a landfill gas meter (Landtec GEM™ 2000, or equivalent). Readings will be collected prior to Summa® canister placement and recorded on the Indoor Air/Outdoor Ambient Air Sampling Form (Appendix B).

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[8] Outdoor ambient air samples will be collected beginning up to 1 hour prior to indoor air sampling and extending until at least 30 minutes prior to completion of indoor air sampling.

3.18.1.2 Indoor/Outdoor Ambient Air Sampling for VOCs and Methane

For indoor air samples collected for VOC and methane analysis, the samples will be collected using individually certified clean 6-liter Summa® canisters connected to a flow-controller calibrated to collect the sample over an 8-hour period (i.e., typical average worker shift length). As described in the SOP for Indoor and Outdoor Ambient Air Sampling (SOP #14, Appendix A), indoor and outdoor air will be monitored immediately prior to sample collection for total organic vapor concentrations using a PID (ppbRae, or equivalent), as well as fixed gases including oxygen, methane, and carbon dioxide using a landfill gas meter (Landtec GEM™ 2000, or equivalent). Readings will be recorded on the Indoor Air/Outdoor Ambient Air Sampling Form (Appendix B).

Attached Table 2-1e shows the sampling plan for indoor, outdoor ambient, and QA samples. Attached Table 2-2d shows the indoor air sampling analyte list, holding time and preservation, and container requirements. Note that operations at the Asphalt Plant Building use VOC-containing products in the preparation of asphalt and, therefore, the presence of background indoor air sources that cannot be removed due to ongoing operations at and adjacent to the building may confound interpretation of indoor air sampling VOC data at this building.

Indoor air sampling locations will be selected based on the following criteria:

- Samples will be collected on the lowest occupied/occupiable level of each structure.
- Sampling equipment will be located in an area where it is unlikely to be disturbed during the measurement period and where there is adequate room for the device.
- Samples will not be collected near known drafts caused by heating, ventilating and air conditioning vents, doors, fans, and windows; near heat sources; in direct sunlight; in areas of high humidity; within 3 feet of doors, windows or other openings to the outdoors; or within one foot of the exterior wall of a building, if possible.
- Sampling equipment will be set at approximate breathing height (3 to 5 feet off the ground).
- Sample locations will focus on occupied portions of a building (i.e., avoid closets, etc.).

Outdoor ambient air sampling locations will be selected based on the following criteria:

- The monitoring device will be set at approximate breathing height (3 to 5 feet off the ground).
- Sampling locations will be chosen generally upwind of the building being sampled. It is currently assumed one outdoor air sample will be collected outside of each building but, depending on wind direction and building locations, one outdoor ambient air sample may be used to cover multiple buildings.
- Sampling locations will be 5 to 15 feet away from the buildings and away from trees, walls, or other physical obstructions that may inhibit or alter air flow to the sample(s), as much as possible. Sample security will also be considered.
- Representative sample locations should be selected to minimize bias toward obvious sources of ambient VOCs, as much as possible (e.g., automobiles, lawnmowers, oil storage tanks, gasoline stations, etc.).

3.18.1.3 Indoor/Outdoor Ambient Air Sampling for Radon and Radon Decay Products

Both short-term and long-term radon testing will be completed within each building. The short-term radon and radon decay product testing will be conducted with a continuous monitoring device to provide real-time, but short-duration data[9]. In addition, long-term radon testing will be performed to obtain long-duration data. Short-term and long-term radon testing will only be completed during the first indoor air sampling event.

Radon and radon decay product samples will be collected from indoor air in each of the four selected buildings and at the outdoor ambient air sampling location. Both short-term and long-term radon measurements will be performed at the four buildings in general accordance with the protocols described in Indoor Radon and Radon Decay Product Measurement Device Protocols (USEPA 402-R-92-004; USEPA 1992); Protocols For Radon And Radon Decay Product Measurements In Homes (USEPA 402-R-92-003; USEPA 1993a); and Protocol for Conducting Measurements of Radon and Radon Decay Products in Homes (ANSI/AARST 2019).

Short-term radon testing will be performed using a continuous radon monitoring device with a solid-state alpha detector such as the RAD7, or equivalent. This device collects a filtered air sample so that only radon gas can enter the monitor chamber. As the radon decays, its decay products are electrostatically bound to the internal detector. The detector then records the alpha radiation emitted from the subsequent decay of radon decay products (e.g., polonium 218). The energy derived from the alpha decay allows the device to differentiate between radon decay products, allowing it to simultaneously measure radon and its decay products. The short-term monitoring will be conducted as described in the SOP for Short-Term Radon Testing (SOP #15, Appendix A) and Section 4.2 of the RAD7 User Manual for Continuous Monitoring (Appendix C), and documented on the Short-Term Radon Monitoring Field Form (Appendix B).

Typical short-term testing consists of continuous radon monitoring over a 48-hour period within a closed building with no air exchange system or ventilation fans running. Given the active nature of the on-Site buildings, a modified short-term radon test will be conducted where occupants can enter/exit the building consistent with normal Site operations throughout the 48-hour monitoring period. In the Engineering Office and the Scale House, short-term radon samples will be collected with the current odor/mitigation systems in operation[10]. For outdoor ambient air sampling, the continuous radon monitor will be placed adjacent to each outdoor canister sampling location. The radon outdoor air sample will be collected for the same period of time (48-hours) as the indoor air radon sample.

Long-term radon testing will be performed using long-term electret ion chambers for a period of at least 90 days, deployed in accordance with the SOP for Long-Term Radon Testing (SOP #16, Appendix A), and documented on the Long-Term Radon Monitoring Field Form (Appendix B). These devices consist of a special plastic canister (ion chamber) containing an electrostatically charged disk detector (electret). The electrets start with a known voltage that will be decreased by the ionization and decay of radioactive gas. The change in voltage will be proportional to the amount of radon gas that has entered the chamber containing the electret. The initial and final voltages are measured at the analytical laboratory, and a calculation performed using the instrument manufacturer's formula or software, including a minor regional correction factor for background-level gamma radiation.

3.18.2 Soil Gas Sampling—Sub-Slab, Near-Slab and Exterior Soil Gas

Sub-slab soil gas sampling will be completed on Site in conjunction with the indoor air sampling. If sub-slab sampling is not possible due to building floor construction or access, near-slab/exterior soil gas

[9] Short term radon measurement collection will be modified from general operating procedures as building use (e.g., doors opening and closing, HVAC use) cannot be limited during the monitoring event due to ongoing Site operations. General building use will be documented during the monitoring event.

[10] Due to building use/operations, the odor/mitigation systems will not be able to be turned off for a period long enough to cover the full 48 hour short-term radon testing period, therefore short-term radon will be monitored while systems are in operation.

samples or crawlspace samples[11] (if present) will be collected. Soil gas sampling may be completed at on- and off-Site locations to evaluate the potential for vapor migration or VI, if warranted based on the perimeter landfill gas data from Bridgeton Landfill, OU-1, and OU-2 and the evaluation of the groundwater data collected as part of the OU-3 RI work plan. Considering the age of the wastes, the brief half-life of radon, and the proposed remedial action, no landfill gas monitoring is currently being conducted at or is proposed as part of the OU-1 design investigation. The potential for underlying groundwater to contribute to VI will be evaluated as described below and investigated accordingly. OU-1 is in the process of developing an Explosive Gas Monitoring Plan to establish baseline conditions relative to landfill gas occurrences along the outer margins of OU-1 Areas 1 and 2, which will supplement the data being obtained as part of the Bridgeton Landfill and OU-2 explosive gas monitoring plans. Upon implementation of the OU-1 plan, OU-3 will review the results to further evaluate the potential for VI of landfill gas.

The following criteria will be used to initiate an evaluation of off-Site soil gas:

- Methane concentrations observed during the Bridgeton Landfill, OU-1, and OU-2 landfill gas perimeter survey that exceed 1 percent methane[12] (i.e., three times the detection limit of the landfill gas meter, which is 0.3 percent methane)
- Groundwater VOC concentrations observed during activities detailed in this RI Work Plan that are collected at the water table and exceed USEPA Vapor Intrusion Screening Levels (VISLs)[13]. VISLs are set at a target cancer risk of 10^{-5}, a non-cancer hazard quotient of 0.1, and a groundwater temperature of 20 degrees Celsius (with the exception of TCE[14]) under a residential receptor scenario.

The following sections describe sub-slab soil gas probe installation and sampling methodologies and near-slab/exterior soil gas probe installation and sampling methodologies. Probe construction, QA/QC checks and sampling details are included in the SOP for Soil Gas Probe Installation and Sampling (SOP #17, Appendix A) and the SOP for Sub-Slab Soil Gas Probe Installation and Sampling (SOP #20, Appendix A). Attached Table 2-2d shows the analytes, holding time and preservation, and container requirements for the vapor samples.

3.18.2.1 Sub-Slab Soil Gas Sampling

The following section details the installation and sampling of sub-slab soil gas probes to be used to further evaluate the VI pathway. Probes will be installed following the procedures described in the SOP for Sub-Slab Soil Gas Probe Installation and Sampling (SOP #20, Appendix A).

Sub-Slab Probe Installation

A pilot 1.5-inch diameter hole will be drilled to a depth of approximately 1.75 inches into the concrete slab using an electric hammer drill. A 5/8-inch-diameter hole will then be drilled through the remaining thickness of the slab and approximately 1 inch into the sub-slab material to form a void. The hole will be cleared with a pipe brush, and the loose cuttings will be removed with a shop vacuum. A Vapor Pin™ with a silicone sleeve will be placed over the hole and tapped into place using a dead blow hammer. The

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[11] If crawlspace samples are deemed appropriate the sampling procedures for indoor air sampling will be followed to collect a crawlspace sample.

[12] 1 percent methane was chosen as the criterion for additional VI investigations as this threshold is far enough above the instrument detection limit to provide an indication of landfill gas. This screening value is also conservative relative to the municipal solid waste landfill action level of 1.25 percent methane.

[13] If a compound does not have a USEPA VISL, a screening level will be calculated using Henry's law.

[14] GW VISLs for TCE are based on Region 7 Specific TCE Action Level for indoor air used to calculate a groundwater screening level (USEPA 2018b).

silicone sleeve forms a water and airtight seal with the concrete. Each Vapor Pin™ will be left in place for at least 2 hours to allow to equilibrate before sampling. The above method allows for the sub-slab probe to be installed flush with the floor. If this is not possible due to slab conditions, building use or property owner requests, probes can also be installed as short "stick ups" using the same procedures as above but excluding the initial 1.5-inch pilot hole. In such cases, the 5/8-inch diameter hole will be drilled from floor surface through the full thickness of the slab. Installation will be documented on the Vapor Probe Construction Form (Appendix B).

After probe installation, QA checks and then sampling, the probes may be removed, and the hole will be sealed with cement and smoothed with a trowel to a flush finish. Depending on the sampling plan, probes may be left in place for use in multiple sampling events prior to removal.

Sub-Slab Leak Testing, Purging and Differential Pressure Monitoring

Sub-slab probe seal integrity will be verified using a water dam as described in the SOP for Sub-Slab Soil Gas Probe Installation and Sampling (SOP #20, Appendix A). The water dam leak test will replace the helium tracer test for sub-slab sample probes only. The water dam test is effective for sub-slab probes because the probe is sealed against a concrete surface. The water dam creates a visual indicator (i.e., the water level inside the dam will fall) if there is a leak between the newly installed vapor probe and the concrete floor. If leaks are observed, the leak will be identified and sealed or the Vapor Pin™ will be removed and replaced until the probe passes the water dam test.

Following the water dam test, the probe will be minimally purged using a plastic syringe. Sub-slab probes are 5/8 inch in diameter and are typically between 3 and 8 inches long, so three tubing volumes is typically less than 0.5 liters. A minimum of three purge volumes will be removed, collected in the Tedlar bag and discharged outside. The permeability of the subsurface materials will be qualitatively assessed during the probe purge. If there is resistance or difficulty pulling back on the syringe plunger during the purge, the sample probe may be blocked or set in tight subsurface materials and may need to be replaced or moved.

Sub-slab soil gas probes will be connected to a micro-manometer to measure the static pressure differential between the sub-slab and indoor air. Measurements will be collected for approximately 5 minutes and recorded on the Soil Gas Sampling Form (Appendix B). Documentation of QA/QC checks will be recorded on either the Soil Gas Sampling Form (Appendix B) or the Vapor Probe Construction Form (Appendix B) as applicable.

Sub-Slab Soil Gas Sample Collection

Sub-slab soil gas sample collection can begin a minimum of 2 hours after probe installation to allow for subsurface conditions to equilibrate.[15] The soil vapor samples will be collected in certified clean Summa® canisters connected to a cleaned flow-controller calibrated to collect the sample at a rate of 200 mL/min. Prior to sampling, the sampling train (i.e., the tubing connected from the probe to the canister) will be checked for integrity by completing a shut-in leak test. Results will be documented on the Soil Gas Sampling Form (Appendix B).

Following sub-slab soil vapor sampling for VOCs, methane, and fixed gases, the soil vapor will be field screened for total organic vapors using a PID and for oxygen, carbon dioxide, and methane using a multi-gas meter. The PID and multi-gas meter will be calibrated prior to conducting measurements in

[15] Equilibration time following sub-slab probe installation is minimal (2 hours) as probe installation does not entail significant disturbance of the subsurface materials. The Vapor Pin® is sealed using a silicone sleeve so time is not needed to wait for concrete or bentonite to set.

accordance with the manufacturer's guidance. Data will be recorded on the Soil Gas Sampling Form (Appendix B).

Radon and radon decay product activity in sub-slab soil vapor will be measured using the methods documented in the SOP for Short-Term Radon Testing (SOP #15, Appendix A). Data will be recorded on the Radon Soil Gas Monitoring Form (Appendix B).

3.18.2.2 Near-Slab and Exterior Soil Gas Sampling

The following section details the installation and sampling of near-slab and exterior soil gas probes to be used, if warranted, to further evaluate the VI pathway. Probes will be installed following the procedures described in the SOP for Soil Gas Probe Installation and Sampling (SOP #17, Appendix A). Near-slab soil gas probes are typically installed if sub-slab sampling is not feasible. Exterior soil gas probes are typically installed when soil gas sampling is not targeting a specific building.

Near-Slab/Exterior Probe Installation

Soil gas probes may be installed as single probes or as a set of nested probes. Nested probes will be completed with collocated shallow (approximately 5 feet bgs) and deep probes (approximately 15 feet bgs), as appropriate.[16] The deep probe will be installed close to the water table, but above the capillary fringe to reduce the likelihood of collecting a soil gas sample with elevated moisture content. Surface completions will be generally consistent with those discussed for monitoring wells in Section 3.10.

QA/QC checks will be performed in accordance with the SOP for Soil Gas Probe Installation and Sampling (SOP #17, Appendix A), and may include seal testing, shut-in leak testing, pneumatic testing, and helium leak testing. Probe construction and associated QA/QC checks will be documented on the Vapor Probe Construction Form (Appendix B).

Leak Testing, Purging, and Differential Pressure Monitoring

Near-slab/exterior soil gas probe seal integrity will be verified using a helium leak test as described in the SOP for Soil Gas Probe Installation and Sampling (SOP #17, Appendix A). If leaks are observed, the leak will be identified and sealed or the probe will need to be removed and replaced until the probe passes the leak test.

In conjunction with the helium leak test, the soil gas probe will also be purged of approximately three volumes of air. Purged air will be collected in a Tedlar bag and screened for helium (as part of the leak test) as well as VOCs and fixed gases. Results of the helium leak test and readings collected during probe purge will be documented on the Vapor Probe Construction form (Appendix B). If nested probes are installed, then a seal test may also be completed in addition to the helium leak test as described in SOP #17 (Appendix A).

Depending on subsurface stratigraphy encountered during probe installation, pneumatic testing (similar to that of a traditional aquifer step-test) may also be appropriate to document that the permeability of soils is sufficient to allow for active soil gas sample collection without application of excessive vacuum to the subsurface.

The soil gas probe will also be monitored for differential pressure between the subsurface and the outdoor ambient air. A digital micromanometer will be connected to the probe tubing and differential pressure readings will be collected for approximately 5 minutes. Measurements will be collected and recorded on the Soil Gas Sampling Form (Appendix B).

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[16] If the depth to groundwater or bedrock is too shallow to facilitate installation of a nested probe, then a single soil gas probe will be installed.

Documentation of the above QA/QC checks and monitoring information will be recorded on either the Soil Gas Sampling Form (Appendix B) or the Vapor Probe Construction Form (Appendix B) as applicable.

Near-Slab/Exterior Soil Gas Sample Collection

Near-slab/exterior soil gas sampling can begin a minimum of 48 hours after probe installation to allow subsurface conditions to equilibrate[17]. Each soil gas sample will be collected in a certified clean, Summa® canister with a cleaned flow controller (maximum rate of 200 mL/min). After connection of the Summa® canister to the probe, the sampling train (i.e., the tubing connected from the probe to the canister) will be checked for integrity by completing a shut-in leak test prior to initiation of sample collection, as described in the SOP for Soil Gas Probe Installation and Sampling (SOP #17, Appendix A). Flow controlled soil gas samples will be collected for a 5- to 30-minute period (depending on canister size). Upon completion of sampling, a residual vacuum of 3 to 5 inches of mercury should be maintained in the Summa® canister.

Following collection of a soil gas sample for analyses of VOCs, methane and fixed gases, the soil vapor will be field screened for total organic vapors using a PID and for oxygen, carbon dioxide, and methane using a multi-gas meter. The PID and multi-gas meter will be calibrated prior to conducting measurements in accordance with the manufacturer's guidance. Data will be recorded on the Soil Gas Sampling Form (Appendix B).

Radon and radon decay product activity in soil gas will be measured using the methods documented in the SOP for Short-Term Radon Testing (SOP #15, Appendix A). Using manufacturer-supplied desiccant and tubing, a RAD7 radon detector will be connected to the well probe to collect readings. Data will be recorded on the Radon Soil Gas Monitoring Form (Appendix B).

3.19 Third-Party Data Collection

As part of the OU-3 RI/FS, third-party data will be collected for evaluation from the Bridgeton Landfill, National Oceanic and Atmospheric Administration's National Climatic Data Center's on-Site meteorological (MET) station, and from the USGS stream gage 06935965 at St. Charles, Missouri.

3.19.1 MDNR—Bridgeton Sanitary Landfill Data

Bridgeton Landfill reports temperature monitoring probe data in a Weekly Data Submittal to MDNR, which includes temperature by depth and leachate levels in the leachate collection sumps.[18]

Bridgeton Landfill reports daily flare monitoring data in a Monthly Data Submittal to MDNR, which includes average device flow in standard cubic feet per minute from flares FL-100, FL-120, and FL-140, inlet gas composition, and temperature.

Quarterly Landfill Gas Corrective Action Plan Updates reported by Bridgeton Landfill to MDNR will be evaluated for weekly gas monitoring probe data, barometric pressure, and relative pressure.

3.19.2 Precipitation Data

Precipitation data will be collected from National Oceanic and Atmospheric Administration's National Climatic Data Center's St. Louis Lambert Airport International Station (USW00013994). Daily records of precipitation showing the 24-hour amount of rain and snow are reported in inches. Monthly data sets will

[17] Near-slab/exterior soil gas sampling probes will take longer to equilibrate than sub-slab sampling probes due to the depth to which the subsurface was disturbed during installation. The longer equilibration time is also needed to allow for concrete or bentonite, used during installation, to set.

[18] Depending on the LCS, the level is recorded as height above the quarry floor in feet or depth below grade in feet.

be downloaded as ASCII text files and include the station, station name, geographic location, date, measurement, quality flag, source flag, and time of observation. The Lambert Airport Station is shown on Figure 3-9.

Precipitation data will also be collected from the on-Site MET station, which records precipitation every minute to the nearest hundredth of an inch. The MET station is shown on Figure 3-9.

3.19.3 USGS Data

Gauge height data from USGS staff gage[19] 06935965 at St. Charles, Missouri will be downloaded for evaluation. This staff gage has a surveyed elevation of 413.47 feet above mean sea level NAVD 88 and a drainage area of approximately 524,000 square miles. The gage height data will be corrected to determine the water level in feet above sea level in NAVD 88 datum by adding 413.47 feet to gauge height. The USGS staff gage is shown on Figure 3-9.

3.20 Documentation

Field books and field forms will provide the means of recording the data collection activities. All field books and field forms will be scanned to create portable document format (PDF) files for electronic archiving with the central project file. Field data recorded on field forms will not be duplicated in the field book, and vice versa. Field documentation will be submitted to the Field Team Leader and reviewed by the Project Manager. Original field forms will be stored in the project files.

3.20.1 Field Books

Field books will be used to document field observations and activities. The field notes will be clear, with sufficient detail, so that events can be reconstructed later, if necessary. Field books will document deviations from the RI/FS Work Plan and/or FSP, as well as the reason for the changes. General requirements for book entries include the following:

- One main field book will be maintained for all activities conducted by ERM at the Site.
- Field books will be bound, with consecutively numbered pages.
- Entries will be made legibly with dark, indelible ink.
- Unbiased, accurate language will be used.
- Entries will be made while activities are in progress, or as soon afterward as possible, with the date and time that the notation is made.
- General weather information will be noted at the beginning of each day (e.g., “cloudy” or “sunny”).
- A single stroke with the field staff’s initials will be used to manage unused space left on a page.
- Each consecutive day’s first entry will begin on a new, blank page.
- The date and time, based on military time, will be recorded on each page.
- When a field activity is complete, the field book will be entered into the permanent project file.
- The person recording the information will print and sign each page of the field book. If more than one individual makes entries on the same page, each recorder will print and sign the entry.

[19] The spelling gage is used specifically by USGS.

- Field book corrections will be made by drawing a single line through the original entry, initialed, and dated.

3.20.2 Field Forms

Field forms will be used when appropriate to achieve efficient and standardized recording of field measurements and observations. The type of field form and the information recorded on it may vary by activity. At a minimum, field forms will be completed for each sample to document the unique sample identifier assigned, to provide information on whether the sample is representative of a primary sample or a quality control sample (i.e. field blank, field duplicate, etc.), and to provide information regarding the sample matrix, sample date, sample location, and sampling team members. Information from the field forms will be entered into the project database, as needed. Field forms may also be used to document information such as water level gauging data, field observations and measurements, soil sample characteristics, well construction details, etc.

To the extent possible, electronic field forms (i.e., EQuIS™ Collect forms) will be used. Following submittal of each EQuIS™ Collect form to the project database, a formatted pdf report document will be generated, saved to the project SharePoint site, and included in the appropriate report. For any data that is collected using a hard copy field form, the completed form will be scanned to PDF and then maintained in a 3-ring spiral notebook at the project Site; the PDF version will be saved to the project SharePoint site and included in the appropriate report. Data from electronic and hard copy forms will be transferred to the USEPA-accessible database. Copies of hard copy field forms that may be used during the activities described in this Field Sampling Plan are attached in Appendix B.

3.20.3 Photographic Documentation

Photos may be taken over the course of field activities to augment or verify information recorded in the field book and to document general conditions at the Site. Photos will be taken with a rugged field tablet using GIS-enabled software to allow for georeferencing. All photographs will be recorded with the date, time, direction, photographer, subject, and scale, as appropriate.

4. CALIBRATION PROCEDURES

This section describes the calibration procedures and the frequency at which these procedures will be performed for field instruments. The calibration procedures listed in this section are specific to the field instruments currently proposed during completion of the OU-3 RI/FS. If calibration of any instrument or meter is not described herein, it will follow the manufacturer's specified calibration procedures.

4.1 Field Instruments

An overview of field equipment and instruments that will be used during this project is presented below. Detailed calibration procedures for field equipment are provided in the relevant SOPs in Appendix A. Calibration information, including the date and time, equipment model and serial number, and name of person performing the calibration, will be recorded on the applicable calibration forms, which are included in Appendix B, or in the field book.

1. Electric water level meter (Solinst 102, or similar)—Prior to first use, the water level probes will be calibrated. Calibration procedures are included in the SOP for Fluid Level Measurements (SOP #10, Appendix A). The water level meters will be re-calibrated on an annual basis.
2. Multi-gas meter (BW Gas Alert Microclip, or equivalent)—Routine periodic calibration along with bump tests will be conducted to verify that the monitoring equipment is operating within its acceptable calibration settings. The multi-gas meter will be inspected and calibrated according to the manufacturer's recommendations, at least once every 180 days.
3. PID (ppbRae 3000 with 10.6 eV lamp, or equivalent)—The PID will be calibrated daily prior to use with fresh air and a 100-ppm isobutylene standard. Calibration procedures are included in the SOP for Field Screening Using a PID (SOP #05, Appendix A).
4. Landfill Gas Meter (Landtec GEM™ 2000, or equivalent)—The landfill gas meter will be calibrated daily against a standard reference gas for methane, carbon dioxide and oxygen. Calibration procedures are included in the SOP for Field Screening Using a Landfill Gas Meter (SOP #06, Appendix A).
5. Geophysical tools (i.e., NMR, optical/acoustic televiewer, caliper probe, electromagnetic induction probe, fluid temperature and resistivity probe, natural gamma, spectral gamma, CDFM)—Calibration certificates for geophysical tooling will be requested from the geophysics subcontractor or equipment provider (NMR) prior to use.
6. Water quality meter (YSI ProDSS, or equivalent)—The water quality meter will be calibrated daily prior to use for dissolved oxygen, specific conductivity, pH, and oxidation-reduction potential, at a minimum. Turbidity will be checked daily, and calibrated as needed. Calibration procedures are included in the SOP for Groundwater Sampling (SOP #13, Appendix A).
7. Water pressure transducer and barometric compensation probe (Solinst Levelogger Model 3001 and Solinst Barologger Model 3001, or equivalent)—The transducer is factory calibrated. As long as the transducer is used within its specified range, it should be calibrated for the lifetime of the instrument.
8. Electronic radon detector (RAD7)—The RAD7 is factory calibrated. It is recommended to be returned to the manufacturer annually for recalibration.
9. Helium detector (Dielectric Technologies MGD-2002 Multi-Gas Detector) —The MGD-2002 is factory calibrated. It is recommended to be returned to the manufacturer annually for recalibration.

5. DECONTAMINATION PROCEDURES

Drilling tools and sampling equipment, such as bits, augers, rods, and split spoons will be decontaminated between each boring, as described in the SOP for Equipment Decontamination (SOP #18, Appendix A). Disposable equipment intended for one-time use will not be decontaminated prior to use.

Equipment will be decontaminated in a predesignated area on pallets or plastic sheeting, and clean bulky equipment will be stored on plastic sheeting in uncontaminated areas. Cleaned small equipment will be stored in aluminum foil. Materials to be stored for more than a few hours will also be covered.

Fluids generated during decontamination will be collected and stored on-Site within a temporary tank pending analytical data.

Decontamination procedures for equipment will be logged as performed in the field book.

6. INVESTIGATION DERIVED WASTE MANAGEMENT

In the process of conducting the investigation activities described in this Field Sampling Plan, the sampling team will generate different types of potentially contaminated IDW, including but not limited to:

- Used personal protective equipment (PPE);
- Disposable sampling equipment;
- Decontamination fluids;
- Soil and bedrock cuttings from drilling activities;
- Materials used during or generated by well installation, repair, and abandonment, including old tubing, old pumps, and well construction materials; and
- Purged groundwater from well development and sampling activities.

The USEPA's National Oil and Hazardous Substances Pollution Contingency Plan requires that management of IDW generated during sampling comply with all applicable or relevant and appropriate requirements to the extent practicable. The sampling plan will follow the Office of Emergency and Remedial Response Directive 9345.3-02 (May 1991), which provides the guidance for the management of IDW. In addition, other legal and practical considerations that may affect the handling of IDW will be considered.

- Used PPE and disposable equipment will be double bagged and placed in a municipal refuse dumpster. These wastes are not considered hazardous and can be sent to a municipal landfill. Any PPE and disposable equipment that is to be disposed of, which can be reused, will be rendered inoperable before disposal in the refuse dumpster. Any PPE generated within OU-1 will be managed according to the OU-1 Radiation Safety Plan (Ameriphysics 2020).
- Decontamination fluids that will be generated in the sampling event will consist of distilled water containing potential residual constituents of concerns and water with non-phosphate detergent. Water-based decontamination fluid will be containerized and stored on Site within a temporary tank pending characterization for proper disposal. Any decontamination fluids generated within OU-1 will be managed per the OU-1 Site protocols and in accordance with the OU-1 Radiological Safety Plan (Ameriphysics 2020).
- Drill cuttings generated during the subsurface sampling will be containerized, pending waste characterization and profiling, for proper disposal.
- Purged groundwater will be containerized and stored on Site within a temporary tank pending waste characterization and profiling. It is anticipated that the proposed analytical suite will be sufficient for waste characterization purposes. Any purged groundwater generated within OU-1 will be managed per the OU-1 Site protocols and in accordance with the OU-1 Radiological Safety Plan (Ameriphysics 2020).

All off-Site shipments will be managed as required by the ASAOC and will comply with USEPA’s Guide to Management of Investigation Derived Waste 9345.3-03FS (January 1992).

7. DATA MANAGEMENT AND EVALUATION

The RI/FS will generate and compile an extensive amount of information that will require proper management to support both the risk assessment and the remedy selection decisions. Procedures will be followed to facilitate the quality, validity, and security of the data. Additional details are included in the QAPP. Data will also be evaluated and compiled into text, tables, figures, and 3-D visualizations to help evaluate and identify any remaining data gaps.

7.1 Data Management

ERM uses a variety of commercially available data management software packages to handle environmental project requirements. ERM utilizes EQuIS™ as the primary environmental data and decision support system. The data is hosted by EarthSoft on a fully managed Microsoft Azure Cloud Services SQL database that is secure and has built in backups and redundancies to prevent the potential for data loss.

7.1.1 Project Database

The EQuIS™ relational project database is the main data lake that feeds data pertaining to environmental chemistry, biology, geology, geotechnical, hydrology, limnology, air, and associated compliance monitoring activities to other data analytics and visualization software such as ArcGIS, EVS, Power BI, and R Markdown, etc.

In general, the OU-3 database will include well construction details, well development data, survey information, geochemical data, field data, analytical results and field parameters, fluid levels, laboratory qualifiers, additional qualifiers, and other summary information relevant to the investigation.

ERM will submit deliverables to USEPA in the requested format after appropriate data quality checks have been performed, and the final report is ready for submittal.

7.1.2 Spatial Data

Data will be submitted to the USEPA in an appropriate electronic data deliverable format. Spatial data will be submitted in the ESRI File Geodatabase format and as un-projected geographic coordinates in decimal degree format using North American Datum 1983. Spatial data will be accompanied by metadata, which will be compliant with the Federal Geographic Data Committee, Content Standard for Digital Geospatial Metadata and its USEPA profile, the USEPA Geospatial Metadata Technical Specification.

An add-on metadata editor for ESRI software, the USEPA Metadata Editor, will be used, as needed. Each file will include an attribute name for each Site unit or sub-unit. Spatial data that will be submitted does not, and is not, intended to define the boundaries of the Site.

8. FIELD EVENTS SCHEDULE

A detailed OU-3 RI/FS schedule is included as Figure 8-1. It is anticipated that the schedule will be updated monthly during the project.

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TABLES

Table 2-1a: Sampling Plan and QA Samples for Groundwater Analyses
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Category	Analytical Group	Analytical Method	Matrix	Number of Samples[1]	Number of Duplicates[2]	Number of Equipment Blanks[3]	Number of Filter Blanks[3]	Number of Field Blanks[3]	Number of Trip Blanks[3]	Number of MS/MSDs[4]	Total Number of Samples
Total Metals	Total Metals	USEPA 6010B	WG	1369	138	69	0	69	0	69	1714
	Total Metals	USEPA 6020	WG	1369	138	69	0	69	0	69	1714
	Total Mercury	USEPA 7470A	WG	1369	138	69	0	69	0	69	1714
	Chromium (III)	Calculation	WG	1369	138	69	0	69	0	69	1714
	Chromium (VI)	USEPA 7199	WG	1369	138	69	8	69	0	69	1722
Dissolved Metals	Dissolved Metals	USEPA 6020	WG	1369	138	0	8	0	0	69	1584
	Dissolved Metals	USEPA 6010B	WG	1369	138	0	8	0	0	69	1584
	Dissolved Mercury	USEPA 7470A	WG	1369	138	0	8	0	0	69	1584
Semi-Volatile Organic Compounds	Semi-Volatile Organic Compounds	USEPA 8270C	WG	1369	138	69	0	69	0	69	1714
	Semi-Volatile Organic Compounds	USEPA 8270C SIM*	WG	1369	138	69	0	69	0	69	1714
Volatile Organic Compounds	Volatile Organic Compounds	USEPA 8260C Low Level	WG	1369	138	69	0	69	69	69	1783
	Volatile Organic Compounds	USEPA 8011	WG	1369	138	69	0	69	69	69	1783
PCBs	Polychlorinated Biphenyls (PCBs)	USEPA 8082A	WG	1369	138	69	0	69	0	69	1714
Hydrocarbons	C6 Aliphatics	TX 1006	WG	1369	138	69	0	69	69	69	1783
	C6-C8 Aliphatics	TX 1006	WG	1369	138	69	0	69	69	69	1783
	C8-C10 Aliphatics	TX 1006	WG	1369	138	69	0	69	69	69	1783
	C10-C12 Aliphatics	TX 1006	WG	1369	138	69	0	69	69	69	1783
	C12-C16 Aliphatics	TX 1006	WG	1369	138	69	0	69	69	69	1783
	C16-C21 Aliphatics	TX 1006	WG	1369	138	69	0	69	69	69	1783
	C21-C35 Aliphatics	TX 1006	WG	1369	138	69	0	69	69	69	1783
	C7-C8 Aromatics	TX 1006	WG	1369	138	69	0	69	69	69	1783
	C8-C10 Aromatics	TX 1006	WG	1369	138	69	0	69	69	69	1783
	C10-C12 Aromatics	TX 1006	WG	1369	138	69	0	69	69	69	1783
	C12-C16 Aromatics	TX 1006	WG	1369	138	69	0	69	69	69	1783
	C16-C21 Aromatics	TX 1006	WG	1369	138	69	0	69	69	69	1783
	C21-C35 Aromatics	TX 1006	WG	1369	138	69	0	69	69	69	1783
	TPH C6-C12	TX 1005	WG	1369	138	69	0	69	69	69	1783
	TPH C12-C28	TX 1005	WG	1369	138	69	0	69	69	69	1783
	TPH C28-C35	TX 1005	WG	1369	138	69	0	69	69	69	1783
	TPH C6-C35	TX 1005	WG	1369	138	69	0	69	69	69	1783
Chlorinated Herbicides	Chlorinated Herbicides	USEPA 8151A	WG	1369	138	69	0	69	0	69	1714
Radiological Chemistry	Total Isotopic Thorium (Th-228, Th-230, Th-232)	HASL-300 Method U-02	WG	1369	138	69	0	69	0	69	1714
	Dissolved Isotopic Thorium (Th-228, Th-230, Th-232)	HASL-300 Method U-02	WG	1369	138	0	8	0	0	69	1584
	Total Isotopic Uranium (U-234, U-235, U-238)	HASL-300 Method U-02	WG	1369	138	69	0	69	0	69	1714
	Dissolved Isotopic Uranium (U-234, U-235, U-238)	HASL-300 Method U-02	WG	1369	138	0	8	0	0	69	1584
	Total Isotopic Radium-226	USEPA 903.1	WG	1369	138	69	0	69	0	69	1714
	Total Isotopic Radium-228	USEPA 904.0	WG	1369	138	69	0	69	0	69	1714
	Dissolved Isotopic Radium-226	USEPA 903.1	WG	1369	138	0	8	0	0	69	1584
	Dissolved Isotopic Radium-228	USEPA 904.0	WG	1369	138	0	8	0	0	69	1584
	Tritium	USEPA 906.0	WG	1369	138	69	0	69	0	69	1714

Table 2-1a: Sampling Plan and QA Samples for Groundwater Analyses
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Category	Analytical Group	Analytical Method	Matrix	Number of Samples[1]	Number of Duplicates[2]	Number of Equipment Blanks[3]	Number of Filter Blanks[3]	Number of Field Blanks[3]	Number of Trip Blanks[3]	Number of MS/MSDs[4]	Total Number of Samples
Dissolved Gases	Methane	USEPA RSK-175	WG	1369	138	69	0	69	0	0	1645
	Carbon Dioxide	USEPA RSK-175	WG	1369	138	69	0	69	0	0	1645
Geochemistry	Alkalinity	SM 2320B	WG	1369	138	69	0	0	0	0	1576
	Bicarbonate	SM 2320B	WG	1369	138	69	0	0	0	0	1576
	Bromide	USEPA 9056A	WG	1369	138	69	0	0	0	69	1645
	Carbonate (HC03-)	SM 2320B	WG	1369	138	69	0	0	0	0	1576
	Cations + Anions[5]	Calculation	WG	1369	138	69	0	0	0	0	1576
	Chemical Oxygen Demand	USEPA 410.4 Rev 2	WG	1369	138	69	0	0	0	69	1645
	Chloride Fluoride Sulfate	USEPA 9056A	WG	1369	138	69	0	0	0	69	1645
	Cyanide	USEPA 9012A	WG	1369	138	69	0	0	0	69	1645
	Dissolved Organic Carbon	SM 5310C	WG	1369	138	0	8	0	0	69	1584
	Nitrogen, Ammonia	SM 4500-NH_3 G USEPA 350.1	WG	1369	138	69	0	0	0	69	1645
	Nitrogen, Nitrate	USEPA 9056A	WG	1369	138	69	0	0	0	69	1645
	Nitrogen, Nitrate + Nitrite	USEPA 353.2 Rev 2	WG	1369	138	69	0	0	0	69	1645
	Nitrogen, Nitrite	USEPA 9056A	WG	1369	138	69	0	0	0	69	1645
	Iodide	USEPA 9056A	WG	1369	138	69	0	0	0	69	1645
	pH	SM 4500H+B	WG	1369	138	69	0	0	0	0	1576
	Phosphorous	USEPA 365.1	WG	1369	138	69	0	0	0	69	1645
	Sulfide	SM 4500-S^2-D	WG	1369	138	69	0	0	0	0	1576
	Total Dissolved Solids	SM 2540C	WG	1369	138	69	0	0	0	0	1576
	Total Hardness	USEPA 6010B/2340B Calculation	WG	1369	138	69	0	0	0	0	1576
	Total Organic Carbon	SM 5310C	WG	1369	138	69	0	0	0	69	1645
	Total Suspended Solids	SM 2540D	WG	1369	138	69	0	0	0	0	1576

Notes:

* - SVOC-SIM will be used to analyze PAHs.

1: Counts represent a minimum number of planned samples. Assumes: Initial sampling of each newly completed well (81 total), and 8 quarters of sampling all 161 wells (80 existing plus 81 new wells). Additional step-out and background wells will be installed as needed based on characterization study.

2: One duplicate per 10 samples. The number was rounded to account for the separate sampling events.

3: Field blanks and equipment blanks collected at a minimum rate of one per 20 samples. Filter blanks will be collected at a minimum rate of one per manufacturer lot, at the beginning of each sampling event. Trip Blanks will accompany each cooler containing groundwater samples for VOCs and TPH.

4: Considers an MS and MSD as one sample on methods where the laboratory completes MS/MSDs in accordance with the SOPs.

5: Cations and Anions analytes are noted in QAPP Table 3-1a.

Abbreviations:

MS/MSD: Matrix Spike/Matrix Spike Duplicate

PCBs: Polychlorinated biphenyl

SIM: Selective Ion Monitoring

SM: Standard Methods for the Examination of Water and Wastewater

SOP: Standard Operating Procedure

TPH: Total Petroleum Hydrocarbons

USEPA: United States Environmental Protection Agency

WG: Groundwater Matrix

Table 2-1b: Sampling Plan and QA Samples for Leachate Analyses
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Category	Analytical Group	Analytical Method	Matrix	Number of Samples[1]	Number of Duplicates[2]	Number of Equipment Blanks[3]	Number of Filter Blanks[3]	Number of Field Blanks[3]	Number of Trip Blanks[3]	Number of MS/MSDS[4]	Total Number of Samples
Total Metals	Total Metals	USEPA 6010B	WL	64	8	0	0	8	0	8	88
	Total Metals	USEPA 6020	WL	64	8	0	0	8	0	8	88
	Total Mercury	USEPA 7470A	WL	64	8	0	0	8	0	8	88
	Chromium (III)	Calculation	WL	64	8	0	0	8	0	8	88
	Chromium (VI)	USEPA 7196A	WL	64	8	0	8	8	0	8	96
Dissolved Metals	Dissolved Metals	USEPA 6020	WL	64	8	0	8	0	0	8	88
	Dissolved Metals	USEPA 6010B	WL	64	8	0	8	0	0	8	88
	Dissolved Mercury	USEPA 7470A	WL	64	8	0	8	0	0	8	88
Semi-Volatile Organic Compounds	Semi-Volatile Organic Compounds	USEPA 8270C	WL	64	8	0	0	8	0	8	88
	Semi-Volatile Organic Compounds	USEPA 8270C SIM*	WL	64	8	0	0	8	0	8	88
Volatile Organic Compounds	Volatile Organic Compounds	USEPA 8260C Low Level	WL	64	8	0	0	8	8	8	96
	Volatile Organic Compounds	USEPA 8011	WL	64	8	0	0	8	8	8	96
PCBs	Polychlorinated Biphenyls (PCBs)	USEPA 8082A	WL	64	8	0	0	8	0	8	88
Hydrocarbons	C6 Aliphatics	TX 1006	WL	64	8	0	0	8	8	8	96
	C6-C8 Aliphatics	TX 1006	WL	64	8	0	0	8	8	8	96
	C8-C10 Aliphatics	TX 1006	WL	64	8	0	0	8	8	8	96
	C10-C12 Aliphatics	TX 1006	WL	64	8	0	0	8	8	8	96
	C12-C16 Aliphatics	TX 1006	WL	64	8	0	0	8	8	8	96
	C16-C21 Aliphatics	TX 1006	WL	64	8	0	0	8	8	8	96
	C21-C35 Aliphatics	TX 1006	WL	64	8	0	0	8	8	8	96
	C7-C8 Aromatics	TX 1006	WL	64	8	0	0	8	8	8	96
	C8-C10 Aromatics	TX 1006	WL	64	8	0	0	8	8	8	96
	C10-C12 Aromatics	TX 1006	WL	64	8	0	0	8	8	8	96
	C12-C16 Aromatics	TX 1006	WL	64	8	0	0	8	8	8	96
	C16-C21 Aromatics	TX 1006	WL	64	8	0	0	8	8	8	96
	C21-C35 Aromatics	TX 1006	WL	64	8	0	0	8	8	8	96
	TPH C6-C35	TX 1006	WL	64	8	0	0	8	8	8	96
	TPH C6-C12	TX 1005	WL	64	8	0	0	8	8	8	96
	TPH C12-C28	TX 1005	WL	64	8	0	0	8	8	8	96
	TPH C28-C35	TX 1005	WL	64	8	0	0	8	8	8	96
	TPH C6-C35	TX 1005	WL	64	8	0	0	8	8	8	96
Chlorinated Herbicides	Chlorinated Herbicides	USEPA 8151	WL	64	8	0	0	8	0	8	88
Radiological Chemistry	Total Isotopic Thorium (Th-228, Th-230, Th-232)	HASL-300 Method U-02	WL	64	8	0	0	8	0	8	88
	Dissolved Isotopic Thorium (Th-228, Th-230, Th-232)	HASL-300 Method U-02	WL	64	8	0	8	0	0	8	88
	Total Isotopic Uranium (U-234, U-235, U-238)	HASL-300 Method U-02	WL	64	8	0	0	8	0	8	88
	Dissolved Isotopic Uranium (U-234, U-235, U-238)	HASL-300 Method U-02	WL	64	8	0	8	0	0	8	88
	Radium-226	USEPA 903.1	WL	64	8	0	0	8	0	8	88
	Radium-228	USEPA 904.0	WL	64	8	0	0	8	0	8	88
	Dissolved Isotopic Radium-226	USEPA 903.1	WL	64	8	0	8	0	0	8	88
	Dissolved Isotopic Radium-228	USEPA 904.0	WL	64	8	0	8	0	0	8	72
	Tritium	USEPA 906.0	WL	64	8	0	0	8	0	8	88

Table 2-1b: Sampling Plan and QA Samples for Leachate Analyses
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Category	Analytical Group	Analytical Method	Matrix	Number of Samples[1]	Number of Duplicates[2]	Number of Equipment Blanks[3]	Number of Filter Blanks[3]	Number of Field Blanks[3]	Number of Trip Blanks[3]	Number of MS/MSDS[4]	Total Number of Samples
Dissolved Gases	Methane	USEPA RSK-175	WL	64	8	0	0	8	0	0	80
	Carbon Dioxide	USEPA RSK-175	WL	64	8	0	0	8	0	0	80
Geochemistry	Alkalinity	SM 2320B	WL	64	8	0	0	0	0	0	72
	Bromide	USEPA 9056A	WL	64	8	0	0	0	0	8	80
	Carbonate	USEPA 2320B	WL	64	8	0	0	0	0	0	72
	Cations + Anions[5]	Calculation	WL	64	8	0	0	0	0	0	72
	Chemical Oxygen Demand	USEPA 410.4 Rev 2	WL	64	8	0	0	0	0	8	80
	Chloride Fluoride Sulfate	USEPA 9056A	WL	64	8	0	0	0	0	8	80
	Cyanide	USEPA 9012A	WL	64	8	0	0	0	0	8	80
	Dissolved Organic Carbon	SM 5310C	WL	64	8	0	8	0	0	8	88
	Iodide	USEPA 9056A	WL	64	8	0	0	0	0	8	80
	Nitrogen, Ammonia	SM 4500-NH_3 G USEPA 350.1	WL	64	8	0	0	0	0	8	80
	Nitrogen, Nitrate	USEPA 9056A	WL	64	8	0	0	0	0	8	80
	Nitrogen, Nitrate + Nitrite	USEPA 353.2 Rev 2	WL	64	8	0	0	0	0	8	80
	Nitrogen, Nitrite	USEPA 9056A	WL	64	8	0	0	0	0	8	80
	pH	SM 4500H+B	WL	64	8	0	0	0	0	0	72
	Phosphate	USEPA 365.1	WL	64	8	0	0	0	0	8	80
	Sulfide	SM 4500-S^2-D	WL	64	8	0	0	0	0	0	72
	Total Dissolved Solids	SM 2540C	WL	64	8	0	0	0	0	0	72
	Total Hardness	USEPA 6010BCalc	WL	64	8	0	0	0	0	0	72
	Total Organic Carbon	SM 5310C	WL	64	8	0	0	0	0	8	80
	Total Suspended Solids	SM 2540D	WL	64	8	0	0	0	0	0	72

Notes:
* - SVOC-SIM will be used to analyze PAHs.
1: Assumes a maximum number of 8 leachate collection sumps sampled for 8 events = 64 samples.
2: One duplicate per sampling event (8 events).
3: Field blanks will be collected one per sampling event (8 events). Filter blanks will be collected at a minimum rate of one per manufacturer lot, at the beginning of each sampling event. No equipment blanks will be collected for leachate samples.
4: Considers an MS and MSD as one sample on methods where the laboratory completes MS/MSDs in accordance with the SOPs.
5: Cations and Anions analytes are noted in QAPP Table 3-1a.
Abbreviations:
MS/MSD: Matrix Spike/Matrix Spike Duplicate
PCBs: Polychlorinated biphenyl
SIM: Selective Ion Monitoring
SM: Standard Methods for the Examination of Water and Wastewater
SOP: Standard Operating Procedure
TPH: Total Petroleum Hydrocarbons
USEPA: United States Environmental Protection Agency
WL: Leachate Water Matrix

Table 2-1c: Sampling Plan and QA Samples for Alluvial Aquifer Matrix Analyses
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Category	Analytical Group	Analytical Method	Matrix	Number of Samples[1]	Number of Duplicates[2]	Number of Equipment Blanks[3]	Number of Field Blanks[3]	Number of Trip Blanks[3]	Number of MS/MSDs[4]	Total Number of Samples
Total Metals	Total Metals	USEPA 6010B	SO	40	0	2	0	0	2	44
	Total Metals	USEPA 6020	SO	40	0	2	0	0	2	44
Radiological Chemistry	Isotopic Uranium (U-234, U-235, U-238)	HASL-300 Method U-02	SO	40	0	2	0	0	2	44
	Isotopic Thorium (Th-228,Th-230, Th-232)	HASL-300 Method U-02	SO	40	0	2	0	0	2	44
	Radium-226	USEPA 901.1M	SO	40	0	2	0	0	2	44
	Radium-228	USEPA 901.1M	SO	40	0	2	0	0	2	44
Mineralogical	Cation Exchange Capacity	USEPA 9081	SO	40	0	2	0	0	0	42
Geochemistry	pH	USEPA 9045C	SO	40	0	2	0	0	0	42
	Total Organic Carbon	Walkley-Black Procedure	SO	40	0	2	0	0	2	44
	Total Alkalinity (carbonate and bicarb)	SM 2320B	SO	40	0	2	0	0	0	42
	Bromide, Iodide, Fluoride, Chloride, and Sulfate	USEPA 9056A	SO	40	0	2	0	0	2	44
Geotechnical	Moisture Content and Density	ASTM D7263	SO	40	0	2	0	0	0	42

Notes:

1: Counts represent a minimum number of planned samples. Assumes: 20 samples per boring (4 locations) during well boring installation. Additional step-out and background wells will be installed as needed based on charactericzation study..

2: Field duplicates are not planned for alluvium samples.

3: Equipment blanks collected at a rate of one per day of sampling per sampling crew or at a rate of one per 20 samples, whichever is larger. No Trip and Field Blanks proposed for alluvium samples.

4: Considers an MS and MSD as one sample on methods where the laboratory completes MS/MSDs in accordance with the SOPs.

Abbreviations:

ASTM: American Society for Testing and Materials

HASL: Health and Safety Laboratory

M: Modified

MS/MSD: Matrix Spike/Matrix Spike Duplicate

SO: Solid Matrix

SM: Standard Methods for the Examination of Water and Wastewater

USEPA: United States Environmental Protection Agency

Table 2-1d: Sampling Plan and QA Samples for Bedrock Aquifer Matrix Analyses
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Category	Analytical Group	Analytical Method	Matrix	Number of Samples[1]	Number of Duplicates[2]	Number of Equipment Blanks[3]	Number of Field Blanks[3]	Number of Trip Blanks[3]	Number of MS/MSDs[4]	Total Number of Samples
Total Metals	Total Metals	USEPA 6010B	SO	50	0	3	0	0	3	56
	Total Metals	USEPA 6020	SO	50	0	3	0	0	3	56
Radiological Chemistry	Isotopic Uranium (U-234, U-235, U-238)	HASL-300 Method U-02	SO	50	0	3	0	0	3	56
	Isotopic Thorium (Th-228,Th-230, Th-232)	HASL-300 Method U-02	SO	50	0	3	0	0	3	56
	Radium-226	USEPA 901.1 M	SO	50	0	3	0	0	3	56
	Radium-228	USEPA 901.1 M	SO	50	0	3	0	0	3	56
Mineralogical	Cation Exchange Capacity	USEPA 9081	SO	50	0	3	0	0	0	53
Geochemistry	pH	USEPA 9045C	SO	50	0	3	0	0	0	53
	Total Organic Carbon	Walkley-Black Procedure	SO	50	0	3	0	0	3	56
	Total Alkalinity (carbonate and bicarb)	SM 2320B	SO	50	0	3	0	0	0	53
	Bromide, Iodide, Fluoride, Chloride, and Sulfate	USEPA 9056A	SO	50	0	3	0	0	3	56

Notes:

1: Counts represent a minimum number of planned samples. 10 samples during well boring installation at well MW-604 for the full analysis suite. Sampling at step-out and background wells to be determined.

2: Field duplicates are not planned for bedrock samples.

3: Equipment blanks collected at a rate of one per day of sampling per sampling crew or at a rate of one per 20 samples, whichever is larger. No Trip or Field Blanks proposed for bedrock samples.

4: Considers an MS and MSD as one sample on methods where the laboratory completes MS/MSDs in accordance with the SOPs. MS/MSDs will be performed as sample volume allows.

Abbreviations:

HASL: Health and Safety Laboratory
MCL: Materials and Chemistry Laboratory, Inc.
MS/MSD: Matrix Spike/Matrix Spike Duplicate
SO: Soild Matrix
SM: Standard Methods for the Examination of Water and Wastewater
SOP: Standard Operating Procedure
USEPA: United States Environmental Protection Agency
XRD: X-Ray Diffraction

Table 2-1e: Sampling Plan and QA Samples for Vapor Analyses
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Category	Analytical Group	Analytical Method	Matrix	Number of Indoor Air Samples[3]	Number of Duplicate Indoor Air Samples[4]	Number of Ambient Outdoor Air Samples[5]	Number of Soil Gas Samples (Sub-slab or Near-slab)[6]	Number of Duplicate Soil Gas Samples[4]	Total Number of Samples
Volatiles	Volatile Organic Compounds	TO-15[1]/TO-15 MOD[2]/ TO-15-SIM[1]	AI, AO, GB/GS	28	4	16	24	4	76
Methane	Methane	Method TO-3 Modified	AI, AO, GB/GS	28	4	16	24	4	76
Radon[7]	Long-Term Radon	USEPA 402-R-92-004	AI, AO	6	1	4	NS	NS	11
Fixed Gases[8]	Oxygen, Cabron Dioxide	Method 3C Modified	GB/GS	NS	NS	NS	24	4	28

Notes:

1: The full TO-15 analyte list will be run for each sample. TO-15 SIM will be run with TO-15 for indoor air samples to achieve the lowest reporting limits. Only analytes not included in the TO-15 SIM target analyte list will be reported from TO-15 full scan when both methods are run.

2: TO-15 Modified will be used for samples that also require methods 3c Modified and TO-3 Modified.

3: Up to 6 indoor air samples collected from four buildings. Estimate may be updated based on building layout observed during Building Survey.

4: Duplicate samples collected at a rate of one per 10 samples or 1 per event per sample type, whichever is greater.

5: A total of 4 ambient air sample will be collected, one upwind of each buliding, per event.

6: Sub-slab soil gas samples will be collected under the four buildings if possible. If sub-slab samples are not accessible then near-slab soil gas or other sampling will be completed.

7: Long-term radon samples are planned for only the first of the four quarterly vapor sampling events.

8: Fixed gases (oxygen, carbon dioxide) will be analyzed by the laboratory for soil gas samples only.

Samples for methane and short-term radon (and decay products) will also be collected using handheld meters set to collect continous measurements during one or more of the sampling events.

Abbreviation:

AI: Indoor Air Matrix

AO: Outdoor Air Matrix

GB: Sub-Slab Soil Gas

GS: Soil Gas (near slab or exterior soil gas)

SIM: Selective Ion Monitoring

USEPA: United States Environmental Protection Agency

NS: No samples collected for this category

Table 2-1f: Sampling Plan and QA Samples for Groundwater Screening Analyses
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Analytical Group	Analytical Method	Matrix	Number of Samples[1]	Number of Duplicates[2]	Number of Equipment Blanks[3]	Number of Field Blanks[3]	Number of Trip Blanks[3]	Number of MS/MSDs[4]	Total Number of Samples
Volatile Organic Compounds	USEPA 8260C Low Level	WG	330	0	18	0	100	17	465
Dissolved Metals (Ba, Ca, Fe, Mg, Mn)	USEPA 6010B	WG	330	0	18	0	0	17	365
Alkalinity Bicarbonate Carbonate (HCO3-)	SM 2320B	WG	330	0	18	0	0	17	365
Nitrogen, Nitrate Chloride Sulfate	USEPA 9056A	WG	330	0	18	0	0	17	365

Notes:

1: Assumes: 10 WaterlooAPS samples and 5 alluvium discrete grab samples while drilling per location (18 locations) and 5 bedrock discrete-depth samples per location while pumping (12 locations).

2: No field duplicates will be taken for screening samples.

3: Equipment blanks collected at a rate of one per boring location. Trip Blanks will accompany each cooler containing a sample for VOCs (number based on estimated sampling days). No Field Blanks are proposed for screening samples.

4: Considers an MS and MSD as one sample on methods where the laboratory completes MS/MSDs in accordance with the SOPs.

Abbreviations:

MS/MSD: Matrix Spike/Matrix Spike Duplicate

SM: Standard Methods for the Examination of Water and Wastewater

USEPA: United States Environmental Protection Agency

WG: Groundwater Matrix

Table 2-2a: Analytes, Holding Time and Preservation Requirements for Groundwater/Leachate
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Category	Analytical Group	Analytical Method	Containers (number, size, and type)	Preservation Requirements (chemical, temperature, light protected)	Maximum Holding Time (preparation / analysis)	Laboratory
Total Metals	Total Metals	USEPA 6010B	250mL in plastic container	Nitric Acid to pH <2* Ambient or Cool to ≤6°C	Must be analyzed within 6 months of the collection date.	Pace - I
	Total Metals	USEPA 6020	250mL in plastic container	Nitric Acid to pH <2* Ambient or Cool to ≤6°C	Must be analyzed within 6 months of the collection date.	Pace - I
	Total Mercury	USEPA 7470A	250mL in plastic container	Nitric Acid to pH <2* Ambient or Cool to ≤6°C	Analysis must be completed within 28 days of collection date.	Pace - I
	Chromium (III)	Calculation	NA	NA	NA	Pace - I
	Chromium (VI)	USEPA 7199	50mL plastic vial with plungable filter.	Ammonium sulfate/Ammonium hydroxide Cool to ≤6°C	Method holding time of 24 hours extended to 28 days of collection date with field filtering and preservation	Pace - N
Dissolved Metals	Dissolved Metals	USEPA 6020	250mL in plastic container	Field Filtration Nitric Acid to pH <2* Ambient or Cool to ≤6°C	Must be analyzed within 6 months of the collection date.	Pace - I
	Dissolved Metals	USEPA 6010B	250mL in plastic container	Field Filtration Nitric Acid to pH <2* Ambient or Cool to ≤6°C	Must be analyzed within 6 months of the collection date.	Pace - I
	Dissolved Mercury	USEPA 7470A	250mL in plastic container	Field Filtration Nitric Acid to pH <2* Ambient or Cool to ≤6°C	Analysis must be completed within 28 days of collection date.	Pace - I
Semi-Volatile Organic Compounds	Semi-Volatile Organic Compounds	USEPA 8270C	2x100mL amber glass container with Teflon-lined lid, preferably wide mouth. Additional sample is required if MS/MSD is required.	Cool to ≤6°C	Sample must be extracted within 7 days of collection date and extract must be analyzed within 40 days of extraction date.	Pace - I
	Semi-Volatile Organic Compounds	USEPA 8270C SIM	2x100mL amber glass container with Teflon-lined lid, preferably wide mouth. Additional sample is required if MS/MSD is required.	Cool to ≤6°C	Sample must be extracted within 7 days of collection date and extract must be analyzed within 40 days of extraction date.	Pace - I
Volatile Organic Compounds	Volatile Organic Compounds	USEPA 8260C Low Level	Minimum 3 VOA vials. Additional sample is required if MS/MSD is required.	Acidified w/ 1:1 Hydrochloric Acid to pH<2 No headspace Cool to ≤6°C	pH>2: Analysis must be completed within 7 days of collection date. pH <2: Analysis must be completed within 14 days of collection date. (pH determined post analysis)	Pace - I
	Volatile Organic Compounds	USEPA 8011	Minimum 3 VOA amber vials. Additional sample is required if MS/MSD is required.	Preserved w/ sodium thiosulfate No headspace Cool to ≤6°C	Analysis must be completed within 14 days of collection date.	Pace - I

Table 2-2a: Analytes, Holding Time and Preservation Requirements for Groundwater/Leachate
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Category	Analytical Group	Analytical Method	Containers (number, size, and type)	Preservation Requirements (chemical, temperature, light protected)	Maximum Holding Time (preparation / analysis)	Laboratory
PCBs	Polychlorinated Biphenyls (PCBs)	USEPA 8082A	2x100mL wide mouth amber glass bottle. Additional sample is required if MS/MSD is required.	Cool to ≤6°C	Extract within 6 months of collection and analyze within 40 days of extraction	Pace - I
Chlorinated Herbicides	Chlorinated Herbicides	USEPA 8151A	2x1000mL amber glass container with Teflon-lined lid, preferably wide mouth. Additional sample is required if MS/MSD is required.	Cool to ≤6°C	Sample must be extracted within 7 days of collection date and extract must be analyzed within 40 days of extraction date.	Pace - I
Hydrocarbons	TPH - Aliphatic and Aromatic	TX 1006	2x40 ml HCL vials	No headspace Cool to ≤6°C	Analysis must be completed within 7 days.	Pace - N
	Total TPH	TX 1005	2x40 ml HCL vials	No headspace Cool to ≤6°C	Analysis must be completed within 7 days.	Pace - N
Dissolved Gases	Methane	USEPA RSK-175	2x40mL vials	No headspace Cool to ≤6°C	Analysis must be completed in 14 days.	Pace - B
	Carbon Dioxide	USEPA RSK-175	2x40mL vials	No headspace Cool to ≤6°C	Analysis must be completed in 14 days.	Pace - B
Total Radiological Chemistry	Isotopic Thorium (Th-228, Th-230, Th-232)	HASL-300 Method U-02	1L plastic or glass container	Nitric acid pH<2	Sample must be analyzed within 180 days	Pace - P
	Isotopic Uranium (U-234, U-235, U-238)	HASL-300 Method U-02	1L plastic or glass container	Nitric acid pH<2	Sample must be analyzed within 180 days	Pace - P
	Isotopic Radium-226	USEPA 903.1	1L plastic or glass container	Nitric acid pH<2	Sample must be analyzed within 180 days	Pace - P
	Isotopic Radium-228	USEPA 904.0	1L plastic or glass container	Nitric acid pH<2	Sample must be analyzed within 180 days	Pace - P
	Tritium	USEPA 906.0	500mL amber glass	Cool to ≤6°C	Sample must be analyzed within 180 days	Pace - P

Table 2-2a: Analytes, Holding Time and Preservation Requirements for Groundwater/Leachate
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Category	Analytical Group	Analytical Method	Containers (number, size, and type)	Preservation Requirements (chemical, temperature, light protected)	Maximum Holding Time (preparation / analysis)	Laboratory
Dissolved Radiological Chemistry	Dissolved Isotopic Thorium (Th-228, Th-230, Th-232)	HASL-300 Method U-02	1L plastic or glass container	Field Filtration Nitric acid pH<2	Sample must be analyzed within 180 days	Pace - P
	Dissolved Isotopic Uranium (U-234, U-235, U-238)	HASL-300 Method U-02	1L plastic or glass container	Field Filtration Nitric acid pH<2	Sample must be analyzed within 180 days	Pace - P
	Dissolved Isotopic Radium-226	USEPA 903.1	1L plastic or glass container	Field Filtration Nitric acid pH<2	Sample must be analyzed within 180 days	Pace - P
	Dissolved Isotopic Radium-228	USEPA 904.0	1L plastic or glass container	Field Filtration Nitric acid pH<2	Sample must be analyzed within 180 days	Pace - P
Geochemistry	Alkalinity	SM 2320B	250mL minimum in plastic container	Cool to ≤6°C	Sample must be analyzed within 14 days of collection date.	Pace - I
	Bromide	USEPA 9056A	250mL minimum in plastic container	Cool to ≤6°C	Sample must be analyzed within 28 days of collection date.	Pace - I
	Carbonate	SM 2320B	250mL minimum in plastic container	Cool to ≤6°C	Sample must be analyzed within 14 days of collection date.	Pace - I
	Chemical Oxygen Demand	USEPA 410.4 Rev 2	One 250mL plastic or glass container	Sulfuric Acid to pH <2 Cool to ≤6°C	Sample must be analyzed within 28 days of collection date.	Pace - I
	Chloride, Fluoride, Sulfate, Iodide	USEPA 9056A	250mL in plastic container	Cool to ≤6°C	Analysis must be completed within 28 days of collection date.	Pace - I
	Cyanide	USEPA 9012A	250mL in plastic container	Preserved w/ sodium hydroxide to pH>10 Cool to ≤6°C	Sample must be analyzed within 14 days of collection date.	Pace - I
	Dissolved Organic Carbon	SM 5310C	250mL amber glass bottle	Field Filtration, Sulfuric Acid to pH <2 Cool to ≤6°C	Sample must be analyzed within 28 days of collection date.	Pace - I
	Nitrogen, Ammonia	SM 4500-NH_3 G/USEPA 350.1	250mL in plastic or glass container	Sulfuric Acid to pH <2 Cool to ≤6°C	Sample must be analyzed within 28 days of collection date.	Pace - I
	Nitrogen, Nitrate	USEPA 9056A	250mL in plastic container	Cool to ≤6°C	For unpreserved samples, analysis must be completed within 48 hours of collection.	Pace - I
	Nitrogen, Nitrate + Nitrite	USEPA 353.2 Rev 2	250mL in plastic container	For combined nitrate/nitrite analysis Sulfuric Acid to pH <2	For preserved samples, analysis must be completed within 28 days of collection date.	Pace - I

Table 2-2a: Analytes, Holding Time and Preservation Requirements for Groundwater/Leachate
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Category	Analytical Group	Analytical Method	Containers (number, size, and type)	Preservation Requirements (chemical, temperature, light protected)	Maximum Holding Time (preparation / analysis)	Laboratory
Geochemistry	Nitrogen, Nitrite	USEPA 9056A	250mL in plastic container	Cool to ≤6°C	For unpreserved samples, analysis must be completed within 48 hours of collection.	Pace - I
	pH	SM 4500H+B	250mL minimum in plastic container	Cool to ≤6°C	Sample must be analyzed within 15 minutes of collection date.	Pace - I
	Phosphorous	USEPA 365.1	250mL in glass or plastic container	Preserved with H2SO4 to a pH<2, Cool to ≤6°C	Sample must be analyzed within 28 days of collection date.	Pace - I
	Sulfide	SM 4500-S^2-D	250mL in plastic container. Fill container completely without overflowing.	pH>9 with 1mL of 1:1 Sodium Hydroxide plus 0.5mL of 1N Zinc Acetate per 250mL sample. Cool to ≤6°C	Analysis must be completed within 7 days of collection.	Pace - I
	Total Dissolved Solids	SM 2540C	250mL minimum in plastic container	Cool to ≤6°C	Sample must be analyzed within 7 days of collection date.	Pace - I
	Total Hardness	USEPA 6010B/2340B Calculation	250mL in plastic container	Nitric Acid to pH <2* Ambient or Cool to ≤6°C	Must be analyzed within 6 months of the collection date.	Pace - I
	Total Organic Carbon	SM 5310C	250mL amber glass bottle	Sulfuric Acid to pH <2 Cool to ≤6°C	Sample must be analyzed within 28 days of collection date.	Pace - I
	Total Suspended Solids	SM 2540D	1L minimum in plastic container	Cool to ≤6°C	Sample must be analyzed within 7 days of collection date.	Pace - I

Notes:

* Samples received at pH >2 must be preserved to pH <2 with HNO3 and be allowed to equilibrate for 24 hours before being prepared for analysis. Acidification date and time are recorded in the Sample Preservation Logbook.

Abbreviations:
°C: degrees celsius
HASL: Health and Safety Laboratory
L: Liter
mL: milliliter
MS/MSD: Matrix Spike/Matrix Spike Duplicate
N: Normal
NA: Not Applicable
Pace - B: Pace Analytical Gulf Coast, LLC in Baton Rouge, Louisiana
Pace - I: Pace Analytical Services, LLC in Indianapolis, Indiana
Pace - K: Pace Analytical Services, LLC in Lenexa, Kansas
Pace - P: Pace Analytical Services, LLC in Pittsburgh, Pennsylvania
Pace - N: Pace Analytical National Center for Testing and Innovation in Mt. Juliet, Tennessee
PCBs: Polychlorinated biphenyl
SIM: Selective Ion Monitoring
SM: Standard Methods for the Examination of Water and Wastewater
TPH: Total Petroleum Hydrocarbons
USEPA: United States Environmental Protection Agency
VOA: Volatile Organic Analysis

Table 2-2b: Analytes, Holding Time and Preservation Requirements for Alluvial Aquifer Matrix
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Category	Analytical Group	Analytical Method	Containers (number, size, and type)	Preservation Requirements (chemical, temperature, light protected)	Maximum Holding Time (preparation / analysis)	Laboratory
Total Metals	Total Metals	USEPA 6010B	4-oz glass with Teflon Lid	None	Must be analyzed within 6 months of the collection date.	Pace - I
	Total Metals	USEPA 6020	4-oz glass with Teflon Lid	None	Must be analyzed within 6 months of the collection date.	Pace - I
Radiological Chemistry	Total Isotopic Uranium (U-234, U-235, U-238)	HASL-300 Method U-02	4-oz glass with Teflon Lid	None	Sample must be analyzed within 180 days	Pace - P
	Total Isotopic Thorium (Th-228,Th-230, Th-232)	HASL-300 Method U-02	4-oz glass with Teflon Lid	None	Sample must be analyzed within 180 days	Pace - P
	Total Isotopic Radium-226	USEPA 901.1M	16-oz glass with Teflon Lid	None	Sample must be analyzed within 180 days	Pace - P
	Total Isotopic Radium-228	USEPA 901.1M	16-oz glass with Teflon Lid	None	Sample must be analyzed within 180 days	Pace - P
Mineralogical	Cation Exchange Capacity	USEPA 9081	4-oz glass with Teflon Lid	Cool to ≤6°C	Sample must be analyzed within 180 days	Pace - K
Geochemistry	pH	USEPA 9045C	4-oz glass with Teflon Lid	Cool to ≤6°C	Immediately	Pace - I
	Total Organic Carbon	Walkley-Black Procedure	4-oz amber glass with Teflon Lid	Cool to ≤6°C	28 days	Pace - N
	Total Alkalinity (carbonate and bicarbonate)	SM 2320B	4-oz glass with Teflon Lid	Cool to ≤6°C	14 days	Pace - I
	Bromide, Iodide, Fluoride, Chloride, and Sulfate	USEPA 9056	4-oz amber glass with Teflon Lid	Cool to ≤6°C	28 days	Pace - I
Geotechnical Parameter	Moisture Content and Density	ASTM D7263	Core Sample[1]	None	Sample must be analyzed within 180 days	Advanced Terra Testing

Notes:
1: Density and moisture content cannot be run on a bulk sample, and can only be completed if there is enough intact sample to complete the analysis
Abbreviations:
ASTM: American Society for Testing and Materials
°C: degrees celsius
HASL: Health and Safety Laboratory
oz: ounce
Pace - I: Pace Analytical Services, LLC in Indianapolis, Indiana
Pace - K: Pace Analytical Services, LLC in Lenexa, Kansas
Pace - P: Pace Analytical Services, LLC in Pittsburgh, Pennsylvania
Pace - N: Pace Analytical National Center for Testing and Innovation in Mt. Juliet, Tennessee
SM: Standard Methods for the Examination of Water and Wastewater
USEPA: United States Environmental Protection Agency

Table 2-2c: Analytes, Holding Time and Preservation Requirements for Bedrock Aquifer Matrix
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Category	Analytical Group	Analytical Method	Containers[1] (number, size, and type)	Preservation Requirements (chemical, temperature, light protected)	Maximum Holding Time (preparation / analysis)	Laboratory
Total Metals	Total Metals	USEPA 6010B	NA	None	Must be analyzed within 6 months of the collection date.	Pace - I
	Total Metals	USEPA 6020	NA	None	Must be analyzed within 6 months of the collection date.	Pace - I
Radiological Chemistry	Total Isotopic Uranium (U-234, U-235, U-238)	HASL-300 Method U-02	NA	None	Sample must be analyzed within 180 days	Pace - P
	Total Isotopic Thorium (Th-228,Th-230, Th-232)	HASL-300 Method U-02	NA	None	Sample must be analyzed within 180 days	Pace - P
	Total Isotopic Radium-226	USEPA 901.1M	NA	None	Sample must be analyzed within 180 days	Pace - P
	Total Isotopic Radium-228	USEPA 901.1M	NA	None	Sample must be analyzed within 180 days	Pace - P
Mineralogical	Cation Exchange Capacity	USEPA 9081	NA	Cool to ≤6°C	Sample must be analyzed within 180 days	Pace - K
Geochemistry	pH	USEPA 9045C	NA	Cool to ≤6°C	Immediately	Pace - I
	Total Organic Carbon	Walkley-Black Procedure	NA	Cool to ≤6°C	28 days	Pace - N
	Total Alkalinity (carbonate and bicarbonate)	SM 2320B	NA	Cool to ≤6°C	14 days	Pace - I
	Bromide, Iodide, Fluoride, Chloride, and Sulfate	USEPA 9056	NA	Cool to ≤6°C	28 days	Pace - I

Notes:
1: Bedrock cores will be submitted to the laboratory for crushing and analysis. Approximately 1500g total are needed for the bedrock analytical suite. An approximately 8-inch core will be submitted to the laboratory.
Abbreviations:
°C: degrees celsius
HASL: Health and Safety Laboratory
M: Modified
NA: Not Applicable
Pace - I: Pace Analytical Services, LLC in Indianapolis, Indiana
Pace - K: Pace Analytical Services, LLC in Lenexa, Kansas
Pace - P: Pace Analytical Services, LLC in Pittsburgh, Pennsylvania
Pace - N: Pace Analytical National Center for Testing and Innovation in Mt. Juliet, Tennessee
SM: Standard Methods for the Examination of Water and Wastewater
USEPA: United States Environmental Protection Agency

Table 2-2d: Analytes, Holding Time and Preservation Requirements for Vapor
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Analytical Group	Analytical Method	Containers (number, size, and type)	Preservation Requirements (chemical, temperature, light protected)	Maximum Holding Time (preparation / analysis)	Laboratory
Volatile Organic Compounds	TO-15[1]/TO-15 MOD[2]/ TO-15-SIM[1]	1x6 Liter Summa Can[3]	NA	30 Days	ALS-S
Methane	TO-3 Modified	1x6 Liter Summa Can[3]	NA	30 Days	ALS-S
Long Term Radon[4]	USEPA 402-R-92-004	Electret Ion Chamber	NA	NA	ALS-W
Fixed Gases [5]	Method 3C Modified	1x6 Liter Summa Can[3]	*NA*	*30 Days*	*ALS-S*

Notes:
1: The full TO-15 analyte list will be run for each sample. TO-15 SIM will be run with TO-15 for indoor air samples to achieve the lowest reporting limits. Only analytes not included in the TO-15 SIM target analyte list will be reported from TO-15 full scan when both methods are run.
2: TO-15 Modified will be used for samples that also require methods 3c Modified and TO-3 Modified.
3: VOCs, fixed gases (if needed), and methane will be analyzed from the same canister.
4: Long Term Radon will be analyzed by the laboratory for indoor/outdoor samples only.
5: Fixed gases (oxygen, carbon dioxide) will be analyzed by the laboratory for soil gas samples only.
Abbreviations:
ALS-S: ALS Simi Valley, CA
ALS-W: ALS Winnipeg, MB
SIM: Selective Ion Monitoring
MOD: Modified
NA: Not applicable
USEPA: United States Environmental Protection Agency

Table 2-2e: Analytes, Holding Time and Preservation Requirements for Groundwater Screening
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Analytical Group	Analytical Method	Containers (number, size, and type)	Preservation Requirements (chemical, temperature, light protected)	Maximum Holding Time (preparation / analysis)	Laboratory
Volatile Organic Compounds	USEPA 8260C Low Level	Minimum 2 VOA vials (3 if volume allows). Additional sample is required if MS/MSD is required.	Acidified w/ 1:1 Hydrochloric Acid to pH<2 No headspace Cool to ≤6°C	pH>2: Analysis must be completed within 7 days of collection date. pH <2: Analysis must be completed within 14 days of collection date. (pH determined post analysis)	Pace - I
Dissolved Metals (Ba, Ca, Fe, Mg, Mn)	USEPA 6010B	250mL in plastic container (100 mL minimum)	Field Filtration Nitric Acid to pH <2* Ambient or Cool to ≤6°C	Must be analyzed within 6 months of the collection date.	Pace - I
Alkalinity, Bicarbonate, Carbonate	SM 2320B		Field Filtration Cool to ≤6°C	Sample must be analyzed within 14 days of collection date.	Pace - I
Chloride, Sulfate	USEPA 9056A	250mL in plastic container (200 mL minimum)	Field Filtration Cool to ≤6°C	Analysis must be completed within 28 days of collection date.	Pace - I
Nitrogen, Nitrate	USEPA 9056A		Field Filtration Cool to ≤6°C	Analysis must be completed within 48 hours of collection.	Pace - I

Notes:

* Samples received at pH >2 must be preserved to pH <2 with HNO3 and be allowed to equilibrate for 24 hours before being prepared for analysis. Acidification date and time are recorded in the Sample Preservation Logbook.

Abbreviations:
°C: degrees celsius
mL: milliliter
MS/MSD: Matrix Spike/Matrix Spike Duplicate
Pace - I: Pace Analytical Services, LLC in Indianapolis, Indiana
SM: Standard Methods for the Examination of Water and Wastewater
USEPA: United States Environmental Protection Agency
VOA: Volatile Organic Analysis

Table 2-3: Sample Collection Order
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Sampling Order	Category
1	Volatile Organic Compounds
2	Dissolved Gases
3	Semivolatile Organic Compounds
4	Total Metals, Total Hardness
5	Hexavalent Chromium - field filtered
6	Total Radiological Chemistry (Isotopic Thorium, Isotopic Uranium, Isotopic Radium-226/228)
7	Dissolved Metals - field filtered
8	Dissolved Radiological Chemistry (Isotopic Thorium, Isotopic Uranium, Isotopic Radium-226/228) - field filtered
9	Dissolved Organic Carbon - field filtered
10	Total Organic Carbon, Chemical Oxygen Demand, Ammonia, Nitrate and Nitrite, Phosphorous
11	Tritium
12	Total Petroleum Hydrocarbons
13	Alkalinity, Total Dissolved Solids, Nitrate, Nitrite, Chloride, Fluoride, Sulfate, Iodide, Bromide, Carbonate, pH
14	Total Suspended Solids
15	Cyanide
16	Sulfide
17	Polychlorinated Biphenyls
18	Chlorinated Herbicides

Table 3-1a: Summary of All Current Wells—Construction Details
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Well ID	Alias	Install Date	Borehole Diameter (in)	Pipe Size (in)	Pipe Type	Perforation Detail	Surface Casing	Boring Depth (ft bgs)	2012 Cap Height (ft ags)	Current Cap Height (ft ags)	Screen Length (ft)	Screen From (ft bgs)	Screen To (ft bgs)	Construction Source
D-12*	WL-216A	01-10-95	8.25	2	Sch. 80 PVC	0.010 slotted	Locking steel protective cover	143.7	2.579	2.51	10	133.7	143.7	As-built
D-13*	WL-224	01-10-95	8.25	2	Sch. 80 PVC	0.010 slotted	Locking steel protective cover	133	2.5123	2.7	10	123	133	As-built
D-14	WL-109B	01-10-95	8.25	2	Sch. 40 PVC	0.010 slotted	Locking steel protective cover	58.5	2.2604	3.27	5	53.5	58.5	As-built
D-3*	WL-105A	01-08-95	8.25	2	Sch. 80 PVC	0.010 slotted	Locking steel protective cover	106.5	3.22	3.12	10	96.5	106.5	As-built
D-6*	WL-206	01-08-95	8.25	2	Sch. 40 PVC	0.010 slotted	Locking steel protective cover	106.5	3.291	3.2	10	96.5	106.5	As-built
D-81	NA	13-08-84	5" (0–15 ft), 4 1/2" (15–61.5 ft)	2	PVC	0.01 inch machine slot	NA	61.5	2.58	3	15	45	60	RIA
D-83*	NA	16-08-84	5" (0–15 ft) 4 1/2" (15–115.3 ft)	2	PVC	0.01 inch machine slot	NA	115.3	3.369	3.2	20	77	97	RIA
D-85	NA	01-08-84	5" (0–10 ft) 4 1/2" (10–84.1 ft)	2	PVC	0.01 inch machine slot	NA	84.1	3.007	3	20	62	82	RIA
D-87	NA	01-08-84	5" (0–30 ft) 4 1/2" (30–111.7 ft)	2	PVC	0.01 inch machine slot	NA	111.7	3.251	3	20	91	111	RIA
D-89	NA	27-08-84	5" (0–25 ft) 4 1/2" (25–49 ft)	2	PVC	0.01 inch machine slot	NA	49	NA	3	15	33	48	RIA
D-90	NA	07-08-85	4", 3 7/8"	2	PVC	0.01 inch machine slot	NA	47	NA	NA	NA	37	47	RIA
D-91	NA	01-08-85	4", 3 7/8"	2	Sch 50 PVC Riser, Sch 20 PVC Screen	200 slots	NA	45	NA	5	10	35	45	RIA
D-92	NA	09-04-85	4" (0–40 ft), 3 7/8" (40–143.6 ft)	2	PVC	0.01 inch machine slot	NA	143.6	NA	-0.2	20	123	143	RIA
D-93*	NA	18-04-85	6" (0–8 ft) 4 7/8" (8–119.2ft)	2	PVC	0.01 inch machine slot	NA	119.2	2.556	3.3	20	92	112	RIA
D-94	NA	01-04-85	3 7/8"	2	PVC	0.01 inch machine slot	NA	109	NA	2.6	20	86	106	RIA
D-95	NA	01-04-85	3 7/8"	2	PVC	0.01 inch machine slot	NA	101	NA	3.3	20	81	101	RIA
F-1-D	NA	01-08-90	8"	2	Sch 40 PVC	10 slot	Locking steel protective cover	79.5	NA	2.85	5	NA	NA	RIA
F-1-S	NA	01-08-90	8"	2	Sch 40 PVC	10 slot	Locking steel protective cover	32.9	NA	2.4	10	22.5	32.5	As-built
F-2	NA	10-08-90	8"	2	Sch 40 PVC	10 slot	Locking steel protective cover	25.7	NA	2.25	15	10.3	25.3	As-built
F-3	NA	01-08-90	8"	2	Sch 40 PVC	10 slot	Locking steel protective cover	46	NA	2.3	10	32.8	42.8	As-built
I-11*	WL-216C	01-08-95	8.25	2	Sch. 80 PVC	0.010 slotted	Locking steel protective cover	93	2.526	2.67	10	80.5	90.5	As-built
I-2	NA	Unknown	8.25	2	Sch. 40 PVC	0.010 slotted	Locking steel protective cover	52	NA	3.21	10	39.5	49.5	As-built
I-4	WL-105B	01-08-95	8.25	2	Sch. 40 PVC	0.010 slotted	Locking steel protective cover	79	2.789	2.57	10	66.5	76.5	As-built
I-50	N-1	01-10-83	NA	NA	NA	NA	NA	40.6	NA	4.48	10	30.6	40.6	RIA
I-55	35	26-06-78	6"	2	PVC	NA	NA	60	NA	NA	NA	NA	NA	RIA
I-56	34	27-06-78	6"	2	PVC	NA	NA	60	NA	NA	NA	NA	NA	RIA
I-58	40	28-06-78	6"	2	PVC	NA	NA	60	NA	NA	NA	NA	NA	RIA
I-59	N-2	01-10-83	NA	NA	NA	NA	NA	43.5	NA	NA	NA	NA	NA	RIA
I-62*	N-3	01-10-83	NA	NA	NA	NA	NA	44	1.7984	1.98	10	34	44	RIA
I-65	N-4	01-10-83	NA	NA	NA	NA	NA	36	2.3269	3.3	10	26	36	RIA
I-66	N-5	01-10-83	NA	NA	NA	NA	NA	36.9	2.7373	4.1	10	26.9	36.9	RIA
I-67	N-6	01-10-83	NA	NA	NA	NA	NA	35.4	2.342	2.58	10	25.4	35.4	RIA
I-68	N-7	01-10-83	NA	NA	NA	NA	NA	31.2	2.794	7.42	10	21.2	31.2	RIA
I-7	WL-207	Unknown	8.25	2	Sch. 40 PVC	0.010 slotted	Locking steel protective cover	50	NA	2.47	10	37.5	47.5	As-built
I-72	39	01-06-78	NA	NA	NA	NA	NA	50	NA	2.7	3	47	50	RIA
I-73	38	01-06-78	NA	NA	NA	NA	NA	50	3.1019	3.7	3	43.2	46.2	RIA
I-9*	WL-229	01-09-95	8.25	2	Sch. 40 PVC	0.010 slotted	Locking steel protective cover	55.6	1.964	2.49	10	43.1	53.1	As-built
LR-100	NA	04-10-95	8 1/4"	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	26	2.77	1.92	4.8	19.7	24.5	As-built
LR-101	NA	10-10-95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	RIA
LR-102	NA	08-10-95	8 1/4"	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	76	NA	1.52	4.8	54.9	59.7	As-built
LR-103	NA	20-10-95	8 1/4"	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	40	3.371	1.1	9.8	28.6	38.4	As-built
LR-104	NA	18-10-95	8 1/4"	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	40	1.8591	1.73	9.8	28.4	38.2	As-built

Table 3-1a: Summary of All Current Wells—Construction Details
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Well ID	Alias	Install Date	Borehole Diameter (in)	Pipe Size (in)	Pipe Type	Perforation Detail	Surface Casing	Boring Depth (ft bgs)	2012 Cap Height (ft ags)	Current Cap Height (ft ags)	Screen Length (ft)	Screen From (ft bgs)	Screen To (ft bgs)	Construction Source
LR-105	NA	03-10-95	8 1/4"	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	38	2.843	2.59	9.8	26.2	36	As-built
MO-3-SDR	NA	14-08-15	5 7/8"	NA	NA	NA	NA	210.08	NA	-0.28	20	190.08	210.08	MDNR
MO-3-SS	NA	12-08-15	5 7/8"	NA	NA	NA	NA	170	NA	-0.2	20	150.4	170.4	MDNR
MW-101	NA	01-04-90	8	2	PVC	0.010 slotted	Locking steel protective cover	25	NA	2.3	10	17.3	27.3	As-built
MW-102	NA	01-04-90	8	2	PVC	0.010 slotted	Locking steel protective cover	25	2.173	2.3	10	16.8	26.8	As-built
MW-103	NA	01-04-90	8	2	PVC	0.010 slotted	Locking steel protective cover	18	1.85	2.7	10	8.4	18.4	As-built
MW-104	NA	01-04-90	8	2	PVC	0.010 slotted	Locking steel protective cover	17	3.003	2.9	10	9.9	19.9	As-built
MW-105	NA	12-04-90	8	2	PVC	0.010 slotted	Locking steel protective cover	15	NA	2.3	10	5	15	As-built
MW-106	NA	12-04-90	8	2	PVC	0.010 slotted	Locking steel protective cover	15	NA	NA	10	5	15	As-built
MW-107	NA	01-04-90	8	2	PVC	0.010 slotted	Locking steel protective cover	15	NA	NA	10	5	10	As-built
MW-1201	PZ-1201-SS & 1201	01-03-85	NA	NA	NA	NA	NA	250	NA	2.24	197	53	250	RIA
MW-1202	NA	01-03-85	NA	NA	NA	NA	NA	250	NA	2.08	NA	NA	NA	RIA
MW-1203	NA	01-07-85	NA	NA	NA	NA	NA	250	NA	2.91	NA	NA	NA	RIA
MW-1204	NA	01-04-91	8	2	Sch. 80 PVC	0.010 slotted	Locking steel protective cover	227	2.267	2.3	10	213.5	223.5	As-built
MW-1205	NA	01-04-91	11 and 6	2	Sch. 80 PVC	0.010 slotted	Locking steel protective cover	132	NA	2.3	10	113	123	As-built
MW-1206	NA	01-03-91	8	2	Sch. 80 PVC	0.010 slotted	Locking steel protective cover	73	NA	2.3	10	63	73	As-built
MW-41	NA	01-06-78	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	RIA
PZ-100-KS	1209	17-02-95	10 1/4" (0–34 ft) 5 7/8" (34–391 ft)	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	391.2	1.134	1.88	9.8	374	383.8	As-built
PZ-100-SD	1208	23-02-95	10 1/4 "(0–51 ft) 5 7/8" (51–246 ft)	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	246	1.592	1.47	9.8	234.8	244.6	As-built
PZ-100-SS	1207	25-02-95	10 1/4 "(0–51 ft) 5 7/8" (51–94.5 ft)	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	94.5	1.312	1.49	19.64	73.96	93.6	As-built
PZ-101-SS	1210	06-03-95	10 1/4 "(0–14 ft) 5 7/8" (14–140 ft)	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	140	2.214	1.79	9.8	129.48	139.28	As-built
PZ-102R-SS	1211	18-06-95	10 1/4 "(0–35 ft) 5 7/8" (35–90.3 ft)	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	90.3	1.874	1.12	9.8	79.83	89.63	As-built
PZ-102-SS	NA	12-03-95	10 1/4 "(0–37 ft) 5 7/8" (37–90.4 ft)	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	90.4	2.185	1.8	9.8	79.7	89.5	As-built
PZ-103-SS	1212	26-02-95	10 1/4 "(0–51 ft) 5 7/8" (51–145.5 ft)	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	145.5	3.899	2.39	9.8	134.7	144.5	As-built
PZ-104-KS	1215	19-06-95	10 1/4 "(0–249 ft) 5 7/8" (249–408 ft)	2	Sch 80 PVC	0.01 inch machine slot	6 5/8" Steel Casing elev 483.3–233.32	408	2.359	1.72	9.8	397.37	407.17	As-built
PZ-104-SD	1214	17-06-95	10 1/4 "(0–38 ft) 5 7/8" (38–252.5 ft)	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	252.5	2.277	1.59	9.8	235.2	245	As-built
PZ-104-SS	1213	04-06-95	10 1/4 "(0–37 ft) 5 7/8" (37–145 ft)	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	145	1.948	2.07	9.8	134.5	144.3	As-built
PZ-105-SS	1216	24-05-95	10 1/4 "(0–45 ft) 5 7/8" (45–149 ft)	2	Sch 80 PVC	0.01 inch machine slot	6 5/8" Steel Casing elev 482.7–436.22	149	2.83	2.39	9.8	138.5	148.3	As-built
PZ-106-KS	1219	23-03-95	10 1/4 "(0–204 ft) 5 7/8" (204–375 ft)	2	Sch 80 PVC	0.01 inch machine slot	6 5/8" Steel Casing elev 463.3–257.77	375	2.181	2.49	9.8	363.75	373.57	As-built
PZ-106-SD	1218	24-03-95	10 1/4 "(0–26 ft) 5 7/8" (26–201.1 ft)	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	201.1	2.017	1.97	9.8	190.79	200.59	As-built
PZ-106-SS	1217	05-04-95	10 1/4 "(0–23 ft) 5 7/8" (23–165.4 ft)	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	165.4	1.752	1.75	9.8	155.3	165.1	As-built
PZ-107-SS	1220	22-05-95	10 1/4 "(0–32ft) 5 7/8" (32–103 ft)	2	Sch 80 PVC	0.01 inch machine slot	6 5/8" Steel Casing elev 463.6–407.63	103	2.151	2.03	9.8	92.6	102.4	As-built
PZ-108-SS	1221	29-03-95	10 1/4 "(0–20ft) 5 7/8" (20–143.9 ft)	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	143.9	NA	2.08	9.8	133.54	143.35	As-built
PZ-109-SS	1222	25-04-95	10 1/4 "(0–15ft) 5 7/8" (15–135.7 ft)	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	135.7	2.002	1.73	9.8	125.7	135.5	As-built
PZ-110-SS	1223	20-05-95	10 1/4 "(0–61ft) 5 7/8" (61–111.5 ft)	2	Sch 80 PVC	0.01 inch machine slot	6 5/8" Steel Casing elev 457.3–395.84	111.5	3.0292	2.07	9.8	100.9	110.7	As-built

Table 3-1a: Summary of All Current Wells—Construction Details
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Well ID	Alias	Install Date	Borehole Diameter (in)	Pipe Size (in)	Pipe Type	Perforation Detail	Surface Casing	Boring Depth (ft bgs)	2012 Cap Height (ft ags)	Current Cap Height (ft ags)	Screen Length (ft)	Screen From (ft bgs)	Screen To (ft bgs)	Construction Source
PZ-111-KS	1225	06-05-95	14 3/4 "(0–84ft) 10" (84.0–215.5) 5 7/8" (215.5–368.8 ft)	2	Sch 80 PVC	0.01 inch machine slot	10 7/8" Steel Casing elev 459.9–375.38; 6 5/8" Steel Casing elev 460.2–243.88	368.8	4.0621	1.69	9.8	357.15	366.96	As-built
PZ-111-SD	1224	21-04-95	10" (0–98 ft) 5 7/8" (98–210 ft)	2	Sch 80 PVC	0.01 inch machine slot	6 5/8" Steel Casing elev 459.7–361.22	210	4.2226	2.33	9.8	199.4	209.2	As-built
PZ-111-SS	NA	29-08-17	8"	2	Sch 80 PVC	0.01 inch machine slot	6" Steel Casing 0–93 ft bgs	0	NA	0	0	462.11	462.11	RIA
PZ-112-AS*	1226	10-04-95	8 1/4"	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	36	3.722	1.9	4.8	29.6	34.4	As-built
PZ-113-AD	1228	03-05-95	10 1/4"	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	108.7	2.368	1.6	9.8	98.6	108.4	As-built
PZ-113-AS	1227	11-04-95	8 1/4"	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	40	2.203	1.5	9.8	28.9	38.7	As-built
PZ-113-SS	1229	20-05-95	9 3/4" (0–115 ft) 5 7/8" (115–159 ft)	2	Sch 80 PVC	0.01 inch machine slot	6 5/8" Steel Casing elev 460.4–344.96	159	2.601	1.81	9.8	148.57	158.37	As-built
PZ-114-AS	1230	20-04-95	10 1/4"	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	30.5	2.175	1.53	9.8	19.9	29.7	As-built
PZ-115-SS	1231	21-05-95	9 7/8" (0–39ft) 5 7/8" (39–85ft)	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	85	2.284	1.69	9.8	74.68	84.48	As-built
PZ-116-SS	1232	20-06-95	10 1/4 "(0–33ft) 5 7/8" (33–162 ft)	2	Sch 80 PVC	0.01 inch machine slot	6 5/8" Steel Casing elev 451.6–411.61	162	2.49	1.8	9.8	151.4	161	As-built
PZ-1201-SS	NA	07-07-95	Unknown (0–53 ft) 5 7/8" (53–250)	2	Sch 80 PVC	0.01 inch machine slot	6 5/8" Steel Casing elev 483–427.41	250	NA	2.01	9.6	137.69	147.29	RIA
PZ-200-SS	NA	28-02-95	10 1/4 "(0–27.5ft) 5 7/8" (27.5–98.3 ft)	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	98.7	2.28	2.02	88.02	9.62	97.64	As-built
PZ-201A-SS	1223	23-04-95	10 1/4 "(0–33ft) 5 7/8" (33–90 ft)	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	90	2.058	1.81	9.8	80	89.8	As-built
PZ-201-SS	NA	06-03-95	10 1/4 "(0–33ft) 5 7/8" (33–39 ft)	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	89	NA	2.32	78.56	9.75	88.31	As-built
PZ-202-SS	1234	12-03-95	10 1/4" (0–33.5 ft) 5 7/8" (33.5–90 ft)	2	Sch 80 PVC	0.01 inch machine slot	6 5/8" Steel Casing elev 480–445.01	90	1.942	2.16	48.9	40.2	89.1	As-built
PZ-203-SS	1235	03-06-95	10 1/4" (0–56 ft) 5 7/8" (56–110 ft)	2	Sch 80 PVC	0.01 inch machine slot	6 5/8" Steel Casing elev 484.7–428.08	110	2.66	2.41	9.8	99.6	109.4	As-built
PZ-204A-SS	1236	21-08-95	10 1/4" (0.0–14 ft) 5 7/8" (14–90 ft)	2	Sch. 80 PVC	0.010 slotted	Locking steel protective cover	90	0	1.5	9.6	79.5	89.1	As-built
PZ-204-SS	NA	10-03-95	10 1/4" (0–14 ft) 5 7/8" (14–90.3 ft)	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	90.3	0	2.6	78.4	10.95	89.35	As-built
PZ-205-AS	1237	05-05-95	14 3/4 "(0–29ft) 8 1/4" (29–49ft)	2	Sch 80 PVC	0.01 inch machine slot	6 5/8" Steel Casing elev 460–430.33	49	1.944	1.66	9.8	38.55	48.35	As-built
PZ-205-SS	1238	21-05-95	9 3/4" (0–54 ft) 5 7/8" (54–90 ft)	2	Sch 80 PVC	0.01 inch machine slot	6 5/8" Steel Casing elev 460.5–405.53	99	2.256	1.66	9.8	88.57	98.37	As-built
PZ-206-SS	1239	24-04-95	10" (0–52 ft) 5 7/8" (52–125.5 ft)	2	Sch 80 PVC	0.01 inch machine slot	6 5/8" Steel Casing elev 459.1–406.38	125.5	2.1958	1.82	9.8	115	124.8	As-built
PZ-207-AS	1240	10-04-95	8 1/4"	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	40	2.088	1.69	4.8	34.9	39.7	As-built
PZ-208-SS	1241	18-06-95	10 1/4" (0–17 ft) 5 7/8" (17–99.2 ft)	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	99.2	2.311	1.72	9.8	88.7	98.5	As-built
PZ-209-SD	NA	04-10-13	9" for soil, 6" for rock	2	Sch. 80 PVC	0.010 slotted	Locking steel protective cover	250	NA	2.34	10	240	250	As-built
PZ-209-SS	NA	15-10-13	9" for soil, 6" for rock	2	Sch. 80 PVC	0.010 slotted	Locking steel protective cover	150	NA	2.29	10	140	150	As-built
PZ-210-SD	NA	16-10-13	9" for soil, 6" for rock	2	Sch. 80 PVC	0.010 slotted	Locking steel protective cover	248	NA	2.52	10	238	248	As-built
PZ-210-SS	NA	16-10-13	9" for soil, 6" for rock	2	Sch. 80 PVC	0.010 slotted	Locking steel protective cover	148	NA	2.37	10	138	148	As-built
PZ-211-SD	NA	07-10-13	9" for soil, 6" for rock	2	Sch. 80 PVC	0.010 slotted	Locking steel protective cover	247	NA	2.63	10	237	247	As-built
PZ-211-SS	NA	08-10-13	9" for soil, 6" for rock	2	Sch. 80 PVC	0.010 slotted	Locking steel protective cover	147	NA	2.35	10	137	147	As-built
PZ-212-SD	NA	21-10-13	7.25	2	Sch. 80 PVC	0.010 slotted	Locking steel protective cover	245	NA	2.24	10	234	244	As-built
PZ-212-SS	NA	18-10-13	9" for soil, 6" for rock	2	Sch. 80 PVC	0.010 slotted	Locking steel protective cover	150	NA	2.63	10	134	144	As-built
PZ-300-AD	NA	24-09-95	8 1/4"	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	42.2	NA	1.52	4.8	37.1	41.9	As-built
PZ-300-AS	NA	26-09-95	8 1/4"	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	20	NA	2.16	9.8	9.9	19.7	As-built
PZ-300-SS	NA	26-09-95	9 7/8" (0–46ft) 5 7/8" (46–93ft)	2	Sch 80 PVC	0.01 inch machine slot	6 5/8" Steel Casing elev 447.6–402.4	94.5	NA	1.2	9.8	83.88	93.7	As-built

Table 3-1a: Summary of All Current Wells—Construction Details
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Well ID	Alias	Install Date	Borehole Diameter (in)	Pipe Size (in)	Pipe Type	Perforation Detail	Surface Casing	Boring Depth (ft bgs)	2012 Cap Height (ft ags)	Current Cap Height (ft ags)	Screen Length (ft)	Screen From (ft bgs)	Screen To (ft bgs)	Construction Source
PZ-301-SS	NA	23-09-95	8 1/4" (0–19 ft) 5 7/8" (19–161.5 ft)	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	161.5	NA	1.61	9.8	150.9	160.7	As-built
PZ-302-AI	NA	26-09-95	8 1/4"	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	43	1.423	1.15	9.8	32.6	42.4	As-built
PZ-302-AS	NA	25-09-95	8 1/4"	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	22.3	2.217	1.92	9.8	12.2	22	As-built
PZ-303-AS	NA	05-10-95	8 1/4"	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	26.5	2.237	2.38	9.8	16	25.8	As-built
PZ-304-AI	NA	02-10-95	8 1/4"	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	50	2.395	2.42	9.8	39	48.8	As-built
PZ-304-AS	NA	27-09-95	8 1/4"	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	28	2.159	2.31	9.8	17.1	26.9	As-built
PZ-305-AI	NA	19-10-95	8 1/4"	2	Sch 80 PVC	0.01 inch machine slot	Locking steel protective cover	64	1.8917	1.68	9.8	53.2	63	As-built
S-1	NA	03-06-05	8.25	2	Sch. 40 PVC	0.010 slotted	Locking steel protective cover	25	NA	3.21	20	2.5	22.5	As-built
S-10*	WL-216C; WL-232	01-09-95	8.25	2	Sch. 40 PVC	0.010 slotted	Locking steel protective cover	54.5	2.497	2.78	20	32	52	As-built
S-5*	WL-105C	01-08-95	8.25	2	Sch. 40 PVC	0.010 slotted	Locking steel protective cover	49.3	3.203	2.95	10	30	40	As-built
S-51	HL-3	03-06-05	NA	NA	NA	NA	NA	25.8	NA	1.42	3	22.8	25.8	RIA
S-52	HL-2	03-06-05	NA	NA	NA	NA	NA	25.2	NA	2.38	3	22.2	25.2	RIA
S-53	HL-1	03-06-05	NA	NA	NA	NA	NA	23.7	3.058	4.2	3	20.7	23.7	RIA
S-54	36	Unknown	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	RIA
S-60	S-2	01-07-81	NA	NA	NA	NA	NA	21	NA	3.83	NA	NA	21	RIA
S-61	S-1	01-07-81	NA	NA	NA	NA	NA	21.5	3.706	4.57	NA	NA	21.5	RIA
S-75	37	Unknown	NA	NA	NA	NA	NA	26	NA	1.1	3	23	26	RIA
S-76	37A	01-06-78	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	RIA
S-8	WI-228	01-09-95	8.25	2	Sch. 40 PVC	0.010 slotted	Locking steel protective cover	29.3	2.3847	2.43	20	6.8	26.8	As-built
S-80	NA	28-08-84	5"	2	PVC	0.01 inch machine slot	NA	22	NA	5	10	10	20	RIA
S-82*	NA	27-08-84	5"	2	PVC	0.01 inch machine slot	NA	26.5	1.941	3	10	15.5	25.5	RIA
S-84	NA	01-08-84	5"	2	PVC	0.01 inch machine slot	NA	31.5	2.804	4	10	20.9	30.9	RIA
S-88	NA	01-08-84	5" (0–30 ft), 4 1/2" (30–41.5)	2	PVC	0.01 inch machine slot	NA	41.5	NA	2.7	10	30	40	RIA

Notes:

* = Monitoring well may be in the footprint of OU-1 removal activities and potentially scheduled for future decommissioning.

Abbreviations:

ags = above ground surface
bgs = below ground surface
D = Deep
ft = feet
F = Foth
in = inches
I = Intermediate
LR = Leachate Riser
MDNR = Missouri Department of Natural Resources
MW = Monitoring Well
NA = Not available
PVC = Polyvinyl Chloride
PZ = Piezometer
RIA = Remedial Investigation Addendum
S = Shallow
Sch. = Schedule

Table 3-1b: Summary of All Current Wells—Survey Data
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Well ID	Northing (ft)	Easting (ft)	Measuring Point Elevation (ft amsl)	Ground Surface Elevation (ft amsl)	Bottom Elev (ft amsl)	Top Screen Elevation (ft amsl)	Bottom Screen Elevation (ft amsl)	Survey Source
D-12*	1069877.227	835110.755	479.736	477.157	330.798	343.298	333.298	EMSI 2012 Survey
D-13*	1070527.015	835776.562	470.2467	467.7344	334.998	344.998	334.998	EMSI 2012 Survey
D-14	1068988.873	836700.023	482.9692	480.7088	425.098	430.598	425.598	EMSI 2012 Survey
D-3*	1069177.97	836047	468.338	465.118	357.798	370.298	360.298	EMSI 2012 Survey
D-6*	1070235.1	834723.492	447.623	444.332	334.998	347.498	337.498	EMSI 2012 Survey
D-81	1067378.728	834638.553	450.654	448.074	385.898	402.398	387.398	EMSI 2012 Survey
D-83*	1070970.858	834807.792	448.2116	444.8426	328.698	366.998	346.998	EMSI 2012 Survey
D-85	1069667.265	836605.173	457.264	454.257	372.648	390.698	370.698	EMSI 2012 Survey
D-87	1069252.38	835579.372	464.472	461.221	347.898	368.598	348.598	EMSI 2012 Survey
D-89	1067010.97	835274.7	456.698	453.698	404.698	420.698	405.698	EMSI 2018—Calculated
D-90	1066200.97	834474.7	450.198	445.598	398.598	408.598	398.598	EMSI 2018—Calculated
D-91	1065260.97	833944.7	452.968	447.598	402.598	412.598	402.598	EMSI 2018—Calculated
D-92	1069800.97	835264.7	474.968	475.098	331.498	352.098	332.098	EMSI 2018—Calculated
D-93*	1069369.757	834443.556	450.839	448.283	337.798	358.298	338.298	EMSI 2012 Survey
D-94	1070685.97	835994.7	442.278	438.098	329.098	352.098	332.098	EMSI 2018—Calculated
D-95	1070861.545	836524.519	452.688	449.598	348.598	368.598	348.598	Georeferenced/ Calculated
F-1-D	1068649.65	836034.74	461.228	458.378	NA	NA	NA	McLaren Hart 1996
F-1-S	1068643.97	836040.05	460.948	458.698	NA	438.448	428.448	McLaren Hart 1996
F-2	1067725.97	834591.7	449.698	447.498	NA	439.398	424.398	EMSI 2018
F-3	1070530.77	835994.53	468.828	466.528	NA	436.028	426.028	McLaren Hart 1996
I-11*	1069860.187	835099.736	480.108	477.582	386.698	396.698	386.698	EMSI 2012 Survey
I-2	1069739.23	834386.88	446.008	442.798	393.298	403.298	393.298	McLaren Hart 1996
I-4	1069189.97	836064.6	465.74	462.951	389.098	399.098	389.098	EMSI 2012 Survey
I-50	1065231.29	834006.66	453.258	448.598	407.998	417.998	407.998	McLaren Hart 1996
I-55	1067827.97	834649.7	NA	471.498	NA	NA	NA	EMSI 2018

Table 3-1b: Summary of All Current Wells—Survey Data
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Well ID	Northing (ft)	Easting (ft)	Measuring Point Elevation (ft amsl)	Ground Surface Elevation (ft amsl)	Bottom Elev (ft amsl)	Top Screen Elevation (ft amsl)	Bottom Screen Elevation (ft amsl)	Survey Source
I-56	1068097.97	834661.7	NA	474.698	NA	NA	NA	EMSI 2018
I-58	1068914.97	834632.7	NA	477.098	NA	NA	NA	EMSI 2018
I-59	1069372.97	834463.7	NA	444.498	NA	NA	NA	EMSI 2018
I-62*	1070979.147	834821.334	446.1413	444.3429	399.698	409.698	399.698	EMSI 2012 Survey
I-65	1070994.104	835507.994	441.257	438.9301	402.098	412.098	402.098	EMSI 2012 Survey
I-66	1070645.385	836025.955	441.696	438.9587	400.398	410.398	400.398	EMSI 2012 Survey
I-67	1070142.391	836418.549	441.683	439.341	400.698	410.698	400.698	EMSI 2012 Survey
I-68	1069612.97	836861.2	450.199	447.405	409.298	419.298	409.298	EMSI 2012 Survey
I-7	1070784.02	834474.57	446.568	444.098	396.598	406.598	396.598	McLaren Hart 1996
I-72	1067930.97	835519.7	464.998	462.298	412.298	415.298	412.298	EMSI 2018—Calculated
I-73	1067735.843	835745.292	461.0784	457.9765	412.298	415.298	412.298	EMSI 2012 Survey
I-9*	1069358.403	834444.232	449.879	447.915	394.998	404.998	394.998	EMSI 2012 Survey
LR-100	1067334.448	835068.653	468.113	465.343	442.298	447.098	442.298	EMSI 2012 Survey
LR-101	1068443.22	834893.11	NA	NA	NA	NA	NA	Golder 1996
LR-102	1068978.18	834962.83	513.118	511.598	451.898	456.698	451.898	Golder 1996
LR-103	1068567.541	835392.182	470.2369	466.8659	420.998	431.098	421.298	EMSI 2012 Survey
LR-104	1068105.763	835808.49	459.6505	457.7914	419.098	429.198	419.398	EMSI 2012 Survey
LR-105	1067750.35	834699.951	485.205	482.362	447.498	457.598	447.798	EMSI 2012 Survey
MO-3-SDR	1066547.224	835637	460.85	461.13	251.05	271.05	251.05	MDNR
MO-3-SS	1066537.009	835641	461.69	461.89	291.89	311.49	291.49	MDNR
MW-101	1070871.45	834598.7	446.428	444.958	NA	429.128	419.128	McLaren Hart 1996
MW-102	1070135.676	834707.412	447.833	445.66	NA	431.033	421.033	EMSI 2012 Survey
MW-103	1068668.893	834508.8	438.915	437.065	NA	430.515	420.515	EMSI 2012 Survey
MW-104	1067565.651	834513.706	440.812	437.809	NA	430.912	420.912	EMSI 2012 Survey
MW-105	1067565.651	833405.95	439.768	442.068	15	434.768	424.768	McLaren Hart 1996*

Table 3-1b: Summary of All Current Wells—Survey Data
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Well ID	Northing (ft)	Easting (ft)	Measuring Point Elevation (ft amsl)	Ground Surface Elevation (ft amsl)	Bottom Elev (ft amsl)	Top Screen Elevation (ft amsl)	Bottom Screen Elevation (ft amsl)	Survey Source
MW-106	1065996.72	833791.62	443.378	439.768		438.378	428.378	McLaren Hart 1996
MW-107	1064711.71	833775.82	447.738	NA	NA	NA	NA	McLaren Hart 1996
MW-1201	1067343.97	837077.7	482.438	480.198	230.198	427.198	230.198	EMSI 2018
MW-1202	1067383.97	837049.7	482.178	480.098	230.098	NA	NA	EMSI 2018
MW-1203	1067229.97	837129.7	483.608	480.698	230.698	NA	NA	EMSI 2018
MW-1204	1066461.146	835998.972	485.358	483.091	NA	271.858	261.858	EMSI 2012 Survey
MW-1205	1067428.36	835795.45	386.368	384.098	NA	273.368	263.368	Foth & Van Dyke 1991
MW-1206	1067437.24	835799.07	388.078	385.798	NA	325.078	315.078	Foth & Van Dyke 1991
MW-41	1069327.97	834551.7	NA	NA	NA	NA	NA	EMSI 2018
PZ-100-KS	1068883.062	837386.265	485.954	484.82	99.228	109.358	99.558	EMSI 2012 Survey
PZ-100-SD	1068892.808	837369.99	486.084	484.492	239.018	249.148	239.348	EMSI 2012 Survey
PZ-100-SS	1068908.761	837349.65	486.147	484.835	390.018	409.988	390.348	EMSI 2012 Survey
PZ-101-SS	1068513.92	836797.322	491.161	488.947	334.878	345.008	335.208	EMSI 2012 Survey
PZ-102R-SS	1068172.734	837033.545	486.05	484.176	394.138	404.268	394.468	EMSI 2012 Survey
PZ-102-SS	1068128.683	837062.591	484.245	482.06	390.818	401.948	392.148	EMSI 2012 Survey
PZ-103-SS	1067701.303	836897.822	483.803	479.904	332.548	342.678	332.878	EMSI 2012 Survey
PZ-104-KS	1067034.018	836995.216	484.197	481.838	74.418	84.548	74.748	EMSI 2012 Survey
PZ-104-SD	1067054.135	837009.268	483.751	481.474	236.368	246.498	236.698	EMSI 2012 Survey
PZ-104-SS	1067068.815	837021.987	483.596	481.648	336.528	346.658	336.858	EMSI 2012 Survey
PZ-105-SS	1066462.138	836405.054	483.635	480.805	332.188	342.318	332.518	EMSI 2012 Survey
PZ-106-KS	1066744.652	835606.899	464.324	462.143	87.468	97.618	87.798	EMSI 2012 Survey
PZ-106-SD	1066755.685	835590.703	463.435	461.418	260.118	270.258	260.458	EMSI 2012 Survey
PZ-106-SS	1066767.07	835574.642	462.704	460.952	295.118	305.248	295.448	EMSI 2012 Survey
PZ-107-SS	1067204.044	835429.345	465.003	462.852	359.498	369.628	359.828	EMSI 2012 Survey
PZ-108-SS	1067719.34	836147.31	455.798	453.698	310.038	320.178	310.368	Golder 1996

Table 3-1b: Summary of All Current Wells—Survey Data
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Well ID	Northing (ft)	Easting (ft)	Measuring Point Elevation (ft amsl)	Ground Surface Elevation (ft amsl)	Bottom Elev (ft amsl)	Top Screen Elevation (ft amsl)	Bottom Screen Elevation (ft amsl)	Survey Source
PZ-109-SS	1068052.306	836318.498	458.8977	456.8957	320.538	330.668	320.868	EMSI 2012 Survey
PZ-110-SS	1068376.97	836094.3	461.0591	458.0299	345.138	355.538	345.738	EMSI 2012 Survey
PZ-111-KS	1068661.958	836025.206	465.3987	461.3366	91.478	101.628	91.818	EMSI 2012 Survey
PZ-111-SD	1068678.166	836009.004	466.1727	461.9501	249.318	259.418	249.618	EMSI 2012 Survey
PZ-111-SS	1068631.93	835989.4	464.228	461.708	NA	NA	NA	Feezor 2017
PZ-112-AS*	1069042.848	835849.449	462.132	458.41	422.798	427.928	423.128	EMSI 2012 Survey
PZ-113-AD	1069273.97	835934.5	461.835	459.467	350.728	360.858	351.058	EMSI 2012 Survey
PZ-113-AS	1069264.97	835922.4	461.783	459.58	420.488	430.618	420.818	EMSI 2012 Survey
PZ-113-SS	1069282.97	835951.3	462.255	459.654	300.858	310.988	301.188	EMSI 2012 Survey
PZ-114-AS	1069459.999	836942.992	451.739	449.564	419.348	429.478	419.678	EMSI 2012 Survey
PZ-115-SS	1069449.628	836929.871	452.497	450.213	365.398	375.528	365.728	EMSI 2012 Survey
PZ-116-SS	1066451.146	836018.584	486.038	483.548	321.338	331.268	331.668	EMSI 2012 Survey
PZ-1201-SS	1067343.39	837078.26	482.018	479.998	229.998	342.308	332.708	Golder 1996
PZ-200-SS	1068537.089	837146.557	485.828	483.548	385.238	473.588	385.568	EMSI 2012 Survey
PZ-201A-SS	1067872.76	837021.163	481.928	479.87	387.818	397.948	388.148	EMSI 2012 Survey
PZ-201-SS	1067860.52	837036.76	479.928	477.598	388.968	467.858	389.298	Golder 1996
PZ-202-SS	1067361.152	837276.124	481.416	479.474	389.178	438.408	389.508	EMSI 2012 Survey
PZ-203-SS	1066702.372	836782.546	486.783	484.123	374.078	384.178	374.378	EMSI 2012 Survey
PZ-204A-SS	1066470.424	835731.272	464.8759	464.8759	376.828	386.758	377.158	EMSI 2012 Survey
PZ-204-SS	1066470.424	835731.272	464.8759	464.8759	376.948	455.678	377.278	EMSI 2012 Survey
PZ-205-AS	1067504.507	835637.878	460.482	458.538	410.248	420.378	410.578	EMSI 2012 Survey
PZ-205-SS	1067524.521	835652.192	461.872	459.616	360.428	370.558	360.758	EMSI 2012 Survey
PZ-206-SS	1068071.821	835984.015	460.3876	458.1918	332.978	342.978	333.178	EMSI 2012 Survey
PZ-207-AS	1069685.45	836212.47	462.244	460.156	421.448	426.578	421.778	EMSI 2012 Survey
PZ-208-SS	1069260.125	837344.084	474.791	472.48	373.298	383.428	373.628	EMSI 2012 Survey

Table 3-1b: Summary of All Current Wells—Survey Data
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Well ID	Northing (ft)	Easting (ft)	Measuring Point Elevation (ft amsl)	Ground Surface Elevation (ft amsl)	Bottom Elev (ft amsl)	Top Screen Elevation (ft amsl)	Bottom Screen Elevation (ft amsl)	Survey Source
PZ-209-SD	1067116.709	837279.115	489.178	486.838	236.838	246.838	236.838	H&A As-Built
PZ-209-SS	1067112.511	837283.267	489.278	486.988	336.988	346.988	336.988	H&A As-Built
PZ-210-SD	1066865.005	836947.817	486.598	484.078	236.078	246.078	236.078	H&A As-Built
PZ-210-SS	1066869.351	836952.107	486.498	484.128	336.128	346.128	336.128	H&A As-Built
PZ-211-SD	1067097.668	837191.308	487.058	484.428	237.428	347.428	237.428	H&A As-Built
PZ-211-SS	1067101.755	837195.851	487.008	484.658	337.658	347.658	337.658	H&A As-Built
PZ-212-SD	1067536.663	838155.084	482.318	480.078	235.078	246.078	236.078	H&A As-Built
PZ-212-SS	1067531.957	838151.155	482.388	479.758	329.758	345.758	335.758	H&A As-Built
PZ-300-AD	1065254.81	834002.76	449.218	447.698	405.498	410.598	405.798	Golder 1996
PZ-300-AS	1065539.41	834042.53	450.258	448.098	428.098	438.198	428.398	Golder 1996
PZ-300-SS	1065245.72	834024.51	449.198	447.998	353.998	364.118	354.298	Golder 1996
PZ-301-SS	1064842.65	835691.69	514.308	512.698	351.698	361.798	351.998	Golder 1996
PZ-302-AI	1067250.868	834895.669	451.194	449.771	406.898	416.998	407.198	EMSI 2012 Survey
PZ-302-AS	1067238.22	834912.693	451.572	449.355	426.798	436.898	427.098	EMSI 2012 Survey
PZ-303-AS	1067703.94	834600.481	453.277	451.04	424.298	434.398	424.598	EMSI 2012 Survey
PZ-304-AI	1068166.325	834609.398	454.151	451.756	402.098	412.198	402.398	EMSI 2012 Survey
PZ-304-AS	1068187.019	834609.304	453.89	451.731	423.798	433.898	424.098	EMSI 2012 Survey
PZ-305-AI	1068119.659	835797.892	459.9808	458.0891	393.898	403.998	394.198	EMSI 2012 Survey
S-1	1069726.8	834379.71	446.108	442.898	417.898	440.398	420.398	McLaren Hart 1996
S-10*	1069868.787	835106.242	480.1	477.603	422.598	445.098	425.098	EMSI 2012 Survey
S-5*	1069196.97	836075.6	466.225	463.022	415.998	435.298	425.298	EMSI 2012 Survey
S-51	1066202.28	834495.42	449.168	445.898	420.098	423.098	420.098	McLaren Hart 1996
S-52	1066510.97	834374.7	446.678	444.298	419.098	422.098	419.098	EMSI 2018—Calculated
S-53	1066911.169	834671.966	444.099	441.041	420.698	423.698	420.698	EMSI 2012 Survey
S-54	1067646.97	834642.7	NA	469.598	NA	NA	NA	EMSI 2018

Table 3-1b: Summary of All Current Wells—Survey Data
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Well ID	Northing (ft)	Easting (ft)	Measuring Point Elevation (ft amsl)	Ground Surface Elevation (ft amsl)	Bottom Elev (ft amsl)	Top Screen Elevation (ft amsl)	Bottom Screen Elevation (ft amsl)	Survey Source
S-60	1069790.97	834484.7	446.528	442.698	421.698	NA	421.698	EMSI 2018—Calculated
S-61	1070200.944	834754.559	449.202	445.496	423.698	NA	423.698	EMSI 2012 Survey
S-75	1067291.38	834893.45	461.678	458.398	432.398	435.398	432.398	McLaren Hart 1996
S-76	1067446.97	834743.7	NA	473.998	NA	NA	NA	EMSI 2018
S-8	1071085.014	834898.674	443.9346	441.5499	411.898	434.398	414.398	EMSI 2012 Survey
S-80	1065232.74	834033.05	452.708	447.998	425.998	437.998	427.998	McLaren Hart 1996
S-82*	1069352.643	834447.496	450.113	448.172	420.798	431.798	421.798	EMSI 2012 Survey
S-84	1069674.22	836614.269	457.044	454.24	420.998	431.598	421.598	EMSI 2012 Survey
S-88	1068439.36	835408.73	462.358	459.598	418.098	429.598	419.598	McLaren Hart 1996

Notes:

Coordinate system updated to NAD83 State Plane Missouri East using conversion in Work Plan

* = Monitoring well may be in the footprint of OU-1 removal activities and potentially scheduled for future decommissioning.

Abbreviations:

amsl = above mean sea level
D = Deep
EMSI = Environmental Management Support, Inc
ft = feet
F = Foth
I = Intermediate
LR = Leachate Riser
MDNR = Missouri Department of Natural Resources
MW = Monitoring Well
NA = Not available
PZ = Piezometer
S = Shallow

Table 3-1c: Summary of All Current Wells—Proposed OU-3 Monitoring Network
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Well ID	Current Monitoring Status	Proposed OU-3 Monitoring Status	Proposed Transducer Install
D-12*	Inactive	X	
D-13*	Inactive	X	
D-14	Abandoned		
D-3*	Inactive	X	
D-6*	Inactive	X	
D-81	Inactive	X	
D-83*	Inactive	X	X
D-85	Active	X	
D-87	Inactive	X	
D-89	Inactive	X	
D-90	Abandoned		
D-91	Abandoned		
D-92	Abandoned		
D-93*	Inactive	X	X
D-94	Abandoned		
D-95	Abandoned		
F-1-D	Abandoned		
F-1-S	Abandoned		
F-2	Abandoned		
F-3	Abandoned		
I-11*	Inactive	X	
I-2	Abandoned		
I-4	Inactive		
I-50	Abandoned		
I-55	Abandoned		

Table 3-1c: Summary of All Current Wells—Proposed OU-3 Monitoring Network
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Well ID	Current Monitoring Status	Proposed OU-3 Monitoring Status	Proposed Transducer Install
I-56	Abandoned		
I-58	Abandoned		
I-59	Abandoned		
I-62*	Inactive	X	X
I-65	Inactive	X	
I-66	Inactive	X	
I-67	Inactive	X	
I-68	Active	X	
I-7	Unknown		
I-72	Abandoned		
I-73	Active	X	
I-9*	Inactive	X	X
LR-100	Inactive	X	
LR-101	Abandoned		
LR-102	Abandoned		
LR-103	Inactive		
LR-104	Inactive		
LR-105	Inactive		
MO-3-SDR	Inactive	X	
MO-3-SS	Inactive	X	
MW-101	Abandoned		
MW-102	Abandoned		
MW-103	Inactive	X	
MW-104	Inactive	X	
MW-105	Abandoned		

Table 3-1c: Summary of All Current Wells—Proposed OU-3 Monitoring Network
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Well ID	Current Monitoring Status	Proposed OU-3 Monitoring Status	Proposed Transducer Install
MW-106	Abandoned		
MW-107	Abandoned		
MW-1201	Inactive		
MW-1202	Abandoned		
MW-1203	Abandoned		
MW-1204	Active	X	
MW-1205	Abandoned		
MW-1206	Abandoned		
MW-41	Abandoned		
PZ-100-KS	Active	X	X
PZ-100-SD	Active	X	X
PZ-100-SS	Active	X	X
PZ-101-SS	Active	X	X
PZ-102R-SS	Active	X	
PZ-102-SS	Active	X	
PZ-103-SS	Active	X	
PZ-104-KS	Active	X	
PZ-104-SD	Active	X	
PZ-104-SS	Active	X	
PZ-105-SS	Active	X	
PZ-106-KS	Active	X	
PZ-106-SD	Active	X	
PZ-106-SS	Active	X	
PZ-107-SS	Active	X	
PZ-108-SS	Abandoned		

Table 3-1c: Summary of All Current Wells—Proposed OU-3 Monitoring Network
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Well ID	Current Monitoring Status	Proposed OU-3 Monitoring Status	Proposed Transducer Install
PZ-109-SS	Active	X	
PZ-110-SS	Inactive		
PZ-111-KS	Active	X	X
PZ-111-SD	Active	X	X
PZ-111-SS	Active	X	X
PZ-112-AS*	Active	X	
PZ-113-AD	Active	X	X
PZ-113-AS	Active	X	X
PZ-113-SS	Active	X	X
PZ-114-AS	Active	X	
PZ-115-SS	Active	X	
PZ-116-SS	Active	X	
PZ-1201-SS	Abandoned		
PZ-200-SS	Active	X	
PZ-201A-SS	Active	X	
PZ-201-SS	Abandoned		
PZ-202-SS	Active	X	X
PZ-203-SS	Active	X	
PZ-204A-SS	Active	X	
PZ-204-SS	Active	X	
PZ-205-AS	Active	X	X
PZ-205-SS	Active	X	X
PZ-206-SS	Active	X	
PZ-207-AS	Active	X	
PZ-208-SS	Active	X	

Table 3-1c: Summary of All Current Wells—Proposed OU-3 Monitoring Network
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Well ID	Current Monitoring Status	Proposed OU-3 Monitoring Status	Proposed Transducer Install
PZ-209-SD	Active	X	X
PZ-209-SS	Active	X	X
PZ-210-SD	Active	X	
PZ-210-SS	Active	X	
PZ-211-SD	Active	X	X
PZ-211-SS	Active	X	X
PZ-212-SD	Active	X	
PZ-212-SS	Active	X	
PZ-300-AD	Abandoned		
PZ-300-AS	Abandoned		
PZ-300-SS	Abandoned		
PZ-301-SS	Abandoned		
PZ-302-AI	Inactive	X	
PZ-302-AS	Inactive	X	
PZ-303-AS	Inactive	X	
PZ-304-AI	Inactive	X	X
PZ-304-AS	Inactive	X	X
PZ-305-AI	Inactive		
S-1	Abandoned		
S-10*	Inactive	X	
S-5*	Inactive	X	
S-51	Abandoned		
S-52	Abandoned		
S-53	Inactive	X	
S-54	Abandoned		

Table 3-1c: Summary of All Current Wells—Proposed OU-3 Monitoring Network
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Well ID	Current Monitoring Status	Proposed OU-3 Monitoring Status	Proposed Transducer Install
S-60	Abandoned		
S-61	Abandoned		
S-75	Abandoned		
S-76	Abandoned		
S-8	Inactive	X	X
S-80	Abandoned		
S-82*	Inactive	X	X
S-84	Active	X	
S-88	Abandoned		

Notes: 25

* = Monitoring well may be in the footprint of OU-1 removal activities and potentially scheduled for future decommissioning.

Abbreviations:
D = Deep
F = Foth
I = Intermediate
LR = Leachate Riser
MW = Monitoring Well
PZ = Piezometer
S = Shallow

Table 3-2: Summary of Proposed New Wells and Construction Details
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Location	Well ID	Port Number	Zone	Well Location Rationale	Well Construction
Perimeter Wells	MW-213	1	Alluvium	Data gap - no shallow alluvial wells at I-67	4-in PVC CHS multi-screen well
		2			
	MW-302	NA	Alluvium	Data gap - no deep alluvial wells at PZ-302 cluster	2-in PVC single screen well
	MW-303	1	Alluvium	Data gap - no intermediate or deep alluvial wells at PZ-303 cluster	4-in PVC CHS multi-screen well
		2			
	MW-304	1	Alluvium	Data gap - further assess extent of observed COPCs in PZ-304 shallow and intermediate wells	4-in PVC CHS multi-screen well
		2	Bedrock	Data gap - no deep or bedrock wells at PZ-304 cluster	
		3			
	MW-306	1	Alluvium	Data gap - further assess extent of observed COPCs at MW-103	4-in PVC CHS multi-screen well
		2			
	MW-400	1	Alluvium	Area 2 perimeter well, further assess extent of observed COPCs at D-6	4-in PVC CHS multi-screen well
		2			
		3			
		4	Bedrock		
		5			
	MW-401	1	Alluvium	Area 2 perimeter well, further assess extent of observed COPCs at D-83	4-in PVC CHS multi-screen well
		2			
		3			
	MW-402	1	Alluvium	Area 2 perimeter well, further assess extent of observed COPCs at D-13	4-in PVC CHS multi-screen well
		2			
		3			
	MW-403	1	Alluvium	Data gap - Area 2 perimeter well, replace nearby well I-65	4-in PVC CHS multi-screen well
		2			
		3			
	MW-404	1	Alluvium	Area 2 perimeter well, further assess extent of observed COPCs at S-82, I-9 and D-93	4-in PVC CHS multi-screen well
		2			
		3			
		4	Bedrock		
		5			
	MW-405	1	Alluvium	Data gap - Area 2 perimeter well	4-in PVC CHS multi-screen well
		2			
		3			
	MW-406	1	Alluvium	Data gap - Area 2 perimeter well	4-in PVC CHS multi-screen well
		2			
		3			
		4	Bedrock		
		5			
	MW-407	1	Alluvium	Data gap - Area 2 perimeter well	4-in PVC CHS multi-screen well
		2			
		3			

Table 3-2: Summary of Proposed New Wells and Construction Details
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Location	Well ID	Port Number	Zone	Well Location Rationale	Well Construction
Downgradient	MW-500	1	Alluvium	Evaluate nature and extent of impacts off-site and regional gradients	4-in PVC CHS multi-screen well
		2			
		3			
		4	Bedrock		
		5			
	MW-501	1	Alluvium	Evaluate nature and extent of impacts off-site and regional gradients	4-in PVC CHS multi-screen well
		2			
		3			
	MW-502	1	Alluvium	Evaluate nature and extent of impacts off-site and regional gradients	4-in PVC CHS multi-screen well
		2			
		3			
		4	Bedrock		
		5			
	MW-503	1	Alluvium	Evaluate nature and extent of impacts off-site and regional gradients	4-in PVC CHS multi-screen well
		2			
		3			
	MW-504	1	Alluvium	Evaluate nature and extent of impacts off-site and regional gradients	4-in PVC CHS multi-screen well
		2			
		3			
	MW-505	1	Alluvium	Evaluate nature and extent of impacts off-site and regional gradients	4-in PVC CHS multi-screen well
		2			
		3			
Background	MW-600	1	Alluvium	Evaluate background alluvial groundwater quality	4-in PVC CHS multi-screen well
		2			
		3			
	MW-601	1	Alluvium	Evaluate background alluvial groundwater quality	4-in PVC CHS multi-screen well
		2			
		3			
	MW-602	1	Alluvium	Evaluate background alluvial and bedrock groundwater quality	4-in PVC CHS multi-screen well
		2			
		3			
		4	Bedrock		
		5			
	MW-603	1	Bedrock	Evaluate background bedrock groundwater quality	4-in PVC CHS multi-screen well
		2			
	MW-604	1	Bedrock	Evaluate background bedrock groundwater quality	4-in PVC CHS multi-screen well
		2			
	MW-605	1	Bedrock	Evaluate background bedrock groundwater quality	4-in PVC CHS multi-screen well
		2			

Table 3-2: Summary of Proposed New Wells and Construction Details
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

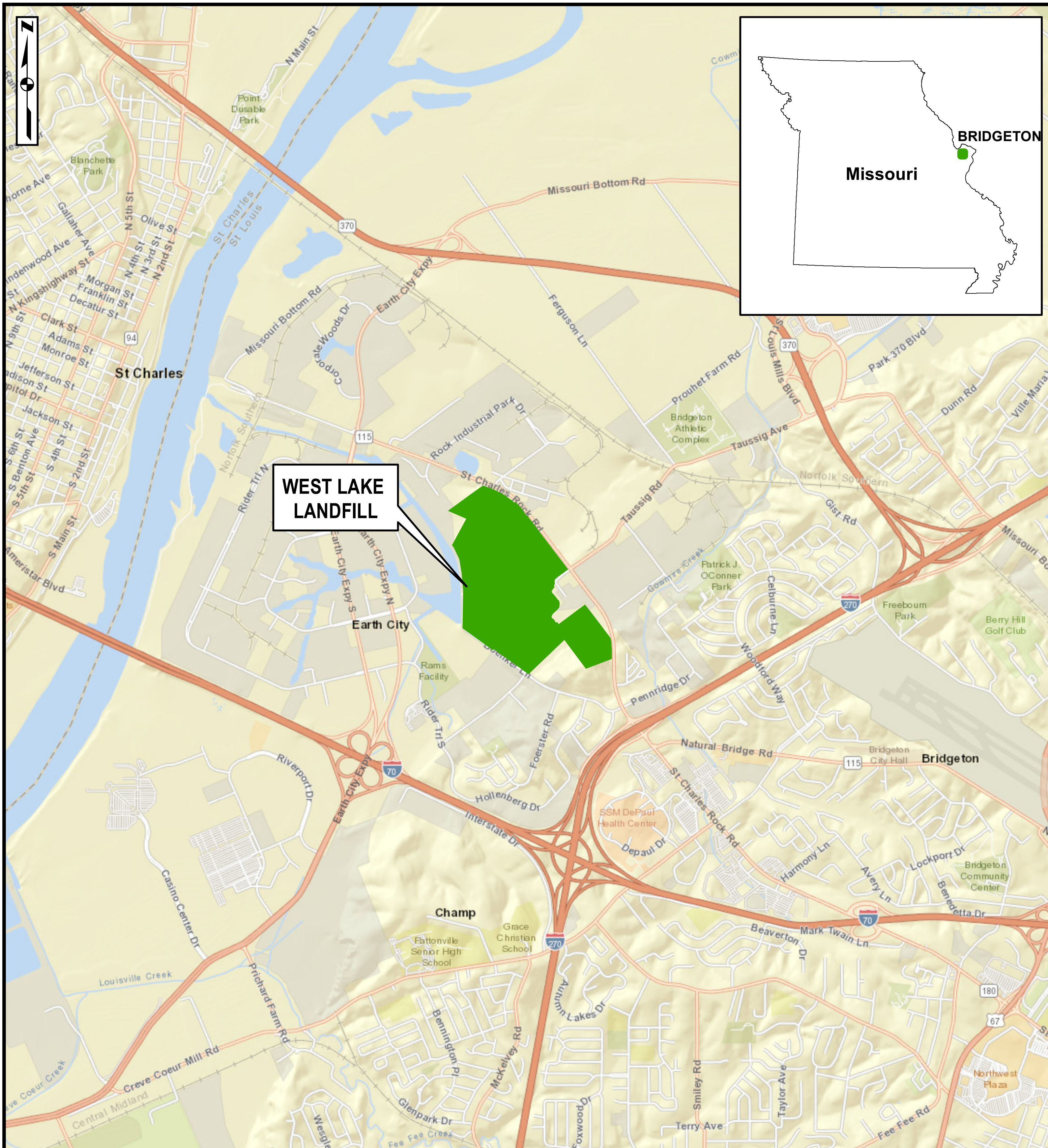
Location	Well ID	Port Number	Zone	Well Location Rationale	Well Construction
Piezometers	PZ-700	NA	Alluvium	Model calibration	2-in PVC single screen well
	PZ-701	NA	Alluvium	Model calibration	2-in PVC single screen well
	PZ-702	NA	Alluvium	Model calibration	2-in PVC single screen well
	PZ-703	NA	Alluvium	Model calibration	2-in PVC single screen well
	PZ-704	NA	Alluvium	Model calibration	2-in PVC single screen well
Infill	MW-111	1	Alluvium	Data gap - no alluvial wells at PZ-111 cluster	4-in PVC CHS multi-screen well
		2			
		3			
	MW-113	NA	Bedrock	Data gap - no deep bedrock well at PZ-113 cluster	2-in PVC single screen well
	MW-205	NA	Bedrock	Data gap - no deep bedrock well at PZ-205 cluster	2-in PVC single screen well

Note:
CHS = Cased Hole Sampler by FLUTe™
COPCs = Constituents of Potential Concern
in = inch
NA = Not applicable
PVC = Polyvinyl chloride
This table summarizes the wells that are currently proposed to be installed during the initial phase of the OU-3 Remedial Investigation.
The need for additional step-in/step-out or background drilling locations will be evaluated throughout the high-resolution characterization program.

Table 3-3: Proposed Geophysical Logging Methods
West Lake Landfill OU-3
Remedial Investigation/Feasibility Study
Field Sampling Plan

Geophysical Method	Targeted Aquifer Zone	Data Acquisition Considerations Pertinent to OU-3	Physical Property Measured/Observed	Derrived Hydrogeologic Properties
Nuclear Magnetic Resonance	Alluvium and bedrock	Consolidated materials or non-metallic cased wells; Borehole diameter a minimum 2-inch smaller than tool sensitive shel Proximal sources of background electromagnetic noise; Soils with high iron content (magnetite)	Effect of magnetic fields on hydrogen molecules in pore fluid; hydrogen index, translational spin echo (T2) decays, fluid diffussivity	Total porosity, pore size distribution (mobile/capilary bound/clay bound porosity), hydraulic conductivity, transmissivity, lithology, residual water saturation (vadose zone)
Dual Induction	Alluvium and bedrock	Consolidated materials or non-metallic cased wells; Borehole diameter less than 10-inch preferred	Bulk conductivity of matrix and pore fluid	Lithology, pore fluid chemistry (TDS)
Natural Gamma	Alluvium and bedrock	Consolidated materials or non-metallic cased wells; borehole diameter less than 10-inch preferred	Gamma radiation eminating from bulk formation materials	Lithology, presence of anthropogenic gamma emitting radionuclides
Spectral Gamma	Alluvium and bedrock	Consolidated materials or non-metallic cased wells; borehole diameter less than 10-inch preferred	Natral gamma energy spectra from uranium, thorium, potassium-40 and anthropogenic radioactive isotopes	Identify and quantify the amount of uranium, thorium, and potassium-40 isotopes in boreholes from natural or anthropogenic sources
Caliper	Bedrock	Consolidated materials; open borehole	Borehole diameter deviations	Stability of borehole, presence of washouts, location of fractures
Fluid Temperature/Resistivity	Bedrock	Consolidated materials; open, fluid-filled boreholes	Vertical profile of borehole fluid temperature and electrical resistivity	Intervals of groundwater fluid moving into or out of borehole (e.g., open fractures)
Optical Televiewer	Bedrock	Consolidated materials; open boreholes; cased wells; non-turbid fluid in borehole	Optical image of borehole wall or casing interior	Identify lithologic bedding and contacts, fractures, fracture aperature and orientation; Identify well construction and integrity (run in well casing)
Acoustic Televiewer	Bedrock	Consolidated materials; fluid-filled open boreholes; cased wells	Acoustic image of borehole wall or casing interior using ultrasonic pulses	Identify lithologic bedding and contacts, fractures, fracture aperature and orientation; Identify well construction and integrity (run in well casing)
Corehole Dynamic Flowmeter	Bedrock	Consolidated materials; fluid-filled open boreholes	Ambient vertical flow in borehole or well screen; vertical flow in borehole while pumping	Identify intervals of groundwater flow into or out of the borehole; quantify flow volumes from yielding intervals; estimate hydraulic conductivity of yielding intervals or fractures; identify and quantify ambient flow under vertical gradients; aquifer hydraulic conductivity from short-term aquifer pumping test
Downhole Discrete-Point Sampler	Bedrock	Consolidated materials; fluid-filled open boreholes; screen intervals of cased wells	Descrete depth water sample	Water quality associated with identified water-yielding intervals

FIGURES



Legend

Landfill Property Extent

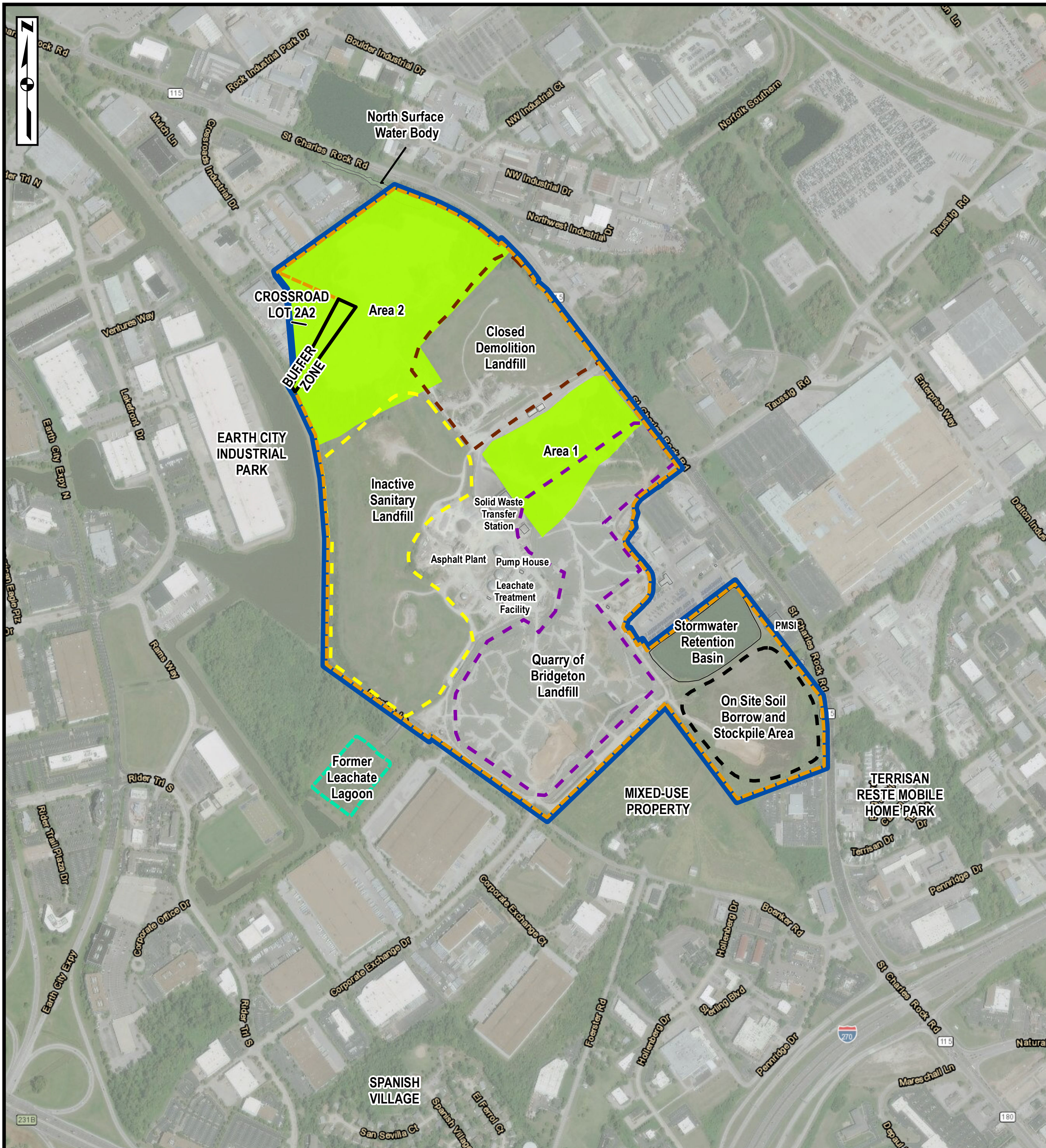
0 0.5 1
Miles

Figure 1-1: Site Location

Remedial Investigation/
Feasibility Study
Field Sampling Plan
West Lake Landfill OU-3
Bridgeton, Missouri

ERM

Q:\Boston\Team\DMM\Clients_V_Z\WestLake\WestLakeLandfill_MO\MXD\2020_07_FSP\Figure1-1_SiteLocation.mxd - Sarah.Poulin - 7/28/2020



Legend

- Former Leachate Lagoon
- Landfill Property Boundary
- Superfund Site Boundary
- Operable Unit 1

0 700 1,400

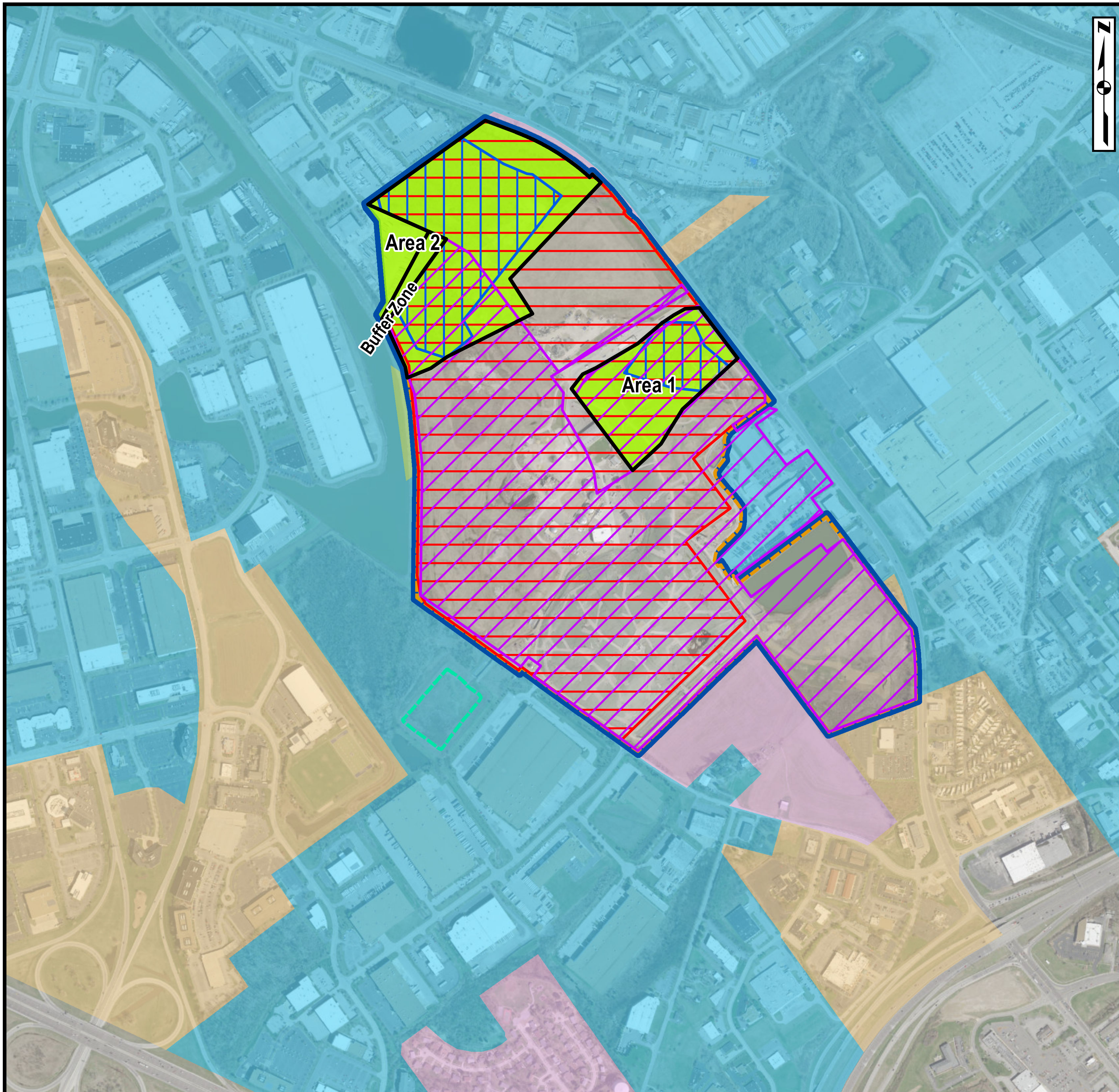
Feet

Figure 1-2: Site Layout

Remedial Investigation/
Feasibility Study
Field Sampling Plan
West Lake Landfill OU-3
Bridgeton, Missouri

ERM

Q:\Boston\Team\DMMV\Clients_V_Z\WestLake\WestLakeLandfill_MO\MXD\2020_07_FSP\Figure1-2_SiteLayout_20201029.mxd - Sarah.Poulin - 10/29/2020



Legend

Restrictive Covenants

- June 1997
- January 1998
- August 2005
- October 2016

Surrounding Land Use

- Commercial/Business
- Industrial
- Non-Urban
- Residential

Site Features

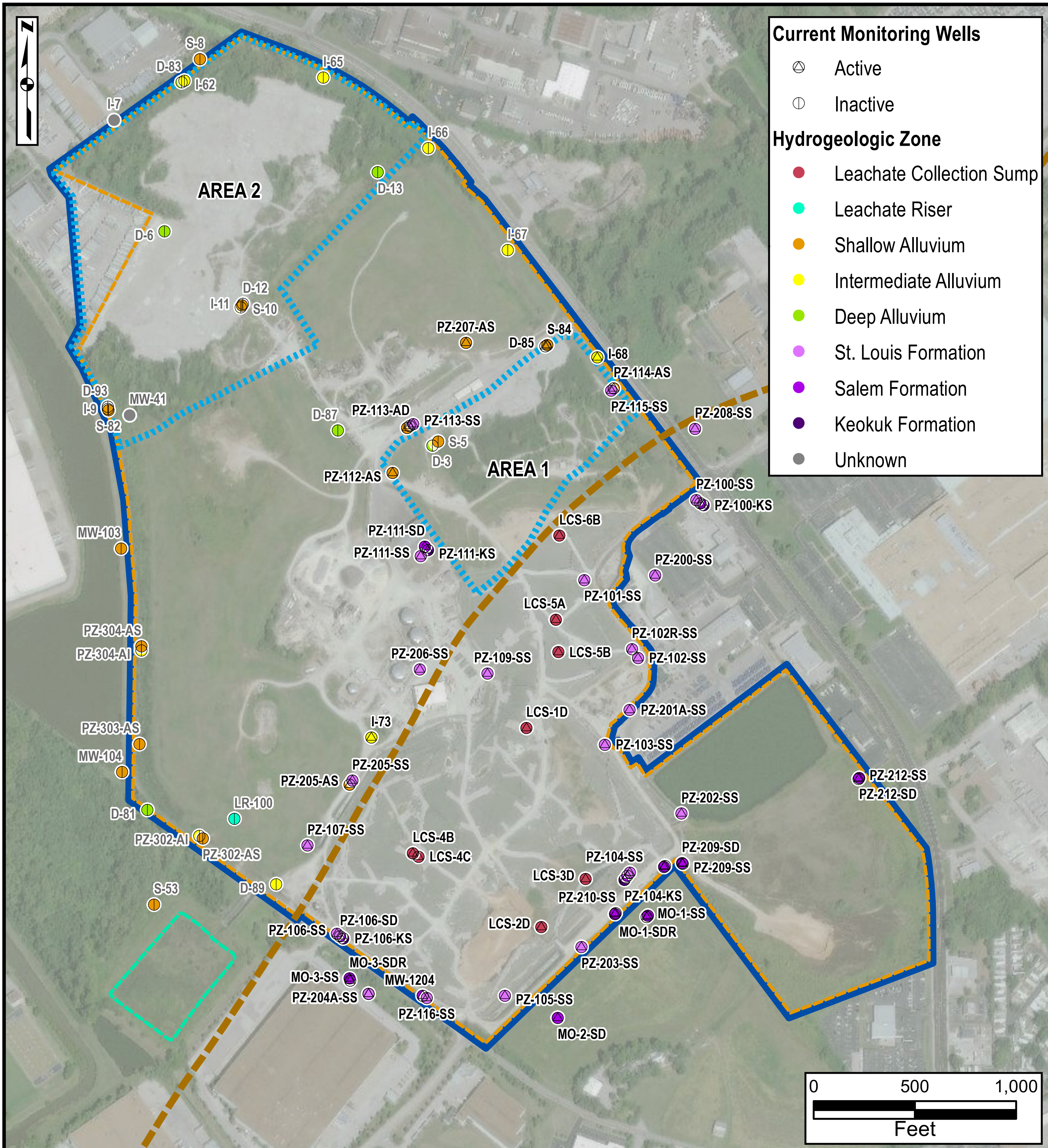
- Landfill Property Boundary
- Operable Unit 1
- Former Leachate Lagoon
- Superfund Site Boundary

0 500 1,000
Feet

Figure 1-3: Land Use Restrictions and Surrounding Land Use

Remedial Investigation/
Feasibility Study
Field Sampling Plan
West Lake Landfill OU-3
Bridgeton, Missouri
August 2020

ERM



Legend

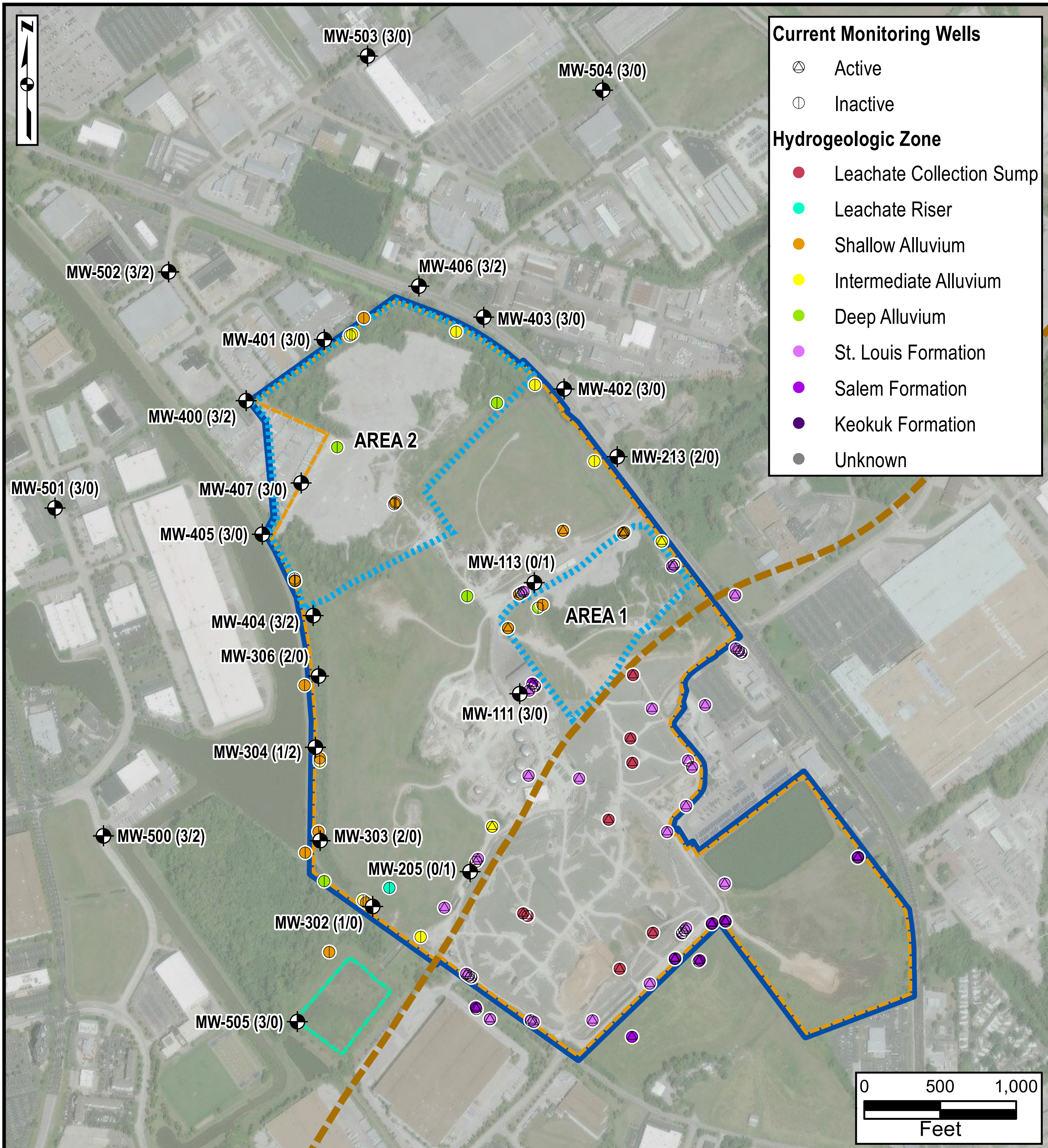
- Edge of Alluvium (approximate)
- OU-1
- Former Leachate Lagoon
- Landfill Property Boundary
- Superfund Site Boundary

Figure 3-1: Current Well Network

Remedial Investigation/
Feasibility Study
Field Sampling Plan
West Lake Landfill OU-3
Bridgeton, Missouri

ERM

Q:\Boston\Team\DMM\Clients_V_Z\WestLake\WestLakeLandfill_MO\MXD\2020_07_FSP\Figure3-1_CurrentWellNetwork_20200731.mxd - Sarah.Poulin - 8/12/2020



Legend

- Proposed Well Location
- Edge of Alluvium (approximate)
- OU-1
- Former Leachate Lagoon
- Landfill Property Boundary
- Superfund Site Boundary

NOTE:
- Numbers in parentheses next to the Well IDs correspond to the number of proposed well screens in the alluvium/bedrock

Figure 3-2: Proposed Well Network
Remedial Investigation/ Feasibility Study
Field Sampling Plan
West Lake Landfill OU-3
Bridgeton, Missouri

ERM

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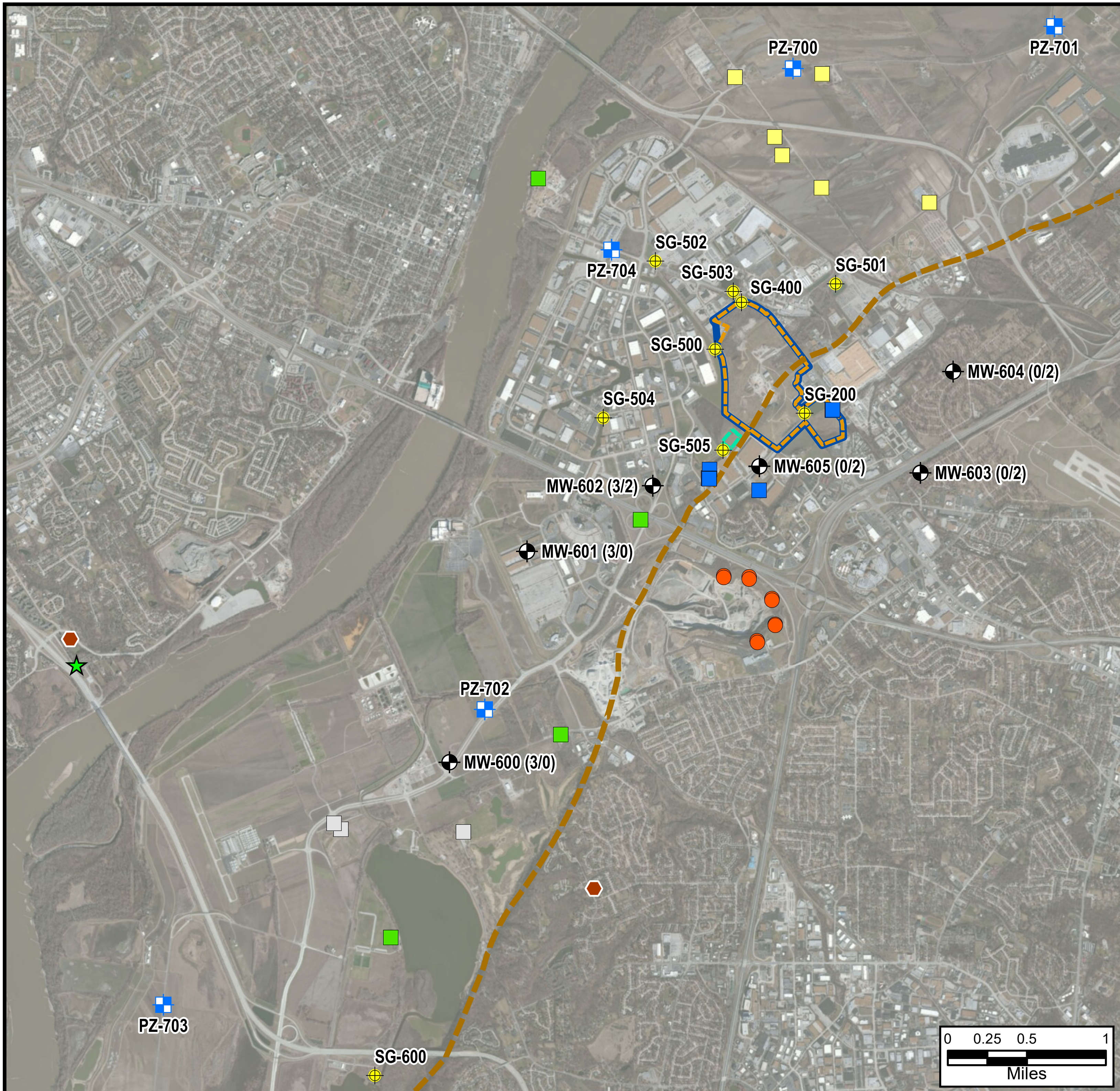


Legend

- Proposed Stilling Well
- Proposed Piezometer
- Proposed Background Monitoring Well
- Edge of Alluvium (approximate)
- Former Leachate Lagoon
- Landfill Property Boundary
- Superfund Site Boundary

USGS Background Data Source

- WLL Respondents 2013 Sample
- USEPA 2013 Alluvial Well Sample
- USGS-RP 2013 Alluvial Well Sample
- USGS-RP 2013 Bedrock Sample
- MDNR Champ Landfill Expansion Sample
- Historical USGS Data
- MDNR Public-Drinking Water Branch

NOTES:

1. Background Locations digitized from USGS 2015
2. Proposed locations tentative
3. Numbers in parentheses next to the Well IDs correspond to the number of proposed well screens in the alluvium/bedrock

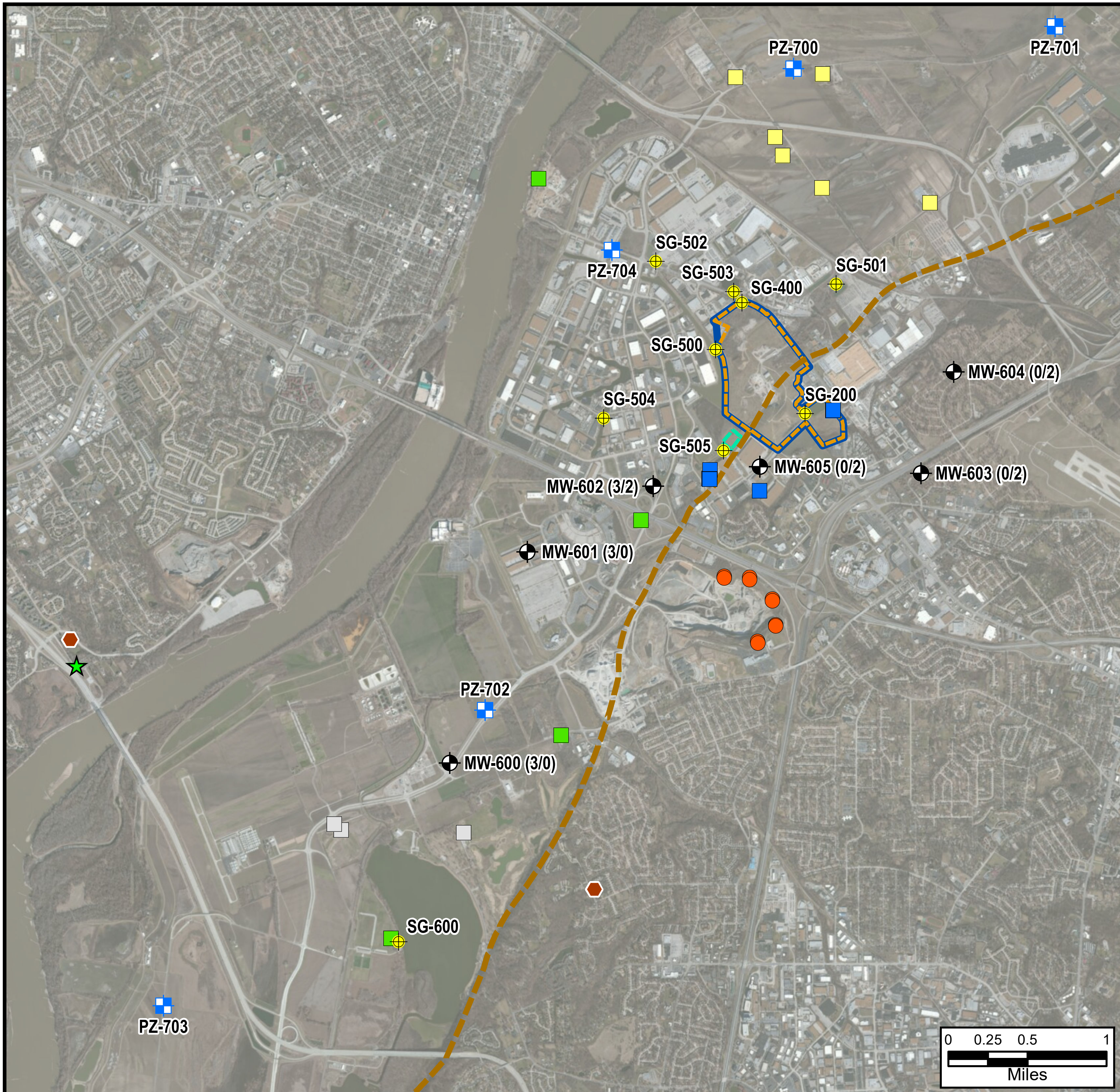
Figure 3-3: Proposed Background Monitoring Wells

Remedial Investigation/ Feasibility Study Field Sampling Plan

West Lake Landfill OU-3
Bridgeton, Missouri
October 2020

ERM

Q:\Boston\Team\DMM\Clients_V_Z\WestLake\WestLakeLandfill_MO\MXD\2020_07_FSP\Figure3-3_BackgroundMW_20200918.mxd - Sarah.Poulin - 10/8/2020



Legend

- Proposed Stilling Well
- Proposed Piezometer
- Proposed Background Monitoring Well
- Edge of Alluvium (approximate)
- Former Leachate Lagoon
- Landfill Property Boundary
- Superfund Site Boundary

USGS Background Data Source

- WLL Respondents 2013 Sample
- USEPA 2013 Alluvial Well Sample
- USGS-RP 2013 Alluvial Well Sample
- USGS-RP 2013 Bedrock Sample
- MDNR Champ Landfill Expansion Sample
- Historical USGS Data
- MDNR Public-Drinking Water Branch

NOTES:

1. Background Locations digitized from USGS 2015
2. Proposed locations tentative
3. Numbers in parentheses next to the Well IDs correspond to the number of proposed well screens in the alluvium/bedrock

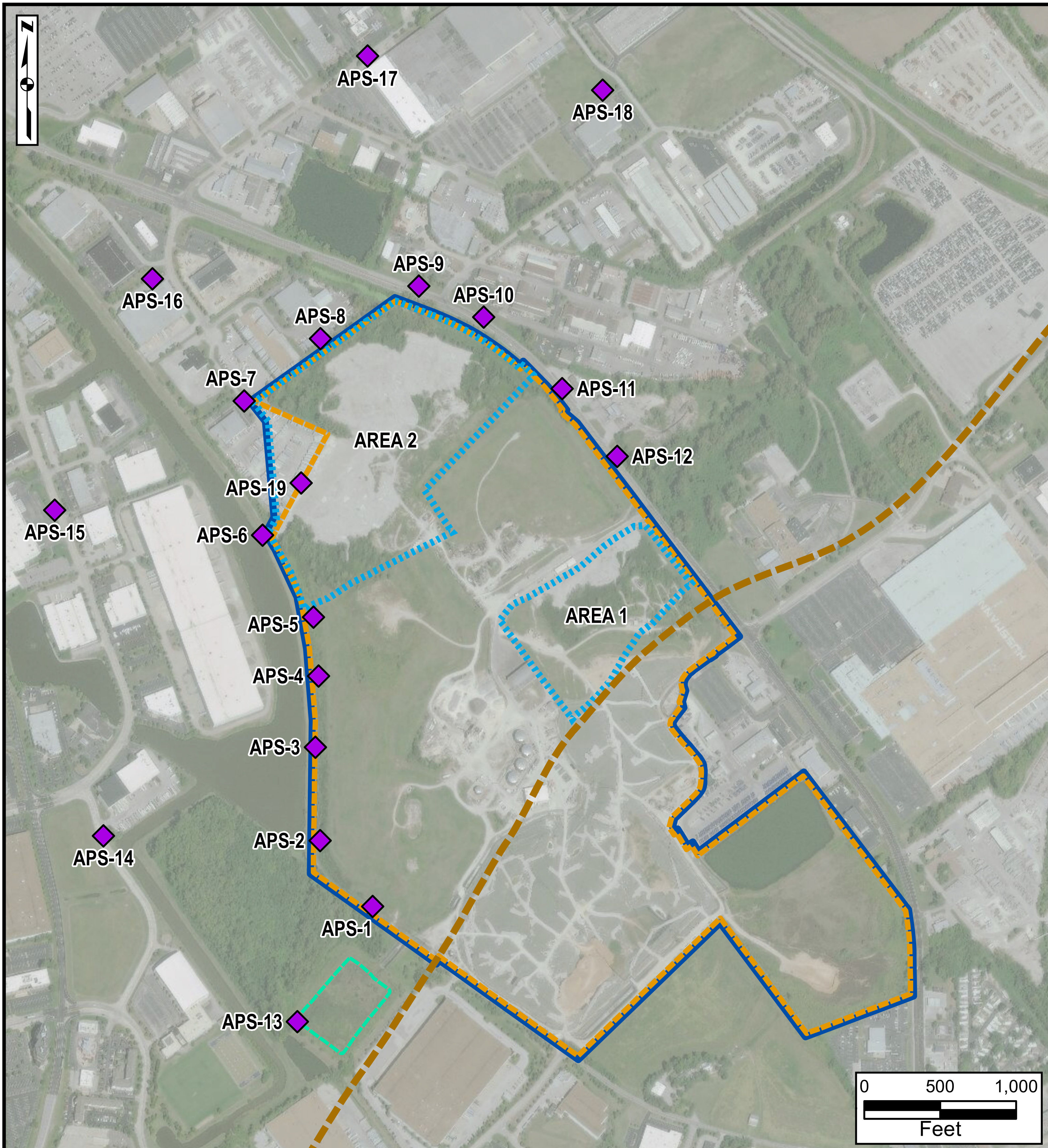
Figure 3-3: Proposed Background Monitoring Wells

Remedial Investigation/ Feasibility Study Field Sampling Plan

West Lake Landfill OU-3
Bridgeton, Missouri
November 2020

ERM

Q:\Boston\Team\DMM\Clients_V_Z\WestLake\WestLakeLandfill_MO\MXD\2020_07_FSP\Figure3-3_BackgroundMW_20200918.mxd - Sarah.Poulin - 11/2/2020



Legend

- WATERLOO APS Sampling Location
- Edge of Alluvium (approximate)
- OU-1
- Former Leachate Lagoon
- Landfill Property Boundary
- Superfund Site Boundary

Figure 3-4: Proposed WATERLOO APS Locations

Remedial Investigation/ Feasibility Study
Field Sampling Plan
West Lake Landfill OU-3
Bridgeton, Missouri

ERM

Q:\Boston\Team\DMMV\Clients_V_Z\WestLake\WestLakeLandfill_MO\MXD\2020_07_FSP\Figure3-4_ProposedAPSLocations_20201109.mxd - Sarah.Poulin - 11/9/2020

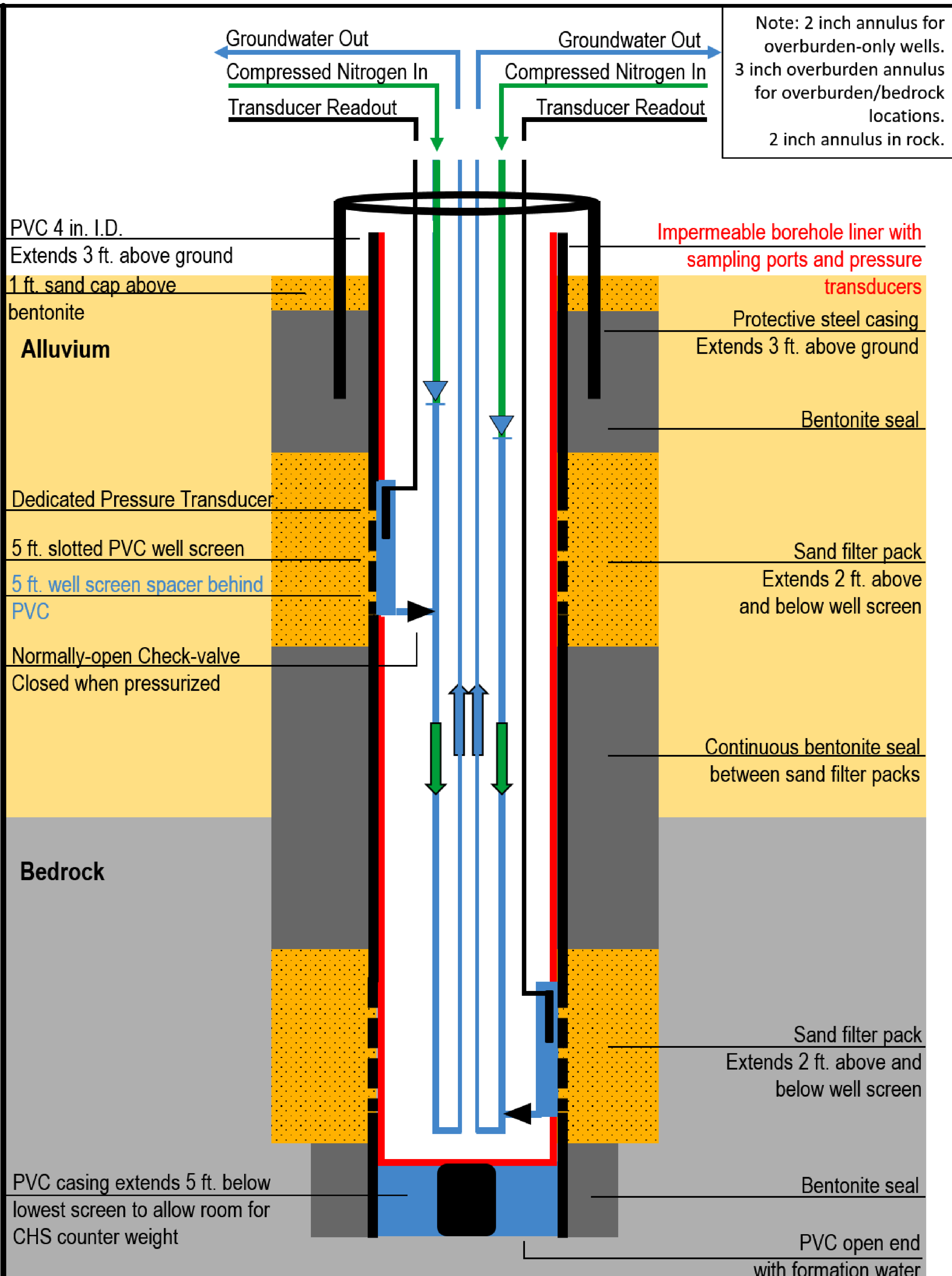


Figure 3-5: CHS Schematic
Remedial Investigation/ Feasibility Study
Field Sampling Plan
West Lake Landfill OU-3
Bridgeton, Missouri

NOTES:
CHS = Cased Hole Sampler

ERM

Q:\BostonTeam\DMM\Clients_V_Z\WestLakeLandfill\WestLakeLandfill_MO\MXD\2020_07_FSP\Figure3-5_CHS_Schematic.mxd - Sarah.Poulin - 8/17/2020

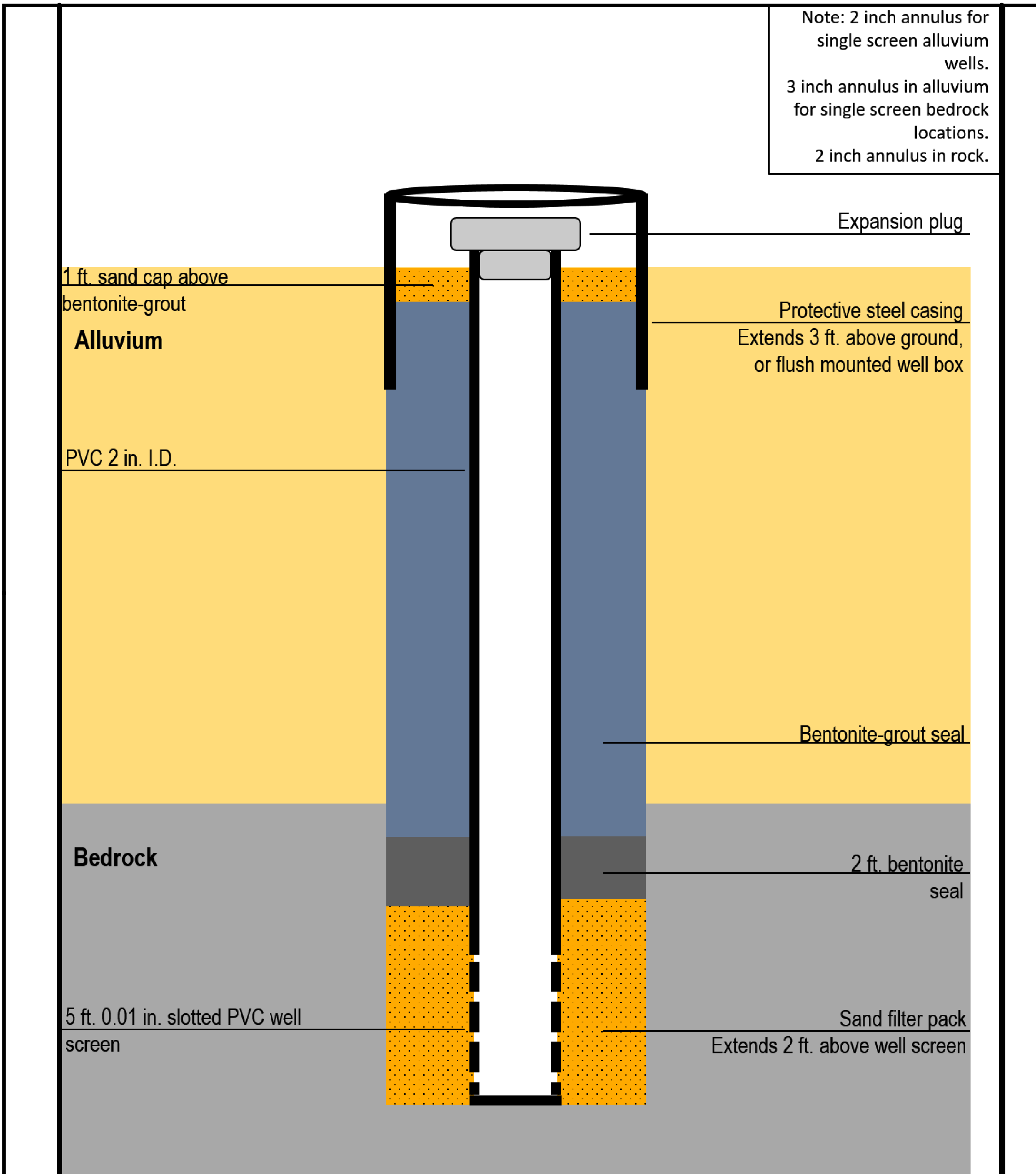


Figure 3-6: Conventional Monitoring Well Schematic

Remedial Investigation/ Feasibility Study

Field Sampling Plan

West Lake Landfill OU-3

Bridgeton, Missouri

ERM

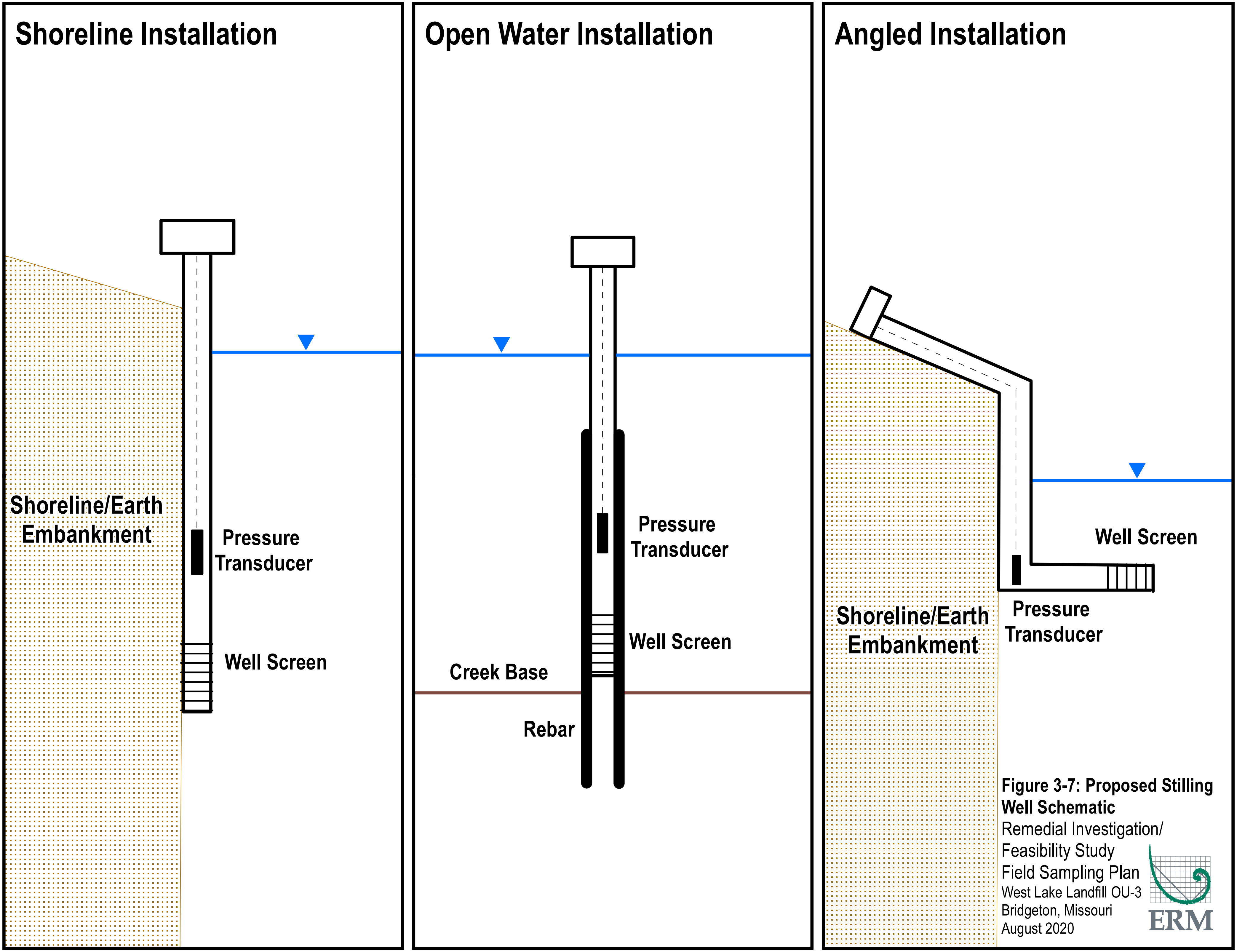
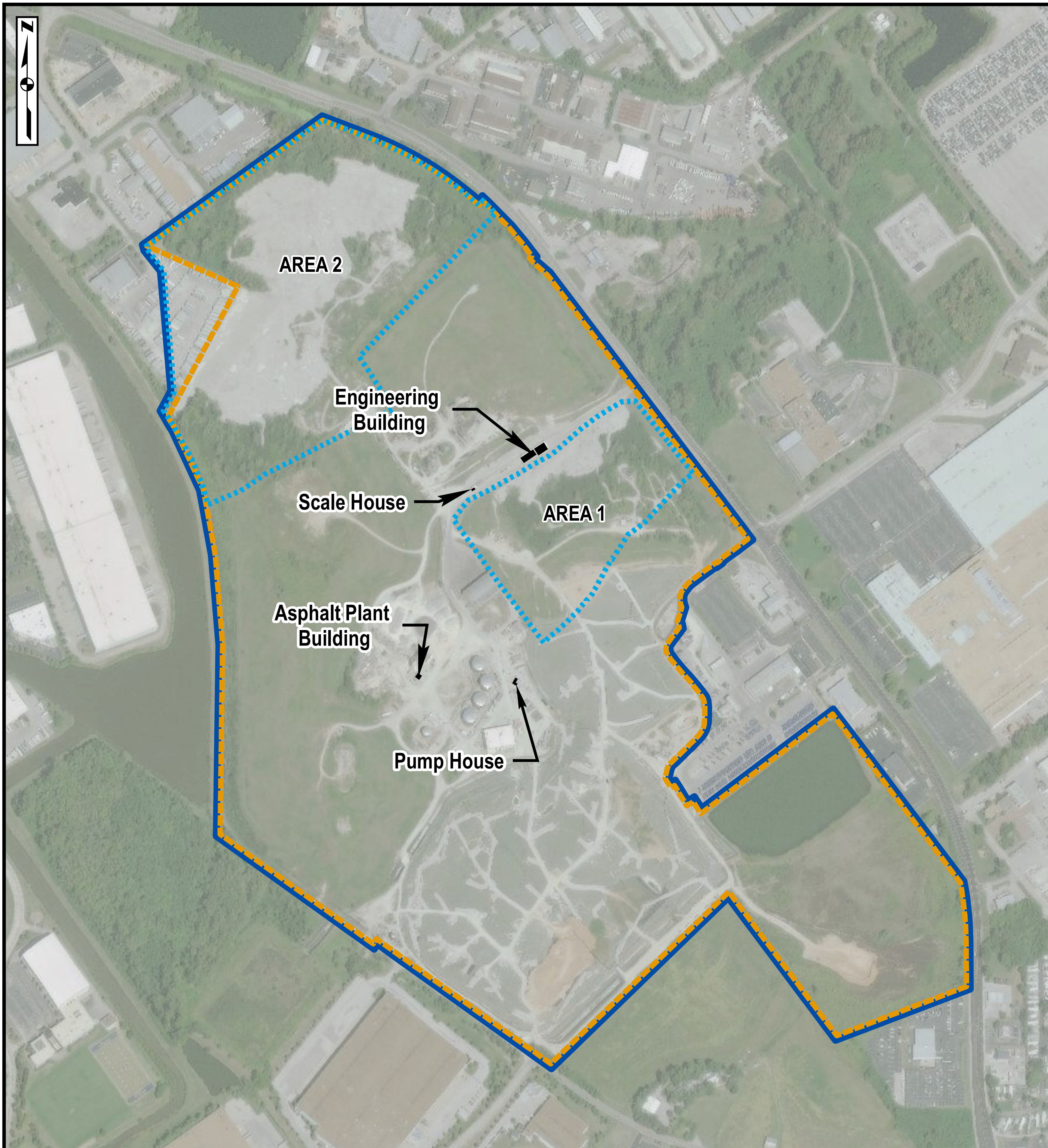


Figure 3-7: Proposed Stilling Well Schematic
Remedial Investigation/ Feasibility Study Field Sampling Plan
West Lake Landfill OU-3
Bridgeton, Missouri
August 2020



Legend

- Building
- OU-1
- Landfill Property Boundary
- Superfund Site Boundary

0 500 1,000
Feet

Figure 3-8: Vapor Investigation

Remedial Investigation/
Feasibility Study
Field Sampling Plan
West Lake Landfill OU-3
Bridgeton, Missouri

ERM

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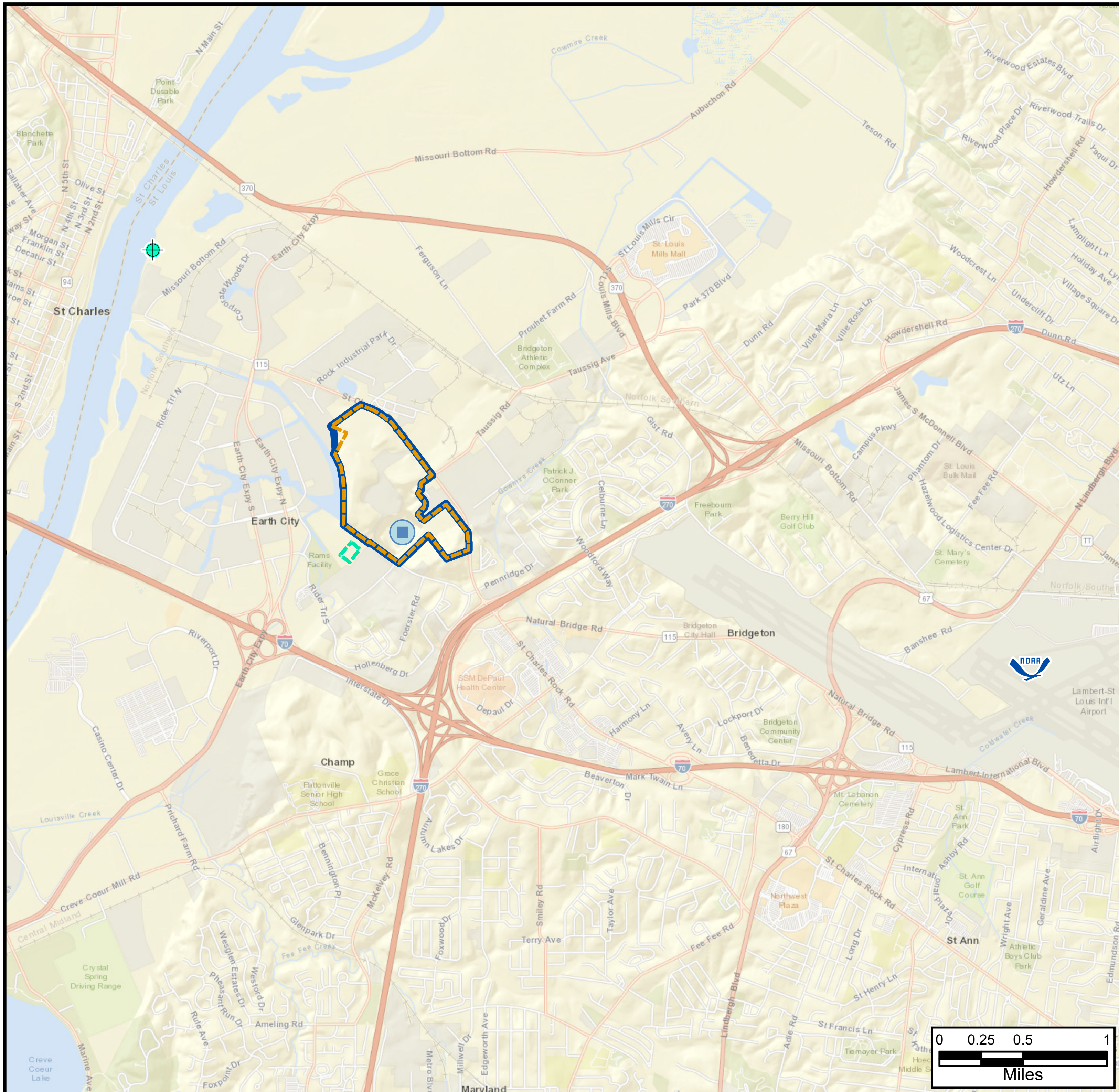

Legend

- Missouri River Staff Gage - USGS06935965
- On-Site Precipitation
- St. Louis Lambert Precipitation Gauge
- Former Leachate
- Landfill Property Boundary
- Superfund Site Boundary

Figure 3-9: Surface Water and Precipitation Gauges

Remedial Investigation/ Feasibility Study Field Sampling Plan

West Lake Landfill OU-3
Bridgeton, Missouri
August 2020

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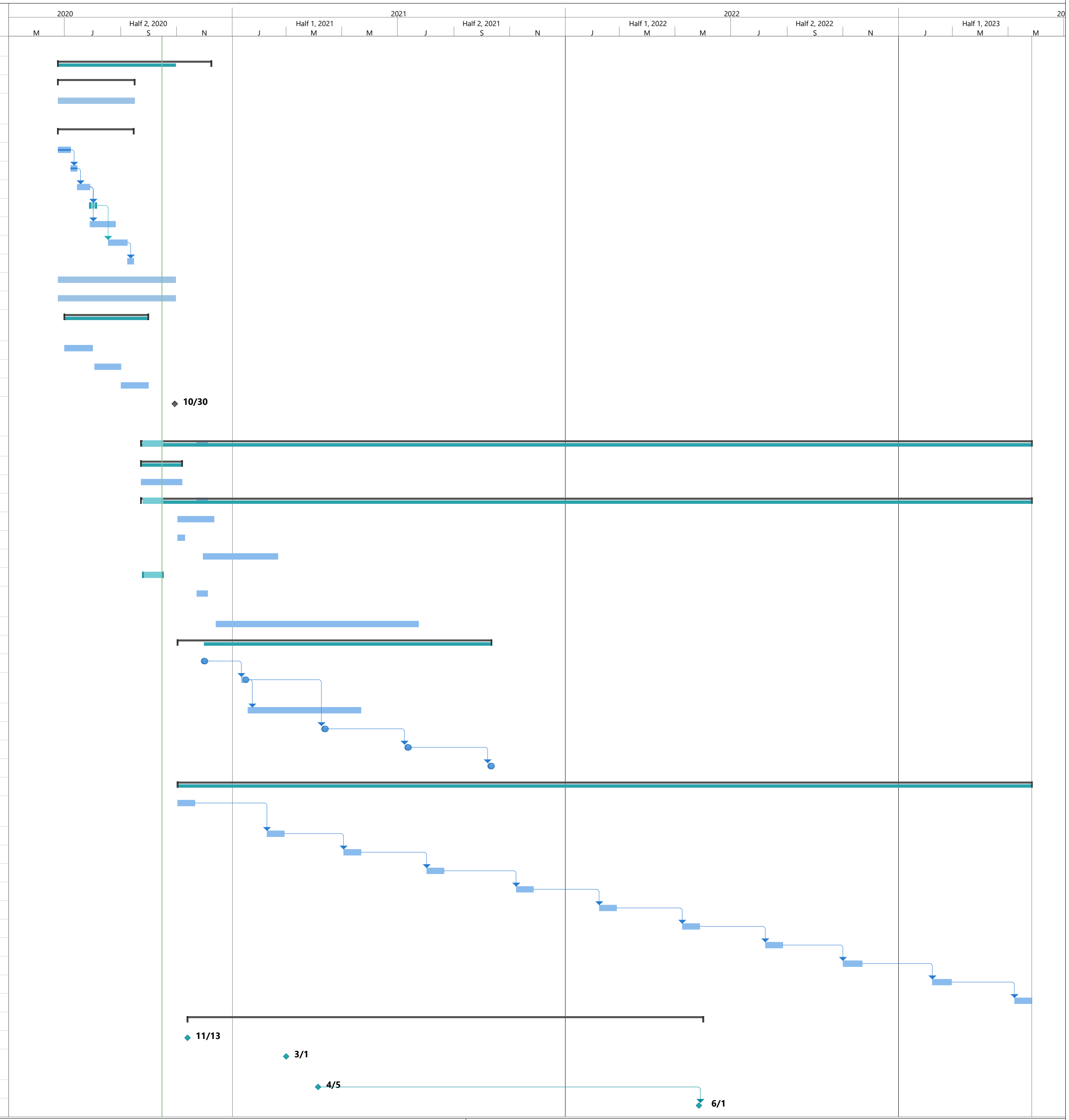
FIGURE 8-1: Project Schedule
Remedial Investigation/Feasibility Study
Field Sampling Plan
West Lake Landfill OU-3

ID	Task Name	Duration	Start	Finish
1	**OU-3 RI/FS Order Effective Date**	**0 days**	**Wed 2/6/19**	**Wed 2/6/19**
2	**Initial Tasks**	**120 days**	**Wed 6/24/20**	**Tue 12/8/20**
3	**Well Inventory**	**60 days**	**Wed 6/24/20**	**Tue 9/15/20**
4	Offsite Well Inventory (MDNR/EDR/Water Records Research)	60 days	Wed 6/24/20	Tue 9/15/20
5	**Onsite Well Inventory (Existing Wells)**	**59 days**	**Wed 6/24/20**	**Mon 9/14/20**
6	Field Preparation	10 days	Wed 6/24/20	Tue 7/7/20
7	Fluid Levels and Total Depths	5 days	Wed 7/8/20	Tue 7/14/20
8	Sediment Removal	10 days	Wed 7/15/20	Tue 7/28/20
9	Downhole Camera Inspection	5 days	Wed 7/29/20	Tue 8/4/20
10	Well Redevelopment	20 days	Wed 7/29/20	Tue 8/25/20
11	Well Repair	15 days	Tue 8/18/20	Mon 9/7/20
12	Well Survey	5 days	Tue 9/8/20	Mon 9/14/20
13	Apply For Well Permits	93 days	Wed 6/24/20	Fri 10/30/20
14	Access Agreements	93 days	Wed 6/24/20	Fri 10/30/20
15	**Monthly Fluid Levels (Existing Wells, Leachate, Surface Water)**	**66 days**	**Wed 7/1/20**	**Wed 9/30/20**
16	July 2020	23 days	Wed 7/1/20	Fri 7/31/20
17	August 2020	21 days	Mon 8/3/20	Mon 8/31/20
18	September 2020	22 days	Tue 9/1/20	Wed 9/30/20
19	**USEPA Approval of the OU-3 RI/FS Work Plan**	**0 days**	**Fri 10/30/20**	**Fri 10/30/20**
20	**OU-3 RI Implementation**	**698 days**	**Wed 9/23/20**	**Fri 5/26/23**
21	**Prepatory Activities**	**33 days**	**Wed 9/23/20**	**Fri 11/6/20**
22	Planning, Coordinating, and Subcontracting	33 days	Wed 9/23/20	Fri 11/6/20
23	**Field Activities**	**698 days**	**Wed 9/23/20**	**Fri 5/26/23**
24	Geophysical Logging at Existing Locations	30 days	Mon 11/2/20	Fri 12/11/20
25	Mobilize to Site and Set Up Temporary Facilities	6 days	Mon 11/2/20	Mon 11/9/20
26	WATERLOO APS Profiling	60 days	Mon 11/30/20	Fri 2/19/21
27	Transducer Deployment at Existing Wells	16 days	Fri 9/25/20	Fri 10/16/20
28	Surface Water Gauge Installation (pending access approval)	10 days	Mon 11/23/20	Fri 12/4/20
29	Sonic Drilling, Logging, and Well Installation	160 days	Mon 12/14/20	Fri 7/23/21
30	**Vapor Intrusion Investigation**	**246 days**	**Mon 11/2/20**	**Mon 10/11/21**
31	Initial Building Inspection	1 day	Tue 12/1/20	Tue 12/1/20
32	VI Sampling - Round 1 and Short-Term Radon Testing	5 days	Mon 1/11/21	Fri 1/15/21
33	Long-Term Radon Testing	90 days	Mon 1/18/21	Fri 5/21/21
34	VI Sampling - Round 2	1 day	Mon 4/12/21	Mon 4/12/21
35	VI Sampling - Round 3	1 day	Mon 7/12/21	Mon 7/12/21
36	VI Sampling - Round 4	1 day	Mon 10/11/21	Mon 10/11/21
37	**Quarterly Groundwater Monitoring**	**670 days**	**Mon 11/2/20**	**Fri 5/26/23**
38	Groundwater Monitoring - Round 1 (existing wells only)	15 days	Mon 11/2/20	Fri 11/20/20
39	Groundwater Monitoring - Round 2	15 days	Mon 2/8/21	Fri 2/26/21
40	Groundwater Monitoring - Round 3	15 days	Mon 5/3/21	Fri 5/21/21
41	Groundwater Monitoring - Round 4	15 days	Mon 8/2/21	Fri 8/20/21
42	Groundwater Monitoring - Round 5	15 days	Mon 11/8/21	Fri 11/26/21
43	Groundwater Monitoring - Round 6	15 days	Mon 2/7/22	Fri 2/25/22
44	Groundwater Monitoring - Round 7	15 days	Mon 5/9/22	Fri 5/27/22
45	Groundwater Monitoring - Round 8	15 days	Mon 8/8/22	Fri 8/26/22
46	Groundwater Monitoring - Round 9	15 days	Tue 11/1/22	Mon 11/21/22
47	Groundwater Monitoring - Round 10 (as needed)	15 days	Tue 2/7/23	Mon 2/27/23
48	Groundwater Monitoring - Round 11 (as needed)	15 days	Mon 5/8/23	Fri 5/26/23
49	**Reporting Activities**	**403 days**	**Fri 11/13/20**	**Wed 6/1/22**
50	Well Inventory Summary Report	0 days	Fri 11/13/20	Fri 11/13/20
51	Annual Hydrogeologic Investigation and Groundwater Characterization Report	0 days	Mon 3/1/21	Mon 3/1/21
52	Groundwater Modeling Work Plan	0 days	Mon 4/5/21	Mon 4/5/21
53	Groundwater Modeling Report	0 days	Wed 6/1/22	Wed 6/1/22



Reporting schedule dependent on agency review times.
Routine monthly gauging of monitoring wells will continue for a minimum period of 24 consecutive months.
Quarterly sampling of monitoring wells will continue until each well has been sampled a minimum of 8 times.

Legend Task | Milestone | Summary | Manual Task | Deadline

APPENDIX A STANDARD OPERATING PROCEDURES

Standard Operating Procedure #01: Field Documentation

Version #1
August 2020

West Lake Landfill Site
Operable Unit 3
Bridgeton, MO

Prepared for:
U.S. Environmental Protection Agency, Region 7
11201 Renner Boulevard
Lenexa, KS 66219

Prepared by:
ERM Consulting & Engineering, Inc.
One Beacon Street, 5th Floor
Boston, MA 02108

CONTENTS

1. INTRODUCTION

The purpose of this standard operating procedure (SOP) is to describe documentation requirements during the implementation of Remedial Investigation and Feasibility Study activities for Operable Unit 3 at the West Lake Landfill Site in Bridgeton, Missouri. Field documentation activities include the use of field books and field forms. Procedures regarding chain of custody documentation are provided in a separate SOP (SOP #02, Appendix A of the Field Sampling Plan).

All employees recording field notes must be aware that the field book is a legal document that can be heavily scrutinized. It is therefore the responsibility of the individual to record accurate and legible notes that permit the re-creation of field activities when the field book is reviewed by other parties (e.g., Project Manager, Legal Counsel, etc.). This SOP is applicable to all field staff conducting field activities, and should be used in conjunction with other applicable SOPs for accurate documentation of field activities. Field form examples are located in Appendix B of the Field Sampling Plan.

2. PROCEDURE

Field activities vary widely; however, it is the responsibility of the Field Team Lead to properly document activities, observations, conversations and any other event that affects field activities. Field books and field forms are to be completed in a timely basis by the Field Team Lead or other designated responsible party.

General procedures for field documentation are as follows:

- The first page of each field book will contain a sign-in page. All persons assigned the Field Lead role that have documented Site activities in the field book are required to complete this page. The sign-in page shall include printed name, signature, and initials. This page is completed to allow easier identification of signatures and initials within the field book.
- Use permanent black ink. Ultra Fine Point Sharpie® pens work well under most conditions. The use of black ink or marker makes photocopying easier.
- The field book is intended for recording observations and recording data. Do not include opinions or interpretations within the field book.
- There should not be blank pages or blank lines on a page. Use as much of each line and each page as is practical. No lines should be left blank in between field book entries. If you reserve a blank page for later use (such as a listing of photoionization detector [PID] readings, depth-to-water measurements, soil logging) and end up not using it, draw a diagonal line across the page and initial.
- If you make a mistake, draw a line through it such that it is still legible, initial, and write the correct information next to it. The incorrect information must not be erased, made illegible, or otherwise obscured so it cannot be read.
- Write the date and ERM-specific project number on top of each page.
- Number the pages, including the total number of pages (i.e., “Page 1 of 2”, where “1” is the current page and “2” is the total number of pages).

- At the beginning of each field day, at a minimum, the following information must be entered into the field book:
  - Names of field staff on-Site (initials are permissible for ERM field staff), names of contractors on-Site, and time of arrival and departure.
  - A brief summary of the daily Tailgate Health and Safety Meeting, including attendees and any issues or concerns that were raised.
  - A brief summary of anticipated activities for the day including details of any equipment and/or methods to be used.
  - Current atmospheric conditions—temperature, cloudiness, wind, precipitation. Note if there has been substantial precipitation in the last 24 hours or so, or if there is standing snow. If relevant to the project, note whether ground is frozen, mushy, thickly vegetated, etc. Any changes in the atmospheric conditions throughout the day must also be recorded.
  - Observations from Site walk. Note any changes to the Site since previous field book entry and current Site conditions (e.g., damage to wells or equipment, new construction, things added to or removed from work area, appearance of trespassers, etc.).
  - Names of visitors (ERM, contractors, clients, regulators, etc.) entering and leaving the Site, the times of arrival and departure, and purpose of visit.
  - Conversations, teleconferences or meetings with Project Manager, contractors, clients, regulators, etc.; record time, participants in discussion, topics discussed, any decisions made and who made them.
- If instruments are used, document the make, model, and specifications (e.g., PID lamp strength), and calibration activities (i.e., calibration standard used and instrument response), unless otherwise documented on separate calibration or sampling forms.
- Locations of sample collection or measurements if different from established points. Measure out or pace out distances from any new measurement locations to known points. Include a sketch of Site showing permanent structures/utilities and sampling points.
- Document the collection of quality assurance/quality control samples (i.e., field duplicate samples, matrix spike samples, field blank samples, equipment blank samples, trip blank samples).
  - For blind duplicate samples, record the parent location in the field book and on the associated sampling form.
  - For equipment blank samples, record the make, model, and unique serial number for the equipment from which the sample was collected, and note the origin of the water used to collect the sample (i.e., lab provided).
- Beginnings and endings of lunch, breaks, and/or downtime, specifically for subcontractors.
- Management or disposal of investigation-derived wastes.
- If field procedures or methods vary from SOPs or are modified on a project or activity basis (drilling, PID screening, measuring distances, sample procedure), record which method is used each time. However, if you are using only one procedure/method without changing, it may be noted only once.

Standard Operating Procedure #02: Chain of Custody

Version #1
August 2020

West Lake Landfill Site
Operable Unit 3
Bridgeton, MO

Prepared for:
U.S. Environmental Protection Agency, Region 7
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CONTENTS

1. INTRODUCTION

The purpose of this standard operating procedure (SOP) is to provide the requirements for completing Chain of Custody (CoC) documentation for Operable Unit 3 at the West Lake Landfill Site in Bridgeton, Missouri. A CoC is a standard document for recording important data associated with each individual sample. A CoC is used to record three types of information: field information, laboratory information, and the name of each person who handled the sample.

This SOP is applicable to all field staff collecting environmental media samples for laboratory analysis. It is the responsibility of the individual to accurately and legibly record sample collection information to permit review by other parties (e.g., Project Manager, Field Technician, Sample Custodian, Legal Counsel).

Example CoCs are included in Appendix B of the Field Sampling Plan.

2. DEFINITIONS

Chain of Custody is a legal document designed to track persons who are responsible for the preparation of the sample container, sample collection, sample delivery, sample storage, and sample analysis.

Custody Seal is a label placed on the outside of the cooler to help track sample integrity during handling and transport. Custody seals may be provided by the laboratory, or may be created by the Sample Custodian by placing a piece of duct tape or similar material across the cooler seal.

Field Lead is the person who will conduct oversight of field activities and has overall responsibility for the investigation in the field, including checking the completion of CoC forms.

Sample Number is a unique number given to each sample. This number is provided in the sample label and on the CoC.

Sampler is the person who collects the samples in the field.

Sample Custodian is any person who assumes custody of the samples from the sampler. If the sampler does not relinquish custody after collection, the sampler becomes the Sample Custodian. The sample custodian role may be filled by several people as the samples are collected, consolidated, and shipped.

3. PROCEDURE

3.1 Creating the CoC

A CoC is created for each sampling event. Typically, a CoC has three sections: field information, lab information, and signature information. The CoC should be a carbon-copy document and must be completed legibly with black ballpoint pen.

- **Project Information:** The CoC should contain the project information, including project number, project manager, project contact, billing information, etc.
- **Field Information:** The CoC must contain the following information: sample number, sample date and time, type of sample, type of sample container, requested analysis, and preservative for each sample.
- **Signatures:** The CoC must contain places for all people who handle the sample to sign his/her name. This is a record of persons (i.e., the Sample Custodians) who had custody of the sample

during all steps of the sampling process from sample collection, sample storage, transport, and sample analysis. Signature lines to relinquish custody of the sample and to receive custody of the sample must be completed.

3.2 Filling Out the CoC

The CoC should be completed by the sampler(s), and checked by the Field Lead. At least one of the individuals who collected the samples on the CoC needs to sign the first “relinquished by” line. The “received by” line will be completed by the person receiving custody of the samples from the sample collector. The person who transports the sample to the laboratory or relinquishes the samples to the shipping agency signs last.

After all samples have been recorded on the CoC, the remaining lines must be crossed out and initialed. This indicates that there are no additional CoCs or samples. Similarly, additional unused spaces for requested analyses should be lined out and initialed.

If multiple CoC forms are completed, the CoCs should be numbed “Page X of XX” (where X is the current page, and XX is the total number of pages). If multiple coolers are used to transport samples, the CoC should indicate the total number of coolers. Errors must be lined out and initialed, and the correction written in. A completed copy of the CoC must not be destroyed or discarded and must be retained in the project files.

3.3 Container Preparation

The CoC should be initiated at the time of sampling. The CoC header information, including general project information, may be filled out ahead of time. The sample label should include project number, date and time, requested analysis, preservative, and sampler initials. All information contained on the sample label should be identical to the information on the CoC.

3.4 Sample Collection

The personnel who receives the sample containers, transports them to the field, collects the samples, and places them in to the coolers should sign the first received line along with data and time. Samples should be collected in accordance with other applicable SOPs.

3.5 Sample Storage

If the samples are relinquished to secured storage, the sample custodian should complete the “relinquished by” line on the CoC. The sample custodian should complete a “relinquished by” line on the CoC and print “To Secure Storage” in the “received by” line.

3.6 Sample Shipping

When the samples are prepared for shipping, a CoC should be enclosed in a plastic bag within the sealed cooler. The sample custodian should complete a “relinquished by” line on the CoC and print “To Shipping Company” in the “received by” line.

In addition to filling out the CoC, the Sample Custodian will place custody seals on each sample cooler to document the integrity of the shipping container. A minimum of one custody seal will be placed on each cooler in a manner that the cooler cannot be opened without breaking the seal. Each custody seal will be signed and dated by the person packing the cooler and the seals covered by clear packing tape to prevent accidental loss or damage during shipping.

Standard Operating Procedure #03: Sample Packing and Shipping

Version #1
August 2020

West Lake Landfill Site
Operable Unit 3
Bridgeton, MO

Prepared for:
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CONTENTS

1. INTRODUCTION

The purpose of this standard operating procedure (SOP) is to describe the procedures that will be used to package and ship samples for laboratory analysis from Operable Unit 3 at the West Lake Landfill Site in Bridgeton, Missouri. The procedures described herein are recommended for handling and shipping laboratory samples to minimize the loss of samples associated with breakage and to help make sure that samples are received at laboratory-required temperatures. These procedures are mandatory for laboratory samples being transported by project personnel, laboratory courier, or shipping carrier. Project personnel include ERM employees as well as personnel directly employed by the analytical laboratory (courier). Third-party courier services, regardless of whether contracted internally or by the analytical laboratory, are always considered non-project personnel. Strict adherence to these procedures will protect sample integrity during transport, even if delivery is delayed.

2. EQUIPMENT AND MATERIALS

- Clear packing tape to keep cooler lids sealed during transport;
- Completed chain of custody (CoC) with record of all samples contained in cooler(s);
- Custody seals with sampling personnel signature and date to indicate if sample shipments have been tampered during release and transport;
- Packing material such as bubble wrap to minimize sample breakage during transport; and
- Mailing labels (in addition to any shipping papers), which include either the laboratory or ERM account number and contact number of the sampling personnel. The tracking number will be retained by sampling personnel to minimize delays.

3. PROCEDURE

3.1 Coolers

Coolers are the most common package or containment device used to ship samples. Coolers are also used during sampling efforts to store and transport samples prior to shipping. The samples will be placed in iced coolers immediately after collection to protect integrity of sample concentrations and as a method of preservation. The ice in the cooler used for shipping will be positioned such that melt does not infiltrate sample bottles. The following procedures will be used when packing the cooler for shipment:

1. Secure the drain on the cooler with tape (or alternate seal) to prevent accidental release of ice melt or sample water in the case of breakage.
2. Place each individual sample (soil and/or groundwater) in polypropylene bags to minimize cross-contamination. Vials that are aliquots from the same sample can be placed in the same bag. The vials should be wrapped with bubble wrap or foam to prevent breakage during transportation and shipping.
3. Position the samples in the cooler so there is minimal contact between containers. The positioning and padding of sample containers with bubble wrap, foam, or ice will prevent breakage of glass containers or seal breakage of plastic bottleware (whichever may be required for the analysis).
4. Use bubble wrap, foam, or absorbent pads as packing support to prevent the samples from colliding and breaking during transportation and shipping. A layer of absorbent material/ bubble wrap on the

bottom interior of the cooler may prevent sample breakage. Avoid using shredded paper or Styrofoam™ as packing material. If the paper becomes wet, it will no longer be useful to prevent samples from colliding. A limited amount of packing material should be used as these materials insulate the samples and prevent them from being properly chilled. Plastic sample containers or cardboard can be placed between glass containers. Bags of ice may be also be used as packaging material between samples. Sample containers should be neatly organized in such a way that minimal movement would be anticipated in the cooler during transportation and shipment.

5. Fill the cooler with ice or double-bag the ice in polypropylene bags. Do not use chemical ice packs ("blue ice"). In order to maintain the required sample temperature as stipulated by the laboratory (typically 4 degrees Celsius) 40 to 50 percent of the cooler capacity should contain ice. If a commercial carrier such as Federal Express (FedEx) or United Parcel Service (UPS) is used for sample shipping, additional ice will be packaged in the coolers in case delivery is delayed. Less ice may be used if the samples will be delivered via courier or sampling personnel. As a rule of thumb, an average cooler with a capacity of approximately 48 quarts will require two to three 8-pound bags of ice.

6. Place the CoC with record of all contained samples in a polypropylene bag. If samples are packed in multiple coolers, the number of coolers should be marked on the CoC.

7. Use packing tape to secure the cooler shut to prevent accidental opening or potential leakage. Do not tape down or otherwise restrict access to the cooler handles. Coolers used for shipping should not have broken or missing handles.

8. Custody seals will then be placed on the cooler to document the integrity of the shipping container. A minimum of one custody seal will be placed on each cooler in a manner that the cooler cannot be opened without breaking the seal. Each custody seal will be signed and dated by the person packing the cooler and the seals covered by clear packing tape to prevent accidental loss or damage during shipping.

9. If necessary, affix a mailing label with the laboratory's address on the cooler. Apply clear tape over the address label to prevent accidental loss or damage during shipping. The label should be used in addition to any shipping papers required by carriers and shall include, at a minimum, shipping account numbers and telephone number of personnel knowledgeable on the sample details.

3.2 Boxes

Some samples do not require temperature control and may be shipped in cardboard boxes. The boxes should be sturdy enough to withstand rough handling. No liquids will be shipped in boxes. Materials suitable to be shipped by cardboard box include:

- Air samples in SUMMA® canisters, air-tight gas sampling bags, or other non-pressurized sample containers; and
- Soil samples for geotechnical analyses.

These materials may be packaged and secured in a suitable cardboard box. The box will be sealed with packing tape and affixed with address labels and custody seals as described above.

Standard Operating Procedure #04: Subsurface Clearance

Version #1
August 2020

West Lake Landfill Site
Operable Unit 3
Bridgeton, MO

Prepared for:
U.S. Environmental Protection Agency, Region 7
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CONTENTS

1. INTRODUCTION

The purpose of this standard operating procedure (SOP) is to establish the procedures for conducting subsurface clearance (SSC) of utilities and structures prior to any ground disturbance activities for Operable Unit 3 at the West Lake Landfill Site in Bridgeton, Missouri. The SSC Procedure applies to all ERM employees and subcontractors for any ERM-controlled operation, including supervision or oversight, or where ERM is legally or contractually responsible for SSC activities, including at the West Lake Landfill Site in Bridgeton, Missouri.

For the purposes of this SOP, ground-disturbance activities are activities that require penetration of the ground surface to any depth, and/or the drilling, coring, or removal of engineered surfaces (pavement, concrete, etc.). Examples of ground-disturbance activities include, but are not limited to: hand digging, hand augering, drilling, direct-push or Geoprobe® borings, well installation, well over-drilling, excavation, trenching, grading, concrete coring, drilling/installation of soil vapor points, and driving of posts, stakes, rods, poles, or sheet piles.

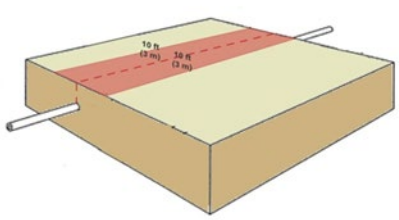
1.1 Definitions

Abandoned/Decommissioned: A subsurface structure that has been confirmed by the owner/operator as inactive and in a state of zero energy. For high value/high hazard subsurface structures (as defined later in this section), confirmation must be made on-Site by qualified personnel (representing the Site and/or owner/operator of the line, unless these entities cannot be identified), witnessed by ERM, and include positive verification of a zero-energy state. Otherwise, these lines must be considered potentially active.

Compressed Air Excavation: The use of compressed air to make a cut, cavity, trench, or depression in the earth's surface. Also known as "Vacuum Extraction," "Vac-Ex," "Air Knifing," and/or "Soft Digging."

Contact Person: A representative of the Site where ground disturbance activities will be conducted who is knowledgeable of the subsurface and/or historical operations at the work location. The contact person may be a client employee or the employee of a third party.

Critical Zone: 10 feet (3 meters) distance in all directions from the surface projection of all known or suspected subsurface structures, taking into account the diameter and spatial extent of the structure (e.g., the outer diameter of a pipe or the outer edges of a tank). Critical Zones do not apply to structures that have been confirmed as abandoned/decommissioned and do not need to be protected.

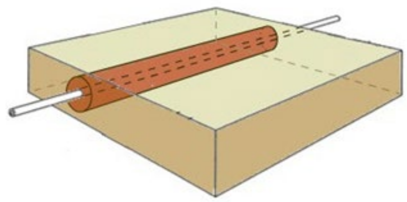


Example Critical Zone illustration, associated with an underground pipe

Detection Equipment: Any equipment used for the detection of subsurface structures, including, but not limited to, devices that utilize electromagnetic detection, magnetic detection, ground-penetrating radar (GPR), acoustic detection, and video surveillance (e.g., sewer cameras).

Excavation: Any man-made cut, cavity, trench, or depression in the earth's surface, NOT including point disturbances as defined later in this section.

Excavation Buffer: A 2-foot (0.6-meter) distance in all directions from the outermost extents of subsurface structures that will be exposed or partially exposed during excavation activities, and within which mechanical digging is prohibited. Excavation Buffers do not apply to structures that have been confirmed as abandoned/decommissioned and do not need to be protected.



Example illustration of Excavation Buffer associated with underground line

Ground Disturbance Activities: Activities which require penetration of the ground surface to any depth, and/or the drilling, coring, or removal of engineered surfaces (pavement, concrete, etc.). Examples of ground-disturbance activities include, but are not limited to: hand digging, hand augering, drilling, direct-push or Geoprobe® borings, well installation, well over-drilling, excavation, trenching, grading, concrete coring, drilling/installation of soil vapor points, and driving of posts, stakes, rods, poles, or sheet piles.

Hand Augering: Use of a manual auger to make a cavity or depression in the earth's surface.

Hand Digging: Use of manual digging tools and equipment (shovel, trowel, or post-hole-digger) to make a cut, cavity, trench, or depression in the earth's surface.

High Value/High Hazard: Subsurface structures, including electrical conductors/cable equal or greater than 110 volts, fiber optic cable, gas lines, petroleum pipelines, or structures containing hazardous substances.

Point Disturbance: Ground-disturbance activities associated with a distinct and definable location that, in general, will result in a ground disturbance that has a larger vertical extent (i.e., depth) than lateral extent (i.e., disturbed surface area). Examples include, but are not limited to, locations involving the following activities: soil sampling, soil borings (regardless of diameter), and methods involving any of the following types of tools/techniques: hand digging, hand auger, drilling, direct-push, or Geoprobe®), well installation, and well over-drilling.

Point Disturbance Clearance: Methods used to identify the presence or absence of subsurface structures at a particular point disturbance location by removal of overburden and direct observation and/or contact. Approved point disturbance clearance methods include: compressed air excavation, pressurized water excavation, hand digging, hand auger, and soil probe.

Pressurized Water Excavation: The use of pressurized water to make a cut, cavity, trench or depression in the earth's surface.

Site Services Model: A depiction of both the aboveground and underground utilities and services that are present or unaccounted for at a site. The site services model is developed from all available sources of information including, but not limited to: discussions with knowledgeable contact persons, review of maps and as-built drawings, observation of visual clues, and information obtained from utility locate services.

Soil Probe Rod: A blunt-nosed probe with a T-handle that is pushed manually into the ground to check for obstructions that may indicate the presence of subsurface structures.

SSC Experienced Person (EP): An ERM employee with requisite qualifications and experience in performing SSC activities who will ensure execution of the SSC process, both in the planning stages and in the field.

SSC General Employee (GE): An ERM employee that works on, manages, serves as Partner-in-Charge (PIC), or is responsible for issuing waivers or making other safety-critical decisions on projects where ground-disturbance activities are performed, but does not serve in the role of SSC EP.

Subsurface Structures: Man-made structures (excluding man-made debris) located beneath the surface of the ground or within or below engineered surfaces., These may include, but are not limited to: pipes, cables, conduits, drains, galleries, tanks or other containers, wells, or any other useful property (as defined later in this section).

Useful Property: A subsurface structure that, if damaged, would need to be repaired or replaced, regardless of who makes the repairs or who is liable for the cost.

Unexploded Ordnance (UXO)/Munitions and Explosives of Concern (MEC): Ammunition that was fired but did not explode, or munitions (unfired ammunition, land mines, etc.) that could explode.

2. EQUIPMENT AND MATERIALS

- Field forms and field book;
- Field Sampling Plan, Health and Safety Plan (HASP), Subsurface Clearance (SSC) Plan;
- Personal protective equipment (PPE) in accordance with the project HASP;
- Clipboard;
- Permanent ink and waterproof pens; and
- Ground disturbance tools (to be supplied by the subcontractor).

3. HEALTH AND SAFETY

SOPs are designed to provide technical guidance and do not provide detailed or comprehensive guidance related to health and safety, nor do they represent guidance on safe work procedures for the tasks described. Appropriate tips related to health and safety issues associated with specific tasks may be included within technical descriptions for information’s sake only.

Health and safety aspects of all projects and project tasks should be assessed and planned using ERM’s established Health and Safety planning procedures. Drilling and other subsurface intrusive work presents specific hazards and proper safety precautions must be observed performing any subsurface work. These hazards, as well as those associated with constructing and installing monitoring wells, should be addressed by a Site-specific HASP. The safety guidelines within the HASP should be used to complement the judgment of an experienced professional. For all subsurface drilling activities, the project-specific health and safety requirements must be reviewed by ERM field staff and subcontractors.

4. PROCEDURE

The primary objective of the SSC process is to develop a complete understanding of the subsurface structures that are present at a project site. This is done by developing a Site Services Model, as defined in Section 2. The activities outlined in this section are performed in order to construct a Site Services Model. These activities are presented in the general order they should be conducted.

4.1 Assignment of an SSC EP to the Project

All SSC planning and field execution activities must be performed or directly overseen by an ERM employee who has an active SSC EP certificate. The name of the SSC EP must be documented in the SSC Project Plan. The SSC EP role can be shared on a project, provided all employees serving in the role are currently certified as an SSC EP and listed in the SSC Project Plan.

4.2 Gathering and Review of Site Information

The following steps are required:

1. Identify any local regulatory, industry, or client requirements that are not otherwise covered by the ERM SSC Procedure. Document these additional SSC requirements in the SSC Project Plan.

2. Assess the potential for the presence of UXO/MEC. If UXO/MEC is present or potentially present, specialist technical assistance must be obtained to assist with project planning and Site clearance. In the case of sites where UXO/MEC risks are present, adherence to the clearance plan developed by the specialist provider may supersede certain requirements of the SSC process. If the UXO/MEC clearance plan deviates in any way from this SSC Procedure, a project-specific variance plan must be developed by the project team and approved by the Regional CEO and Local Managing Partner (MP).

3. Identify any contact persons knowledgeable of the subsurface and/or historical operations at the work location. Request any available information from them and review the preliminary SSC Project Plan with them. Request the participation of the contact person(s) during the Site walk and visual clues survey.

4. Obtain all available (and in particular the most recent) as-built drawings and/or Site plans showing subsurface structures. Requests should be made and followed up diligently until all available documents are received, or a positive confirmation is given that no such documents are available.

5. Where available and/or required by local legislative or regulatory requirements, obtain as-built drawings from third-party public agencies or private companies with subsurface structures in the area where ground disturbance will occur. Requests should be made and followed up diligently until all available documents are received, or a positive confirmation is given by the entities contacted that no such documents are available.

6. Obtain and review any additional Site-related information such as easements, rights-of-way, historical plot plans, current and historical aerial photographs, fire insurance plans, tank (dip) charts, SSC information obtained as part of previous Site investigations or Phase I environmental Site assessments, soil surveys, boring logs, etc., as relevant to the planned ground-disturbance activities.

7. Document the available preliminary information about the presence of known or suspected subsurface structures at the work location in the SSC Project Plan. This must include a Site plan or map (drawn to scale) that identifies:

a. The routes and locations of known services;

b. Gaps – those services suspected but not yet located based on currently available information;

c. Any Critical Zones and/or Excavation Buffers; and

d. The preliminary disturbance location plan (boring location map, excavation plan, etc.) accounting for any Critical Zones, Excavation Buffers, gaps in subsurface information, and project objectives.

4.3 Public Utility Locates

The following steps are required:

1. Where they exist, the public utility locator(s) must be contacted to provide all available information and services. In jurisdictions where they provide this service, they should also be asked to physically mark utilities at and/or in the vicinity of the work location, in accordance with local regulatory requirements.

2. Ensure compliance with local regulations and guidelines governing public utility locates, including, but not limited to:

    a. The process and required lead times for contacting public utility locators;

    b. Marking planned ground-disturbance areas at the work location;

    c. Maintaining any required permits or dig tickets and ensuring public locator markings remain clear and visible for the duration of the project;

    d. Any additional requirements for high hazard/high value subsurface structures;

    e. Any restrictions for excavating within close proximity to underground structures (i.e., “tolerance zones”); and

    f. What to do if a subsurface structure or utility is encountered and how to report damage.

3. Determine if there are utility owners/operators (including municipal water and sewer) that are not subscribers to the public utility service. If there are utility owners/operators that do not subscribe to the service or if a public one-call service is not available, identify and contact the owners/operators of known or suspected utilities in the vicinity of the work area and request they mark area lines.

4. Verify a response by each public utility locator prior to proceeding with any ground-disturbance activities.

5. If at any time during ground disturbance activities the public utility locator markouts are not clear or visible, do not agree with other available sources of information, or are suspected to be inaccurate for any reason; the locators must be called back to the Site to confirm their markouts.

6. Document the activities performed and results of the public utility locate in the SSC Project Plan.

4.4 Site Walk and Visual Clues Survey

The following steps are required:

1. A visual survey of all planned ground-disturbance locations and surrounding areas must be conducted to identify signs of potential subsurface structures.

2. During the Site walk, the routes and locations of services should be confirmed using visual clues, which include, but are not limited to, the following:

   - Utility poles with conduit leading to the ground
   - Lights
   - Signage
   - Sewer drains/cleanouts
   - Cable markers
   - Utility boxes
   - Manholes
   - Pavement scarring
   - Pipeline markers
   - Vegetative evidence (e.g., linear patterns or areas of distressed vegetation)
   - Remote buildings with no visible utilities
   - Equipment locations
   - Fire hydrants
   - Sprinkler systems
   - Water meters
   - Natural gas meters
   - Sewer manholes and drop inlets
   - Underground storage tanks fill ports and vent pipes
   - Steam lines
   - Solar panels/wind power generation

   Elevation changes across the Site must also be noted and factored into clearance depth determinations.

3. Confirm overhead clearances with equipment operators for safely deploying equipment to the location. The minimum horizontal distance from any point on the equipment to the nearest overhead utility line must adhere to the minimum clearance requirements stipulated by regulation, utility companies, client requirements, and/or local industry best practice. If the equipment is closer than the minimum clearance distance to the overhead utility, the utility must be de-energized or an alternate plan developed with approval from the PIC and client/Site owner.

4. Where possible and practical (i.e., active industrial Sites), work with the Site contact(s) to identify the location and individual(s) responsible for key energy isolation devices and shutoff valves for Site services. This information is to be included in the SSC Project Plan as part of emergency/contingency planning.

5. Whenever available, Site contact person(s) are to participate in the Site walk and approve planned ground-disturbance locations. Approval (or lack thereof) must be documented on the SSC Project Plan.

6. Any proposed changes to ground-disturbance locations made by a Site contact person must be assessed by the SSC EP using the other available lines of evidence and only accepted after a determination is made that the change is safe. The SSC Project Plan must be updated and the changes approved by the PIC.

7. Similarly, follow-up communication must be made to the Site contact person when any changes are made to approved ground-disturbance locations without their direct knowledge.

8. Document the activities performed and results of the visual clues survey in the SSC Project Plan.

4.5 Private Utility Markouts

The following steps are required:

1. Engage a qualified private utility locate subcontractor or a trained and competent ERM employee to locate and mark subsurface structures on the project Site.

2. If using a private utility locate subcontractor, they must be prequalified and approved to conduct private locates through the ERM subcontractor prequalification process. The PIC and Project Manager must make sure the subcontractor work order details the type of equipment to be used,

mode of operation, reporting requirements (field summary and final), and method of markouts. Confirm documentation of relevant and currently valid training and experience of all subcontractor personnel to be used. The SSC EP must be present on-Site to directly oversee the private utility locate subcontractors.

3. If using an ERM employee to locate and mark subsurface structures, they must have current training documented on ERM Academy to operate the detection equipment to be used, and must be approved by the PIC in the SSC Project Plan.

4. All available and Site-appropriate detection equipment and methods must be used, and documented in the SSC Project Plan, including noting any limitations in the methods and equipment used.

5. Verify that all detection equipment (whether ERM-owned, rented, or brought to the Site by subcontractors) is:

   a. Maintained according to manufacturer specifications with maintenance records available;

   b. Calibrated according to manufacturer specifications (calibrations must be documented); and

   c. Calibrated or tested at the start of each work day and confirmed to be in proper working condition.

6. A Job Hazard Analysis (JHA) must be developed that covers all utility locating tasks. The JHA must be specific to the equipment and methods to be used, and must be reviewed by the SSC EP and PIC.

7. Clear any vegetation, vehicles, equipment, or other obstructions to facilitate private utility markouts.

8. Using detection equipment, confirm the locations and routes of all identified or suspected subsurface structures, based on the data gathered during the other steps in the SSC process.

9. Using detection equipment, scan the area within a minimum 10-foot (3-meter) distance around each planned ground-disturbance location (a larger, more inclusive distance may be specified in the SSC Project Plan based on input from SSC EP and PIC), to assess the potential presence of any as-yet unknown subsurface structures.

10. When using electromagnetic tools and equipment such as a cable avoidance tool, scanning should be done using passive – “power” mode, passive – “radio” mode, and active mode using conductive or inductive methods with the signal generator. Scanning should confirm the locations of known or suspected structures, as well as assess for the presence of any as yet unknown structures.

11. Mark all subsurface structures identified within the defined boundaries of the work area with paint or other semi-permanent markings whose meaning is understood by the project team. Markings must remain clear and visible for the duration of the ground-disturbance activities, and re-marked if necessary. Note that markings should be assessed by the SSC EP by evaluating the method(s) used to mark the utility locations, any limitations, and whether or not other lines of evidence corroborate or conflict with the markings.

12. The results and findings of the private utility locate must be documented in the field by either the subcontractor or the SSC EP. If using a subcontractor, ask that they provide a signed and dated report including a summary of equipment used, mode(s) of operation, names of operators, and a general map/sketch of findings.

13. Document the activities performed and results of the private utility locate in the SSC Project Plan.

4.6 Final Critical Zone Determination

The following steps are required:

1. In conjunction with Site contact person(s), public and private utility locators, and any other knowledgeable persons identified during the Site walk, confirm the status of all identified services (e.g., energized/de-energized, active/inactive, idled, abandoned/decommissioned, etc.).

2. Use the information gathered from all previous steps in the SSC process to determine the final Critical Zones near each planned ground-disturbance location. Update the SSC Project Plan.

3. If any disturbance locations (or boundaries of disturbance areas) fall within a Critical Zone, they must be re-located or a waiver must be approved to proceed with work inside the Critical Zone. Any waivers must be documented in the SSC Project Plan.

4. For any work inside a Critical Zone, energized pipes or cables must be de-energized. If this is not possible, a specific JHA must be developed that covers the specific task steps, equipment, and methods associated with work around these energized structures. Appropriate safety measures, including the need for specialized personal protective equipment (PPE), must be evaluated with input from subject matter experts (SMEs). JHAs must be reviewed by the SSC EP and PIC.

4.7 Review Meeting and Approval of Completed SSC Project Plan

The SSC Project Plan must be reviewed and approved by the PIC after completion of the SSC process steps in Sections 3.1 through 3.6, and BEFORE any further SSC or ground-disturbance activities occur. This review must be completed through a verbal conversation, whether in-person or by phone or video conference. Documentation of review can be via e-mail initially, but must be followed up with signatures in the final SSC Project Plan. A copy of the SSC Project Plan must be maintained at the work location for the duration of ground-disturbance activities and filed in the project folder upon completion of the field activity.

4.8 Concrete Coring/Cutting

In the case where concrete coring or cutting must be performed prior to ground disturbance, the following steps are required:

1. The preferred course of action is to use a prequalified and approved subcontractor. Where concrete coring/cutting services are not available for hire, the PIC must determine if there is a sufficiently trained and experienced ERM employee to accomplish the task using rented or ERM-owned equipment. Training documentation must be current on ERM Academy and attached to the Health and Safety Plan (HASP), with written approval from the PIC.

2. A JHA must be developed that covers all concrete coring/cutting tasks. The JHA must be specific to the equipment and methods to be used, and be reviewed by the SSC EP and PIC.

3. Concrete coring/cutting equipment must:

    a. Be inspected prior to use and maintained according to manufacturer specifications with maintenance records available;

    b. For rig- or stand-mounted coring equipment, be anchored to the floor using proper anchors;

    c. Be operated with ground fault circuit protection;

d. Be operated by trained and qualified personnel; and

e. Any additional safety requirements for this equipment must be outlined in the task-specific JHA.

4. Concrete core diameters must be large enough to allow for visual inspection during subsequent point-disturbance clearance. For point-disturbance locations that will be advanced with mechanical equipment (e.g., drill rig or direct-push) after initial clearance, core diameters must meet or exceed the larger of: 4 inches or 125 percent (%) of the outside diameter (OD) of the largest downhole tool to be used.

4.9 Point-Disturbance Clearance

Approved equipment and methods to be utilized for point-disturbance clearance include the following, listed in order of preference:

- Compressed air excavation;
- Pressurized water excavation;
- Hand digging tools;
- Hand augering tools; and
- Soil probe rod.

Blades on shovels and post-hole diggers must have rounded or blunt noses. Pick axes, pointed spades, or any other tool that comes to a point are not to be used for point-disturbance clearance. Crow bars, pinch bars or pry bars must not be used to break hardened soil or backfill. The ERM EP or field staff lead may authorize the use of bars only to loosen materials like bricks or larger stones so that removal of these materials is possible. Bars must not be used with excessive force.

The following steps are required when clearing point-disturbance locations:

1. A JHA must be developed that covers all clearance tasks. The JHA must be specific to the general location of the project as well as the equipment and methods to be used. Unless the project team can positively determine that no subsurface structures are present, all tools and equipment used in the clearance process must be selected based on the potential risks (i.e., energized electrical lines, fiber optic cables, natural gas pipeline, etc.) that cannot be ruled out. In addition to selecting tools and equipment, appropriate safety measures, including the need for specialized PPE, must be evaluated with input from SMEs. JHAs must be reviewed by the SSC EP and PIC.

2. Re-verify that appropriate overhead clearance requirements can be maintained at ground-disturbance locations prior to mobilizing any equipment.

3. In the case of sites where UXO/MEC risks are present, review and adhere to the clearance plan developed by the specialist provider, which will supersede the instructions in this section.

4. The SSC EP must consider Site-specific conditions and soil types when determining the equipment to be used.

5. If a hand auger will be used, an SSC EP must select the appropriate cutting head(s) based on the soil type, and if resistance is encountered that would require an inordinate/atypical amount of force to be applied for advancement, then augering must not continue.

6. For point-disturbance locations that will be advanced with mechanical equipment (e.g., drill rig or direct-push) after initial clearance, clearance must be performed as follows:

   a. Clear the location using one of the approved methods outlined in this section. The selected clearance method must be documented in the SSC Project Plan. ERM's preferred clearance method is compressed air excavation. If this method is not used, the rationale and approval for using one of the other approved methods must also be documented in the SSC Project Plan.

7. Clear to a minimum depth as follows:

   a. Outside Critical Zones, to 5 feet (1.5 meters).

   b. Inside Critical Zones, to 8 feet (2.4 meters) at a minimum. However, clearance MUST extend at least 2 feet (0.6 meters) beyond the known or suspected bottom depth of all subsurface structure(s) in the Critical Zone; therefore it may be necessary to clear to depths greater than 8 feet for deeper structures.

   c. For locations with frozen soils, to 2 feet (0.6 meters) beyond the bottom of the frost line at the Site.

   d. Clear to a minimum diameter that is the LARGER OF:

      - 4 inches (10 centimeters); or
      - At least 125% of the OD of the largest downhole mechanized tool (e.g., drilling auger, direct-push sampler) to be advanced.

      In all cases, clearance diameters must be large enough to allow visual inspection of the cleared hole. If hand augers are used to clear, multiple holes may need to be advanced to achieve clearance diameters.

   e. For angled (non-vertical) drilling, clear to a minimum diameter of 125 percent of the OD of the largest downhole mechanized tool, taking into account the angle of the boring.

   f. For locations where difficult soil or geologic conditions prevent the full clearance of a point-disturbance location, a waiver must be obtained prior to proceeding with mechanized equipment. The waiver can be applied to multiple point-disturbance locations across the Site, provided each location is specified in the SSC Project Plan.

8. During clearance (and subsequent ground-disturbance activities), watch for any warning signs indicating non-native soil, fill materials, and/or the presence of unexpected subsurface structures. If warning signs are observed, work must be stopped, the Project Manager and PIC contacted, and this change managed per the requirements outlined in Section 8. Warning signs may include, but are not limited to:

   a. Any at-grade or above-grade visual clues;

   b. Refusal;

   c. Warning tape;

   d. Pea gravel/sand/non-native materials;

   e. Red concrete ;

f. Colored plastic covers;

g. Voids/cavities, or abrupt absence of soil;

h. Any unexpected change from native soil;

i. Any signs of damaged utilities in cuttings (broken materials, odors, etc.); and

j. Any other unexpected condition.

4.10 Excavations

Blades on shovels and post-hole diggers must have rounded or blunt noses. Pick axes, pointed spades, or any other tool that comes to a point are not to be used for excavation. Crow bars, pinch bars or pry bars must not be used to break hardened soil or backfill. The ERM EP or field staff lead may authorize the use of bars only to loosen materials like bricks or larger stones so that removal of these materials is possible. Bars must not be used with excessive force.

The following steps are required:

1. JHAs must be developed that cover all excavation/trenching tasks. The JHA must be specific to the general location of the project, as well as the equipment and methods to be used. Unless the project team can positively determine that no subsurface structures are present, all tools and equipment used must be selected based on the potential risks (i.e., energized electrical lines, fiber optic cables, natural gas pipeline, etc.) that cannot be ruled out. In addition to selecting tools and equipment, appropriate safety measures, including the need for specialized PPE, must be evaluated with input from SMEs. JHAs must be reviewed by the SSC EP and PIC.

2. For excavation involving removal or working in close (2 feet [0.6 meters]) proximity to subsurface structures (including those that are abandoned/decommissioned), the JHA must include appropriate emergency response measures, any additional PPE, and safe excavation and removal methods to prevent spills, damage to other structures, etc.

3. Inform all ERM field staff and excavation subcontractor(s) of information regarding the location of subsurface structures, Critical Zones, and Excavation Buffers. Verify that the following are clearly marked and communicated to all field staff, for all subsurface structures crossing through the excavation/trench perimeter or located within the Critical Zone around the excavation/trench perimeter:

    a. Locations/routes, including Excavation Buffers; and

    b. Expected excavation depths to the Excavation Buffer.

4. During ground-disturbance activities, watch for any warning signs indicating non-native soil, fill materials, and/or the presence of unexpected subsurface structures. Warning signs may include, but are not limited to:

    a. Any at-grade or above-grade visual clues;

    b. Refusal;

    c. Warning tape;

    d. Pea gravel/sand/non-native materials;

   e. Red concrete;
   f. Colored plastic covers;
   g. Voids/cavities, or abrupt absence of soil;
   h. Any unexpected change from native soil;
   i. Any signs of damaged utilities in cuttings (broken materials, odors, etc.); and
   j. Any other unexpected condition.

5. Material inside an Excavation Buffer can ONLY be removed by the following methods (this is not subject to waiver):
   a. Compressed air excavation or pressurized water excavation (only with documented approval from the owner/operator of the utility or structure, and where allowed by law); and
   b. Hand digging tools.

5. WAIVERS

There are four waivers to the SSC Procedure that can be granted:

1. Waive the requirement for direct ERM supervision of ground-disturbance activities as follows:
   a. Waive the requirement for a certified SSC EP to oversee execution of the SSC process, and allow instead for an SSC GE to do so (this could include the entire project or specific tasks); or
   b. Waive the requirement for direct ERM oversight of subcontractors, provided the scope of work is restricted to ground disturbance on a Remote/Greenfield site or will only involve shallow hand digging no deeper than 1.5 feet (0.5 meters). The use of subcontractors without direct ERM oversight shall be done in accordance with ERM's Subcontractor Basic Use Standards (SUBS) process.
2. Waive the requirement for private utility locates (performed by ERM subcontractors or ERM employees);
3. Waive the requirement for clearance of point-disturbance locations prior to advancing with mechanized equipment (including no clearance or partial clearance); and
4. Waive the requirement prohibiting ground-disturbance activities within a Critical Zone.

Both the Project PIC and Local MP (or designee) must approve any waivers, with documentation in the ERM SSC Project Plan (can be documented in the field via notation of verbal approval or e-mail, with signature after project completion). If the Local MP is also the PIC on the project, then they must delegate the second review to another SSC-certified Partner (certified to GE or EP level) and BOTH must approve the waiver. To reiterate: two separate SSC-certified Partners must review and approve all waivers.

PICs and Local MPs (or designees) must work with the SSC EP and broader project team to make sure the SSC Procedure is executed and to use available information to make safe decisions regarding waivers. A member of the Health and Safety (H&S) Team and/or a locally identified SME may also be consulted regarding waiver decisions, in particular when the project involves some degree of complexity or uncertainty. Additional guidance on conducting this evaluation is presented in Appendix 4, along with illustrative examples of waiver decisions.

Waivers should only be issued when exceptional circumstances limit the execution of parts of the SSC Procedure. PICs and Local MPs (or designees) cannot waive compliance with any legislative or regulatory requirement; nor can they waive any client-mandated requirements without prior discussion with, and documented approval by, the authorized client representative.

6. TRAINING AND COMPETENCY REQUIREMENTS

There are two levels of certification for ERM staff engaged in SSC activities:

- **SSC GE Certification:** SSC GEs must be certified by completing all of the requirements of the SSC GE Certification on ERM Academy and maintaining a status of “Certified/Renewal in Progress.”
- **SSC EP Certification:** Employees who will serve in the role of SSC EP must be certified as SSC EPs by completing all of the requirements of the SSC EP Certification on ERM Academy and maintaining a status of “Certified/Renewal in Progress.”

The Local MP must assess the skills and experience level of all prospective SSC EPs and provide documented approval to the ERM Academy Team in order for an employee to become fully certified as an SSC EP. The Local MP may also revoke SSC EP certification, at their discretion, based on feedback from others, inability of the EP to demonstrate competency, or other identified performance issues.

SSC GEs that lack the qualifications and experience to be SSC EPs must participate in mentoring to develop the skills and experience to become SSC EPs. SSC GEs can utilize the “SSC Mentorship Card” template to document field mentoring received by different SSC EPs.

ERM employees and subcontractors operating detection equipment must have experience and current training specific to the equipment they will be operating. Documentation of currently valid training must be obtained and included with the project HASP and in the project files.

Training records for ERM employees must also be documented in ERM Academy.

If subsurface or overhead utilities will be de-energized by ERM employees or subcontractors, they must have formal and documented training for their role as required by local legislation and/or regulation.

Each region must develop a list of approved instructors for ERM SSC training, to be approved by the Regional H&S Leader in consultation with the regional management team.

Any changes to SSC training requirements are communicated to all affected employees via the ERM Academy Certification process.

7. DOCUMENTATION

Thorough and complete documentation of the execution of the SSC Procedure must be maintained at the project Site for the duration of ground-disturbance activities, with copies maintained in the project files.

The SSC Procedure must be documented in the SSC Project Plan (ERM-1511-FM1). This plan is required for each phase of ground-disturbance activities at a project site. The SSC Project Plan includes the scope of authorized ground disturbance and SSC activities to be performed, available sources of information, summary of subsurface structures, documentation of SSC field activities, and approval of any waivers. The completed SSC Project Plan must be reviewed and approved by the PIC before any point-disturbance clearance or ground-disturbance activities may begin. If waivers will be granted, the SSC Project Plan must also be approved and signed by the Local MP (or designee). Approvals can be initially documented in the field via notation of verbal approval or e-mail, with signature after SSC completion.

8. MANAGEMENT OF CHANGE

Any change that occurs during the execution of the SSC Procedure or subsequent ground-disturbance activities must be managed safely and effectively. Examples of change may include, but are not limited to:

- Changes to the location, scope, extent, or depth of ground-disturbance activities;
- Changes to the equipment or methods used;
- Changes in personnel;
- Changes in schedule;
- Changes in encountered field conditions, including subsurface conditions (e.g., change in soil type or refusal); and
- Safety events.

To manage change:

1. Work must be stopped or paused and the PIC and Project Manager contacted. As warranted based on the nature of the change (see below for additional guidance), a member of the Safety Team should also be contacted.
2. A re-assessment of the risks must be conducted with the input of the PIC, Project Manager, and SSC EP (or field staff lead for sites with no EP assigned). Additional input must be sought from the Local MP (or designee) for waivers, and a member of the Safety Team should also be consulted as warranted based on the nature of the risks involved.
3. SSC project documentation must be updated as necessary to reflect the change(s). The HASP, JHA(s), and other Safety planning documents must also be updated as necessary.
4. Any site or client contacts must also be notified of the change(s).
5. Work cannot be re-started without the concurrence of the PIC, Project Manager, and SSC EP (or field staff lead for sites with no EP assigned).

Standard Operating Procedure #05: Field Screening Using a Photoionization Detector

Version #1
August 2020

West Lake Landfill Site
Operable Unit 3
Bridgeton, MO

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CONTENTS

1. INTRODUCTION

The purpose of this standard operating procedure (SOP) is to establish procedures for field screening using a photoionization detector (PID) for Operable Unit 3 at the West Lake Landfill Site in Bridgeton, Missouri. The PID is a portable, nonspecific, vapor and gas detector that uses photoionization to detect a variety of chemical compounds, both organic and inorganic, in air. PIDs will be used at the Site for two main purposes: health and safety monitoring for field staff, and field screening for various environmental samples, including soil, soil gas, and indoor air.

The PID responds to most vapors that have an ionization potential less than or equal to that supplied by the ionization source, which is an ultraviolet lamp. Typical lamps range between 8.4 and 11.7 electron volts (eV), and should be selected based on the ionization potential of expected compounds of interest. As described in the Field Sampling Plan, a PID equipped with 10.6 eV lamp has been selected for use at the Site, due to its ability to detect a broad range of compounds, including known compounds of interest at the Site.

2. EQUIPMENT AND MATERIALS

- Field forms and field book;
- Site Health and Safety Plan (HASP);
- PID capable of reading parts per billion (ppb), equipped with 10.6 eV lamp (ppbRAE 3000, or equivalent);
- PID battery charger and spare batteries;
- External filters (to prevent moisture from entering the PID);
- Calibration gas (e.g., 100 parts per million [ppm] isobutylene gas);
- Tedlar® gas bags; and
- Equipment user manual.

3. HEALTH AND SAFETY

PIDs will be used for health and safety monitoring of field staff conducting investigation activities, as described in the HASP, and summarized below.

- During drilling activities, the PID will be kept in the sampling area and near the field staff breathing zone (between 3 to 5 feet off the ground) to monitor the ambient air that field staff may be reasonably exposed to.
  - For ambient PID readings below 1 ppm, sustained for 1 minute, Level D personal protective equipment (PPE) is acceptable.
  - For ambient PID readings between 1 and 10 ppm, sustained for 1 minute, Level C PPE should be used (full-face or half-mask, air-purifying respirator).
  - For ambient PID readings above 10 ppm, sustained for 1 minute, STOP WORK and re-evaluate working conditions before proceeding.
- Any elevated ambient air PID readings and responses taken will be noted in the field book.

4. PROCEDURE

4.1 Calibration

Field staff will inspect and calibrate PID equipment at the start of each field day the instrument is being used, at a minimum. The PID will be re-calibrated if readings appear to drift over the course of the day or if a spike results and the PID reading doesn't recover.

The following steps will be taken for PID calibration, in accordance with the ppbRAE User Manual:

1. Enter the calibration mode.
2. First, select Zero Calibration.
3. Connect the instrument to a "fresh" air source or use clean ambient air without detectable contaminants.
4. Select start calibration; the instrument will perform the calibration automatically.
5. When the Zero Calibration is complete, record the reading.
6. Second, select Span Calibration.
7. Fill the Tedlar® bag with 100-isobutylene by connecting the bag to the connection on the 100-isobutylene cylinder and open the gas valve. Do not fill the Tedlar bag completely.
8. Once the Tedlar® bag has been filled, connect the bag to the inlet port of the instrument.
9. Enter the Span Calibration and start the calibration; the instrument will perform the calibration automatically.
10. When the Span calibration is complete, record the reading.
11. Exit the calibration menu.

4.2 Air and Soil Gas Screening

The PID may be used to collect screening readings during vapor intrusion activities, including indoor and outdoor air sampling, and sub-slab and exterior soil gas sampling, as described below.

- If collecting a reading from a soil gas probe, inspect the soil gas probe for damage, paying special attention to conditions that may compromise the atmospheric integrity of the soil gas probe such as cracked or heaved surface seals, bent or cracked riser pipes, or frozen valves or riser pipes. Refer to the SOP for Soil Gas Probe Installation and Sampling for additional steps on checking probes for leaks prior to sampling (SOP #17, Appendix A of Field Sampling Plan). Readings may be collected from a Tedlar® bag or may be collected directly from the probe. If collecting readings directly from the probe, install flexible tubing into hose barb connection at the inlet port and connect to the soil gas probe, if applicable.
- Monitor the soil gas probe or indoor/outdoor ambient air for vapors until the readings remain stable for approximately 45 seconds. Record the stabilized reading, as well as any peak/highest reading. The peak/highest reading may occur at the onset of monitoring if there is an accumulation in the casing, but in most cases occurs as the reading stabilizes. Therefore, it is not uncommon for the

peak and stable reading to be the same. Reading from a probe screened in a silt layer could take an hour or more to stabilize if an appropriate monitoring pump is not used.

- In addition to recording the gas concentrations on the sampling form, record the sample location, date, time, observed weather conditions, and barometric pressure. Atmospheric pressure data can be obtained from a local weather station for the monitoring period.
- Allow the instrument to return to atmospheric conditions after collection of a soil gas probe sample, and prior to collecting indoor or outdoor ambient air samples.

4.3 Headspace Field Screening

The PID may be used to collect headspace field screening readings during drilling activities, as described below.

- Cut open the liner of each soil core with a utility knife.
- Fill a dedicated re-sealable bag (e.g., Ziploc®) approximately 1/2 to 2/3 full with soil.
- Seal the bag.
- Manually break the soil within the bag to aid the release of volatile organic compounds (VOCs) from the soil matrix.
- Allow the sample to equilibrate for several minutes out of direct sunlight in a 60 to 80 degrees Fahrenheit (°F) temperature environment (i.e., automobile or field office location).
- Insert the probe of the PID into the bag without opening the bag significantly (e.g., through a small hole in the bag).
- Observe the PID display for the maximum organic vapor reading.
- Record the sample number, depth, and maximum headspace reading in the field book and boring log form.

Standard Operating Procedure #06: Field Screening Using a Landfill Gas Meter

Version #1
August 2020

West Lake Landfill Site
Operable Unit 3
Bridgeton, MO

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CONTENTS

1. INTRODUCTION

The purpose of this standard operating procedure (SOP) is to describe the method for the inspection, maintenance, and calibration of field equipment and field screening for oxygen, carbon dioxide, and methane using a landfill gas meter for Operable Unit 3 at the West Lake Landfill Site in Bridgeton, Missouri. The approach detailed here is based on relevant guidance and documents and is intended to enable field staff to measure oxygen, carbon dioxide, and methane concentrations in soil gas, indoor air, or outdoor ambient air in a competent and reproducible manner.

2. EQUIPMENT AND MATERIALS

- Appropriate health and safety equipment per the Site Health and Safety Plan;
- Field book;
- Calibration and sampling forms;
- Landfill gas meter (e.g., Landtec GEM 2000™, or equivalent);
- Calibration gases;
- Tedlar® gas bags;
- Operational manual for landfill gas meter;
- Tools and/or keys required for opening soil gas probes (if applicable); and
- Tubing/hoses for connecting to the soil gas probe (if applicable).

3. HEALTH AND SAFETY

A landfill gas meter may be used for health and safety monitoring of field staff conducting investigation activities, as described in the HASP, and summarized below.

- During drilling activities, the landfill gas meter will be kept in the sampling area and near the field staff breathing zone (between 3 to 5 feet off the ground) to monitor the ambient air that field staff may be reasonably exposed to.
  - For ambient readings below 10% the lower explosive limit (LEL), monitor readings. Evacuate if working in a confined space.
  - For ambient readings between 10 and 25% LEL, there is a potential fire or explosion hazard. STOP WORK and re-evaluate working conditions before proceeding.
  - For ambient readings above 25% LEL, there is a fire or explosion hazard. STOP WORK immediately and evacuate the premises.
- Any elevated ambient air PID readings and responses taken will be noted in the field book.

4. PROCEDURE

4.1 Calibration Procedure

Field staff will inspect and calibrate the landfill gas meter used at the start of each field day prior to use. Instrument calibration may be checked or repeated anytime during the field day if unexpected or unexplained readings are obtained. Calibration records will be maintained on calibration logs and the calibration date and time should be noted in a field book or on the calibration log itself following instrument calibration. Calibration procedures are described further below.

1. Inspect the equipment to ensure that all contents are clean and accounted for. If something is missing or appears to be defective, notify the Project Manager. Allow the instrument to reach ambient temperature, pressure, and air concentration prior to use.

2. Calibrate the instrument according to the manufacturer’s specifications, with a two-point process using “fresh air” and reference gas standards.

3. When using the standard reference gas, select the appropriate calibration option on the menu and the reference gas that will be used. Apply the relevant known certified gas concentration through the inlet port of the instrument, wait until the current gas reading has stabilized, and then confirm the required calibration on the menu. The standard used should have a concentration similar to the anticipated concentration of the gas being monitored. For example, if levels of methane gas below 100 parts per million (ppm) are anticipated, then a 100 ppm methane gas standard would be more practical to use for a calibration check than a 1,000 ppm methane gas standard. Likewise, if the anticipated methane concentration to be monitored is 10,000 ppm, a methane gas standard of this concentration would be more applicable to use for a calibration check than a 100 ppm methane gas standard.

4. Record the manufacturer's serial number or use other means to uniquely identify calibrated equipment on the calibration log and/or in the field book. Also document the calibration standards, lot number, expiration date, and the calibration results (final reading).

5. Document that calibration was conducted, including the time and the instrument involved, in the field book or on a calibration log.

6. If a suspicious or unexpected reading is collected, verify calibration by testing the equipment using the calibration standard.

7. If the equipment fails calibration or becomes inoperable during use, troubleshoot by replacing the batteries, performing a “fresh air” calibration in atmospheric air, or consult the operational manual. If the equipment cannot be restored to operable use and cannot be recalibrated, remove it from service and segregate to prevent inadvertent use. Note the problem in the field book or calibration sheet and order replacement equipment.

4.2 Field Screening Procedure

Indoor/outdoor ambient air and soil gas probe screening procedures are listed below.

- It should be noted that measurements of methane by a landfill gas meter can be affected by the presence of other hydrocarbons (e.g., petroleum hydrocarbons). If these are present in air or soil gas, the methane reading may be higher than actually methane concentrations. If necessary a charcoal filter can be used to filter this cross-gas effect. Oxygen and carbon dioxide readings are not significantly affected by the presence of other landfill gasses.

- If collecting a reading from a soil gas probe, inspect the soil gas probe for damage, paying special attention to conditions that may compromise the atmospheric integrity of the soil gas probe such as cracked or heaved surface seals, bent or cracked riser pipes, or frozen valves or riser pipes. Refer to the SOP for Soil Gas Probe Installation and Sampling for additional steps on checking probes for leaks prior to sampling (SOP #17, Appendix A of Field Sampling Plan). Readings may be collected from a Tedlar® bag or may be collected directly from the probe. If collecting readings directly from the probe, install flexible tubing into hose barb connection at the inlet port and connect to the soil gas probe, if applicable.

- Monitor the soil gas probe or indoor/outdoor ambient air for oxygen, carbon dioxide, and methane concentrations until the readings remain stable for approximately 45 seconds. Record the stabilized reading, as well as any peak/highest reading. The peak/highest reading may occur at the onset of monitoring if there is an accumulation in the casing, but in most cases occurs as the reading stabilizes. Therefore, it is not uncommon for the peak and stable reading to be the same. Typically the methane readings from a soil gas probe screened in a sand layer should stabilize in less than 3 minutes. Reading from a probe screened in a silt layer could take an hour or more to stabilize if an appropriate monitoring pump is not used.
- In addition to recording the gas concentrations on the sampling form, record the sample location, date, time, observed weather conditions, and barometric pressure. Atmospheric pressure data can be obtained from a local weather station for the monitoring period.
- Verify that the soil gas/methane concentrations being recorded are within the detection limits of the instrument/meter being used. Values of 6 percent (%) LEL or less and 0.3% by volume or less may be verified by using an instrument/meter that measures in ppm.
- If methane is measured at a concentration outside of safe working conditions, evacuate the area immediately.
- Allow the instrument to return to atmospheric conditions after collection of a soil gas probe sample, and prior to collecting indoor or outdoor ambient air samples.
- Useful measurement conversions are as follows:

  - $\%CH_4$ (in air) = $\%CH_4$ (LEL) x 0.05
    = CH_4 (ppm) x 1% / 10,000 ppm
  - %CH4 (LEL) = %CH4 (in air) x 20
    =CH_4 (ppm) x 1% / 10,000 ppm x 20
  - CH4 (ppm) = %CH4 (in air) x 10,000 ppm / 1%
    = $\%CH_4$ (LEL) x 0.05 x 10,000 ppm / 1%

Examples of these formulas are:

- 100% LEL = 5% by volume = 50,000 ppm
- 20% LEL = 1% by volume = 10,000 ppm
- 1% LEL = 0.05% by volume = 500 ppm
- 0.1% by volume = 1, 000ppm

5. REFERENCES

Landtec. 2010. GEM™2000 Gas Analyzer & Extraction Monitor Operation Manual.

Standard Operating Procedure #07: Drilling Oversight

Version #1
August 2020

West Lake Landfill Site
Operable Unit 3
Bridgeton, MO

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CONTENTS

1. INTRODUCTION

The purpose of this standard operating procedure (SOP) is to provide standard procedures for drilling oversight activities for Operable Unit 3 at the West Lake Landfill Site in Bridgeton, Missouri. Currently proposed drilling techniques at the Site include direct-push for piezometer installation and WATERLOO APS™ profiling, and sonic drilling for borehole advancement and well installation.

Drilling services will be provided by qualified drilling subcontractor(s), who are licensed by the State of Missouri, and after performing utility clearance as described in the SOP for Subsurface Clearance (SOP #04, Appendix A of the Field Sampling Plan). Drilling activities will be performed in accordance with all local and state-level regulations, including contacting the Missouri One Call System and obtaining all necessary permits.

2. EQUIPMENT AND MATERIALS

- Field forms and field book;
- Site Health and Safety Plan (HASP) and Subsurface Clearance Project Plan;
- Personal protective equipment (PPE) in accordance with the project HASP;
- Permanent-ink and waterproof pens, clipboard, and drawing template;
- Whiteboard and marker;
- Safety cones, traffic tape, and/or barricades;
- Documentation of any local permits or contract documents;
- Spatula for cutting/removing soil samples from liner;
- Stainless steel trowel and/or shovel;
- 6-foot folding ruler;
- Trundle wheel or long field measuring tape;
- Safety knife;
- Hand lens;
- 50-foot cloth or fiberglass tape with weight;
- Water level meter (Solinst® 102 or equivalent);
- Photoionization detector (PID) equipped with a 10.6 electron volt lamp (such as a ppbRAE 3000 or equivalent), fitted with a moisture filter to reduce moisture interference;
- Re-sealable plastics bags;
- Rags, probe wipes;
- Lumber marking crayon (do not use spray paint, it contains toluene);

- Decontamination supplies (e.g., non-phosphate detergent [Liquinox® or equivalent] and distilled water);
- Transit and/or level, tripod, survey rod, if ERM field staff will perform relative elevation survey;
- 55-gallon steel drums (for drill cuttings and fluids) and labels for drums (non-hazardous, hazardous, awaiting classification);
- Decontamination station for drilling equipment/rig decontamination; and
- Spill response equipment (if needed).

3. HEALTH AND SAFETY

Drilling and other subsurface intrusive work presents specific hazards and proper safety precautions must be observed performing any subsurface work. These hazards, as well as those associated with constructing and installing monitoring wells, should be addressed by a Site-specific HASP. The safety guidelines within the HASP should be used to complement the judgment of an experienced professional. For all subsurface drilling activities, the project-specific health and safety requirements must be reviewed by ERM field staff and subcontractors.

Health and safety requirements specific to the tasks described in this SOP may include the following:

- During drilling, all field staff within the exclusion zone should pay close attention to all rig operations. Rotating drilling tools can catch or snag loose clothing causing serious injury. Sampling hammers can often create pinch points and/or crush hazards. Improper handling of casing can also create potential pinch points (hands and feet), crush hazards, and back strain.
- Clear communication signals must be established with the drilling crew, since verbal communication may not be heard during the drilling process. Hearing protection should be used during all drilling operations.
- ERM field staff must stop work immediately and order all direct subcontractors to stop work wherever an unsafe condition is recognized. Contact the Project Manager (PM) immediately. Work cannot continue until the unsafe condition is corrected.
- If any non-drilling personnel enter the exclusion zone, work should be immediately stopped until the person can be briefed on safety procedures.
- In a situation where an unsafe condition exists that is beyond the control of the ERM field staff (such as an unsafe practice by an independent contractor not under ERM supervision) but is potentially dangerous to the ERM field staff or subcontractors, stop work, evacuate the area, and contact the PM immediately.
- ERM field staff are not authorized to drive contractor trucks or operate or borrow their equipment.

4. PROCEDURE

This section addresses the basic requirements and procedures involved with oversight of direct-push and sonic drilling. These sections include information on the selection of methods and equipment, planning and preparation requirements, health and safety requirements, drilling procedures, and key practices for ensuring quality. As stated above, this SOP will not address well installation, for procedural details related to well installation, please refer to the SOP for Monitoring Well Installation and Development (SOP #09, Appendix A of the Field Sampling Plan).

The details within this SOP should be used in conjunction with project-specific work plans. Information regarding anticipated total depths of soil borings, sampling methodologies, and equipment to be used should be outlined in the project-specific work plan.

4.1 Selection of Methods and Equipment

During project coordination, the ERM PM and/or Field Staff Lead will evaluate the project Site to determine the type of equipment that is appropriate for the project based on anticipated subsurface lithology, boring location and accessibility, and anticipated depth of the boring among other Site-specific factors. There are several equipment considerations that can generally be applied to direct-push and sonic technologies, including:

- Use of track-mounted versus truck-mounted drilling rigs. Track-mounted sonic rigs, sometimes referred to as all-terrain-rigs, are positioned on a pair of tracks and can be utilized in areas where access is not feasible by truck or in otherwise uneven terrains. Overhead utilities should be considered when selecting the type of rig, as track-mounted rigs generally have lower clearance.
- Lubricating compounds. Only Teflon™-based thread compounds may be used to lubricate auger bolts or threaded portions of any drill string assembly. No other compound may be used unless otherwise directed in the project work plans. Such directed use in the project work plans should take into account applicable regulatory agency requirements and/or approval.
- Proper sampling string apparatus are to be available at the sizes and lengths needed to properly drill the desired diameters in the formation(s) to be encountered.
- During drilling, no additives (except potable water) may be added to the borehole and interior portion of the auger string without appropriate regulatory approval and/or concurrence with project-specific requirements. Only potable water may be added to the borehole and interior portion of the drill string, and only after discussion with and approval by the ERM field staff overseeing drilling.

4.2 Drilling Site Mobilization

To the extent possible, basic Site preparation should be performed before mobilization to the Site (e.g., clearing brush, utility surveys). The project team, including at least one member of the field staff and management teams, coordinate these efforts with the client contact as needed. A list of basic Site preparation and mobilization requirements and procedures are as follows:

- A decontamination area should be established. The area should be located so that it does not interfere with Site operations or expose clean drill tooling and other equipment to potential cross contamination. Prior to advancement of any boring, drilling and sampling equipment should be decontaminated as specified in the SOP for Equipment Decontamination (SOP #18, Appendix A of the Field Sampling Plan).
- The logistics of drilling, logging, sampling, cuttings/fluid containment, and/or well construction should be determined before mobilizing. The Site should be prepared in accordance with the project work plans.
- Before mobilization, the client contact and ERM field staff should assess the drilling Site. This assessment should identify potential hazards (e.g., slip/trip/fall, overhead, soft or sloping ground, etc.) and determine how drilling operations may impact the environment (e.g., dust, debris, noise).

Potential hazards should be evaluated and corrected, or the borehole location changed or shifted in accordance with the project work plans.

- Before drilling begins, utility clearance must be completed as described in the SOP for Subsurface Clearance (SOP #04, Appendix A of the Field Sampling Plan).
- Overhead obstructions such as trees, tall shrubs, and building overhangs should be evaluated and avoided for safety reasons, as they can impair the proper function of drill mast components.
- Once Site preparation is completed, the rig is mobilized to the Site and positioned over the identified borehole location. The rig should then be leveled with a set of hydraulic pads at the front and rear of the equipment. Once the rig is leveled, the mast should be raised slowly and carefully to prevent tipping or damaging the rig and to avoid hitting any obstructions or hazards.
- The driller and the ERM field staff should inspect the drilling equipment for proper maintenance and appropriate decontamination. All clutches, brakes, winches, and drive heads should be in proper working order. Cables and hydraulic hoses should be in good condition. Tooling connections, bolts (if applicable), sampling rod joints, and plug rod joints should be in good condition with no significantly worn threads, cracked or worn joint connections, or other signs of excessive wear. ERM field staff should measure the length and diameter of the drill tooling to confirm it is appropriate for the project scope-of-work.
- Appropriate barriers and markers should be in place prior to drilling, in accordance with the project HASP. Plastic sheeting may be required beneath the rig and around the drilling area. When plastic is placed in the general vicinity of rotating equipment, extra precaution may be necessary to make sure that the plastic does not pose a safety hazard or unwarranted distraction or nuisance to the drill crew.
- Any leakage of fluids from the rig should be immediately repaired. If the rig requires additional decontamination, it should be removed from the drilling area and decontaminated before it is allowed to remobilize to the Site.
- Appropriate containment for cuttings and other investigation-derived waste should be set up on-Site prior to the commencement of drilling.

4.3 General Drilling Requirements and Procedures

The ERM field staff should not leave the drill Site whenever drilling operations are conducted and the borehole is being advanced. ERM field staff should be present at all times when subcontractor personnel are on the project Site. The ERM field staff will fully describe and record all tasks performed in support of drilling activities in a field book or log sheet, including logging the samples, monitoring drilling operations, recording water losses/gains and groundwater data, preparing the boring logs and well diagrams, and recording the temporary well installation procedures of the rig. Details regarding well installation are included in the SOP for Monitoring Well Installation and Development (SOP #09, Appendix A of the Field Sampling Plan).

The following key practices should be followed to ensure the quality of proper boring advancement and installation:

- Immediately prior to drilling, safety sampling and monitoring equipment should be calibrated according to manufacturer's specifications and appropriate project-specific requirements and/or procedures. The field staff breathing zone should be monitored with a photoionization detector (PID) and 4-gas meter based on the applicable HASP requirements.

- Establish a datum for measuring borehole depth (top of drill platform, stake in ground, etc.). The borehole depth is determined by keeping track of the length of rod/bit assemblies and comparing the position relative to the established datum.
- During drilling operations, as the borehole is advanced, ERM field staff will generally do the following:
  - Observe and monitor rig operations;
  - Conduct all health and safety monitoring and sampling, and supervise health and safety compliance; and
  - Document drilling progress and other appropriate observations on appropriate forms.
- Prepare a boring log from cuttings or soil samples as specified by applicable ERM SOPs and project-specific requirements.
- Supervise the collection and preparation of any samples.
- As drilling progresses, ERM field staff should observe and be in frequent communication with the driller regarding drilling operations. Conditions noted should include relative rates of penetration (as indicated by fast or slow drilling), rotation speeds, chattering and bucking of the rig, hard or sticky drilling, drilling refusal, etc. These conditions, including penetration rates, should be recorded in the field book.
- Drilling should not be allowed to progress faster than the ERM field staff can adequately observe conditions, compile logs, and supervise safety and sampling activities.
- ERM field staff should also observe the fitting and placement of drill string connections, as well as the make-up and tightening of drill rods for the center plug and/or sampling string. Any observed drilling problems and causes, including significant down time, should be recorded on the appropriate forms.
- Cutting and fluid containment during drilling should be observed and supervised by the ERM field staff in accordance with the project work plan.
- Petroleum jelly, Teflon tape, or lithium grease shall not be used on the threads of downhole drilling equipment. If a lubricating agent is required, the proposed lubricant must be reviewed for approval by ERM field staff. Adequate time and information, such as Safety Data Sheets (SDS), must be provided for the ERM's review. Food grade vegetable oil is an example of an approved lubricant. Additives containing either lead or copper will not be allowed. In addition, polychlorinated biphenyls (PCBs) will not be contained in hydraulic fluids or other fluids used in the drilling rig, pumps, or other field equipment and vehicles.
- Surface runoff or other fluids will not be allowed to enter any boring or well during or after drilling/construction. Likewise, re-circulated drilling fluids will be contained in the work area during installation of borings and not allowed to runoff into the surrounding areas.
- Antifreeze used to keep equipment from freezing will not contain rust inhibitors and sealants. If antifreeze is added to a piece of machinery in contact with drilling fluid, the antifreeze will be completely purged from the equipment before used in drilling, mud mixing, or any integral part of the overall drilling operation.

4.4 Direct-Push Drilling for WATERLOO APS^{TM} Profiling

WATERLOO APS^{TM} activities will include drilling of pilot test boreholes and collection of a continuous hydrostratigraphic log and discrete-depth groundwater samples using the WATERLOO APS^{TM} hydraulic profiling tool.

The following procedure will be used for the advancement of the WATERLOO APS^{TM} profiling tool:

1. The drilling subcontractor will assemble the direct-push drill rig in accordance with the manufacturer's instructions.
2. The drilling subcontractor will decontaminate non-dedicated sampling equipment prior to first use and following sampling of each location. All parts of the equipment coming in contact with groundwater must be decontaminated with high-pressure steam cleaning within a designated area on-Site.
3. The WATERLOO APS^{TM} Profiler tip will be assembled for peristaltic mode or gas drive mode, depending on the estimated depth to water, by the subcontractor per the manufacturer's instructions.
4. The WATERLOO APS^{TM} Profiler tip will be added the bottom of the drill rod as the drive point with the stainless steel tubing threaded through the estimated amount of drill rods.
5. The hydraulic conductivity profiling system and water quality monitoring system will be calibrated and assembled by the drilling subcontractor per manufacturer's instructions then attached to the stainless steel tubing.
6. The drilling subcontractor will advance the borehole while hydraulic conductivity data is collected in real time.
7. The drive rod will be stalled when zones of high conductivity are located, or every five feet (whichever occurs first).
8. Water will be purged through the system to obtain water quality parameter data from the water quality monitoring system.
9. Samples will be collected at depths and locations in accordance with the Field Sampling Plan, or as adjusted in the field based on further Site knowledge. Samples will be collected using a peristaltic pump under low flow conditions (generally between 100 and 300 milliliters per minute), or a gas drive if the water table is too deep for the use of a peristaltic pump. Samples will be stored in a cooler with ice, pending shipment.
10. All data will be recorded by the drilling subcontractor and provided in electronic format to ERM in a timely fashion (i.e., on a daily basis).
11. Boreholes will be completed to the target depth, hard refusal, or push-rate refusal, as defined by the driller. After completion, the borehole will be pressure-grouted from the bottom to ground surface to avoid cross contamination.
12. ERM will coordinate the shipment of samples in coolers to the analytical laboratory under proper chain of custody procedures as described in the SOPs for Chain of Custody and Sample Packing and Shipping (SOP #02 and SOP #03, Appendix A of the Field Sampling Plan).

4.5 Soil and Rock Boring Logs

During drilling, the ERM field staff will compile a boring log that includes the following:

- Borehole location (distance to nearest landmarks and latitude/longitude);
- Name of the field staff, drilling company, and driller;
- Dates and times of drilling events, including when drilling began, the total depth and when it was reached, intermediate milestones, and any changes in equipment;
- Sampling depths and recovery of soil or rock samples;
- PID readings;
- Water content in soil;
- Percentages of gravel, sand, and fines in soil;
- Lithologic data and descriptions in accordance with the SOP for Solid Matrix Logging and Sampling (SOP #08, Appendix A of the Field Sampling Plan);
- Premature total depth due to refusal and the cause of refusal (if known); and
- Any other observed drilling conditions, such as observed groundwater levels, zones of hard or soft drilling, flowing sands, etc.

4.6 Sonic Drilling in Alluvium

The following procedure will be used for the advancement of sonic borings:

1. The drilling subcontractor will assemble the sonic drill rig in accordance with the manufacturer's instructions.
2. Prior to sampling and between sampling locations, the sample equipment must be decontaminated according to the procedures in the SOP for Equipment Decontamination (SOP #18, Appendix A of the Field Sampling Plan).
3. Establish a convention with the driller to consistently identify and orient the "top of sample".
4. An inner barrel is advanced into the subsurface to collect a soil core sample. Generally, the core barrel is 10 feet in total length; however, 5-foot and 20-foot sections may also be used.
5. After the inner barrel has been advanced to the terminal depth of the sample run, a larger diameter outer drill rod (6-inch, 8-inch, 10-inch, or 12-inch) is advanced over the inner rod to both ream the hole and dislodge the advanced inner rod. The larger diameter rod also acts as temporary casing supporting the borehole from collapse while the inner rod is removed from the borehole.
6. The inner rod is then removed from the borehole and the soil core is extruded from the barrel into plastic sheathing for examination by the ERM field staff. The subcontractor will mark or note the depth range of the run on the plastic sheathing, and the ERM field staff should also confirm the interval for each core.
7. The sequence (Step 2 through 4) is repeated to collect the next length of soil core.
8. Each time a soil core is extracted, the ERM field staff should record the depth interval of the full core.

9. A weighted tape should be used to verify the depth of the boring within the casing. Measurement should be made with reference to the ground surface. It is important to measure depth at the start of sampling intervals and at total depth of the boring. If slough is present, it should be removed by forcing a sampler into it and retrieving and emptying the sampler of slough. If water is introduced to the boring, the drilling subcontractor may also use mechanical means to clear the borehole of slough. Slough is generally easy to identify based on jumbled internal textures, lighter density, macroscopic and unmineralized void spaces, greater softness and malleability, and decreased cohesion, as compared to in situ material that has not been dislodged prior to the sampling process.
10. Retrieve the soil core bag and transport it to the sample management location. Sample and describe the core in accordance with the SOP for Solid Matrix Logging and Sampling (SOP #08, Appendix A of the Field Sampling Plan).
11. Photograph each core, including a scale (e.g., tape measure) and location name and depth of top and bottom of each interval (e.g., using a dry erase board)

4.7 Basic Rock Coring Procedure

Borings at locations selected for installation of new bedrock monitoring wells will be advanced into rock only after characterization of the alluvium has been completed. For wells to be completed in both alluvium and bedrock, the outer casing used to over-drill the temporary alluvial casing will be 10 inches in diameter. Once the 10-inch casing is set approximately 5 feet into bedrock, an 8-inch diameter drill casing will then be used to advance through rock. Similar to the alluvium, the core barrel will be advanced in 10-foot increments to retrieve continuous 4-inch diameter sections of rock core. While portions of the core may exhibit increased disintegration from the vibratory drilling, we anticipate being able to recover intact sections of core up to about 3 feet in length.

1. The drilling subcontractor will assemble the core barrel according to manufacturer’s instructions and inspect the core barrel for wear, dents, galls, and clearances.
2. Prior to sampling and between sampling locations, the core barrel, inner tube, drill rods, and any tools to be used down the borehole or to handle the cores must be decontaminated as specified in the SOP for Equipment Decontamination (SOP #18, Appendix A of the Field Sampling Plan).
3. Establish a convention with the driller to consistently identify and orient the "top of sample".
4. The inner tube of the core barrel is inserted and the lead drill rod and core rod (with core barrel) is attached to the drill mechanism through the spindle or below the drill head.
5. The drilling subcontractor starts drill-head rotation, and drills in 10-foot increments. Drilling speed should also be appropriate for the material to be cored.
6. Rotation and down-force pressure are stopped when the required depth is reached, slightly raising the core barrel off the borehole bottom.
7. The drill rods are raised and the core barrel and core are removed from the borehole (if not using a wire line).
8. The core barrel is disassembled and the core is removed.
9. The drilling subcontractor checks the core barrel for wear or damage, reassembles the core barrel and drill rod and returns them to the borehole. The use of two core barrels can greatly speed up the coring operations. When one core barrel is in use the other can be cleaned and reassembled.

10. Retrieve the rock core and transport it to the sample management location. Sample and describe the core in accordance with the SOP for Solid Matrix Logging and Sampling (SOP #08, Appendix A of the Field Sampling Plan).

11. Photograph each core, including a scale (e.g., tape measure) and location name and depth of top and bottom of each interval (e.g., using a dry erase board).

12. The sequence (Step 4 through 11) is repeated to collect the next length of rock core. Drilling depth is increased by adding drill-rod sections to the top of the previously advanced drill-rod column.

The rock core shall be recovered continuously from the borehole. If core recovery drops below an acceptable level, the drilling procedure should be modified to increase recovery to the extent feasible by adjusting the drilling revolutions per minute (RPM), down-feed pressure, or drilling fluid type. The type and size of core barrel and bit used may be changed until core recovery is improved to a level acceptable to the project field staff. Mechanical breaks in the core should be minimized as much as possible. In many instances, 100 percent recovery of core is not possible and significant intervals of no recovery occur during coring. This may be due to a variety of factors related to the formations encountered and drilling and coring methods used. If problems with core recovery occur, the ERM field staff should consult with the driller to determine if core recovery can be improved and what actions should be taken to improve recovery. If it is determined that recovery cannot be improved with any corrective action, the coring may continue after consultation with the PM, or designee. The corresponding decision(s) and rationale to continue coring should be documented on the appropriate forms and records.

Once the total depth of the borehole is reached and the coring is completed, the borehole should be abandoned according to the project work plan.

4.8 Core Handling, Care, Preservation, Packaging, and Storage

The following tasks should be completed for core samples requiring routine care:

1. Remove the core from the core barrel with a minimum of disturbance.

2. Mark the top and bottom of the core with a felt-tip or other permanent marker.

3. Photograph the core in color and with a color strip-chart in the picture for reference.

4. Perform initial core logging, including identification of the borehole and field staff, equipment used, datum, coring depth, contact depths, and any information required or useful for the detailed logging.

5. Place the core in rigid wooden or waxed boxes with appropriate partitions. Mark the top and bottom and core depths inside the box. Orient the core segments to their original relative positions by fitting tops and bottoms of adjacent core segments together to the extent feasible. Once the core is oriented to the extent feasible, mark entire length of cores with adjacent felt-tip markers of two different colors to preserve their relative positions. Optionally, place the core in loose-fitting polyethylene sleeves following marking.

6. Add core blocks/spacers (Photo 1) for intervals of no recovery; add packing to the core box and seal.

***Photo 1**: Core Blocks/Spacers*

7. Mark both the top and one edge of the core box with the following information: company name, project name, drill-hole number or location, core box number in sequence down the hole, and depths from a specified datum to the top and bottom of the core.

8. Handle the core boxes gently and transport them by company vehicles, if possible, to avoid core damage. Protect the core from excess heat and freezing during transportation.

9. Store the core in an environment that will not cause alteration of physical properties and structure.

10. Catalog the core and maintain a record of the core, including company and project name, drill hole number and location, orientation of the borehole, elevation of the datum, dates of coring, core box number and depth intervals, date and name of the person doing the initial logging, boring log, and photographs of the core.

4.9 Collection and Disposal of Drill Cuttings

The drilling contractor will be responsible for containerizing all drill cuttings and other wastes generated during drilling activities. An accumulation area for all investigation-derived wastes should be coordinated with the Site contacts prior to initiating drilling activities. The project-specific scope of work will outline details regarding proper containerization, transport, and disposal for derived wastes.

Standard Operating Procedure #08: Solid Matrix Logging and Sampling

Version #2
November 2020

West Lake Landfill Site
Operable Unit 3
Bridgeton, MO

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CONTENTS

1. INTRODUCTION

The purpose of this standard operating procedure (SOP) is to provide standard procedures for solid matrix sample logging and sampling activities for Operable Unit 3 at the West Lake Landfill Site in Bridgeton, Missouri. Solid matrix samples (i.e., alluvium and bedrock cores) will be recovered during sonic drilling, as described in the SOP for Drilling Oversight (SOP #07, Appendix A of the Field Sampling Plan). Samples will be collected from select locations, as detailed in the Field Sampling Plan. This SOP provides the standard practice for collecting samples from the cores and logging soil and rock classifications. The SOP includes the minimum recommended steps and quality checks that employees are to follow when performing the task.

The goal of solid matrix sample logging and sampling is to obtain representative data and samples that meet project data quality objectives and industry acceptable standards of accuracy, precision, comparability, and completeness. Data collected during the sampling process (e.g., field observations and core description) may be used to infer subsurface conditions and assist in interpreting laboratory analytical results and developing a conceptual Site model.

2. EQUIPMENT AND MATERIALS

- Field forms and field book;
- Permanent-ink and waterproof pens, drawing template, and engineering scale;
- Clipboard;
- Stainless steel knife spatula for cutting/removing soil samples from liner;
- Digital camera;
- Measuring tape or rule;
- Field Sampling Plan, Health and Safety Plan (HASP), Subsurface Clearance Plan;
- Personal protective equipment (PPE) in accordance with the project HASP;
- Grain-size chart, Unified Soil Classification System (USCS) guide, Munsell color chart, and other aids for field classification of soils;
- Hand lens;
- Appropriate sample containers (e.g., laboratory-provided);
- Cooler and ice (if samples are to be collected);
- Labels, chain of custody (CoC), and custody seals;
- Bubble wrap, shipping papers and shipping tape (if shipping instead of via courier); and
- Decontamination supplies (e.g., non-phosphate detergent [Liquinox® or equivalent] and distilled water).

3. HEALTH AND SAFETY

SOPs are designed to provide technical guidance and do not provide detailed or comprehensive guidance related to health and safety, nor do they represent guidance on safe work procedures for the tasks described. Appropriate tips related to health and safety issues associated with specific tasks may be included within technical descriptions for information's sake only.

Health and safety aspects of all projects and project tasks should be assessed and planned using ERM's established Health and Safety planning procedures. Drilling and other subsurface intrusive work presents specific hazards and proper safety precautions must be observed performing any subsurface work. These hazards, as well as those associated with constructing and installing monitoring wells, should be addressed by a Site-specific HASP. The safety guidelines within the HASP should be used to complement the judgment of an experienced professional. For all subsurface drilling activities, the project-specific health and safety requirements must be reviewed by ERM field staff and subcontractors.

4. PROCEDURE

4.1 Soil Sample Collection

Prior to sampling, field staff will ensure that the amount and type of sample containers selected and the various preservation techniques to be used are in compliance with the requirements established in the QAPP.

The following procedure will be used for the collection of soil samples:

- Following retrieval of the soil core bag, the ERM field staff will use a decontaminated safety knife to cut the plastic open parallel to its length to expose the core.
- Don a clean pair of nitrile gloves and open the sample tool. If the sample is removed from a re-usable sampling tool, place the core into a clean, decontaminated sample tray. If the sample was collected using an expendable liners, zip-cut the liner lengthwise to expose the soil core.
- Using a clean, decontaminated stainless steel knife or spatula, scrape the wall of the soil core to expose a clean surface. Identify and discard any obvious slough from the top of the soil core.
- Using a clean, decontaminated stainless steel knife or spatula, collect aliquots for headspace screening or run the photoionization detector (PID) along each core, as required by the FSP. The procedure for headspace field screening is described in the SOP for Field Screening Using a Photoionization Detector (SOP #05, Appendix A).
- For soil samples required by the FSP, place samples in laboratory-provided sample containers for the analyses listed in the QAPP.
- Record the sample name, sample type, analytical methods, sample date, sample time, and sampler name on the boring log, label, and CoC, as applicable.
- Bag, label, and store additional soil samples at a designated location for further testing, if required.
- Decontaminate the sampling equipment as specified in the SOP for Equipment Decontamination (SOP #18, Appendix A of the Field Sampling Plan).

- Label, package, and ship coolers to the analytical laboratory under proper CoC procedures as described in the SOPs for Chain of Custody and Sample Packing and Shipping (SOP #02 and SOP #03, Appendix A of the Field Sampling Plan).

4.2 Soil Classification

In general, soil descriptions will be written in the following format, using the procedures based upon the USCS, United States Department of Agriculture, or Burmister Classification System as directed by the Project Manager to meet the project's needs.

Major components will be shown in capital letters (e.g., SAND), as following example demonstrates: hard brown silty CLAY with a trace of sand and gravel, moist, fractured. Attached Figure 1a and Figure 1b depict soil characterization guidance charts for reference.

Record the following soil characteristics based on visual examination of the soil cores in the field:

1. Soil type and grain size based on the USCS (e.g., gravel, sand, silt);
2. Color;
3. Angularity and sphericity (i.e., angular vs. well rounded; flat vs. spherical);
4. Stratification, when appropriate, using the following terms:
    a. Massive—thickness greater than 3.3 feet (1 meter);
    b. Bedded—thickness of 0.5 inches to 3.3 feet (1 centimeter to 1 meter); and
    c. Laminated—thickness of 1 millimeter to 0.4 inches (1 centimeter).
5. Moisture (i.e., dry, moist, wet, saturated);
6. Depth at which water is encountered;
7. PID screening value (where appropriate); and
8. Other distinguishing or notable features (e.g., presence of organic material, unusual colors, noticeable odors, or any other unusual features or observations).

4.3 Rock Core Sample Collection

General sample collection methods are listed below.

- Retrieve the sampling tool and transport it to the sample management location.
- Don a clean pair of nitrile gloves and open the sample tool. If the sample is removed from a re-usable sampling tool, place the core into a clean, decontaminated sample tray. If the sample was collected using an expendable liners, zip-cut the liner lengthwise to expose the core.
- Place samples in laboratory-provided sample containers for the analyses listed in the QAPP.
- Record the sample name, sample type, analytical methods, sample date, sample time, and sampler name on the boring log, label, and CoC, as applicable.

- Decontaminate the sampling equipment as specified in the SOP for Equipment Decontamination (SOP #18, Appendix A of the Field Sampling Plan).
- Samples will be labeled, packaged, and shipped in coolers to the analytical laboratory under proper CoC procedures as described in the SOPs for Chain of Custody and Sample Packing and Shipping (SOP #02 and SOP #03, Appendix A of the Field Sampling Plan).

4.4 Logging Rock Core

The Rock Coring Log should include general information such as the name of Site and project number, Site location, ERM field staff name, drilling subcontractor company and name of contractor field lead driller, reference sketch for the drilling location, date and time for the start and completion of the boring, type and model of drill rig used (e.g., sonic or cable-tool), weather conditions, method of drilling (e.g., air-rotary), size of the borehole, and the length, diameter, and type of all downhole casing and sampling materials.

The following standard procedure should be followed when describing rock core:

1. Field screen the rock core by running the PID along each 10-foot core at a distance of 0.5 to 1 inch above the core. The highest PID results from the 10-foot interval, in parts per billion, will be recorded on field forms for each sample depth and location.
2. Photograph each core, including a scale (e.g., tape measure) and location name and depth of top and bottom of each interval (e.g., using a dry erase board).
3. Describe the rock name in capital letters (e.g., SHALE, LIMESTONE) followed by additional descriptions.
4. Describe the color of the rock.
5. Record the recovery and rock quality designation (RQD). The recovery is the total amount recovered divided by the total length of the run. RQD is calculated by adding up the total number of intact sections that are a minimum of 4 inches long divided by the length of the run. RQD is a proxy for rock weathering and quality where high RQD (>75%) generally indicates a fresh or slightly weathered rock.
6. Describe any bedding, foliation, or banding. Bedding thickness should be included in the description according to the following table.

Term	Bed Thickness/Spacing
Thinly Laminated	<2 mm
Laminated	2–6 mm
Very Thin	6–20 mm
Thin	20–60 mm
Moderately	60–200 mm
Thin	0.2–0.6m
Thick	0.6–2 m
Very Thick	>2 m

m = meters; mm = millimeters

7. Describe the degree of rock weathering using the following criteria:

   a. Fresh or unweathered: rock mass shows no loss of strength or discoloration;

   b. Slightly weathered: rock mass is not significantly weather than fresh rock, some discoloration and defect;

   c. Moderately weathered: rock is significantly weaker than fresh rock and is discolored;

   d. Highly weathered: most of the original mass strength is lost, materials are discolored;

   e. Extremely weathered: original rock strength is lost and the rock mass has been changed to a soil through chemical decomposition or physical disintegration; rock fabric (e.g., bedding layers) remains intact; and

   f. Residual soil: rock is completely changed to a soil, fabric has been completely weathered.

8. Describe the strength of the rock using the following table.

Grade	Description	Field Identification
R6	Extremely Strong	Rock may not be chipped with hammer
R5	Very Strong	Rock requires many blows to fracture
R4	Strong	Rock requires one blow of a hammer
R3	Medium Strong	Cannot be peeled or scraped with a knife, can be fractured with single blow of hammer
R2	Weak	Can be peeled with knife easily or shallow indentations made with blow of the hammer
R1	Very Weak	Crumbles easily or can be peeled with a pocket knife

9. Describe any fracture and the fracture spacing. Fracture descriptions should include the following:

   a. Density: Very slightly (core lengths >3 feet [ft.]), slightly (core lengths 1 to 3 ft.), moderately (core lengths 4 inches to 1 ft.), highly (core lengths 1 to 4 inches), very highly (mostly chipped and fractures);

   b. Infilling (e.g., clay or none);

   c. Fracture bedding (e.g., planar, stepped, smooth);

   d. Fracture angle; and

   e. Mark mechanical breaks on the core with 2 lines perpendicular to the break using a felt-tip marker. Mechanical breaks should not be included in the fracture analysis.

10. Miscellaneous Notes: This section of the field form should be used to log general observations during the drilling process. Examples include, but are not limited to: information about color and consistency of cuttings, required air pressures to cut rock, notes on drilling rig (e.g., “chatter” while drilling), depth to water, and other observations made by the drilling subcontractor.

11. Write the entire description sequence in lower case except for the rock type and name. For example: SANDSTONE, coarse grained, high quartz content, dark brown, slightly weathered, very hard, no bedding or BASALT, very thickly bedded, black, fresh, hard, slightly fractured.

UNIFIED SOIL CLASSIFICATION AND SYMBOL CHART		
COARSE-GRAINED SOILS (more than 50% of material is larger than No. 200 sieve size.)		
GRAVELS More than 50% of coarse fraction larger than No. 4 sieve size	Clean Gravels (Less than 5% fines)	
	GW	Well-graded gravels, gravel-sand mixtures, little or no fines
	GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines
	Gravels with fines (More than 12% fines)	
	GM	Silty gravels, gravel-sand-silt mixtures
	GC	Clayey gravels, gravel-sand-clay mixtures
SANDS 50% or more of coarse fraction smaller than No. 4 sieve size	Clean Sands (Less than 5% fines)	
	SW	Well-graded sands, gravelly sands, little or no fines
	SP	Poorly graded sands, gravelly sands, little or no fines
	Sands with fines (More than 12% fines)	
	SM	Silty sands, sand-silt mixtures
	SC	Clayey sands, sand-clay mixtures
FINE-GRAINED SOILS (50% or more of material is smaller than No. 200 sieve size.)		
SILTS AND CLAYS Liquid limit less than 50%	ML	Inorganic silts and very fine sands, rock flour, silty of clayey fine sands or clayey silts with slight plasticity
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
	OL	Organic silts and organic silty clays of low plasticity
SILTS AND CLAYS Liquid limit 50% or greater	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
	CH	Inorganic clays of high plasticity, fat clays
	OH	Organic clays of medium to high plasticity, organic silts
HIGHLY ORGANIC SOILS	PT	Peat and other highly organic soils

Source: California Department of Transportation's Unified Soil Classification System: https://dot.ca.gov/-/media/dot-media/programs/maintenance/documents/office-of-concrete-pavement/pavement-foundations/uscs-a11y.pdf.

Figure 1a: Soil Characterization Guidance Chart

Source: United States Department of Agriculture's Natural Resources Conservation Service Guide to Texture by Feel: *https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054311.*

Figure 1b: Soil Texture Characterization Guidance Chart

Standard Operating Procedure #09: Monitoring Well Installation and Development

Version #2
November 2020

West Lake Landfill Site
Operable Unit 3
Bridgeton, MO

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CONTENTS

1. INTRODUCTION

The purpose of this standard operating procedure (SOP) is to establish procedures and methods to be used when designing and installing permanent groundwater monitoring wells for Operable Unit 3 at the West Lake Landfill Site in Bridgeton, Missouri. The advancement of the monitoring well borehole enables observation of geological conditions and soil sample collection, both of which are covered under separate SOPs. Monitoring wells will be installed using sonic drilling methods, as described in the SOP for Drilling Oversight (SOP #07, Appendix A of the Field Sampling Plan).

This SOP includes procedures for preparing wells for groundwater sampling, installing single-casing, monitoring wells and FLUTe™ Cased Hole Sampler (CHS) multi-level wells, well construction, and well development. All monitoring wells will be installed in accordance with Missouri's Code of State Regulations (CSR), pursuant to 10 CSR 23-4, by an environmental professional with a restricted well contractor's permit and by a licensed driller with Missouri Department of Natural Resources (MDNR). Nested and double-cased monitoring wells, and any monitoring wells deviating from 10 CSR 23-4 will require a permit procedure.

2. EQUIPMENT AND MATERIALS

- Field forms and field book;
- Site Health and Safety Plan (HASP) and Subsurface Clearance (SSC) Project Plan;
- Personal protective equipment (PPE) in accordance with project HASP;
- Permanent-ink and waterproof pens, and clipboard;
- Boring logs, monitoring well installation forms and well development forms;
- Submersible pump and surge blocks for well development activities;
- Water level meter (Solinst® 102, or equivalent);
- Turbidity meter;
- Decontamination supplies (e.g., non-phosphate detergent [Liquinox® or equivalent] and distilled water);
- 55-gallon steel drums (for purged development water) and labels for drums (pending analysis); and
- Drilling equipment (provided by the subcontractor).

3. HEALTH AND SAFETY

Drilling and other subsurface intrusive work presents specific hazards and proper safety precautions must be observed performing any subsurface work. These hazards, as well as those associated with constructing and installing monitoring wells, should be addressed by a Site-specific HASP. The safety guidelines within the HASP should be used to complement the judgment of an experienced professional. For all subsurface drilling activities, the project-specific health and safety requirements must be reviewed by ERM field staff and subcontractors.

The driller or designated safety person should be responsible for the safety of the drilling team performing the drilling activities. All field staff conducting drilling activities should be qualified in proper drilling and safety procedures. Before any drilling activity is initiated, utilities should be marked or cleared by the appropriate state or municipal utility protection organization.

Health and safety requirements specific to the tasks described in this SOP may include the following:

- All field staff should wear safety hats, safety glasses, and steel toed boots. Earplugs or other adequate hearing protection (e.g., ear muffs) are required.
- Appropriate work gloves (cotton, leather, etc.) should be worn when working around or while handling drilling equipment.
- The drill rig should be equipped with a kill switch that will immediately shut down the rig when activated. All field staff should know where the kill switch(s) is located in case of emergency.
- All field staff should stay clear of the drill rods or augers while in motion and should not grab or attempt to attach a tool to the drill rods or augers until they have completely stopped rotating. Rod wipers, rather than gloves or bare hands should be used to remove mud, or other material, from drill stem as it is withdrawn from the borehole.
- Do not lean against the drill rig or place hands on or near moving parts while it is operating.
- Keep the drilling area clear of any excess debris, tools, or drilling equipment.
- The driller will direct all drilling activities. No work on the rig or work on the drill Site will be conducted outside of the driller's direction. Overall, drill Site activities will be in consultation with the Site geologist.
- Each drill rig will have a first-aid kit and a fire extinguisher located on the rig in a location quickly accessible for emergencies. All field staff will be familiarized with their location.
- Work clothes will be firm fitting, but comfortable and free of straps, loose ends, strings, or similar parts that might catch on some moving part of the drill rig.
- Rings, watches, or other jewelry will not be worn while working around the drill rig.
- Drilling locations should be assessed for the presence of underground or overhead utilities in accordance with ERM's SSC procedures.
- The drill rig should not be operated within the minimum distance of overhead electrical power lines and/or buried utilities that might cause a safety hazard (ERM's minimum setback distances are defined in the subsurface clearance procedure, however, client or local regulatory requirements should also be applied). In addition, the drill rig should not be operated while there is lightening in the area of the drilling Site. If an electrical storm moves in during drilling activities, if possible, the derrick will be lowered and the area will be vacated until it is safe to return; otherwise, vacate the area immediately.

4. PROCEDURE

4.1 Drilling Method

Monitoring wells will be installed using sonic drilling methods. The sonic drilling method is a type of rotary vibratory drilling that includes rotary motion and oscillation, which causes a high frequency force to be superimposed on the drill string. The sonic drilling technique involves advancing a core barrel and an override casing to prevent the borehole from collapse when the core is retrieved. The technique utilizes uses the rotating and vibrating core barrel and override casing simultaneously to drill a clean borehole minimizing the amount of drill cuttings and maximizing the amount of cored material retrieved for sampling. Continuous soil and rock core samples are generated to allow for field screening and geological logging.

4.1.1 Alluvium

The borehole is first advanced using a 4-inch core barrel inside a 6-inch override casing. The core barrel is advanced at 10-foot intervals, telescoping from below the override casing. For each 10-foot interval, the core barrel is withdrawn from the sub-surface and the core barrel plastic sleeve is removed from the barrel for field logging and sampling of the soil or rock when required. The alluvium samples will remain in the sleeves and all sleeves will be stored together until logging and sampling has been completed. Potable water is added when drilling through formations of insufficient yield for advancing the drill casing. The volume of potable water added during drilling will be kept to a minimum and logged in the borehole log.

Below the depth of the WATERLOO APS™ investigation (approximately 70 feet), the core barrel will be extracted at selected intervals to allow for discrete-depth groundwater sampling using a packer isolation method; A temporary stainless steel screen is placed at the base of the boring, the override casing is lifted approximately 5 feet and the packer inflated to isolate and expose the screen to the alluvium for collection of a groundwater sample. Upon completion, the screen and packer assembly will be extracted and the core barrel replaced to continue coring to the next sampling interval.

If a screen is required in alluvium at the top of bedrock, the borehole is advanced 5 feet into bedrock to accommodate the counterweight attached to the bottom of the CHS system. The core barrel is then removed and a 4-inch temporary blank Schedule 40 polyvinyl chloride (PVC) casing is installed inside the 6-inch override casing to allow for certain borehole geophysical logging. Once the temporary PVC casing is installed, the override casing will be removed to allow for certain methods of geophysical logging. At this point in the drilling process, the various characterization results collected at each borehole location are reviewed with focus on contaminant distribution and permeability. The results will guide selection of the permanent well screens to be installed at each drilling location.

4.1.2 Bedrock

At locations where well screens will be installed in bedrock, the process of drilling through the alluvium interval is identical to the procedure described for alluvium-only wells (Section 4.1.1) before the borehole continues into bedrock. However, instead of using the 8-inch diameter override casing at the base of the alluvium, a 10-inch diameter override casing will be set 5 feet into rock to keep the alluvium interval open. The 6-inch temporary drill casing and the blank 4-inch PVC is then removed and an 8-inch drill casing is used to advance the bedrock portion of the borehole. Bedrock core is retrieved with a 6-inch core barrel. Depending on the quality of the rock, intact core up to several feet in length can be retrieved. The core is marked with top and bottom and inspected. Observations are noted in the field book and photo documented. All rock core is retained until the borehole is completed, all core has been logged and samples have been collected if required.

At this stage, the borehole consists of the 10-inch isolation casing (i.e., the override casing) and an open 8-inch bedrock borehole. Additional down-hole tools are now deployed to characterize the open borehole interval and those results are then used to select well screen intervals in overburden. The multi-level CHS casing is constructed in the same fashion as for the alluvium-only CHS wells, including the 5-foot sump for the counterweight.

Locations where only a single well screen will be installed in alluvium will use a conventional single screen monitoring well. Locations where two or more well screens will be installed in the same borehole will use a modified version of the CHS by FLUTe^{TM}.

4.2 Well Construction

Single screen monitoring wells will be constructed of 2-inch inner diameter, Schedule 40, 0.010-inch slot PVC well screen and threaded flush joint PVC casing above depths of 100 feet. CHS casing will be constructed from Schedule 80 blank PVC and 0.010-inch slotted PVC if the maximum depth is greater than 100 feet per 10 CSR 23-4 unless conditions would grant a waiver to use Schedule 40 PVC. Sand filter packs will consist of Morie #0 grade sand or equivalent, which is sufficiently sized to keep bentonite from entering the filter pack. If a larger grain size is required for the filter pack, that grain size will extend 1 foot above the slotted PVC interval and 1 foot of Morie #0 sand will be placed on top of the larger grain size filter pack to mitigate potential for bentonite intrusion. Coated slow release bentonite pellets will be used as annular seal at depths below the water table. Bentonite chips will be used in dry holes and hydrated after placement. A cement/bentonite grout mix will be tremmied into the annulus above the bentonite seal at single screen well locations. The mix will consist of approximately 95 percent cement and 5 percent bentonite. The cement/bentonite grout will consist of 94 pounds of Portland cement to 5 pounds of high-grade bentonite mixed with between 10 and 15 gallons of water.

4.2.1 Conventional Single Screen Monitoring Wells

The temporary 6-inch drill casing is over-drilled using an 8-inch override casing to the base of alluvium. The temporary 6-inch drill casing and the blank 4-inch PVC casing are then removed. Slotted PVC well screen and blank casing is connected Sections of flush jointed blank 2-inch PVC and slotted PVC screen are threaded together and each section is lowered into the borehole with the slotted screen at the selected depth. Centralizers will be used to keep the PVC centered in the borehole during installation. The annular space between the PVC casing and the borehole wall is 2 inches wide.

The annular fill material is placed in lifts of approximately 5 feet inside the bottom of the temporary override casing. After the first lift, the drill casing is extracted 5 feet to make contact between the fill material and the formation. This process is repeated to ground surface. The annular space is backfilled with a sand filter pack extending 2 feet above and below the top and bottom of each sampling screen. The volume of filter pack needed to fill the annulus should be calculated prior to installation. This will help the field staff determine if bridging has occurred if significantly less sand is needed than estimated. If more sand is needed than anticipated, it suggests significant washouts have occurred during drilling. A two-foot-thick bentonite seal is placed above the sand filter pack and the remaining annular space above the bentonite seal is tremmie grouted with a cement/bentonite mix.

4.2.2 CHS Multi-Level Monitoring Well

The CHS is a multi-level well system, in this case constructed with a positive displacement sampling system and equipped with dedicated pressure transducers at each sampling screen. The sampling screens are located at multiple intervals on the CHS, which corresponds with the screen depths of the PVC well casing. The CHS is constructed with sampling screens fitted to the outside of an impermeable borehole liner constructed from urethane coated nylon fabric. A counter weight at the bottom of the CHS allows the entire system to be lowered into place. Once set at the appropriate depth the liner is filled with water which forces the impermeable fabric against the inside of the PVC casing, creating a seal between the sampling screens.

Once the well screen intervals have been selected, the borehole will be prepared for installation of the CHS well casing. The procedure requires a slightly different procedure for alluvium-only well locations as opposed to locations that also have well screens installed in bedrock. At both alluvium and bedrock boreholes, a drill rig will be used to suspend the well casing during installation. Centralizers will be used to keep the PVC centered in the borehole if available for the 4 inch pipe size. Alternatively, the pipe can be centered using a plumb bob and level.

At alluvium-only locations, the temporary 6-inch drill casing is over-drilled using an 8-inch override casing to the base of alluvium. The temporary 6-inch drill casing and the blank 4-inch PVC casing are then removed. Sections of flush jointed blank 4-inch PVC and slotted PVC screen are then connected together and each section is lowered into the borehole to construct a continuous pipe with slotted screen at the selected depths. The annular space between the PVC casing and the borehole wall is 2 inches wide.

At bedrock locations, sections of blank 4-inch PVC and slotted PVC screen are connected together and each section is lowered into the temporary 10-inch override casing and to the bottom of the bedrock borehole to construct a continuous pipe with slotted screen at the selected depths. The annular space between the PVC and the borehole wall in the alluvium is 3 inches thick, and in bedrock the annulus thickness is 2 inches.

In the bedrock portion of a borehole, annular fill materials are placed continuously to the top of bedrock. In the alluvium, the fill material is placed in lifts of approximately 5 feet inside the bottom of the temporary override casing. After the first lift, the drill casing is extracted 5 feet to make contact between the fill material and the formation. This process is repeated to ground surface. The annular space is backfilled with a sand filter pack extending 2 feet above and below the top and bottom of each sampling screen. The volume of filter pack needed to fill the annulus should be calculated prior to installation. This will help the field staff determine if bridging has occurred if significantly less sand is needed than estimated. If more sand is needed than anticipated, it suggests significant washouts have occurred during drilling.

The intervals above and below the sand filter packs are filled with coated slow release bentonite pellets. If possible, the pellets should be placed using a tremmie pipe to avoid bridging of the borehole. If a tremmie pipe is not available for placement of bentonite, the pellets should not be added to the borehole faster than approximately 2 feet per minute. The upper two feet of the annulus is filled with sand to avoid direct contact with the hydrated bentonite.

4.2.3 Temporary Sealing of Borehole

After completed installation of the CHS well casing, the borehole will be temporarily sealed using a flexible borehole liner. The liner consists of an impermeable urethane coated nylon fabric welded into tubular form. The liner is attached to the top of the CHS casing and potable water is added to the inside of the liner, causing the liner to descend into the borehole under the weight of the hydraulic head. The pressure inside the liner is kept a minimum of ten feet of hydraulic head higher than the pressure below the liner which causes the liner to create a seal against the PVC casing. Once the liner has descended past the deepest screened interval, the borehole is completely sealed and the potential for cross contamination between well screens is eliminated.

In order to remove the liner, for example to allow for well development or installation of the CHS well system, a winch is connected to the tether line which progressively removes the liner starting at the bottom of the borehole. As the liner is pulled up, the water inside the liner is displaced. The water level is controlled by pumping water out of the liner and discharging the water into a temporary storage tank.

4.2.4 Aboveground Riser Pipe and Outer Casing

All protective casings should have sufficient clearance around the inner well casings so that the outer protective casings will not encounter the inner well casings after installation. The protective casings should have a weep hole to allow drainage of accumulated rain or spilled purge water. The weep hole should be approximately 1/4-inch in diameter and drilled into the protective casings just above the top of the concrete surface pad to prevent water from standing inside of the protective casings.

Conventional single screened 2-inch PVC monitoring wells will be fitted with a 4-inch diameter protective steel casing. The steel casing will extend approximately 6 inches above the top of the PVC well casing to allow sufficient clearance between the well expansion plug and the well cover. The 4-inch CHS PVC well casing will be fitted with an 8-inch diameter protective steel casing. The CHS protective steel casing will extend approximately 12 to 16 inches above the CHS PVC casing to allow room for well tubing and transducer cables.

Prior to installing the protective casing, the bentonite grout in the borehole annulus is excavated by hand to a depth of approximately two feet and placing approximately 6 inches of sand at the base of the hole. The sand will allow water to escape from inside the protective casing if necessary. The protective casing is installed by setting the casing at the desired depth and pouring concrete into the excavated hole outside the PVC casing on top of the sand. Care must be taken to center the PVC casing inside the protective casing while the concrete is setting. The cover on the protective casing will be fitted with a lock to prevent tampering. These locks should be keyed alike for all the new wells.

4.2.5 Concrete Surface Pad

A concrete surface pad should be installed around each well at the same time as the outer protective casing is being installed. The surface pad should be formed around the protective well box using a form. Concrete should not be poured inside the protective well box in order to allow water to escape from the base of the well box in case of surface water intrusion.

The size of the concrete surface pad is dependent on the well casing size. In the absence of specific regulation regarding well pads dimensions, a minimum pad dimension extending 2 feet in all directions from the outside of the well casing should be considered. The concrete surface pad can be either square or round. The finished pad should be slightly sloped so that drainage will flow away from the protective casing and off the pad (without creating a nuisance condition or trip hazard). When setting a well at grade in a concrete or other paved area, care must be taken to match the concrete surface pad to surrounding ground level. In unpaved areas, the ground surface should be made suitable for the placing of concrete. Rebar or mesh can be used within the concrete pad to help prevent them from failing, for instance, under the weight of mowing equipment or vehicle traffic.

Flush mounted traffic and manhole covers are designed to extend from the ground surface down into the concrete plug around the well casing. Although flush mounted covers may vary in design, they should have seals that make the unit watertight when closed and secured. The flush-mounted covers should be installed slightly above grade to reduce the potential for standing water over the well and promote runoff. Locking expandable well plugs should be used to cap the well riser to prevent infiltration of rainwater or other fluids that might enter the flush-mount cover and accumulate within the annular space adjacent to the top of the well.

4.2.6 Surface Protection

If monitoring wells with above-grade completions require protection from traffic of other hazards, the installation of bollards or bumper guards consisting of partially-buried steel pipes should be considered. The dimensions of such protective posts can be sized to meet Site-specific conditions; however, these generally consist of steel pipes approximately three to four inches in diameter and buried approximately 40% of their total length (e.g., assuming a total length of five feet, the protective posts would nominally be installed to a depth of two feet below the ground surface and set in a concrete footing). Concrete may also be placed into the steel pipe to provide additional strength. Substantial steel rails and/or other steel materials can be used in place of steel pipe. It is also recommended that the bumper guards are painted yellow to increase visibility to traffic. The size and length of bumper guards and even what color they should be painted may be dictated by the facility within which the wells are installed.

4.3 Well Development

The objectives of monitoring well development are as follows:

- Allow groundwater to enter the well screen freely, thus yielding a representative groundwater sample and water level measurements.
- Remove water that may have been introduced or disturbed during drilling, or well installation activities.
- Remove fine-grained sediment in the filter pack to minimize the turbidity of the groundwater sample and decrease the likelihood of silt entering and settling in the well.
- Maximize the efficiency of the filter pack.

New and existing conventional single screen monitoring wells will be developed using a submersible pump. New CHS well screens will be developed individually using surge blocks mounted to a pump hoist rig to induce vigorous movement of groundwater through each screened interval.

For all new wells, development will take place prior to any water level studies or sampling. Development will take place for existing monitoring wells with more than 10 percent well screen occlusion. For CHS well locations, the well screens will be developed following installation of PVC casing, but prior to installation of the CHS well liner. All wells will be developed no sooner than 48 hours after installation in order to allow the cement/bentonite grout to set. At no time will water be introduced into the well during well development. If submersible pumps are used during development, they will be decontaminated following the procedures discussed in the SOP for Equipment Decontamination (SOP #18, Appendix A of the Field Sampling Plan). A new length of pump tubing will be used as a discharge line for each well to avoid cross contamination.

Development will continue until the turbidity of the recovered well water is less than 10 nephelometric turbidity units (NTUs) over three consecutive readings. Turbidity will be measured by the ERM field staff conducting oversight, at a frequency of at least once per well casing volume. Procedures for field calibration and measurements of turbidity are included in the SOP for Groundwater Sampling (SOP #13, Appendix A of the Field Sampling Plan). At least three standing casing volumes of well water will be removed during development of each well. Casing volumes for CHS wells are calculated individually from the water table to the bottom of the respective well screen. Development water will be containerized in properly labeled 55-gallon drums for disposal, pending analysis.

5. REFERENCES

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American Society for Testing and Materials (ASTM). 2010. Standard Guide for Installation of Direct Push Groundwater Monitoring Wells. D6724—04(2010).

Striggow, Brian. 2013. Design and Installation of Monitoring Wells, Guidance. United States Environmental Protection Agency, Science and Ecosystem Support Division (SESD). Athens, Georgia; SESDGUID-101-R1. January 22. Available online at: https://www.epa.gov/sites/production/files/2016-01/documents/design_and_installation_of_monitoring_wells.pdf. Accessed 21 July 2020.

Standard Operating Procedure #10: Fluid Level Gauging

Version #1
August 2020

West Lake Landfill Site
Operable Unit 3
Bridgeton, MO

Prepared for:
U.S. Environmental Protection Agency, Region 7
11201 Renner Boulevard
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Prepared by:
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CONTENTS

1. INTRODUCTION

The purpose of this standard operating procedure (SOP) is to establish procedures for conducting fluid level gauging for Operable Unit 3 at the West Lake Landfill Site in Bridgeton, Missouri. Fluid level gauging data may be used to support the creation of groundwater table or potentiometric surface maps, and to calculate hydraulic gradient(s) and horizontal groundwater flow direction(s) across the Site.

The objective of fluid level gauging is to accurately measure depth to water relative to a surveyed data point on monitoring wells and piezometers, generally top of casing (TOC), to determine groundwater elevation. New and temporary well locations will be surveyed following installation by a licensed surveyor in relation to the nearest permanent benchmark. Existing well locations may also be re-surveyed on a periodic basis, if deemed necessary by the project team.

2. EQUIPMENT AND MATERIALS

- Field forms and field book;
- Site Health and Safety Plan (HASP);
- Traffic protection equipment (e.g., traffic cones, barriers, and high visibility vests);
- Personal protective equipment (PPE) for splash protection (e.g., gloves and safety glasses);
- Tools for removing the bolt down cover or manway, well cap, and keys for lock on well cap;
- Small manually operated hand pump, or small cup for evacuating standing water from around the well casing, if water is above top of well casing within manway or well cover;
- Non-phosphate detergent solution (Liquinox® or equivalent), buckets, rinse water (distilled water), and clean paper towels;
- Water level meter(s), marked every 0.01 feet, and of sufficient length to measure total depth of the deepest well on-Site (Solinst® 102, or similar);
- Boring logs, completion diagrams, and/or a summary table that describes the well diameter, well depth, stickup, and screen interval; and
- Extra batteries for the water level meter.

3. HEALTH AND SAFETY

SOPs are designed to provide technical guidance and do not provide detailed or comprehensive guidance related to health and safety, nor do they represent guidance on safe work procedures for the tasks described. Appropriate tips related to health and safety issues associated with specific tasks may be included within technical descriptions for information's sake only.

Health and safety aspects of all projects and project tasks should be assessed and planned using ERM's established health and safety planning procedures.

4. PROCEDURE

4.1 Pre-Gauging Activities

The following procedures should be followed in preparation for fluid level gauging activities:

1. Prior to first use, calibrate the water level meters. Unravel the probe and measure it against one, 500-foot reference water level probe to confirm the probe's length. The reference probe will be stored on-Site in a climate-controlled office and will not be used for any field measurements to protect its integrity. Any difference between the probe and the reference probe will be recorded on the associated calibration form so that any necessary adjustments to fluid level measurements can be made following gauging. Probe serial numbers will be noted on the calibration form, gauging form, and sampling forms for tracking purposes. Each water level meter will be re-calibrated on an annual basis.

2. Develop a gauging plan. Measurements should be taken within a 24-hour period or less. The gauging plan should also consider:

   a. Known information about the wells and historical water levels from previous field events (field notes should be reviewed if available);

   b. Other relevant activities to be undertaken at the same time and specific requirements relating to these, including the sequencing of events;

   c. Potential difficulties in accessing the wells, such as:

      i. Are any of the wells located within process areas requiring permits from the facility?

      ii. Are well cover bolts or well cap locks rusted?

      iii. Are there restrictions to access, such as stream crossings or heavy brush with associated physical and biological hazards?

      iv. Are wells located in or near roadways requiring a traffic management plan and/or appropriate PPE (e.g., reflective vests)?

   d. Presence of high concentrations of dissolved-phase constituents in each well. Despite the use of decontamination techniques, it is prudent to proceed in gauging and sampling from least-impacted wells to the most-impacted wells, if known. If unknown, the suspected source area wells should be gauged last.

4.2 Gauging Activities

The following procedures should be followed during fluid level gauging activities:

1. Remove the well cap as soon as possible to allow the water level to reach equilibrium before measurements are taken because pressure inside the well may have changed since the last measurement was taken due to rising or falling water levels. Pressure can also naturally build within a monitor well between measurement and sampling, potentially making a loosened well cap a projectile. Therefore, caution should be taken when opening the wells to avoid potential sudden discharge of air pressure. Technicians should not look directly over the well when opening/removing the well cap. It is not uncommon in some domains to encounter poisonous insects/spiders or snakes in well boxes, thus care should be taken when opening well boxes, vault lids, or manways.

2. Prior to use, decontaminate the water level meter and the portion of the tape that is likely to contact the water using paper towels and a non-phosphate detergent, rinsing with distilled water, and wiping dry with paper towels.

3. If the water level meter has a grounding wire, attach it to the manway cover, the well box, or to a metal rod driven into the ground prior to gauging. In the absence of a grounding wire, the technician should touch a grounded metal object to discharge built up static electricity.

4. The depth to water should be measured relative to an established surveyed reference point on the top of the well casing. The reference point on the well casing should be marked; as a default, if not marked, the TOC is presumed to be the north side of the casing and should be noted in the field forms or field book.

5. To measure the depth to water, slowly lower the probe into the well until a signal (intermittent or constant beep) is heard. Repeat the recording three times by raising and then lowering the probe again across the water table (does not measure while raising the probe, as surface tension may result in aberrant readings). Record the depth to water in feet to two decimal places or meters to three decimal places (i.e., to the millimeter level).

6. The total depth of the well should be measured to determine if the well is silting or damaged. This is done by lowering the probe into the well until the tape just becomes slack and recording the depth from the TOC. If the well is to be sampled for metals, gauging of total depth should not be conducted until sampling has been completed due to potential to create turbid conditions within the well.

7. At the completion of fluid level and/or total depth measurements at each well, the water level meter tape should be retrieved carefully, decontaminated using paper towels and a non-phosphate detergent, rinsed with distilled water, and wiped dry with paper towels.

4.3 Post-Gauging Activities

Following fluid level gauging activities, groundwater elevation data will be compiled and calculated using the following formula:

Groundwater Elevation = TOC – DTW

Where:
TOC = Top of Casing Elevation
DTW = Measured Depth to Water

If any discrepancies were noted during the water level meter calibration, the measured depth to water will be compensated accordingly.

5. REFERENCES

American Society of Testing and Materials (ASTM) D4448 – 01. 2013. Guide for Sampling Ground-water Monitoring Wells.

United States Environmental Protection Agency (USEPA). 2020. Groundwater Level and Depth Measurement Operating Procedure. LSASDPROC-105-R4. Region 4, Laboratory Services and Applied Science Division, May. Available online at: https://www.epa.gov/sites/production/files/2017-07/documents/groundwater_level_and_well_depth_measurement105_af.r3.pdf. Accessed 4 August 2020.

Standard Operating Procedure #11: Pneumatic Slug Testing

Version #1
August 2020

West Lake Landfill Site
Operable Unit 3
Bridgeton, MO

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CONTENTS

1. INTRODUCTION

The purpose of this standard operating procedure (SOP) is to establish procedures for conducting pneumatic slug testing (pulse-interference testing) to better understand the interconnectivity of fractures and flow within bedrock for Operable Unit 3 at the West Lake Landfill Site in Bridgeton, Missouri.

Pneumatic slug tests are conducted by sealing the well head and applying air pressure to depress the water level. As air pressure is increased in the well, the water level falls until the water pressure and the air pressure return to equilibrium. After the water level is stable, air is released from the sealed well head by opening an air release valve. The water level recovery is a rising head slug test and produces very high quality data with little interference. A pressure transducer is used to monitor and record the change of the water level in the well during the pneumatic slug test.

Pneumatic slug tests will be conducted by isolating transmissive fractures identified using a straddle packer system and then conducting a slug test within each interval while monitoring responses in nearby piezometers and monitoring wells using pressure transducers.

Groundwater sampling will not be conducted at any monitoring wells where pneumatic slug tests are performed within one month after the test to allow for re-equilibration of groundwater geochemical conditions in the vicinity of that well.

The data analysis portion of slug testing is not covered in this guidance. It is strongly recommended that the appropriate staff are consulted and involved in the design and analysis phases.

2. EQUIPMENT AND MATERIALS

- Field forms and field book;
- Site Health and Safety Plan (HASP);
- Water level probe (Solinst® 102 or equivalent);
- Solinst® Model 3001 Leveloggers, or equivalent, equipped with Direct Read Cables and Well Cap Assembly;
- Solinst® Barologger, or equivalent, to monitor the atmospheric pressure;
- Solinst® PC Interface Cable for connecting the Direct Read socket to the laptop;
- Laptop or tablet with Solinst® Levelogger software installed;
- Pneumatic well-head test apparatus (such as Midwest Geosciences Pneumatic “Hi-K” Slug® Assembly);
- Air pressurization source (compressed or pump) and appropriate hoses;
- Leak prevention supplies (Teflon® pipe sealant, plumbers putty, or similar product);
- Decontamination supplies for the water level probe/interface meter (i.e., non-phosphate detergent [Liquinox® or equivalent] and distilled water; paper towels);
- Hand tools for opening and closing wells; and
- Watch or stopwatch.

3. HEALTH AND SAFETY

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Health and safety aspects of all projects and project tasks should be assessed and planned using ERM's established health and safety planning procedures.

4. PROCEDURE

1. Conduct a comprehensive gauging round for monitoring wells in the area of interest, including total depth, in accordance with ERM's SOP for Fluid Level Gauging (SOP #10, Appendix A of the Field Sampling Plan).

2. Deploy transducers in the monitoring wells in the area of interest, in accordance with ERM's SOP for Transducer Deployment (SOP #12, Appendix A of the Field Sampling Plan). For the well of interest, affix an air-tight cap with a pressure relief valve to the top of the well.

3. Attach the pneumatic slug test manifold onto the top of the well casing. Tighten the rubber connector to ensure an airtight seal.

4. Place the pressure transducer at the proper depth (deep enough to accommodate initial change in head but no deeper than 6-inches above the well bottom) by measuring the location where the transducer cable will be secured to the compression connector. Also ensure to not exceed the transducer pressure range. Tighten the cable seal by hand to seal the connection to the transducer cable.

5. Program the pressure transducer to record water levels at the following suggested frequencies. Note that the lithologic descriptions and data logger memory should be used to select the highest measurement frequency possible.

    a. In hydrologic settings where high hydraulic conductivity is expected, water levels should be measured at 0.5 second intervals, or the highest frequency available. This measurement frequency should be selected for gravels and sands.

    b. In hydrologic settings where low hydraulic conductivity is expected, water levels should be measured at 1 to 2 second intervals. This measurement frequency should be selected for silts, clays, and fractured bedrock, and is expected to be used at this Site.

6. View the measured water level in real time on the laptop computer. Wait for the water levels to stabilize. Note that temperature fluctuations on the pressure transducer will affect measured water levels (i.e., temperature differences between the above surface and groundwater environments).

7. Close the air release valve.

8. Close the inlet air valve with the pressure regulator closed.

9. Verify incoming pressure is less than safe operating pressure of manifold pressure regulator (<40 pounds per square inch [psi] is necessary) before attaching air hose (not applicable for hand pump).

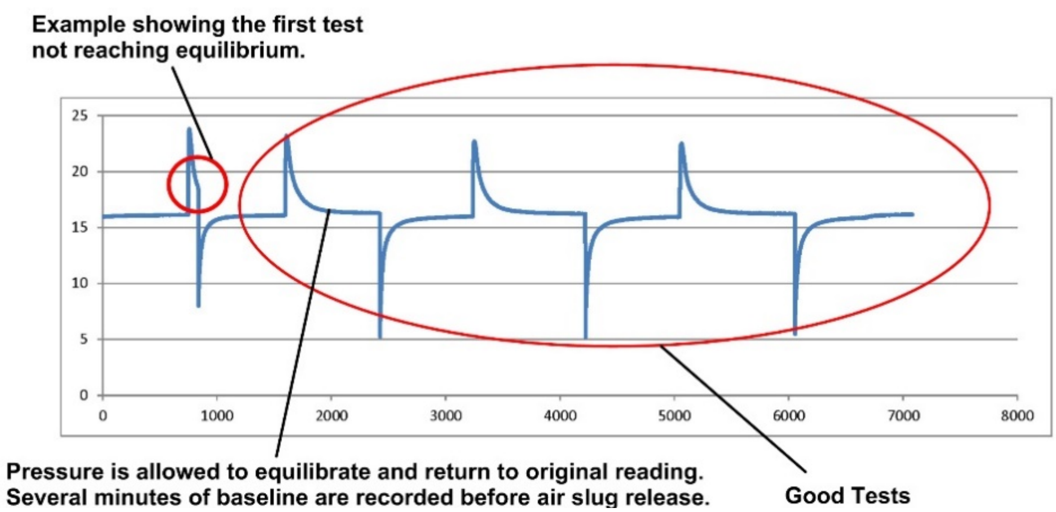
10. Attach air hose and open regulator to verify incoming pressure (not applicable for hand pump).

11. Close regulator and open the inlet air valve.

12. Slowly open the pressure regulator to pressurize the well head and depress water level a maximum of 4 feet without lowering the head below the top of the well screen (2.31 feet of water is equal to 1 psi). Following the initial test, perform two duplicate tests and a third test with double the displacement. Begin with a low pressure and gradually increase the pressure in order to obtain the desired displacement and do not over pressurize the well (do not exceed ~2 psi). If using a hand pump, pressurize the well head with pump with regulator open.

13. Close the regulator and leak check the system with leak detection fluid and fix any leaks. If the leak is very slow, or down the well, the regulator may be used to maintain a constant pressure head.

14. Check the pressure transducer response and air pressure to verify system is stable. This may take a period of time as the pressure transducer is equalizing to both the pressurized atmosphere in the well and the displaced water column (see figure below). Stabilization is reached once the pressure returns to near the original pressure. If it is stable, proceed to the next step; if not, check the seals.



15. Record a baseline pressure for a minimum 3 minutes. Record data on the field book.

16. Close inlet valve and quickly open the release valve to initiate the test.

17. Allow sufficient time for water level to recover to static level. Once the water level has returned to 90 percent of the pre-test level, the rising head test can be terminated, and the transducer recording stopped. Two rising-head tests will be conducted for each well in accordance with The United States Environmental Protection Agency's (USEPA's) Suggested Operating Procedures for Aquifer Pumping Tests (USEPA/540/S-93/503, February 1993).

18. Decontaminate all down-well equipment.

19. Save all data files to the laptop and backup flash drive.

20. Finalize any field notes.

21. Review the data collected to determine the reasonableness of the preliminary results. The observation of apparently anomalous results will be discussed with senior project staff prior to proceeding. The water level record for each test should show static conditions, pressurization of the

well column, and the recovery response. Make notes on the field form and field book concerning any irregularities.

5. REFERENCES

ASTM D4044. 2015. "Standard Test Method for (Field Procedure) for Instantaneous Change in Head (Slug) Tests for Determining Hydraulic Properties of Aquifers." Available online at: https://www.astm.org/Standards/D4044.htm. Accessed August 2020.

United States Environmental Protection Agency (USEPA). 1993. Suggested Operating Procedures for Aquifer Pumping Tests. Available online at: https://www.epa.gov/sites/production/files/2015-06/documents/sopaqu.pdf. Accessed 11 August 2020.

Standard Operating Procedure #12: Transducer Deployment

Version #1
August 2020

West Lake Landfill Site
Operable Unit 3
Bridgeton, MO

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CONTENTS

1. INTRODUCTION

The purpose of this standard operating procedure (SOP) is to establish consistent methodology for deploying transducers for the collection of groundwater levels for Operable Unit 3 at the West Lake Landfill Site in Bridgeton, Missouri. Transducers will be used to evaluate groundwater flow directions and quality over time. Because of the complex hydrogeologic environment at and near the Site, groundwater elevation data will be collected at a high frequency using data-logging pressure transducers. This will allow for evaluation of vertical and horizontal hydraulic gradients, and definition of groundwater flow directions, as well as changes in these conditions over time.

This SOP describes procedures for the deployment of transducers down traditional single-screen monitoring wells only. For cased hole sampler (CHS) well systems, FLUTe™ will incorporate dedicated downhole transducers at each sampling port during fabrication; therefore, discussion of CHS well systems is not included in this SOP.

As described in the Field Sampling Plan, it is expected that transducers will be deployed for at least 2 years at the Site, and data will be downloaded from transducers on a quarterly basis.

2. EQUIPMENT AND MATERIALS

- Field forms and field book;
- Site Health and Safety Plan;
- Hand tools for opening wells;
- Water level probe (Solinst® 102 or equivalent);
- Solinst® Model 3001 Leveloggers or equivalent, equipped with Direct Read Cables and Well Cap Assembly;
- Solinst® Barologger or equivalent to monitor the atmospheric pressure;
- Solinst® PC Interface Cable for connecting the Direct Read socket to the laptop;
- Laptop or tablet with Solinst® Levelogger software installed; and
- Decontamination supplies for the water level probe/interface meter (i.e., non-phosphate detergent [Liquinox® or equivalent] and distilled water; paper towels).

3. HEALTH AND SAFETY

SOPs are designed to provide technical guidance and do not provide detailed or comprehensive guidance related to health and safety nor do they represent guidance on safe work procedures for the tasks described. Appropriate tips related to health and safety issues associated with specific tasks may be included within technical descriptions for information's sake only.

Health and safety aspects of all projects and project tasks should be assessed and planned using ERM's established health and safety planning procedures.

4. PROCEDURE

Transducers will be deployed at select monitoring well locations, as determined by ERM. For newly installed wells, transducers will be deployed at least 24 hours after well development.

The following procedures will be used for deployment of transducers, downloading, and management of transducer data:

1. Gather all necessary equipment and materials, as listed above, and confirm that the appropriate software has been downloaded to your logging device (i.e., laptop or tablet). Prior to mobilization, review typical historical groundwater elevation data, where available, to determine the general ranges of depth to groundwater so transducers remain submerged.

2. Select a monitoring well to allow both a Barologger and pressure transducer to be installed, where the Barologger shall be completed prior to pressure transducers. The Barologger shall be deployed shallow, within the well casing, above and never to come in contact with groundwater. Preferably, the Barologger will hang within the first few feet of a monitoring well. Select a monitoring point that has a deep depth to water to ensure no contact with groundwater.

    a. Per Solinst® guidelines, a Barologger can be used to compensate all the Leveloggers in a 20-mile radius and/or with every 1000-foot change in elevation. It is expected that only one Barologger will be required at the Site. Connecting the transducer to the direct read cable by way of creating a water-tight seal via tightening the coupling on the transducer until the o-ring is no longer visible. Note, do not overtighten as this will compromise the o-ring, but make the connection by cinching-up via hand tightening.

3. For pressure transducers, prior to deployment, collect an initial water level reading using a water level meter, in accordance with the SOP for Fluid Level Gauging (SOP #10, Appendix A of the Field Sampling Plan). Record water level readings in the field book and transducer management spreadsheet, including exact time, to allow for transducer deployment control via understanding and measuring direct read cable length from the top of casing.

4. Both the Barologger and pressure transducer will be attached to a direct read cable, and suspended from the well head.

5. To communicate with the transducer, use the USB communication cable. After connecting using the logging device (laptop or tablet), open the Solinst® Levelogger software (Levelogger 4.4.0 or newer) and select the appropriate USB port via the dropdown to connect to the unit which will show the main Levelogger Software window, with the Datalogger Setting tab open to begin transducer programming, as described below:

    a. Synchronize the transducer with the logging device to ensure that the unit records in the local time zone. Importantly, make sure the logging device is properly set to the correct local time zone before synchronization or the transducer will operate under the wrong time interval.

    b. Within the software, under location, name the unit to the same as the monitoring well. For Project ID, provide a description such as “Groundwater Level Monitoring.” Record transducer name, location, and, serial number as reported in the software for ease of identification and further device management in the transducer management spreadsheet.

    c. Under channels 1 and 2, set units to record in feet (representing water above the transducer) and degrees Fahrenheit for temperature. Under channel 1, set offset to zero.

d. Under Datalogger Sampling Mode, program each unit to collect readings on an hourly basis, using Linear based sampling. Note, select the compressed button. At this point the transducer is ready to begin operation, which is completed by selecting the Start Now icon. After which, the data logger information will report status as “Started.”

e. Check transducer functionality – have the transducer (before deployment) poll data real-time allowing the user to visualize transducer recordings via the software. Note, these are absolute transducers and will report atmospheric pressure, approximately 33.8 feet when out of water. The barologger will also report the same atmospheric pressure. After checking functionality, prepare for deployment.

f. Pay out the direct read cable and measure the deployment length from the top of casing (TOC) to the end of the transducer. Note, this is not required for the barologger, only transducers that will be submerged. In the transducer management spreadsheet, record the cable length. It is important to measure, as accurately as possible, the cable length (to the end of the transducer) to allow for complete and accurate hydrographs to be created.

g. After recording cable length, deploy each transducer to approximately 10 feet below the recorded static water level. Again, start (if previously stopped) real-time polling to ensure the transducer reads the approximate water column above the unit, which will be atmospheric plus the approximate 10 feet of water via unit submergence, on the order of approximately 43 feet. Securely fasten the transducer to the well head to prevent any vertical cable movement to ensure data collection overtime is accurate.

h. Refer to the below referenced user guide for any transducer programming or operating questions, which details aspects discussed in this document.

6. Once the transducer has been deployed, collect another depth to water to coincide with real-time data polling and, again, check transducer accuracy.

7. Following transducer deployment, one round of preliminary data will be collected from the units to check whether transducers are functioning properly. This verification round should be conducted within the first month of transducer installation, and before the first data download. If any equipment malfunction is observed, transducers may be removed for troubleshooting and replaced.

8. Data will be downloaded from all transducers and the Barologger on a quarterly basis. Transducer data will be compensated outside of the Solinst® Levelogger software, programmatically.

5. REFERENCES

Solinst Canada Ltd. User Guide: Levelogger Series – Software Version 4.4.0. March 2020. Available online at: https://www.solinst.com/products/dataloggers-and-telemetry/3001-levelogger-series/operating-instructions/user-guide/3001-user-guide.php. Accessed 28 July 2020.

Standard Operating Procedure #13: Groundwater Sampling

Version #2
November 2020

West Lake Landfill Site
Operable Unit 3
Bridgeton, MO

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CONTENTS

1. INTRODUCTION

The purpose of this standard operating procedure (SOP) is to establish a consistent methodology for collecting representative groundwater samples from monitoring wells for Operable Unit 3 at the West Lake Landfill Site in Bridgeton, Missouri. Two groundwater sampling techniques will be used: low flow sampling at traditional single screen monitoring wells and positive displacement sampling for FLUTe™ Cased Hole Sampler (CHS) multi-level well systems.

The goal of low-flow groundwater sampling is to purge a monitoring well at a similar or lower rate than recharge of the well, thereby obtaining samples that are representative of undisturbed groundwater while minimizing the amount of purge water generated. This technique involves pumping the groundwater at a low flow rate through an in-line flow cell where water quality parameters are monitored until stabilization, after which a groundwater sample is collected and submitted for laboratory analysis.

The positive displacement sampling method involves purging water from each sampling port within a CHS well system using compressed nitrogen gas, until a specified volume of purge water has been achieved. Water quality parameters are not monitored for stabilization criteria prior to collecting samples since the well storage is purged repeatedly and recharged with formation water.

2. EQUIPMENT AND MATERIALS

- Field forms and field book;
- Site Health and Safety Plan (HASP);
- Personal protective equipment (PPE) in accordance with the project HASP;
- Safety cones, traffic tape, and/or barricades;
- A table with monitoring well completion information, or borehole logs and/or well completion diagrams;
- Keys for any locks on well boxes or well caps;
- Hand tools, such as:
  - Socket wrench to open bolt-down well covers;
  - Crescent wrench to tighten valves for CHS sampling;
  - Large wrench (or spanner) to open drum lids;
  - Pry bar or screwdriver to lift manway (well) covers; and
  - Bolt cutters and replacement locks to cut and replace locks from wells without keys or locks that are inoperable.
- Water level meter, marked every 0.01 feet (Solinst® 102 or equivalent);
- Submersible bladder pump with air compressor and controller (QED Environmental Systems Well Wizard® pump Model Numbers P1101M and P1150, or similar);
- Power source for pump (e.g., battery, generator, air compressor) and extra batteries for water quality meter and water level meter;

- Compressed nitrogen gas canister with manifold, valves, and regulator for CHS sampling;
- Tubing – inert tubing compatible with constituents of concern in groundwater (commonly polyethylene, nylon, or Teflon®); 1/4 inch or 3/8 inch (inside diameter) tubing is recommended;
- Flow measuring equipment (e.g., graduated cylinder and stopwatch);
- Multi-parameter water quality meter with flow cell, capable of measuring temperature, pH, specific conductance, oxidation-reduction potential (ORP), dissolved oxygen (DO), and turbidity (YSI ProDSS, or equivalent);
- Field filters:
  - 0.45 micron in-line filters (Waterra® brand, or equivalent); and
  - Laboratory-provided syringe filter kit for hexavalent chromium.
- Laboratory-provided sample bottles:
  - Sufficient number of bottles for all wells to be sampled plus 10 percent extra for potential breakage; and
  - Bottles for quality assurance/quality control (QA/QC) samples as required per the Quality Assurance Project Plan (QAPP), which may include blind duplicates, matrix spike/matrix spike duplicates, field blanks, rinsate blanks, equipment blanks, and trip blanks.
- Distilled water for field and equipment blanks;
- Labels, chain of custody(CoC) forms and custody seals;
- Coolers and ice;
- Bubble wrap, re-sealable bags for ice, and shipping tape (if shipping instead of via courier);
- Container to collect purge water (such as a 5-gallon plastic bucket), preferably with graduated measurements for accurate volume measurements;
- Clamps to secure tubing to buckets while purging;
- Large volume vessel(s) (such as 55-gallon drums or plastic totes) to store purge water pending characterization and disposal; and
- Decontamination supplies (i.e., non-phosphate detergent [Liquinox® or equivalent] and distilled water).

3. HEALTH AND SAFETY

SOPs are designed to provide technical guidance and do not provide detailed or comprehensive guidance related to health and safety nor do they represent guidance on safe work procedures for the taks described. Appropriate tips related to health and safety issues associated with specific tasks may be included within technical descriptions for information's sake only.

Health and safety aspects of all projects and project tasks should be assessed and planned using ERM's establish health and safety planning procedures.

4. PROCEDURE

4.1 Preparation for Groundwater Sampling Event

It is recommended that low-flow sampling be conducted when the air temperature is above 32 degrees Fahrenheit (°F) (0 degrees Celsius [°C]). If the procedure is used below 32°F, special precautions will need to be taken to prevent the groundwater from freezing in the equipment. Minimize the length of tubing exiting the monitoring well to reduce the amount of groundwater exposed to ground surface conditions.

The following tasks should be completed before the groundwater sampling event:

1. Contact facility Site manager or property owner to confirm date of sampling event and arrange for clear access to wells and work permits (if required). Confirm any Site-specific health and safety training, PPE requirements, or other facility requirements (e.g., inspection of equipment).

2. Perform all necessary health and safety pre-planning as dictated by ERM and client-specific requirements. Pre-planning should include a review of the project HASP by all field staff.

3. Check availability of equipment and supplies either from in-house or outside sources and place order for rental and purchased equipment/supplies at least one week in advance of the sampling event to allow for shipping/stock delays. Longer lead time may be needed.

4. Ensure that you have keys for any locks on well boxes or well caps. If the condition of the locks is not known, bolt cutters and replacement locks may be required.

5. Upon receipt of equipment and supplies, check for proper operation, calibration of equipment, and quantities and sizes of supplies.

6. Place bottle order with laboratory at least one week in advance of field work – include enough bottle sets to cover all wells in the sampling program, all QA/QC samples, and a few contingency bottles. If shipping bottles or samples via air freight, check with laboratory regarding special handling and shipping requirements.

7. Prepare paperwork for the field event, including HASP, field forms or field books, Site plan showing all sample locations, previous monitoring data (if available), and any other required permits, forms, etc.

8. In order to reduce potential for cross-contamination, review previous groundwater monitoring results (if available), and if feasible, plan to sample wells in order of lowest to highest concentrations.

4.2 Calibration Activities

The water quality meter will be calibrated daily prior to use for DO, specific conductivity, pH, and ORP, at a minimum. Turbidity will be checked daily, and calibrated as needed, if outside of acceptance criteria. Calibration and calibration check procedures are described below.

4.2.1 Calibration Check

Calibration checks are performed by immersing a sensor into calibration solution, and comparing the readings to the value of the solution. The water quality probe will be pre-rinsed with a small amount of calibration solution prior to the check, and double-rinsed with distilled water in between checking each parameter. If either of the following water quality parameters have drifted past the applicable acceptance criteria, calibrate them during the next part of the procedure.

Turbidity will be checked using a one-point check, using an appropriate solution (i.e., 124 Formazin Nephelometric Units [FNU] calibration solution). The calibration check will be accepted and no further calibration necessary if the reading is within 10 percent (%) of the calibration solution value.

4.2.2 Calibration

Prior to calibration, check that the sensors and calibration cup are clean and free of debris. The water quality probe will be double-rinsed with distilled water in between calibration of each parameter. All calibration results must be recorded on the appropriate calibration field form.

- Temperature will be factory-calibrated and may be checked by comparing it to a traceable thermometer or other known reference in a water bath. Temperature cannot be calibrated in the field, nor is it expected to be required. However, for optimal performance, it is important to keep the temperature sensor free of any deposits. If deposits have formed, use mild soapy water (such as Liquinox®) and a soft bristle cleaning brush.

- DO will be calibrated using a one-point water saturated air calibration, by placing a moist sponge or a small amount of clean water in the calibration cup. Make sure the sensor is in air, not water, and that there are no water droplets on the sensor cap or temperature sensor. Put the probe in the calibration cup without tightening to enable venting to the atmosphere. Turn the instrument on and wait approximately 5 to 10 minutes for the calibration cup to become completely saturated and to allow the sensors to stabilize. Record initial and final DO as a percent and in milligrams per liter (mg/L).

- Specific conductivity will be calibrated using a one-point calibration, using an appropriate solution (i.e., 1413 microsiemens per centimeter [µS/cm]). Pre-rinse the calibration cup and sensors with a small amount of calibration solution and discard. Following the pre-rinse step, fill the calibration cup with fresh calibration solution to above the vent holes on the side of the conductivity sensor. Wait at least 40 seconds for the specific conductivity readings to stabilize, before accepting the calibration point. If the calibration is not accepted by the instrument, verify the calibration solution is fresh, the correct value has been entered into the handheld, or try cleaning the sensor.

- pH will be calibrated using a three-point calibration, using 4, 7, and 10 pH calibration solutions, starting with 7 pH, as recommended by the manufacturer. Pre-rinse the calibration cup and sensors with a small amount of the first calibration solution and discard. Following the pre-rinse step, fill the calibration cup with fresh calibration solution so the pH and temperature sensors are immersed in solution. Wait at least 40 seconds for the pH to stabilize within the range of acceptable millivolts (mV), as listed below, before accepting the calibration point. Repeat this step for each of the pH solutions. The probe will be rinsed with distilled water between each pH calibration point. If the calibration is not accepted by the instrument, verify the calibration solution is fresh, check the glass bulb or electrode body for damage, or clean and recondition the sensor.

  Acceptable pH mV Ranges:
  pH 7 mV value = 0 mV +/- 50 mV
  pH 4 mV value = +165 to +180 from pH 7 buffer mV value
  pH 10 mV value = -165 to -180 from pH 7 buffer mV value

- ORP will be calibrated using a one-point calibration, using a Zobell calibration solution or equivalent. If using the Zobell calibration solution, note that it is temperature-specific, and a chart of solution values per temperature should be consulted before proceeding with calibration. Pre-rinse the calibration cup and sensor with a small amount of calibration solution and discard. Following the pre-rinse step, fill the calibration cup with fresh calibration solution so the ORP and temperature sensors are immersed. Wait at least 40 seconds for the ORP to stabilize before accepting the calibration point. If the calibration is not accepted by the instrument, verify the calibration solution is fresh, or clean and recondition the sensor.

- If turbidity was outside the acceptance criteria in the calibration check above, it will be calibrated using a two-point calibration, using 0 (or distilled water) and 124 FNU calibration solutions. The sensor guard must be used when calibrating turbidity. Pre-rinse the calibration cup and sensors with a small amount of the first calibration solution and discard. Following the pre-rinse step, fill the calibration cup with fresh calibration solution so the turbidity sensor is immersed in solution. Pour the calibration solution slowly down the side of the cup, and tilt the calibration cup when inserting the sensor, to avoid introducing air bubbles into the sample. Wait at least 40 seconds for the turbidity to stabilize before accepting the calibration point. The probe will be rinsed with distilled water between each turbidity calibration point. If the calibration is not accepted by the instrument, verify the calibration solution is fresh, check if that the calibration cup is free of any reflective material, and make sure that the metal sensor guard bottom on the inside of the calibration cup is free of scratches.

4.3 Sampling Activities

Groundwater samples will be collected via low flow sampling for traditional single screen monitoring wells, and via positive displacement sampling for CHS well systems. It is expected that one sampler will be required per monitoring well. Each sampling procedure is described in detail below.

For both types of monitoring wells, the following basic tasks should be completed prior to commencement of sampling:

1. Establish work area at each well upon arrival – ensure safety precautions are implemented in accordance with the HASP (e.g., traffic cones, barricades, and positioning of vehicle).

2. Check the condition of the well(s) upon arrival, and make a note on the field form or in the field book of any observed damage, water in flush mounted roadbox, or potential surface contamination. If there is water in the well box, remove all water to below the top of well casing before removing the well cap to avoid allowing potentially contaminated surface water from entering the well. Note: it is not uncommon to encounter poisonous spiders or other harmful insects in well boxes; use caution when removing lids and visually inspect the well box before you proceed.

3. Measure the depth-to-water before undertaking purging or sampling, in accordance with the SOP for Fluid Level Gauging (SOP #10, Appendix A of Field Sampling Plan).

4.3.2 Low Flow Sampling

The following procedures will be used for low flow sampling:

1. Once the well cap is removed and the depth-to-water has been recorded, lower the bladder pump and tubing into the well, or connect the tubing to the air compressor, if the well already has a dedicated bladder pump and tubing installed. The pump intake should be placed in the middle of the submerged portion of the well screen.

   If there are concerns with the well going dry, pumps will be placed 2 to 3 feet from the bottom of the well to permit reasonable drawdown without disturbing the bottom of the well. For most of the monitored groundwater zones, the pump will be set within the well's screened interval. The exception is within wells with very deep screened intervals that may require drop tubes to be set within the screened interval. A table that includes water levels, intake depths, purge rates, etc. from previous sampling events is a useful reference to maintain consistency between sampling events.

2. Measure the depth-to-water again with the pump/tubing in place and use this measurement as your drawdown reference during purging. Leave the water level meter probe in the well to facilitate collecting water level measurements during purging.

3. Connect the discharge tube from the pump to the inlet of the flow cell. Secure the discharge tube from the flow cell so it discharges into a bucket or other collection vessel (i.e., with clamps).

   Start the pump (noting the time on the Sample Collection Form) and measure and record the flow rate using a graduated cylinder and stopwatch (or similar). The ideal flow rate is between 200 and 500 milliliters per minute (mL/min) and should be adjusted if excessive drawdown of the water level occurs. The United States Environmental Protection Agency (USEPA) guidelines indicate a maximum drawdown target of approximately 0.3 feet. If the minimal drawdown that can be achieved exceeds 0.3 feet, but remains stable, continue purging.

4. Begin recording water quality parameters on the Groundwater Sampling Log. Each record should include time of measurement, depth-to-water, and approximate flow rate. Note any changes to the visual clarity of the water during purging, as well as any unusual properties or odors. Record water quality parameters every 3 to 5 minutes, so that at least one flow cell volume is turned over between measurements. For example, if using a 500 mL flow cell and purging at a flow rate of 100 mL/min, the monitoring frequency would be once every 5 minutes.

   If questionable measurements are noted (e.g., negative DO readings or high DO along with negative ORP), check calibration of the instruments. If questionable measurements continue, contact the Project Manager to discuss whether the sampling should be discontinued until replacement meters are available.

5. Continue purging until the water quality parameters stabilize over three consecutive readings. The stabilization criteria are as follows:

Table 1: USEPA Recommended Water Quality Parameter Stabilization Criteria

Parameter	Stabilization Criteria
pH	± 0.1 standard units
Specific Conductivity	± 3% µS/cm
Temperature	± 3% degrees Celsius
ORP	± 10 mV
DO	± 10% mg/L (when DO >0.5 mg/L); considered stable if 3 readings <0.5 mg/L
Turbidity	± 10% FNUs (when >10 FNUs); considered stable if 3 readings <10 FNUs

Notes: DO = dissolved oxygen; FNU = Formazin Nephelometric Units; mg/L = milligrams per liter; mV = millivolts; µS/cm = microsiemens per centimeter

6. Once the parameters have stabilized, collect the samples in the order described in Section 3.4. Put on fresh disposable gloves, and fill sample bottles directly from the discharge tube. Disconnect the pump discharge tube from the flow cell to ensure that water samples are collected before water passes through the cell.

   The pumping rate should be adjusted as necessary to provide a laminar (non-turbulent) flow into the sample bottles to reduce aeration of the sample, and the water should be allowed to run smoothly down the inside of the bottle. Additional considerations during sample collection are listed in Section 4.5.

If parameters have not stabilized after 2 hours, one of three optional courses may be taken:

a. Continue purging until stabilization is achieved.

b. Discontinue purging and do not collect any sample and record in field book that stabilization could not be achieved (documentation must describe attempts to achieve stabilization).

c. Discontinue purging, collect samples, and provide full explanation of attempts to achieve stabilization.

If the well goes dry while purging or sampling, the sample may be taken after the well has recovered a sufficient amount (generally 90% of its initial volume). If the well goes dry prior to stabilization, water quality parameters will be measured and recorded at the time of sampling but will not be considered stabilized.

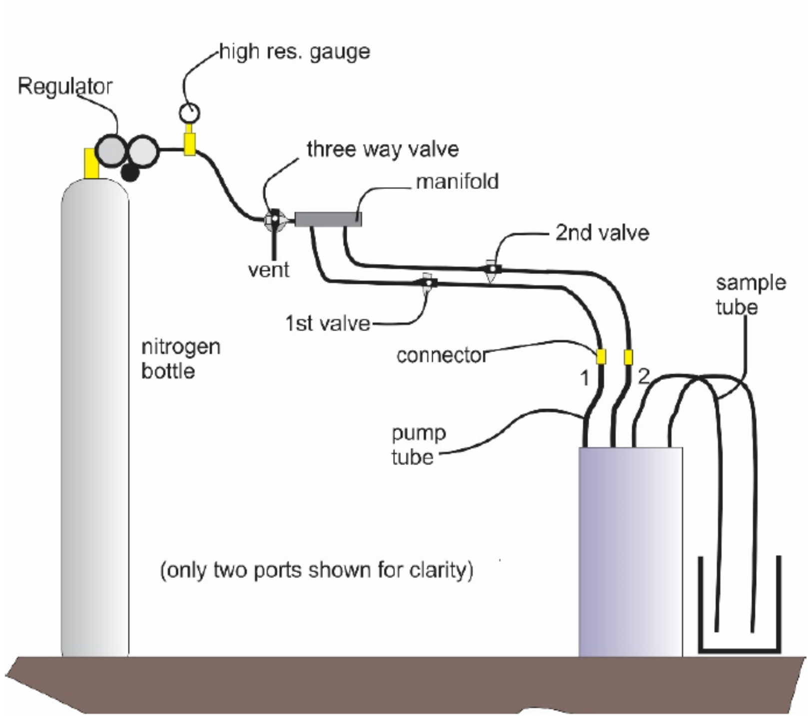
7. Once all sample bottles have been filled, switch off the pump and disconnect the tubing from the air compressor. Take a final water level measurement (and total depth if required).

4.3.3 Positive Displacement Sampling

The following procedures will be used for positive displacement sampling, in accordance with FLUTe^{TM} guidance:

1. Set up a compressed nitrogen gas canister in the work area near the CHS well system. Attach the pressure regulator to the canister and tighten with a crescent wrench (no more than one half turn).

2. Connect the manifold system to the regulator. Tighten each connection with a crescent wrench (no more than one half turn). A simplified diagram of the CHS well system and manifold set up is shown below in ***Figure 1***.



Source: FLUTE™

Figure 1: Simplified diagram CHS well system and manifold set up

3. Close the three-way valve by turning the handle to point to the vent. This blocks the gas flow into the system.

4. Open the valve on the top of the gas canister.

5. Adjust the regulator to the “purge pressure” as seen on the high resolution gauge. Each well system will have a specified purge pressure, based on calculations provided by FLUTe™.

6. Connect the connectors to the pump tubes of the CHS system and close the separate valve for each port. Each port is labeled on the manifold and on the sample tubing. Use clamps to secure each port’s tubing to an individual bucket.

7. Turn the three-way valve handle to point to the nitrogen bottle. This pressurizes the manifold. Open the valve for each port until all are opened. Water will begin to flow out of each sample tube.

8. When gas is begins spurting from a sample tube, close the valve for that port to perpendicular to the tube, stopping the gas flow to that pump tube. Do the same for each port as the gas spurts out of the sample tube.

9. When all valves are closed, turn the three-way valve toward the vent. This drops the pressure in the manifold.

10. Open each port valve to allow the gas pressure release in that tube in order to allow refill of the pump from the port.

11. To pump a second stroke, simply open the three-way valve again toward the manifold.

12. Repeat steps 7 through 9 until the prescribed purge volume has been developed from each port (generally 3 gallons per port). If preferred, by controlling the port valves, one can pump individual or groups of ports simultaneously. Simply keep the port valve closed for a port to not be pumped with each pressure application.

13. Take note of the purge volumes in subsequent strokes of the system. The longer the wait between strokes of the system, the more completely the pump tubes refill, but complete refill is slower and not necessary. The amount of water ejected by each port is a measure of whether the refill time was sufficient.

14. Once the required volume has been purged, set the regulator to the “sample pressure”. Each well system will have a specified sampling pressure, based on calculations provided by FLUTe™. The gas will need to be vented at the three-way valve to allow the gas pressure in the regulator to be reduced. Then close the three-way valve and decrease the regulator setting to the sample pressure.

15. Turn the three-way valve toward the manifold. To transition from purging to sampling, open the valve for one port and let the “discard volume” (to be determined for each port by FLUTe™) flow from the tube into a calibrated cup until the prescribed discard volume is collected. This initial discard volume cannot be used for sample collection.

16. Collect the samples in the order described in Section 3.4. Put on fresh disposable gloves, and fill sample bottles directly from the discharge tube. The sample can be collected at any time after the required volume has been discarded. After the first sample stroke is complete, water will stop flowing out of the discharge tube, but will not spurt aerated water as seen with the purge strokes. When water stops flowing from the discharge tube, the gas pressure can be vented at the three-way valve to allow the system to refill. Turning the three-way valve with the same port valve open will continue the sample water flow. No discard after the first stroke is needed, since none of the water flowing has been exposed to the gas. Repeat this step until all the samples have been collected.

17. After collection of the necessary sample volume, vent the gas pressure at the three-way valve to allow the system to refill. Connect the discharge tube to a flow-through cell with a multi-parameter probe inserted and tightened. Turn the three-way valve to apply gas pressure and allow water to fill and pass through a flow-through cell until the water stops flowing at the pre-set gas pressure. All water quality parameters will be recorded on the applicable field form.

For low-yield sampling intervals, multiple attempts may be required to collect sufficient volume for all analyses. Once sampling has commenced, the field sampler may return multiple times to collect additional samples, to the extent practical.

4.4 Sampling Order

For both conventional low-flow sampling and positive displacement sampling, groundwater samples should be collected in the same order for consistency. In general, samples are collected in order of decreasing volatility and samples for corresponding total and dissolved compounds are collected as concurrently as possible (without removing the field filter) to maximize comparability. If QA/QC samples (blind duplicates and matrix spike/matrix spike duplicates) are to be collected from a given well, samples should be collected in conjunction with the base sample (i.e., collect all volatile organic compound (VOC) samples first, then all the semi-volatile organic compounds (SVOCs), etc.).

Samples collected for hexavalent chromium analysis will be collected after the sample for total metals and will be filtered in the field using a laboratory-provided syringe kit. Immediately following field filtering, the sampler will add the laboratory-provided preservative to the sample container and cap, prior to storing the sample in the cooler. Field preservation will be noted on the associated sampling form. Put on fresh disposable gloves after handling the syringe kit.

Samples for dissolved metals, radiological analyses (excluding tritium), and organic carbon will be filtered in the field using a clean, unused 0.45-micron in-line filter. Each in-line filter will be pre-conditioned by running approximately 25 mL of sample water through the filter prior to collecting the sample. One filter will be used per well, unless the flow rate decreases to 10 percent or less of the initial sample flow rate due to the filter becoming clogged by elevated particulates. Put on fresh disposable gloves after handling the field filter.

Groundwater samples will be collected in the following order, assuming sufficient recharge for the required sample volume:

1. VOCs;
2. Dissolved gases;
3. SVOCs;
4. Total metals, total hardness;
5. Hexavalent Chromium (VI) – field filtered using laboratory-provided syringe kit;
6. Total radiological chemistry (isotopic thorium, isotopic uranium, isotopic radium-226/228);
7. Dissolved metals – field filtered using pre-conditioned 0.45-micron in-line filter;
8. Dissolved radiological chemistry (isotopic thorium, isotopic uranium, isotopic radium-226/228) – field filtered using pre-conditioned 0.45-micron in-line filter;
9. Dissolved organic carbon – field filtered using pre-conditioned 0.45-micron in-line filter;
10. Total organic carbon, chemical oxygen demand, ammonia, nitrate and nitrite, phosphorous;
11. Tritium;
12. Total petroleum hydrocarbons (TPH);
13. Alkalinity, total dissolved solids, nitrate, nitrite, chloride, fluoride, sulfate, iodide, bromide, carbonate, pH;
14. Total suspended solids;
15. Cyanide;
16. Sulfide;
17. Polychlorinated biphenyls; and
18. Chlorinated herbicides.

The first time a well is sampled, attempts will be made to collect sufficient sample volume for all analyses, to the extent feasible. If possible, all samples will be collected from a given well on the same day for comparability. For subsequent sampling events for low-yield wells, sample collection order may be modified based on prior detections at that location and/or detections at proximal locations. For example, if VOCs were not detected above laboratory reporting limits during the initial sampling event, then samples for radiological compounds may be collected before VOCs due to the large volume of water required for radiological analysis. Analyte prioritization may also incorporate adjacent vertical intervals or adjacent locations to facilitate plume delineation. For example, if radium is detected at a shallow interval it may be prioritized in the next deeper screen interval over analytes that were not detected in order to complete vertical delineation of radium. Additionally, if a well is expected to go dry during purging, samples for corresponding total and dissolved analytes may be collected sequentially before starting to collect a sample for a different analyte group. For example, samples for total and dissolved metals may be collected sequentially before starting to collect the larger volumes required for total and dissolved radiological analysis, in case the well goes dry. If multiple attempts are required to collect field filtered samples, a new, clean, pre-conditioned 0.45-micron in-line filter will be used each time.

4.5 Additional Sampling Considerations

While collecting groundwater samples using the methods described above, the following considerations should be taken into account:

- Ambient conditions, such as direct sunlight, may heat up groundwater in the tubing and flow cell, which may result in degassing of VOCs and dissolved gases. When working in warmer conditions, the sampling equipment should be set up in a shaded area, or under an umbrella or tent. If possible, avoid sampling on hot days, or during the hottest time of the day. Minimize the length of tubing exiting the monitoring well to reduce the amount of groundwater exposed to ground surface conditions.

- For samples requiring no headspace (VOCs, dissolved gases, and TPH), each vial must be filled using one single stroke from the bladder pump, or one single stroke from the CHS sampling manifold, resulting in a positive meniscus (i.e., above the rim of the vial) to eliminate the formation of bubbles and headspace before capping. Once the cap is screwed on, turn the vial upside down and gently tap the side of the bottle to see if any air bubbles are present. If there are bubbles, remove the cap, top off the vial and attempt again, or discard the vial and use a fresh vial. Use appropriate care while screwing on the cap, in tapping the vial, and in general handling of the glassware. Do not over tighten sample bottle lids as the bottles may shatter and become a cut hazard.

- For QA/QC purposes, it is preferable to use sample bottles that are pre-preserved by the laboratory (with the exception of hexavalent chromium). Care should be taken during sampling to prevent overflow of water in sample bottles containing acid preservative, as the acid preservative may be washed out. If preserved sample bottles overflow, that bottle should be discarded, and replaced with a new bottle.

4.6 Post-Sampling Activities

Once sample collection is complete, the following steps will be taken:

- The collected samples should be labeled with the appropriate information, and placed immediately in an ice-filled cooler pending shipment or delivery to the laboratory, in accordance with the SOPs for Field Documentation, Chain of Custody, and Sample Packing and Shipping (SOPs #01, 02, and 03, Appendix A of the Field Sampling Plan).

- Any non-disposable, non-dedicated equipment should be decontaminated between each well, in accordance with the SOP for Equipment Decontamination (SOP #18, Appendix A of the Field Sampling Plan).

- The purge water from each well should be stored in an appropriate container on-Site pending characterization and disposal.
- The final recorded water quality parameters from low flow sampling and CHS sampling will be submitted in digital format to the project database (EQuIS^{TM}).

5. REFERENCES

Flexible Liner Underground Technologies (FLUTe). 2019. Use of FLUTe Manifold for Simultaneous Purging of Sampling Systems.

United States Environmental Protection Agency (USEPA). 2002. Ground-Water Sampling Guidelines for Superfund and RCRA Project Managers. (EPA/542-S-02-001). (Yeskis and Zavala).

USEPA. 2006. Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures. (EPA/540/s-95/504). (Puls and Barcelona).

USPEA. 2017. Low Stress (low flow) Purging and Sampling Procedure for the Collection of Groundwater Samples from Monitoring Wells. EQASOP-GW-001. Region 1. Revision No. 4. Available online at: https://www.epa.gov/sites/production/files/2017-10/documents/eqasop-gw4.pdf. Accessed 27 July 2020.

Standard Operating Procedure #14: Indoor Air and Outdoor Ambient Air Sampling

Version #1
August 2020

West Lake Landfill Site
Operable Unit 3
Bridgeton, MO

Prepared for:
U.S. Environmental Protection Agency, Region 7
11201 Renner Boulevard
Lenexa, KS 66219

Prepared by:
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CONTENTS

1. INTRODUCTION

The purpose of this standard operating procedure (SOP) is to detail the procedures to be used to collect indoor air and outdoor ambient air samples for analysis of volatile organic compounds using The United States Environmental Protection Agency's (USEPA's) TO-15 test method as part of a vapor intrusion assessment for Operable Unit 3 at the West Lake Landfill Site in Bridgeton, Missouri.

2. EQUIPMENT AND MATERIALS

- Site map with the sample locations;
- A copy of the Health and Safety Plan, Field Sampling Plan, and Quality Assurance Project Plan;
- SUMMA® canisters;
- Pre-calibrated flow controllers equipped with an in-line particulate filter and vacuum gauge;
- Labels/tags;
- Adjustable wrench;
- Shipping packaging provided by the laboratory;
- Sampling field form;
- Indoor Air Building Survey Checklist or similar;
- Chain of custody (CoC) form; and
- Field book.

3. HEALTH AND SAFETY

SOPs are designed to provide technical guidance and do not provide detailed or comprehensive guidance related to health and safety, nor do they represent guidance on safe work procedures for the tasks described. Appropriate tips related to health and safety issues associated with specific tasks may be included within technical descriptions for information's sake only.

Health and safety aspects of all projects and project tasks should be assessed and planned using ERM's established health and safety planning procedures.

4. PROCEDURE

4.1 General Procedures

- Field staff will avoid activities immediately before and during the sampling that may contaminate the sample (e.g., using markers, fueling vehicles, etc.).
- If possible, all windows and doors of the facility will be closed during sampling and for 24 hours prior to sampling.
- Weather information (temperature, barometric pressure, relative humidity, wind speed, and wind direction) and approximate indoor temperature will be recorded at the beginning of the sampling event. Field staff will record substantial changes to these conditions that may have occurred 24 to 48 hours prior to, and during the course of sampling.

4.2 Sampling Procedures

- The sampling locations will be identified on a floor plan completed with the Building Survey. A floor plan drawing will also be completed that identifies locations of HVAC equipment, chemical storage areas, garages, doorways, stairways, sumps, drains, utility perforations, north direction, and separate footing sections. For the background ambient air sample, a location upwind (on the day of sampling) from the building(s) will be sampled.
- An evacuated SUMMA® canister will be used to collect each sample. The canister will be certified clean and provided by the laboratory, along with a flow controller equipped with an in-line particulate filter and vacuum gauge. Each flow controller will be pre-calibrated by the laboratory for the desired flow rate or duration of sample collection. For the purposes of commercial indoor air sampling, the flow controller will be calibrated for an 8 hour sampling period.
- A photoionization detector (PID) measurement will be collected before sampling begins and prior to the completion of the indoor air sampling. The PID measurements will be recorded on the field sampling form.
- The air intake of each canister will be located at a breathing-zone height of approximately 3 to 5 feet above the floor surface.
- The protective brass plug will be removed from each canister and the pre-calibrated flow controller will be attached.
- The unique identification numbers for each SUMMA® canister and flow controller will be recorded, along with the initial canister pressures on the vacuum gauge. These numbers and values will be recorded on the field sampling form and on the CoC form for each sample.
- The valve on the SUMMA® canister will be opened. The time each valve was opened (beginning of sampling) will be recorded on the field sampling form and on the CoC.
- The outdoor ambient air sample will commence up to 1 hour prior to initiating the indoor air samples and will finish within an hour of the indoor air monitoring being complete to make sure that the indoor air sampling period is covered by the outdoor ambient air sampling period.
- A building survey will be conducted during sample collection to document building conditions and compile a list of any products/chemicals that are present during the sampling event.
- Potential VOC sources will be noted on the building survey.

- Sample collection will be stopped after the scheduled duration of sample collected but when the canister still has approximately 5 inches of mercury remaining in the canister.
- The final vacuum pressure and time will be recorded on the field sampling form after the canister valve has been closed.
- The flow controller from the canister will be removed and the protective brass plug replaced onto the canister intake.
- The sample labels/tags (sample name, time/date of sampling, etc.) will be attached to the canister as directed by the laboratory.
- The canister and other laboratory supplied equipment will be placed in the packaging provided by the laboratory.
- The CoC form will be completed, making sure to include the identification numbers for each canister and flow controller, the start and end times for each canister's sample collection period, and the initial and final canister pressures on the vacuum gauge.
- The sample canisters will be submitted to the laboratory under CoC and analyzed via USEPA Method TO-15. If the pressure reading of a canister is "zero" when logged in by the laboratory, the sample will not be analyzed.

Figure 1: A Typical Indoor Air Sample Setup

Standard Operating Procedure #15: Short-Term Radon Testing

Version #1
August 2020

West Lake Landfill Site
Operable Unit 3
Bridgeton, MO

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CONTENTS

1. INTRODUCTION

The purpose of this standard operating procedure (SOP) is to describe the field procedures for short-term radon testing to determine relatively real-time levels of radon impacts for Operable Unit 3 at the West Lake Landfill Site in Bridgeton, Missouri. Information, in particular indoor air concentrations, may be used to determine if mitigation is necessary when decisions are needed within several days or weeks.

The basics of radon, radon decay chains, and measurement techniques can be found in the RAD7 Electronic Radon Detector User Manual (Durridge 2019). Radon is a dense, colorless, odorless gas derived from the natural decay of uranium-238, uranium-234, and thorium-230, with radium isotopes as intermediate products. Radon-222 is the longest-lived radon isotope and the only one measured in the environment. Radon-222 decays into polonium-218 with a half-life of 3.82 days. This SOP includes monitoring of radon decay products derived from the decay of radon-222. The RAD7 detector (and similar detectors) collects air through a filter so that only radon and non-radioactive gases enter the chamber. As radon decays, the decay products are electrostatically bound to the internal detector. As the bound products decay, the detector records the alpha emissions from the subsequent decays of the radon decay products. Radon decay products can be differentiated by the energy of the alpha particle emissions.

2. EQUIPMENT AND MATERIALS

- Field form and field book;
- Site Health and Safety Plan;
- Equipment user manuals;
- Durridge® RAD7 radon detector or equivalent
  - Detection devices must be listed by the National Radon Proficiency Program (NRPP) or the National Radon Safety Board (NRSB) for having been proven to meet minimal quality requirements.
- Durridge® Inlet filters (one for each sample location);
- Durridge® dust filter (replace as needed);
- Durridge® laboratory drying unit, drying tubes, and/or additional indicating desiccant;
- Tubing – RAD7 Tubing Set or other inert tubing compatible with radon sampling, commonly Teflon®; and
- USB to serial adapter cable and laptop with Durridge® CAPTURE software.

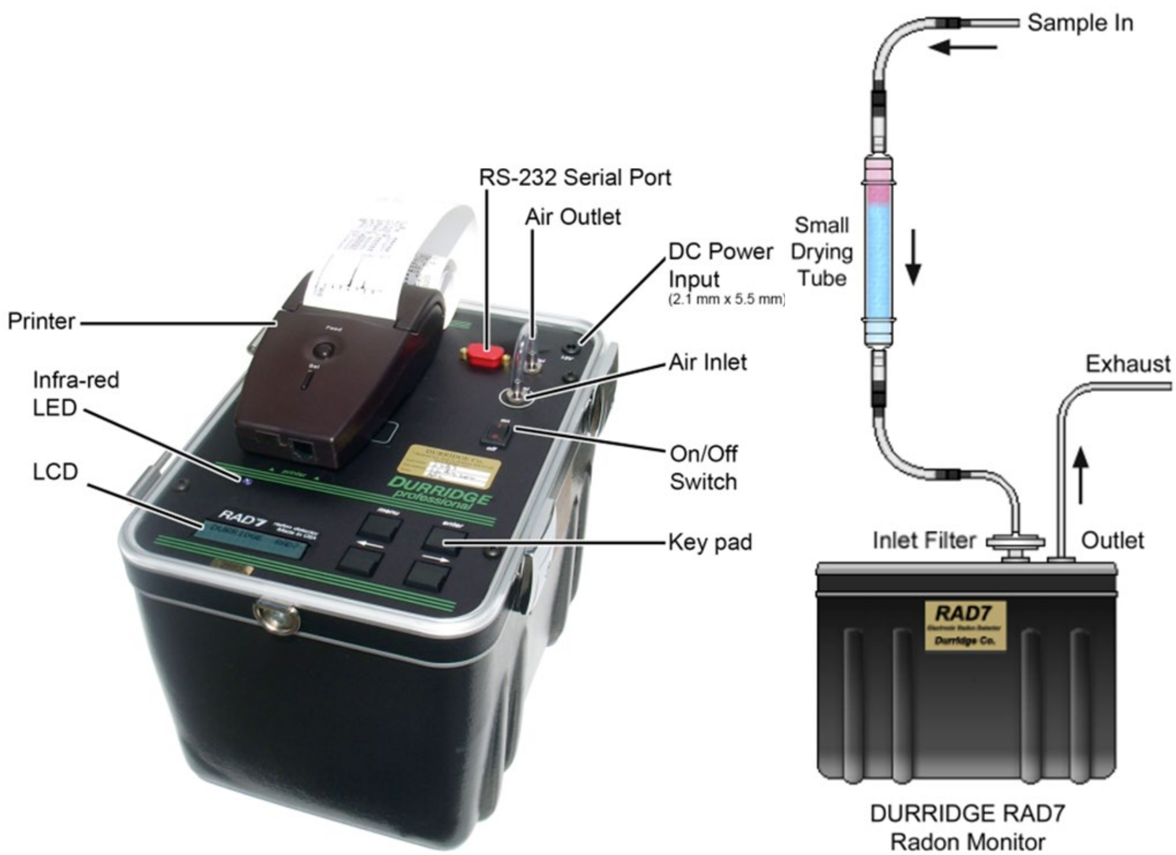

Figure 1: Image of RAD7 Meter

Source: Durridge RAD7 Manual, 2019

3. HEALTH AND SAFETY

SOPs are designed to provide technical guidance and do not provide detailed or comprehensive guidance related to health and safety, nor do they represent guidance on safe work procedures for the tasks described. Appropriate tips related to health and safety issues associated with specific tasks may be included within technical descriptions for information's sake only.

Health and safety aspects of all projects and project tasks should be assessed and planned using ERM's established Health and Safety planning procedures.

4. PROCEDURES

4.1 Radon Gas Sampling: Indoor Air

Radon gas sampling should be conducted in accordance with the time-sensitive testing protocol (AARST 2019; USEPA 1993) and monitoring device manufacturer's protocols (Durridge 2019 or equivalent).

4.1.1 Preparation

1. The building should be closed 12 hours prior to initiating the test, if possible. All exterior windows and doors should be kept closed on all levels of the building, except for momentary entry and exit. Heating and cooling systems should be set to normal with temperature settings between 65 and 80 degrees Fahrenheit (°F). Ventilation systems should be set to the lowest setting that occurs during the year. Fireplaces and whole-house fans should not be operated and other mechanical ventilation (dryers, hoods, or fans) should not be operated. Closed building conditions should be maintained for the duration of the test.

2. If buildings cannot be closed as described above, due to ongoing building operations, measurements may proceed but building conditions should be documented.

3. Identify the location for the test. The test should be performed in a room on the lowest occupied level of the structure. If the lowest level has multiple rooms, select the room that is most likely to be occupied for extended periods of time.

4. Turn on RAD7 device. Set the system time if necessary. Purge system for at least 5 minutes in clean air (e.g., outside) without potential radon sources.[1]

5. Set up the monitoring device in an appropriate location in the room. The device must be placed more than 3 feet from exterior doors and windows, 20 inches above the floor, 1 foot from walls, 1 foot below the ceiling, and 4 inches from other objects or detectors. Do not place the detector in closets or cabinets, near heat sources (e.g., radiators, fireplaces, or direct sunlight), near drafts (e.g., caused by fans or air conditioners), or in humid locations (e.g., bathrooms, laundry room, or kitchens).

6. Plug the power cord into a wall outlet and into the RAD7 meter.

7. Attach the inlet filter to the tubing.

8. Remove both plastic caps from the drying unit (do not discard) and attach the tubing to the drying unit.

9. Attach the filter to the inlet port of the RAD7. See the RAD7 Standard Configuration Diagram in the Operators Manual.

4.1.2 Meter Operation

1. After purging for some time (normally, at least 5 minutes) begin the 2-day test protocol. Confirm that the date/time are properly set and that the units are set to °F and picocuries per liter (pCi/L).

2. Note the relative humidity (RH), temperature, and battery voltage prior to starting the test and periodically during instrument operation. Rising relative humidity may indicate that the desiccant is exhausted or that there is a leak in the sample path. Tighten fittings, check tubing, and/or change out the drying unit. The desiccant will have to be replaced every 7 to 14 days depending on the humidity.

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[1] Fresh air purge may need to be completed away from the landfill at an off-Site location.

The temperature reading gives a base for future reference. Dropping battery voltage may indicate that the power is not connected.

3. Run the 2-day test in accordance with Section 1.4 of the RAD7 User Manual. Select the “2-Day" protocol, set the Format to “Format:short”, then select “Test Start” from the main menu.

4. Prior to the end of the last cycle, turn on the printer, if operational, to obtain a printout of the test results.

5. In addition, download electronic test results using the Durridge® CAPTURE software in accordance with Section 6.2 of the RAD7 Manual. Export data (including all total counts for windows A, B, C, and D [radon decay products]) from the run in a Microsoft Excel compatible format (e.g., csv, xls, or txt) and upload to the ERM networked project folder.

6. Examine the data in accordance with Section 4.2.9 of the RAD7 User Manual. On reviewing a set of data, first check that the relative humidity in the instrument stayed below 10 percent (%) throughout the measurement. If it rose above 10%, it suggests that the desiccant was either removed or became depleted. The RAD7 reads low if the internal RH rises above 10%. The temperature during the measurement should remain fairly steady. Sudden changes of temperature suggest that either the windows were opened or the meter was moved to a different location. Changes should be noted in conjunction with data evaluation.

7. Once testing is completed, purge air through the RAD7 meter in accordance with Section 2.2.5 of the RAD7 User Manual. Outdoor air and a minimum of 10 minutes purge time is usually sufficient to purge moderate amounts of radon from the instrument. Always use an inlet filter and drying tube during purging. To conserve desiccant, the air inlet tube can be connected to the outlet (closed loop).

8. After use, disconnect all tubing and replace the caps on the drying tube.

4.2 Radon Gas Sampling: Soil Gas and Sub-Slab Vapors

Soil gas and sub-slab vapor samples shall be analyzed for radon and radon decay products as described in this section.

4.2.1 Preparation

1. Soil gas and sub-slab vapor probes shall be installed and tested as described in the Field Sampling Plan and associated SOPs.

2. Soil gas and sub-slab vapor probes shall be installed at least 48 hours prior to collecting samples for radon analysis.

3. Turn on the RAD7 device. Set the system time if necessary. Purge system for at least 5 minutes in clean air (e.g., outside) without potential radon sources.

4. Attach the inlet filter to the tubing.

5. Remove both plastic caps from the drying unit (do not discard) and attach the tubing to the drying unit.

6. Attach the filter to the inlet port of the RAD7.

4.2.2 Meter Operation

1. After purging for some time (normally, at least 5 minutes) set the RAD7 meter in “sniff” mode with samples recorded at least every 5 minutes. Confirm that the date/time are properly set and that the units are set to °F and pCi/L.

2. Note the relative humidity, temperature, and battery voltage prior to starting the test and periodically during instrument operation. Rising relative humidity may indicate that the desiccant is exhausted or that there is a leak in the sample path. Tighten fittings, check tubing, and/or change out the drying unit. The desiccant will have to be replaced every 7 to 14 days depending on the humidity. The temperature reading gives a base for future reference. Dropping battery voltage may indicate that the power is not connected.

3. Connect the soil gas or sub-slab vapor probe to the inlet of the RAD7 drying unit with manufacturer supplied tubing.

4. Collect radon activity concentration readings, including decay product isotopes until adequate precision and stabilization is observed, approximately 30 minutes. Adequate stabilization is defined as <10% change in radon activity concentration from the previous two measurements, and precision is considered adequate when the standard deviation is <10% of the radon activity concentration measurement.

5. If adequate precision and stabilization is not observed within 30 minutes, the mode should be changed from “sniff” to “auto.” Configure the RAD7 to record measurements every 5 minutes.

6. Allow the meter to monitor radon until the meter switches to “normal” mode (after 3 hours).

7. After the meter switches to “normal” mode, the meter should be left connected to the soil gas or sub-slab vapor probe for at least 1 hour, continuing to record radon and radon decay product activity for the duration of the measurement.

8. Once testing is completed, disconnect all tubing and replace the caps on the drying tube.

9. Purge air through the RAD7 meter in accordance with Section 2.2.5 of the RAD7 User Manual. Outdoor air and a minimum of 10 minutes purge time is usually sufficient to purge moderate amounts of radon from the instrument. Always use and inlet filter and drying tube during purging. To conserve desiccant, the air inlet tube can be connected to the outlet (closed loop).

10. Prior to the end of the last cycle, turn on the printer, if operational, to obtain a print out of the test results.

11. Download electronic test results using the Durridge® CAPTURE software in accordance with Section 6.2 of the RAD7 Manual. Export data (including all total counts for windows A, B, C, and D [decay products]) from the run in a Microsoft Excel compatible format (e.g., csv, xls, txt) and upload to the ERM networked project folder. Evaluate the data as described in Section 4.1.2 Step #6 above.

5. REFERENCES

American Association of Radon Scientists and Technologists (AARST). 2019. Protocol for Conducting Measurements of Radon and Radon Decay Products in Homes. AARST Consortium on National Radon Standards. ANSI/AARST MAH 2019.

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United States Environmental Protection Agency (USEPA). 1992. Indoor Radon and Radon Decay Product Measurement Device Protocols. EPA 402-R-92-004. Available online at: http://www.epa.gov/radon/pubs/devprot1.html. Accessed August 2020.

USEPA. 1993. Protocols for Radon and Radon Decay Product Measurements in Homes. EPA 402-R-92-003.

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Standard Operating Procedure #16: Long-Term Radon Testing

Version #1
August 2020

West Lake Landfill Site
Operable Unit 3
Bridgeton, MO

Prepared for:
U.S. Environmental Protection Agency, Region 7
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CONTENTS

1. INTRODUCTION

The purpose of this standard operating procedure is to describe the field procedures for performing long-term radon testing using electret ion chambers to more closely evaluate annual exposure to radon when compared with short-term radon testing for Operable Unit 3 at the West Lake Landfill Site in Bridgeton, Missouri. The field procedures described herein present the general methodology for sample collection. If operating procedures are not able to be implemented in their entirety due to field-specific circumstances, deviations and significant modifications to the procedures should be noted by the field staff and discussed with the project team as necessary. The basics of radon and radon decay chains can be found in the RAD7 Electronic Radon Detector User Manual (Durridge 2019).

2. EQUIPMENT AND MATERIALS

- Field forms and field book;
- Site Health and Safety Plan;
- Equipment User Manuals; and
- Rad Elec Inc. S-chamber with long term electret (SLT E-Perm®) or equivalent.
  - Detection devices must be listed by the National Radon Proficiency Program (NRPP) or the National Radon Safety Board (NRSB) for having been proven to meet minimal quality requirements.
  - Monitoring devices should be obtained from the analytical laboratory that will perform the analysis.
  - The SLT E-Perm® is a passive radon measurement device consisting of an electret (LT electret) and ionization chamber (S-chamber).
  - Note: The E-per^m® S-chamber is a 210 milliliter (mL), dome-shaped container with a plunger suitable for long-term radon testing when paired with the correct electret (Figure 1). The LT electret is a positively charged Teflo^n® disk intended for deployments of 3 months to 1 year with an initial voltage of 700+ volts. The electret will lose approximately 5 volts per day in an environment containing 2 picocuries per liter (pCi/L) of radon activity. For a 90-day test, the electret must have an initial voltage of at least 500 volts.

The left picture shows the chamber in the "ON" position. When the top is screwed on tightly (the "OFF" position shown on the right), the chamber will protect the electret from exposure to ambient radon.
Source: Rad Elec Inc.

Figure 1: E-Perm® S-chamber

3. HEALTH AND SAFETY

SOPs are designed to provide technical guidance and do not provide detailed or comprehensive guidance related to health and safety, nor do they represent guidance on safe work procedures for the tasks described. Appropriate tips related to health and safety issues associated with specific tasks may be included within technical descriptions for information's sake only.

Health and safety aspects of all projects and project tasks should be assessed and planned using ERM's established Health and Safety planning procedures.

4. PROCEDURE

Radon gas sampling should be conducted in accordance with the long-term testing protocol (AARST 2019; USEPA 1993) and the monitoring device manufacturer's protocols. Closed building conditions are not required for long-term radon testing. Monitoring devices should be obtained from the laboratory performing the analysis and maintained in the closed position until the beginning of the test.

1. Identify the locations for the test. If the building is larger than 2,000 square feet, multiple electrets should be deployed with 1 electret per 2,000 square feet.

2. A least one monitoring device must be placed on the lowest occupied level of the structure. If the lowest level has multiple rooms, select the room that is most likely to be occupied for extended periods of time.

3. An additional monitoring device must be placed outdoors for an ambient background reading.

4. Coordinate with building operator so the monitoring devices are not disturbed for the duration of the test. Post signage with information and contact information explaining the purpose of the test and the requirement to not disturb the devices.

5. Inspect the monitoring devices per manufacturer's guidelines. Examine the interior to determine that the filter is secure and free of dust and fibers.

6. Set up the monitoring device in an appropriate location in the room. The device must be placed more than 3 feet from exterior doors and windows, 20 inches above the floor, 1 foot from walls, 1 foot below the ceiling, and 4 inches from other objects or detectors. Do not place the detector in closets or

cabinets, near heat sources (radiators, fireplaces, direct sunlight), near drafts (caused by fans or air conditioners), or in humid locations (bathrooms, laundry room, kitchens).

7. Verify that the S chamber is fully opened and secure and note the start time of the test in the field book, chain of custody, and/or field form.

8. At the conclusion of the test period (at least 90 days), inspect the E-Perm® for damage and ensure that the chamber is still fully open. Record the test end time and close the S-chamber fully.

9. Place the sealed E-Perm® in a double-zip bag and ship to the analytical laboratory with a complete chain of custody as detailed in the Quality Assurance Project Plan.

10. Remove all signage and equipment from the test locations.

5. REFERENCES

American Association of Radon Scientists and Technologists (AARST). 2019. Protocol for Conducting Measurements of Radon and Radon Decay Products in Homes. AARST Consortium on National Radon Standards. ANSI/AARST MAH 2019.

Durridge. 2019. RAD7 Electronic Radon Detector User Manual. Durridge Radon Capture & Analytics. 21 May 2019.

United States Environmental Protection Agency (USEPA). 1992. Indoor Radon and Radon Decay Product Measurement Device Protocols. EPA 402-R-92-004. Available online at: http://www.epa.gov/radon/pubs/devprot1.html. Accessed August 2020.

USEPA. 1993. Protocols for Radon and Radon Decay Product Measurements in Homes. EPA 402-R-92-003.

USEPA. 2012. Radiation: Facts, Risks and Realities. EPA-402-K-10-008. April 2012. Available online at: https://www.epa.gov/sites/production/files/2015-05/documents/402-k-10-008.pdf. Accessed August 2020.

Standard Operating Procedure #17: Soil Gas Probe Installation and Sampling

Version #2
November 2020

West Lake Landfill Site
Operable Unit 3
Bridgeton, MO

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CONTENTS

1. INTRODUCTION

The purpose of this standard operating procedure (SOP) is to describe the method for near-slab and exterior soil gas monitoring well construction for active soil gas sampling, specifically designed for quantitative soil gas assessments of volatile organic compounds (VOCs), for Operable Unit 3 at the West Lake Landfill Site in Bridgeton, Missouri. The approach detailed here is based on relevant guidance documents and is intended to enable field staff to install a gas monitoring well suitable for the collection of soil gas samples in a competent and reproducible manner.

If operating procedures are not able to be implemented in their entirety due to field-specific circumstances, deviations and significant modifications to the procedures should be noted by the field staff and discussed with the project team.

2. EQUIPMENT AND MATERIALS

- Site map with sample locations;
- A copy of the Health and Safety Plan and a copy of the Quality Assurance Project Plan (QAPP);
- Hand auger/Geoprobe®/direct-push drill rig equipment and coring equipment or vacuum excavator equipment;
- Installation materials (e.g., 6-inch stainless steel soil gas screen, ¼-inch Nylaflow® tubing or similar, sand, bentonite, road box, and water);
- Tools to open the road box and cut sampling tubing;
- Boring logs, chain-of-custody forms, field books, and sampling forms;
- Laboratory-supplied certified clean summa canisters with gas-tight Swagelock® fittings;
- Pre-calibrated flow controller equipped with an in-line particulate filter and a vacuum gauge;
- Differential pressure meter (digital micro-manometer [e.g., VelociCalc® Multi-Function Ventilation Meter 9565]);
- Sealed lung box and vacuum pump (e.g., SKC pump);
- Tedlar® bags;
- Shut-in leak test equipment;
- Helium shroud test equipment (including helium detector [e.g., Dielectric Helium Leak Detector MGD-2002]);
- Seal test equipment;
- Adjustable wrench;
- Calibrated photoionization detector (PID);
- Calibrated landfill gas meter (e.g., Landtec GEM™2000);

- Sample labels/tags; and
- Shipping packaging supplied by the laboratory.

3. HEALTH AND SAFETY

SOPs are designed to provide technical guidance and do not provide detailed or comprehensive guidance related to health and safety, nor do they represent guidance on safe work procedures for the tasks described. Appropriate tips related to health and safety issues associated with specific tasks may be included within technical descriptions for information's sake only.

Health and safety aspects of all projects and project tasks should be assessed and planned using ERM's established health and safety planning procedures.

4. PROCEDURE

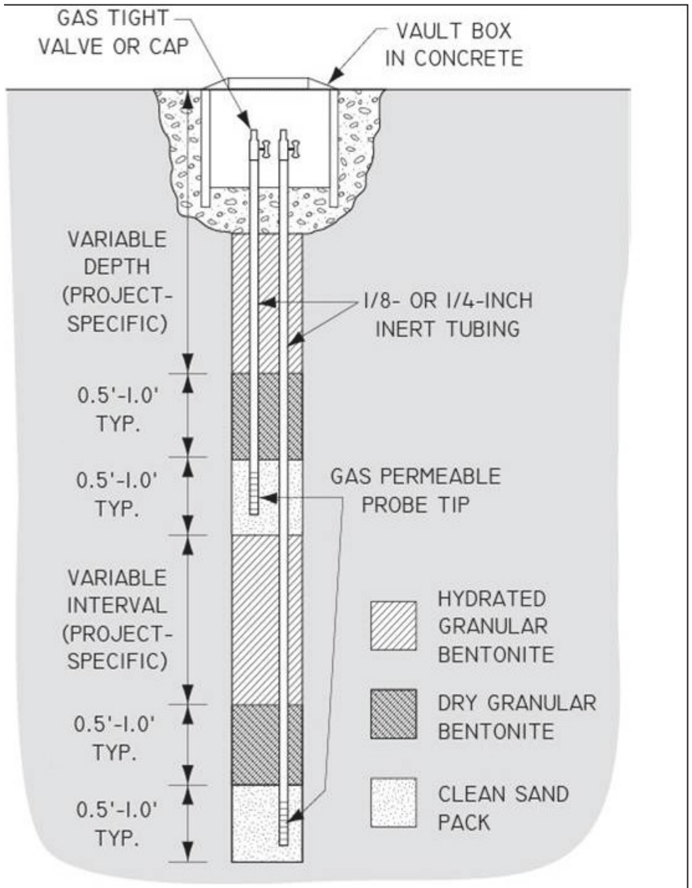
4.1 Preparation Procedures

- Field staff will avoid activities immediately before and during the sampling that may contaminate the sample (using markers, fueling vehicles, etc.).
- Weather information (temperature, barometric pressure, relative humidity, wind speed, and wind direction) and approximate indoor temperature will be recorded at the beginning of the sampling event. Field staff will record substantial changes to these conditions that may have occurred 24 to 48 hours prior to, and during the course of sampling on the sampling field form.

4.2 Installation Procedures

- Before installation begins, utility clearance must be completed as described in the SOP for Subsurface Clearance (SOP #04, Appendix A of the Field Sampling Plan).
- A hand auger, vacuum truck equipped with an air knife or direct-push drill rig will be used to advance a soil boring to the desired depth of sampling. A corer may be needed if drilling through concrete. The sampler overseeing the probe installation will periodically inspect the soil for significantly wet soils, which could indicate a perched water table or other subsurface conditions which may inhibit the proper collection of a soil gas sample.
- Once the boring has been advanced to the desired depth, a 6-inch stainless steel screen will be connected to ¼-inch diameter Nylaflow® (or similar) tubing long enough to extend to the depth of the boring and above the ground surface approximately 24 inches. The screen should touch the bottom of the boring and the tubing should be placed such that it will remain in the middle of the boring.
- Clean sand will be poured down the borehole around the screen and fill to approximately 6 inches above the top of the screen. The screen should stay in the center of the boring.
- Dry bentonite will be filled approximately 6 inches above the filter sand to prevent moisture from leaking into the sand pack.
- Hydrated bentonite/bentonite slurry will then be filled to approximately 6 inches below ground surface or 6 inches below the next soil gas probe installation depth (if installing nested soil gas probes).

- Sand will be used above the hydrated bentonite/bentonite slurry down the borehole for the remaining 6 inches below ground surface or up to the bottom of the next soil gas probe installation depth (if installing nested wells).
- If installing another nested soil gas probe, a second 6-inch stainless steel screen will be connected to ¼-inch diameter Nylaflow® (or similar) tubing, long enough to extend to the desired sample depth and above the ground surface approximately 24 inches. The tubing shall be placed such that it will remain as close to the middle of the boring as possible (adjacent to the tubing from the deeper screen). All tubing for nested wells should be clearly labeled with depth indications for use in differentiating the locations after probe completion. Clean sand will then be poured around the screen and filled to approximately 6 inches above the top of the screen. Dry bentonite (no water added) will be filled approximately 6 to 12 inches above the filter sand and then hydrated bentonite/bentonite slurry (i.e., bentonite chips that are then hydrated) will be filled to approximately 12 inches below ground surface or 6 inches below the next soil gas probe installation and the installation process will be repeated. The final 12 inches to ground surface will be completed with hydraulic cement and the road box or stick up completion materials.
- A road box or similar cover will be secured above the soil gas well containing the sample tubing inside. If more than one soil gas probe is installed, tubing strands will be labeled with tape to note which sample depth each represents.
- A two-way valve will be installed at the end of each tubing line and set to the closed position. If tubing is attached to the opposite side of the two-way valve, a tubing clip can be placed at the end to protect the tubing from dirt or the tubing can be removed and discarded following each sampling event.
- Following installation, the soil gas wells will be allowed to equilibrate for a minimum of 48 hours.



Source: State of Hawai'I Department of Health. Technical Guidance Manual for the Implementation of Hawai'I State Contingency Plan. November 2008. Available online at: http://www.hawaiidoh.org/tgm-pdfs/TGM.pdf. Accessed 28 July 2020.

Figure 1: Typical Nested Soil Gas Probe Schematic

4.3 Seal Test (Nested Probes Only)

Nested soil gas probes have multiple probes within a single borehole making it critical to confirm the competence of the seal between probes. Seal tests will be conducted on newly installed wells using the following procedure.

- Complete a seal testing event at least 48 hours after probe installation
- Select one of the sample depths to test and connect that probe to a vacuum pump and gauge. Connect another different probe in the borehole to a vacuum gauge.
- Use the vacuum pump to draw vacuum on the first probe such that approximately 5 in-H_2O in the probe can be measured, if possible.
- Monitor the second probe that is attached to a vacuum gauge and observe if there is significant response (i.e., vacuum) in the second probe as a result of the vacuum generated in the first probe.
- Move the vacuum gauge to other probes in the nested well, if any, to monitor for leaks in the seal.
- Continue the test until all probe seals have been checked.

4.4 Shut-in Leak Test

- Each soil gas location will be subject to a shut-in leak check to confirm that the connections within the sample train are tight and do not leak. The shut-in leak check may be performed at multiple stages whenever tightness in above ground fittings needs to be checked.
- Confirm valve at the top of the soil gas probe is closed. Connect the probe to tubing and equipment for next sample or test to be performed.
- Use a vacuum pump or plastic syringe to generate a vacuum (approximately 100 in-H_2O or 7 to 10 in-Hg) inside the tubing while keeping the soil gas probe port closed.
- Close the valve between the syringe or vacuum pump and the rest of the sampling train and monitor vacuum for 1 minute. If vacuum is maintained for the observed period, then the tubing train is deemed adequate and sampling or other testing can begin.
- If vacuum is lost during the observation period, then tubing connections will be tightened or altered until there is no observable loss in vacuum during the test. After the shut-in leak check is validated, the tubing train should not be altered or moved.

4.5 Pneumatic Testing (Optional)

Pneumatic testing is an optional quality control check that may be performed to evaluate if soil permeability is sufficient to allow for active soil gas sample collection without application of excessive vacuum to the subsurface. Pneumatic testing will only be completed if geology observed during probe installation or other information indicates that significantly low permeability soils may be present. The following procedures will be followed if pneumatic testing is performed. Alternatively, if pneumatic testing is not performed, a qualitative assessment of permeability will be used that will include observing the fill rate of the Tedlar® bag during helium testing and purging (i.e., the Tedlar® bag should inflate easily over the entire length of the purge) and observing the flow controller vacuum gauge during sampling (i.e., the vacuum should drop consistently through the length of the sampling period).

- Connect the soil gas probe to a vacuum pump and flow meter.
- Induce a flow of approximately 0.1 liter per minute (L/min) and monitor the vacuum response in the probe for 1 to 5 minutes.
- Increase the flow rate and repeat vacuum observations at 0.2 L/min and 0.5 L/min.
- If a vacuum less than 100 in-H_20 is observed during each of these test runs, then the subsurface is sufficiently permeable to allow for soil gas sampling using the procedures described below.
- If high vacuum or no flow can be generated in the probe, the probe may be blocked or the subsurface may be too tight to allow for effective sampling. The probe may need to be reinstalled or a modified sample collection method may need to be adopted and documented.

4.6 Soil Gas Probe Purge and Helium Shroud Test

Prior to sampling, each soil gas probe will be subject to a helium shroud test to confirm the integrity of the soil gas boring surface seals. Pneumatic testing, purging, and/or helium shroud leak testing may be combined in a single step as needed in the field.

- Probe purging and the helium leak test should be repeated every time a sample is collected from this location.

- Calculate the amount of air to be purged from the soil gas probe by estimating the volume of air within the tubing, well screen, and pore space of the sand pack.
- Multiply the volume by three to calculate the volume of air in a three-volume purge.
- Remove sample probe tubing from the well cover.
- A clear plastic shroud or plastic sheeting will be placed around the sampling port, encompassing intake tubing from the helium meter and discharge tubing from the helium gas canister. The end of the soil gas probe tubing should be directed outside of the shroud and into a lung box equipped with a Tedlar® bag and a vacuum pump.
- The edges of the shroud should be weighed down if necessary to hold it in place.
- The helium meter will be zero-calibrated to the atmosphere below the shroud.
- The helium gas will be turned on and slowly fill the shroud to approximately 10 to 20 percent helium gas content, as measured by the helium meter. The approximate helium gas concentration from within the shroud will be recorded on the sampling form.
- When the shroud has reached 10 to 20 percent helium, apply a vacuum to the lung box to create a flow rate of 0.2 L/min. Fill the Tedlar® bag in the lung box with at minimum the volume calculated above as three purge volumes (fill the Tedlar® bag with at least 1 to 1.5 liters [L]). This step may need to be repeated if the three-purge volume doesn't fit in one Tedlar® bag.
- Record the purging rate and volume on the soil gas sampling field form.
- Remove the helium detector intake tubing from the shroud and allow meter to "zero".
- Screen the Tedlar® bag(s) of collected purge air with the helium meter and record the helium concentration on the sampling form. If the helium is less than or equal to 5 percent of the minimum concentration of helium in the shroud, then the soil gas point passes the helium leak test. If helium in the Tedlar® bag is greater than 5 percent of the minimum concentration of helium in the shroud, then the annular seal of the soil gas point should be inspected/adjusted and the helium leak test repeated until the test is completed successfully.
- Use a PID and a landfill gas meter to also screen the Tedlar® bag(s) for total VOCs and fixed gases (oxygen, carbon dioxide, and methane). Record the readings on the sampling form.
- Repeat the above screening for each Tedlar® bag filled (if more than one).
- When testing is complete, the shroud will be removed from the soil gas location.

4.7 Sampling Procedures

Soil gas samples will be collected following the quality control checks listed below.

1. The canister will be opened to collect a soil gas sample. The valve to open the canister should be opened all the way and then closed ~1/4 turn to prevent any chance of locking while open.
2. Soil gas samples will be collected using certified clean Summa® canisters with flow controllers set at 200 milliliters per minute (mL/min) or less. Additionally, blind duplicate samples may be collected using a t-fitting for quality assurance/quality control purposes.

3. Sample canisters will be closed when gauge reads approximately 5 in-Hg and the canister removed from the sampling train.

4. Before closing the soil gas probe, a differential pressure measurement will be collected using a digital micro-manometer. Readings will be collected for up to 1 to 5 minutes and a minimum and maximum reading will be recorded on the field form.

5. At the completion of sampling, the tubing will be disconnected and the two-way valve on the probe will be set to the closed position.

6. The sample labels/tags (sample name, time/date of sampling, etc.) will be attached to the canister as directed by the laboratory.

7. The canister and other laboratory supplied equipment will be placed in the packaging provided by the laboratory.

8. The chain of custody form will be completed, making sure to include the identification numbers for each canister and flow controller, the start and end times for each canister's sample collection period, and the initial and final canister pressures on the vacuum gauge.

Standard Operating Procedure #18: Equipment Decontamination

Version #1
August 2020

West Lake Landfill Site
Operable Unit 3
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CONTENTS

1. INTRODUCTION

The purpose of this standard operating procedure is to establish guidelines and procedures for decontamination of sampling equipment for Operable Unit 3 at the West Lake Landfill Site in Bridgeton, Missouri. Decontamination of reusable, non-dedicated equipment is essential to maintain chemical integrity between sampling locations.

Non-dedicated sampling equipment used to collect environmental samples will be decontaminated prior to its initial use and between each sample location. If visual signs such as discoloration indicate that decontamination was insufficient, the equipment will again be decontaminated. If this observance persists, the equipment will be removed from service until adequate decontamination can be verified.

Verification of the non-dedicated sampling equipment cleaning procedures will be documented by the collection of field blanks, as described in the Quality Assurance Project Plan.

2. EQUIPMENT AND MATERIALS

- Field forms and the Site Health and Safety Plan (HASP);
- Non-phosphate detergent (Liquinox®, or equivalent);
- Distilled water;
- Spray bottles;
- Paper towels;
- Buckets and/or 55-gallon steel drums for containerizing decontamination fluids;
- High temperature, high pressure steam cleaner (provided by the drilling subcontractor); and
- Plastic sheeting and bags.

3. HEALTH AND SAFETY

Standard operating procedures are designed to provide technical guidance and do not provide detailed or comprehensive guidance related to health and safety, nor do they represent guidance on safe work procedures for the tasks described. Appropriate tips related to health and safety issues associated with specific tasks may be included within technical descriptions for information's sake only.

Health and safety aspects of all projects and project tasks should be assessed and planned using ERM's established health and safety planning procedures.

4. PROCEDURE

4.1 General Procedures

Heavy equipment will be decontaminated in a designated area (i.e., decontamination pad), in an area known or believed to be free of surface contamination. The pad should be constructed on a level, paved surface, and should be lined with plastic sheeting to avoid leaking. Water should be removed from the decontamination pad on a regular basis.

Sampling equipment and probes will be decontaminated in an area covered by plastic sheeting near the sampling location. Fluids generated during the decontamination process will be collected into the decontamination pad or other containment vessel and placed in properly labeled Department of Transportation–approved 55-gallon steel drums. The drums will be staged in a designated and secured area for subsequent transport and disposal to a licensed facility.

Disposable sampling equipment will be properly disposed of in drums. Drilling equipment and drilling rods shall be steam-cleaned and rinse blanked prior to mobilization to the Site. Monitoring well construction materials (casing and screens) shall be delivered to the Site sealed in boxes and stored until the time of well construction.

Extraneous contamination and cross-contamination shall be controlled by wrapping the sampling equipment in polypropylene bags or high-density polyethylene (HDPE) plastic sheeting when not in use and the sampler shall change and appropriately dispose of gloves between sample locations and/or intervals.

Decontamination of sampling equipment shall be kept to a minimum in the field, and wherever possible, dedicated sampling equipment shall be used. Field staff directly involved in equipment decontamination shall wear appropriate personal protective equipment, as outlined in the HASP. Used personal protective equipment will be disposed of in accordance with the Field Sampling Plan.

4.2 Drilling Equipment

Drilling equipment shall be decontaminated by steam-cleaning prior to performance of the first intrusive activity at the Site and between all subsequent borings/well installations. This shall include all hand tools, casings, augers, drill rods and bits, and other related tools and equipment. Tremie pipes mobilized to the Site shall be of new, dedicated construction and thoroughly decontaminated between each location.

Water used during drilling operations shall be from an approved potable source. The drilling subcontractor is responsible for obtaining all permits from the local potable water provider and any other concerned authorities, and provision of any required back-flow prevention devices.

4.3 Solid Matrix Sampling Equipment

Solid matrix sampling equipment, such as hand trowels, will be decontaminated prior to and in between use at each sample locations.

The following procedures will be used for decontamination of non-dedicated soil sampling equipment:

1. Non-phosphate detergent wash (Liquinox®, or equivalent);
2. Distilled water rinse; and
3. Air dry or dry with paper towels.

4.4 Groundwater Sampling Equipment

In general, disposable or dedicated equipment will be used for groundwater monitoring, which minimizes the need for decontamination of groundwater sampling equipment. At a minimum, water level meters will be reused between groundwater sampling locations.

The following procedures will be used for decontamination of non-dedicated groundwater sampling equipment:

1. Non-phosphate detergent wash (Liquinox®, or equivalent);
2. Distilled water rinse; and
3. Air dry or dry with paper towels.

5. REFERENCES

United States Environmental Protection Agency (USEPA). 2020. Field Equipment Cleaning and Decontamination. LSASDPROC-205-R4. Region 4, Laboratory Services and Applied Science Division, June. Available online at: https://www.epa.gov/sites/production/files/2017-07/documents/groundwater_level_and_well_depth_measurement105_af.r3.pdf. Accessed 4 August 2020.

Occupational Safety and Health Administration (OSHA). 2019. Decontamination. Available online at: https://www.osha.gov/SLTC/hazardouswaste/training/decon.html. Accessed 23 October 2019.

Standard Operating Procedure #19: Nuclear Magnetic Resonance Logging

Version #1
November 2020

West Lake Landfill Site
Operable Unit 3
Bridgeton, MO

Prepared for:
U.S. Environmental Protection Agency, Region 7
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CONTENTS

1. INTRODUCTION

- This standard operating procedure (SOP) has been adapted from the manufacturer's SOP to conform with ERM's internal standards and project requirements (Vista Clara, Inc. 2020).
- This document describes the SOP for the field acquisition of Nuclear Magnetic Resonance (NMR) borehole logging data using the Javelin logging system. The Javelin system is manufactured by Vista Clara, Inc.
- This document is not intended as an Operator's Manual or User Guide and assumes that the operator has received adequate prior training in the operation of Javelin hardware and software.

2. EQUIPMENT AND MATERIALS

- Field book;
- Site Health and Safety Plan;
- Hand tools for opening wells;
- Water level gage;
- Laptop with Javelin NMR Logging Acquisition Software installed and set of three .INI files loaded;
- Javelin NMR Logging System including the Javelin instrument, Surface Station, downhole cables and cable winch, tripod and sheave wheel, connection cables, noise reference coil;
- Generator (5,000 watts minimum capacity);
- Decontamination equipment (5 gal bucket, disposable rags, spray bottles, Alconox, DI water); and
- Transportation vehicle with securable cargo area of sufficient capacity for equipment.

3. HEALTH AND SAFETY

SOPs are designed to provide technical guidance and do not provide detailed or comprehensive guidance related to health and safety nor do they represent guidance on safe work procedures for the tasks described. Appropriate tips related to health and safety issues associated with specific tasks may be included within technical descriptions for information's sake only.

Health and safety aspects of all projects and project tasks should be assessed and planned using ERM's established health and safety planning procedures. An NMR-specific JHA is available for inclusion with all site health and safety plans.

4. CALIBRATION

4.1 Scaling Factor

Calibration of the physical measurement of the NMR system is conducted immediately prior to all field campaigns. Fundamentally, an NMR logging probe measures voltage, and the peak voltage of an NMR response in groundwater is linearly related to the volume of water in which the NMR response has been induced. Therefore, the calibration can be done empirically using a single data point by measuring the voltage response of an NMR measurement conducted in a tank of 100 percent water under low noise conditions. Prior to every field campaign, this measurement is performed at the equipment facility, the corresponding scaling factor determined, and the scaling factor stored in a calibration file (see 4.2, Calibration files).

4.2 Calibration Files

A set of three .INI files must be loaded into the acquisition software prior to data collection. The software will not allow data acquisition to begin unless the calibration files are selected. These files are specific to the equipment used. Parameters in these files facilitate proper operation of the instrumentation, and also include the NMR response scaling factor (see 4.1 Scaling factor).

The designated set of .INI files for the project will be loaded in the acquisition software by the equipment operator at the time of each logging session. If more than one set of files is provided for a project, the operator will record which files are used for each acquisition.

4.3 Calibration Validation

The scaling factor for the NMR voltage response will be confirmed after a major field mobilization by conducting an NMR measurement in a tank of 100 percent water under controlled conditions. The system passes if it reports water contents of 100 percent, plus or minus 2 percent. Passing this validation confirms validity of data collected since the previous successful calibration.

4.4 Depth Calibration

Depth information is measured during Javelin logging using a pulse-counting encoder wheel. Calibration (scaling factor) for a given encoder wheel will be verified prior to each field campaign at the equipment facility. This scaling factor is programed into the depth counter built into the Javelin Surface Station. The depth calibration can be validated by passing a fixed length of logging cable through the encoder wheel.

4.5 Site-Specific Calibration

Hydrogeologic properties calculated from the measured NMR response (such as bound and mobile water fractions, specific yield and specific retention, hydraulic conductivity, and transmissivity) rely on numerical constants, for which generic lithology-specific values can be used, or site-specific values can be derived by site-specific calibration. This site-specific hydrogeologic calibration is wholly separate from the instrument calibration described in Section 4.1, and can be refined and adjusted during post-processing (see 7.4, Site calibration).

Default numerical constants and parameters will be used during acquisition of logging data, and site-specific values (if applicable) will be applied during post-processing.

5. PROJECT PLANNING

5.1 Tool Selection

Javelin NMR probes are available in a range of sizes for use in PVC-cased wells, fiberglass wells, and open hole environments. In general, larger-diameter probes provide larger diameters of investigation. Because the NMR measurement volume is a thin-walled cylinder surrounding the probe, it is imperative that this measurement is located beyond any drilling disturbance so measurements are indicative of the native formation. Thus, the largest diameter probe (and largest diameter of investigation) that can be safely run in a given hole environment should always be selected. Details of well construction and completion will be reviewed to confirm that the measurement zone of the selected NMR probe samples the volume of interest.

5.2 Centralization

Tool diameter, bore diameter, casing diameter (if present), and degree of casing centralization (if applicable) will be reviewed. If these conditions could allow the measurement zone of the tool to intersect an undesired volume, and if this risk could be minimized by applying tool centralization, then tool centralization will be utilized. Centralizing materials should be non-magnetic and non-metallic (e.g., plastic).

5.3 Metal Casing

NMR measurements are not possible through metal casing. Further, operating the tool at full power (as during data acquisition) while the sensitive zone of the probe is within metal casing has the potential to damage the probe.

Well completion information will be reviewed for the presence of metal casing, metal surface casing, metal screen, or metal centralizers. In some cases, wells partially completed with metal casing (such as metal surface casing or isolated sections of metal screen in otherwise PVC-cased wells) can still be logged with NMR, but care must be taken to avoid data collection in the vicinity of the metal-cased sections.

In some configurations of metal surface casing, the permanent magnets in the probe may make it difficult to advance the probe past these sections. In such cases, tools such as standoffs, centralizers, and push rods should be used

5.4 Stepped Vs. Continuous Logging

The operator may choose to acquire data in a stepped or continuous mode. In stepped mode, the NMR probe is held stationary at a fixed depth during each measurement. In between measurements, the winch is used to raise (or lower) the probe to a new depth. In continuous mode, the winch continuously raises (or lowers) the probe at a controlled rate (see 5.5, Acquisition sequence and logging rate) while data are acquired. It is typically suggested that the user logs in continuous mode, but high-quality data can also be obtained in stepped mode.

5.5 Acquisition Sequence and Logging Rate

One of the .INI calibration files contains acquisition sequence parameters, specifying the timing with which NMR CPMG data are acquired. This acquisition sequence will be configured by an NMR logging expert prior to the field campaign, with consideration for the lithology, characterization objectives, and required production rates. The acquisition sequence will determine the rate at which data files are written, and this rate will be displayed in the Javelin software. The operator will maintain a logging speed slow enough that a complete file is written during the time the probe traverses the nominal vertical resolution. As an example, for a probe with a nominal vertical resolution of 0.5m, if the acquisition sequence produces a file every 1 minute, the logging speed should be less than or equal to 30m/hr.

6. FIELD PROCEDURES

6.1 Safety Requirements

- Operator will adhere to all safety requirements and regulations of the jobsite and those of working partners.
- Operator will inform all persons present during logging of the safety considerations of the Javelin system, including but not limited to: high voltages, strong permanent magnets, tripping and lifting hazards, and winch pinch points.

- Only trained operators will operate any component of the Javelin NMR logging system.

6.2 Field Records

Operator will maintain a paper record for each log, detailing:

1. Date, start time, and stop time
2. Well name
3. Stick-up height of casing, if applicable
4. Zero-reference used
5. File name(s) of digital logging data
6. File/folder name of calibration .INI files
7. Any notes, pertinent observations, or anomalies encountered while logging

6.3 Electrical Connections

- All power and data connections will be made with the designated cables according to manufacturer specifications.
- Power cables and connectors will be rated to the required voltages and currents.
- All cables and connectors will be inspected for damage during setup; logging will only commence with undamaged cables.
- All cables will be arranged at work site to minimize tripping hazards and potential for damage to cables. Care should be taken to avoid overlap of power cables with the data logging cables that are connected through the winch to the probe, as this can generate measurement noise.
- O-rings will be inspected where applicable.

6.4 Equipment Use

- All electrical connections will be made and verified before powering on equipment (see 6.3, Electrical connections).
- All equipment will be operated in accordance within manufacturer's guidelines of intended use.

6.5 Generator

- The generator will be powered on only after all electrical connections are made.
- The generator will have sufficient rated capacity (typically >5000W).
- The generator will not incorporate an inverter, which can introduce measurement noise.

6.6 Depth Reference

- For data acquisition, depth references will be made relative to the top of the NMR probe, at the base of the cable head connector (see "Javelin Manual and Documentation"). This reference point will be visually aligned with a chosen zero reference on the wellhead (typically top of casing). The zero reference chosen will be recorded in the field documentation.

- With the probe reference and zero depth reference aligned, the depth counter will be reset by the operator to read 0.0.
- After the zero reference has been set, the winch must only be run when the surface station is powered on and depth counter cable connected. If the surface station is powered off for any reason, care must be taken to leave the winch position stationary until power is restored.
- When the probe is returned to the surface, any offset in the zero reference will be recorded: the zero reference on the probe will be aligned with the zero reference of the wellhead, and the corresponding reading on the depth counter recorded in the written field record. If there is no offset, this will be noted in the field record. Any depth offset, if present, will be noted in all final data products as an assumed minimum depth uncertainty.

6.7 Winch Operation

- Operator will visually observe winch at all times whenever winch is running to confirm safe operating conditions.
- Operator will maintain winch controls within arm's reach whenever winch is running.
- Operator will be familiar with emergency shutoff procedures for winch.
- Operator will confirm that cable wrapping on drum is orderly and compact and will not damage cable.

6.8 QA/QC

- During logging, operator will monitor data quality using the "Javelin Pro Plus" software. The critical parameter for real-time acceptance of field data is the noise level (reported in the "QC" workspace). Noise levels should be below 15 percent on all frequencies to meet the nominal criteria for acceptable field data. Noise levels are reported on a per-depth basis, and sustained noise levels above 15 percent on any frequency over a continuous depth range of 4 meters or more should be addressed by halting logging and applying noise mitigation steps. These mitigation steps may include deploying (or relocating) a surface reference coil, applying (or changing) station grounding, turning off nearby pumps or electronics (if applicable), increasing the distance between the logging vehicle and the wellhead, or increasing the number of stacks collected during acquisition.
- In some situations, logging may continue even in the presence of sustained high noise levels. These include:
    - Elevated noise levels near the surface. It is not uncommon for noise levels to increase near the ground surface, often in the uppermost 10 meters. If these depths are not of critical project importance, then logging can continue in the presence of high noise levels. If customer or customer's representative is present for or involved in logging operations, operator will inform them of this condition.
    - Elevated noise levels on specific frequencies. In some environmental conditions, elevated noise may be present on specific frequencies in spite of mitigation efforts. An advantage of the Javelin system's multi-frequency logging is that as long as noise levels are acceptable on one or more frequencies, usable field data will be obtained from the unaffected frequencies. In such a situation, the operator will first attempt appropriate noise mitigation techniques (subject to project time constraints). If the operator determines that certain frequencies will not provide acceptable noise levels, then as long as one or more frequencies will provide acceptable noise levels,

logging will proceed. Delivered data products will include information about what frequencies were used to generate final logs (see 7.2, Multi-frequency data).

7. POST-PROCESSING

7.1 QA/QC Criteria

The Javelin Pro Plus processing software presents a number of quality assessment metrics. Logs are reviewed using these metrics to verify proper operation of system and to assess the presence of drilling disturbance in the data.

1. The measurement frequency should show variance of less than 2 percent throughout any log file. If the measurement frequency is observed to exceed 2 percent variance throughout the log file, this anomaly should be noted and may reflect the presence of metal centralizers or other metallic objects or debris in the well.

2. Noise levels of post-processed data should be less than 10 percent after combination of frequencies. Zones in which noise levels exceed 10 percent will be noted and zones with noise levels greater than 20 percent should be flagged as likely unreliable.

3. The influence of drilling disturbance will be assessed by comparing data acquired on multiple frequencies. Drilling disturbance is evidenced by large differences in mobile water content observed using different frequencies at the same depth (e.g., 25-50 percent differences in water content). Zones that may exhibit sensitivity to drilling disturbance will be noted. If drilling disturbance influences a significant portion of the log, a processed result should be delivered using only the outer-most frequency.

7.2 Multi-Frequency Data

Logging data from each operational frequency of the NMR system contains information from an investigation zone of a different diameter. Data records from the different frequencies are preserved independently in the raw data. This allows radial variability in the NMR response to be assessed. In some cases, the effects of drilling disturbance may be observed in the innermost shell(s), in which case these shell(s) can be discarded from the final processed logs.

If all measurement shells are acceptable, the NMR signals from all frequencies are typically merged, increasing the signal-to-noise ratio of the data and thereby the confidence in the final result.

7.3 Deliverables

Vista Clara's proprietary processing and analysis software for Javelin NMR data (Javelin Pro Plus) provides 1D depth logs of the following estimated parameters:

1. Total water content

2. Clay-bound water content

3. Capillary-bound water content

4. Mobile water content

5. Hydraulic Permeability (K) and Transmissivity[1] (T) using the following petrophysical models:
   a. Schlumberger-Doll Research (SDR)
   b. Sum-of-Echoes (SOE)
   c. Timur-Coates (TC)
6. The logarithmic mean of the T2 distribution, MLT2
7. Noise level

Also provided are 2D depth records of spin echo decay and T2 distribution.

Logs are provided (or available) in the following formats:

1. ASCII text
2. LAS 2.0
3. LAS 3.0
4. PNG image
5. PDF image

7.3.1 Written Reports

Written final reports prepared by Vista Clara's scientific staff are provided only if quoted in project proposal. Such reports are scoped and quoted based on customer requirements.

7.4 Site Calibration

Site-specific numerical constants for the calculation of T2 cutoff times, bound/mobile water fractions, specific yield and specific retention, hydraulic conductivity, and transmissivity can be determined given complementary data from sources such as pump tests, packer tests, or slug tests. If provided with such data, Vista Clara's scientific staff can provide this site-specific calibration (at consulting rates). Vista Clara can also provide calibration using NMR analysis of core samples (at consulting rates).

[1] Note: estimates of transmissivity are calculated assuming an interval from the uppermost measurement depth in the well to the specified measurement depth.

8. REFERENCES

Vista Clara, Inc. 2020. *Standard Operating Procedure Javelin NMR Logging.* Revision 1. Vista Clara, Inc. September 2020.

Standard Operating Procedure #20: Sub-Slab Soil Gas Probe Installation and Sampling

Version #1
November 2020

West Lake Landfill Site
Operable Unit 3
Bridgeton, MO

Prepared for:
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CONTENTS

1. INTRODUCTION

This Standard Operating Procedure (SOP) details the procedures to be used to install and collect sub-slab soil gas samples as part of a vapor intrusion (VI) assessment. The approach detailed here is based on relevant guidance documents and is intended to enable field staff to install a sub-slab soil gas monitoring point suitable for the collection of sub-slab soil gas samples in a competent and reproducible manner.

If operating procedures are not able to be implemented in their entirety due to field specific circumstances, deviations and significant modifications to the procedures should be noted by the field team and discussed with the project team.

2. EQUIPMENT AND MATERIALS

- Site map with the sample locations
- A copy of the Health and Safety Plan and a copy of the Quality Assurance Project Plan (QAPP)
- Hammer drill and bits (5/8 inch and 1-1/2 inches)
- Shop vacuum
- Pipe brush
- Stainless steel Vapor Pin® sampling port with silicon sleeve
- Plastic caps
- Threaded secure stainless steel cover
- Dead blow hammer
- SUMMA® canisters
- Leak test kit with gas-tight syringe
- Water dam
- VOC-free clay (plumbers putty or similar)
- Water
- Paper towels
- Sample labels/tags
- Adjustable wrench
- Pre-calibrated flow controller equipped with an in-line particulate filter and a vacuum gauge
- Calibrated photoionization detector (PID)
- Calibrated landfill gas meter (e.g., Landtec GEM2000)

- Chain-of-custody form
- Sampling field form
- Field notebook
- Shipping packaging supplied by the laboratory

3. HEALTH AND SAFETY

SOPs are designed to provide technical guidance and do not provide detailed or comprehensive guidance related to health and safety, nor do they represent guidance on safe work procedures for the tasks described. Appropriate tips related to health and safety issues associated with specific tasks may be included within technical descriptions for information's sake only.

Health and safety aspects of all projects and project tasks should be assessed and planned using ERM's established health and safety planning procedures.

4. PROCEDURES

4.1 Preparation Procedures

- Field staff will avoid activities immediately before and during the sampling that may contaminate the sample (using markers, fueling vehicles, etc.).
- Weather information (temperature, barometric pressure, relative humidity, wind speed, and wind direction) and approximate indoor temperature will be recorded at the beginning of the sampling event. Field personnel will record substantial changes to these conditions that may have occurred 24 to 48 hours prior to, and during the course of sampling. Record on sampling field form.

4.2 Installation Procedures

- Before installation begins, utility clearance must be completed as described in the SOP for Subsurface Clearance (SOP #04, Appendix A of the Field Sampling Plan).
- A pilot 1.5-inch-diameter hole will be drilled to a depth of approximately 1.75 inches deep into the concrete slab using an electric hammer drill. This method will countersink the sub-slab sampling probe to be flush with the concrete surface. If the point is temporary and will be removed immediately after sampling, drilling the 1.5-inch pilot hole can be eliminated.
- A 5/8-inch-diameter hole will be drilled in the center of the pilot hole, through the remaining thickness of the slab and approximately 1 inch into the sub-slab material to form a void.
- The drill be will be removed, the hole will be brushed with a pipe brush, and the loose cuttings will be removed with a shop vacuum.
- A Vapor Pin® with a silicone sleeve will be placed over the hole and tapped into place using a dead blow hammer (the silicone sleeve should form a water and airtight seal with the concrete).
- Sub-slab sampling points will be left in place for at least 2 hours to allow for re-equilibration with the surrounding soil prior to soil gas sampling.
- See Figures 1, 2 and 3 for photos of sub-slab soil gas probes.

4.3 Purging and Leak Testing

Two leak test will be completed on each sub-slab sampling probe. The water dam seal leak test should be completed following probe installation and then prior to each sampling event. The shut-in leak test should be performed on each probe prior to each sampling event. Additional information on the water dam SOP can be found from the Vapor Pin® manufacturer included in Appendix C.

- The sample probe seal will be leak tested using the water dam method. A water dam (e.g., 2-inch PVC coupling) will be placed around the sample port, and sealed to the floor using VOC-free clay or similar material. The 1.5-in countersunk hole may also be used as the water dam. A section of 3/8-inch tubing will be attached to the sample port to prevent water leakage into the port.
- Potable water will be poured inside the water dam.
- The water dam will be observed for a period of approximately 2 minutes. If the water level appears to change, or significant bubbling is observed, the leak test will be not be passed, and the Vapor Pin® will be reinstalled as per the methods above. If the water level does not change, the leak test will be considered successful.
- Concrete may absorb some water however if there is a sudden water drop that will be indicative of a leak.
- If a leak is observed the point may need to be removed and replace or the hole may need to be redrilled in another locations.
- The water dam should be left in place or should be reassembled for probe purging and sample collection.
- For leak testing immediately before purging and sampling, set up the water dam as detailed above as well as the sampling train tubing and SUMMA® canister (see Figures 4 and 5 for example set-ups [note Figure 4 is missing the water dam]).
- Remove the protective brass plug from the canister intake and attach the pre-calibrated flow controller to the canister intake. Tubing will be connected from the flow controller intake to the sub-slab sampling probe two-way valve.
- Confirm valve at the top of the soil gas probe is closed.
- Use a vacuum pump or plastic syringe to generate a vacuum (approximately 100 in-H2O or 7-10 inHg) inside the tubing while keeping the soil gas probe port closed.
- Close the valve between the syringe or vacuum pump and the rest of the sampling train and monitor vacuum for 1 minute. If vacuum is maintained for the observed period, then the tubing train is deemed adequate and sampling or other testing can begin.
- If vacuum is lost during the observation period, then tubing connections will be tightened or altered until there is no observable loss in vacuum during the test. After the shut-in leak check is validated, the tubing train should not be altered or moved.
- Following the shut-in test the sub-slab sampling port will be purged using the syringe or vacuum pump. A three-volume purge will be completed calculated based on the diameter of the concrete hole and thickness of the concrete plus length of above-ground tubing (typically 0.5L or less). Purging will also remove the “dead” air within the tubing prior to sampling.

- A minimum of three purge volumes will be removed, collected in the tedlar bag and discharged outside.

- The permeability of the subsurface materials will also be qualitatively assessed during the probe purge. If there is resistance or difficulty pulling back on the syringe plunger during the purge, the sample probe may be blocked or set in tight subsurface materials and may need to be adjusted.

- The water in the water dam should also be observed during the purge. If the water level in the dam drops suddenly the probe seal is leaking and will need to be replaced.

- A typical sampling train set-up is shown in Figure 5.

4.4 Sampling Procedures

- An evacuated SUMMA® canister will be used to collect the sub-slab soil gas sample. The canister will be certified clean and provided by the laboratory, along with a certified clean flow controller equipped with an in-line particulate filter and a vacuum gauge. The flow controller will be pre-calibrated by the laboratory for the desired flow rate (typically less than 200 ml/min).

- After adequately purging the sampling train, access to the plastic syringe or vacuum pump will be closed and the SUMMA® canister will be opened. Once the sampling canister is opened, sampling personnel will check and record the initial vacuum in each canister at the start of each sample. Initial pressure on the SUMMA® canister should be within approximately 10 percent of the original pressure (typically -30 to -27 in Hg).

- Sample collection time will be based on the size of the sampling canister and the typical 200 ml/min flowrate (i.e., between 5 min for a 1L canister and 30 min for a 6L canister). For larger sampling canisters (i.e. 6L) the remaining canister vacuum and time may be checked and recorded periodically during sample duration.

- Sampling will be stopped when the canister still has approximately 5 in Hg remaining.

- The final vacuum level and time will be recorded on the field form after the canister valve has been closed.

- The flow controller from the canister will be removed and the protective brass plug replaced onto the canister intake.

- Sub-slab sampling ports will be capped and left in place with a Vapor Pin® metal flush-mounted cover until the investigation is complete. However, if the property owner requests that ports be removed, they will be pulled and the hole will be sealed with hydraulic cement or caulk.

- The sample labels/tags (sample name, time/date of sampling, etc.) will be attached to the canister as directed by the laboratory.

- The canister and other laboratory supplied equipment will be placed in the packaging provided by the laboratory.

- The chain-of-custody form will be completed, making sure to include the identification numbers for each canister and flow controller, the start and end times for each canister's sample collection period, and the initial and final canister vacuum reading from the vacuum gauge.

- The sample canisters will be submitted to the laboratory under chain-of-custody.

Figure 1: Two-staged sub-slab drilling for the installation of the Vapor Pin®

Figure 2: Final sub-slab installation appearance of the Vapor Pin®

Figure 3: Protective flush mounted cover over the Vapor Pin®

Source: Alpha Analytical Laboratories

Figure 4: Example 1 Vacuum leak check and sampling configuration (typ)

Source: Cox Colvin & Associates, Inc.

Figure 5: Example 2 Water dam, vacuum leak check and sampling configuration (typ)

APPENDIX B FIELD FORMS

GROUNDWATER FORMS

FLUID LEVEL GAUGING FORM

Page ___ of ___

Project Name: ______________________________ Personnel: ______________________________

Equipment Info (water level meter model, serial number): ______________________________

Well ID	Date	Time	Depth to Water (feet below measuring point)	Measuring Point	Total Depth	Notes

WELL INSPECTION FORM

Page ___ of ___

Project Name: ______________________ Personnel: ______________________ Equipment Info (water level meter model, serial number): ______________________

Date: ______________________ Weather: ______________________

Well ID	Depth to Water (feet below measuring point)	Measuring Point	Total Depth (feet below measuring point)	Label Present?	Padlock Present?	Well Lid Present?	Bolts/Threads Present?	Gasket Present?	Expansion Plug Present?	Inner Casing Condition	Outer Casing Condition	Concrete Pad Condition	Bollard Condition	Notes (repairs needed, equipment in well, accessibility issues?)
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	
				Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Good / Poor	Good / Poor	Good / Poor	Good / Poor	

GROUNDWATER SAMPLING LOG

Project Name:		Date:		Equipment Info (model, serial number, etc)	
Well ID:		Weather:		Water Level Meter:	
Sampler Name:		Sampling Method:	Low-Flow Positive Displacement (for multi-level locations)	Pump Type:	
Total Depth:			Grab (recharge after pumping dry) Other (explain)	Water Quality Meter:	
Initial Depth to Water:		Purge Start Time:		Other Equipment:	
Measuring Point (MP):	Top of Casing Other (explain)	Purge End Time:		Tubing Type:	
Well Diameter:		Total Volume Purged:			
Pump Intake Depth:		Filter(s) Used:		Other Notes or	
Minimum Volume to Be Removed (for CHS):		QA/QC Sample?		Observations:	
Well Condition:		QA/QC ID			

Time	Depth to Water (ft below MP)	Flow Rate (mL/min)	Water Quality Parameters Temp. (°C) +/- 3%	D.O. (mg/L) +/- 10% (if >0.5 mg/L)*	Sp. Cond. (µS/cm) +/- 3%	pH (standard units) +/- 0.1 su	ORP (mV) +/- 10 mV	Turbidity (FNU) +/- 10% (if >10 FNU)*	Notes

Notes:

If collecting samples using low flow method, flow rate should be adjusted to maintain minimal drawdown (no more than 0.3 feet), and water quality parameters will be recorded at a frequency that allows the flow cell to turn over at least once between measurements (generally every 3-5 minutes).

Stabilization criteria based on three most recent consecutive measurements. If D.O. is <0.50 mg/L for 3 consecutive readings or if turbidity is <10 FNU for 3 consecutive readings, consider those parameters stable.

No stabilization criteria are given for samples collected using grab method (recharge after pumping dry), or positive displacement method at multi-level locations. Depth to water is not measured when sampling using the positive displacement method.

Samples Collected:

Analytical Method	Number and Type of Bottles	Preservative	Field Filtered?	Lab

DRILLING FORMS

Subsurface Clearance Project Plan

Site/Project Name: ______________________

Client: ______________________

ERM Project No.: ______________________

This Subsurface Clearance (SSC) Project Plan must be completed for each phase of ground disturbance activities at a project location. A copy of this document must be maintained at the project location for the duration of ground disturbance activities. The ERM Partner-in-Charge (PIC) and SSC Experienced Person (EP) or field team lead must review and approve the completed SSC Project Plan **prior to any point disturbance clearance or ground disturbance activities** (all approvals appear on final page of this document).

Administrative Information	Date Plan Started: Date Plan Completed:	Field Work Start Date: Field Work End Date:
	Project Manager:	Partner In Charge:
	SSC EP [1] / Field Team Lead:	Local MP or designee (for any waivers):
	List any additional SSC General Employees (GEs) working on this project:	
	Describe the Scope of Ground Disturbance Activities:	*Check all that apply:* ☐ Point disturbances (manual / hand digging only) ☐ Point disturbances (using mechanized equipment) ☐ Excavation / trenching / grading ☐ Removal / coring / drilling of concrete, asphalt, etc. ☐ Other - Describe:

Project Information Summary	Yes	No	N/A	Comments
Knowledgeable Contact Person(s) identified, and presence requested during site walk. SSC Project Plan reviewed with knowledgeable contact person(s)	☐	☐	☐	Who:
As-built drawings, site plans, maps, aerial photographs, and other information sources available and reviewed	☐	☐	☐	List (including dates):
Other information obtained (e.g., easements, right-of-ways, historical plot plans, current/historical aerial photographs, fire insurance plans, tank (dip) charts, SSC information obtained as part of previous site investigations, soil surveys, boring logs	☐	☐	☐	List (including dates):
All subcontractors (including ground disturbance, private utility locating, concrete coring, etc.) prequalified and approved	☐	☐	☐	List Private Utility Locate Subcontractor(s):
Specific SSC scope of work items in all work orders for subcontractors involved in SSC and ground disturbance activities (i.e. point disturbance clearance methods and required tools, field documentation and utility markout methods for private utility locate subcontractors, etc.)	☐	☐	☐	List all Ground Disturbance Subcontractors:
Additional client and/or regulatory requirements apply to the project and have been incorporated into H&S plan documents	☐	☐	☐	If yes, specify:
ERM / client / regulatory SSC requirements have been communicated to all field personnel including subcontractors (refer to SSC Review Checklist for Subcontractors - *ERM-1511-FM5*)	☐	☐	☐	
Current and valid SSC training certifications confirmed for all ERM staff (including PIC and PM)	☐	☐	☐	
Current and valid additional training certifications (e.g., detection equipment operation) confirmed for all ERM staff and subcontractor personnel	☐	☐	☐	List additional trainings:
UXO/MEC risks assessed: UXO/MEC is present or potentially present	☐	☐	☐	If Yes, stop work and contact PIC
Project location meets criteria for Remote/Greenfield Site	☐	☐	☐	If Yes, project teams can elect to complete the SSC Project Plan for Remote/Greenfield Sites (ERM-1511-FM2) instead of this form

[1] SSC EP not required for Remote / Greenfield sites, as defined in the ERM Global SSC Procedure (ERM-1511-PR1).

Subsurface Clearance Project Plan

Site Walk					
Identified Visual Clue	**Yes**	**No**	**Identified Visual Clue**	**Yes**	**No**
Lights			Pipeline markers		
Signage			Fire hydrants		
Sewer drains / cleanouts / drop inlets			Sprinkler systems		
Cable markers			Water meters		
Utility poles with conduit leading to the ground			Natural gas meters		
Utility boxes			UST fill ports and vent pipes		
Manholes			Equipment locations		
Pavement scarring			Steam lines		
Distressed vegetation or vegetation in linear pattern			Remote buildings with no visible utilities		
Overhead utility lines			Other (specify):		
Solar panels / wind power generation			Other (specify):		

Comments:

	Yes	No	N/A	Comments
Visual clues / site features (below) integrated into Site Services Model				

Utility Markouts	Yes	No	N/A	Comments
Public Utility Locates completed (where available)?				
Responses received from ALL companies notified?				

List utilities notified:

	Yes	No	N/A	Comments
Private Utility Locates completed [2] (waiver required if "NO")				
Utilities clearly marked with agreed method?				
Private locate findings documented?				

Private Utility Locate Performed by:

Date of most recent training on equipment operation:

Type of equipment / methods used:

Date of most recent calibration of detection equipment:

Note any limitations (e.g., sources of interference, geology, etc.):

[2] Not required for Remote / Greenfield sites, except where required by local regulations or client procedures.

Subsurface Clearance Project Plan

Site Services Model Attach a site plan or drawing (to scale) showing planned ground disturbance location(s), the locations / routes of all identified or suspected subsurface and above-ground utilities and structures, and associated critical zones and excavation buffers.								
	Present?			Anticipated depth (note units)	Located?		Status (active, inactive, abandoned / decommissioned, etc.)	Comments (For each, describe how the utility or structure was located – such as as-built drawings, private locate, public locate, visual clues, etc. – and quality of information available)
Utility / Structure	Yes	No	Un-known		Yes	No		
Electricity	☐	☐	☐		☐	☐		
Gas	☐	☐	☐		☐	☐		
Petroleum Pipeline	☐	☐	☐		☐	☐		
Other Pressurized Lines	☐	☐	☐		☐	☐		
Process Sewer	☐	☐	☐		☐	☐		
Sanitary Sewer	☐	☐	☐		☐	☐		
Storm Sewer	☐	☐	☐		☐	☐		
Potable Water	☐	☐	☐		☐	☐		
Telephone / Communication	☐	☐	☐		☐	☐		
Fiber Optic	☐	☐	☐		☐	☐		
Plant air / steam	☐	☐	☐		☐	☐		
Fuel / oil	☐	☐	☐		☐	☐		
Reclaimed / waste water	☐	☐	☐		☐	☐		
Fire suppression	☐	☐	☐		☐	☐		
Underground tank(s)	☐	☐	☐		☐	☐		
Other (Describe):	☐	☐	☐		☐	☐		

Additional Notes on Site Services Model including identification of any data gaps:

Contact Person(s) Approval of Ground Disturbance at All Locations			
Name (Print)	Company	Name (Sign)	Date / Time

Final Critical Zone Determination				
Are there any ground disturbance locations <u>known</u> or <u>suspected</u> to be inside Critical Zones?	☐ **YES**	PIC and Local MP (or designee) must BOTH grant waiver for work within the Critical Zone. A sketch map must be developed for EACH ground disturbance location inside a Critical Zone (refer to template on last page)	☐ **NO**	

Subsurface Clearance Project Plan

Overhead Clearance	Yes	No	N/A	Comments
Overhead utility lines in the general vicinity of ERM work onsite?	☐	☐	☐	If NO, check N/A for remaining items in this section
If overhead utilities are present, has nominal voltage been determined? If yes, list in comments section.	☐	☐	☐	Voltage:
Overhead clearances confirmed with equipment operators for safely deploying equipment to the location?	☐	☐	☐	Clearance distance(s):
Proximity alarms, spotters, and /or warning signage necessary to ensure safe clearances?	☐	☐	☐	
If the equipment is closer than the minimum clearance distance to the overhead utility, can utility be de-energized?	☐	☐	☐	
If utility cannot be de-energized, alternate plan developed with approval from the PIC and client/site owner?	☐	☐	☐	

Plan for point disturbance clearance at location(s): ______________________________ *(Note that this plan must be reviewed and approved by the PIC before any clearance activities commence)*	*Attach additional sheets to completely describe clearance method, tools and depth if these will vary during the process from location to location.*			
	Yes	**No**	**N/A**	**Comments**
Clearance technique to be used (indicate which method): ☐ Compressed air excavation *(ERM preferred method)* ☐ Pressurized water excavation ☐ Hand digging ☐ Hand augering ☐ Soil probe rod *Pick axes, pointed spades, or any other tool that comes to a point are NOT to be used for point disturbance clearance.* *Note: a waiver is required if no clearance will be performed prior to use of mechanized equipment*	☐	☐	☐	Provide rationale if NOT using preferred method of compressed air excavation: ☐ Scope of work limited to hand digging only ☐ Equipment not available ☐ Cannot meet technical objectives (e.g., vapor pins) ☐ Other (describe):
For locations that will be advanced with mechanized equipment (e.g., drill rig or direct-push) after initial clearance: Diameter of clearance must be to LARGER OF: 4 inches (10 cm), or at least 125% of the diameter of largest downhole tool to be used	☐	☐	☐	Specify diameter (include units) of largest downhole tool: Specify diameter (include units) to be cleared:
For locations that will be advanced with mechanized equipment (e.g., drill rig or direct-push) after initial clearance: Depth of clearance: ☐ Outside Critical Zones, to 5 feet (1.5 meters). ☐ Inside Critical Zones, to 8 feet (2.4 meters) at a minimum, and deeper if necessary to clear to depths greater than 8 feet for deeper utilities and structures ☐ For locations with frozen soils, to 2 feet (0.6 meters) beyond the bottom of the frost line at the site.	☐	☐	☐	Specify depth(s) and units:
Concrete coring / cutting – personnel performing these activities have been verified as trained and competent?	☐	☐	☐	Describe risk mitigation techniques to be employed:

Excavation Plan *(Note that this plan must be reviewed and approved by the PIC before any disturbance activities commence)*	Yes	No	N/A	Comments
Communicate excavation plan and 2-foot (0.6-meter) Excavation Buffer location(s) to subcontractor(s). Delineate all Excavation Buffers.	☐	☐	☐	
If possible, work with contact person / site owner to de-energize subsurface services prior to beginning excavation	☐	☐	☐	
Risk mitigation measures reviewed and acceptable?	☐	☐	☐	Describe:

Subsurface Clearance Project Plan

Approvals			
Review Meeting The SSC Project Plan must be reviewed with the PIC BEFORE any point disturbance clearance or ground disturbance activities occur. This review must be completed through a verbal conversation, whether in person or by phone or video conference. Documentation of review can be indicated as "verbal" or be received via e-mail initially, but must be followed up with signatures in the final SSC Project Plan.			
Reviewed by	**Signature**	**Date of Review**	**Comments**
SSC EP or Field Team Lead (required review):			
PIC (required review):			
Project Manager (optional review):			

Waiver Approvals
Two separate Partners are required to approve waivers. Both Partners must be SSC-certified (either GE or EP)

SSC Component Being Waived:	Waived By (PIC)	Waived by (Local MP)	Date	Rationale
Requirement for direct ERM supervision of ground disturbance activities: • SSC EP to oversee execution of the SSC Process (can include the entire project or specific SSC-related tasks), or • Direct oversight of subcontractors for Remote/Greenfield sites or shallow hand digging no deeper than 1.5 feet / 0.5 m)				Specify scope of waiver:
Performance of private utility markouts				
Clearance of point disturbance locations prior to advancing with mechanized equipment (including no clearance or partial clearance)				Indicate specific locations and scope of waiver:
Prohibition of ground disturbance inside a Critical Zone				Indicate specific locations:

SSC Project Plan Close-out (SSC EP or Field Team Lead)

Name (Print)	Name (Sign)	Date / Time

Additional Notes or Learnings

Subsurface Clearance
Project Plan – Critical Zone Sketch Map

Site/Project Name: ____________________

Client: ____________________

ERM Project No.: ____________________

SSC EP / Field Team Lead: ____________________

A sketch map must be developed for each ground disturbance location inside a Critical Zone (one map per location – attach additional maps as needed). Disturbance within a Critical Zone can only proceed with both PIC and Local MP (or designee) approval.

GROUND DISTURBANCE LOCATION ID:

GROUND DISTURBANCE LOCATION DESCRIPTION:

Instructions:

1. Create a sketch of the disturbance (in the space to left or attach) that is drawn to scale and contains the following information:
   a. The disturbance location
   b. Surface landmarks and overhead obstructions (buildings, roads, overhead lines, etc.)
   c. Subsurface utilities and structures that are:
      i. Identified in the Site Service Model
      ii. Marked by public and private utility locators
      iii. Communicated by knowledgeable contact person(s)
   d. Any surface visual clues as to potential underground services (junction boxes, drains, disturbed concrete, signage, etc.)
2. Use your sketch to mark Critical Zones (3m / 10 feet) around underground utilities and structures.
3. For excavations, use your sketch to mark Excavation Buffers (0.6m or 2 feet) from subsurface utilities and structures.

DRILLING LOG

Location:

Project Name: ____________________
Project Number: ____________________
Client: ____________________
Start Date & Time: ____________________
End Date & Time: ____________________
Weather:

Logged By: ____________________
Contractor: ____________________
Driller: ____________________
Drilling Method: ____________________
Boring Diameter: ____________________
Boring Depth:

PID Model: ____________________
PID Serial Number: ____________________
Notes, observations: ____________________

ERM

DEPTH (FT)	RUN			LITHO DEPTH (FT)		DESCRIPTION										PID (ppb)	LAB SAMPLE COLLECTION
	TOP (FT)	BOT (FT)	REC (IN)	TOP	BOT	COLOR	PRIMARY GRAIN	CONNECTOR	SECONDARY GRAIN	SORTING	QUALIFIER	DIAMETER	STRENGTH/ PLASTICITY	MOISTURE/ MOTTLING	OTHER		

ROCK CORING LOG
Location:

Project Name: ____________
Project Number: ____________
Client: ____________
Start Date & Time: ____________
End Date & Time: ____________
Weather:

Logged By: ____________
Contractor: ____________
Driller: ____________
Drilling Method: ____________
Boring Diameter: ____________
Boring Depth:

PID Model: ____________
PID Serial Number: ____________
Notes, observations: ____________

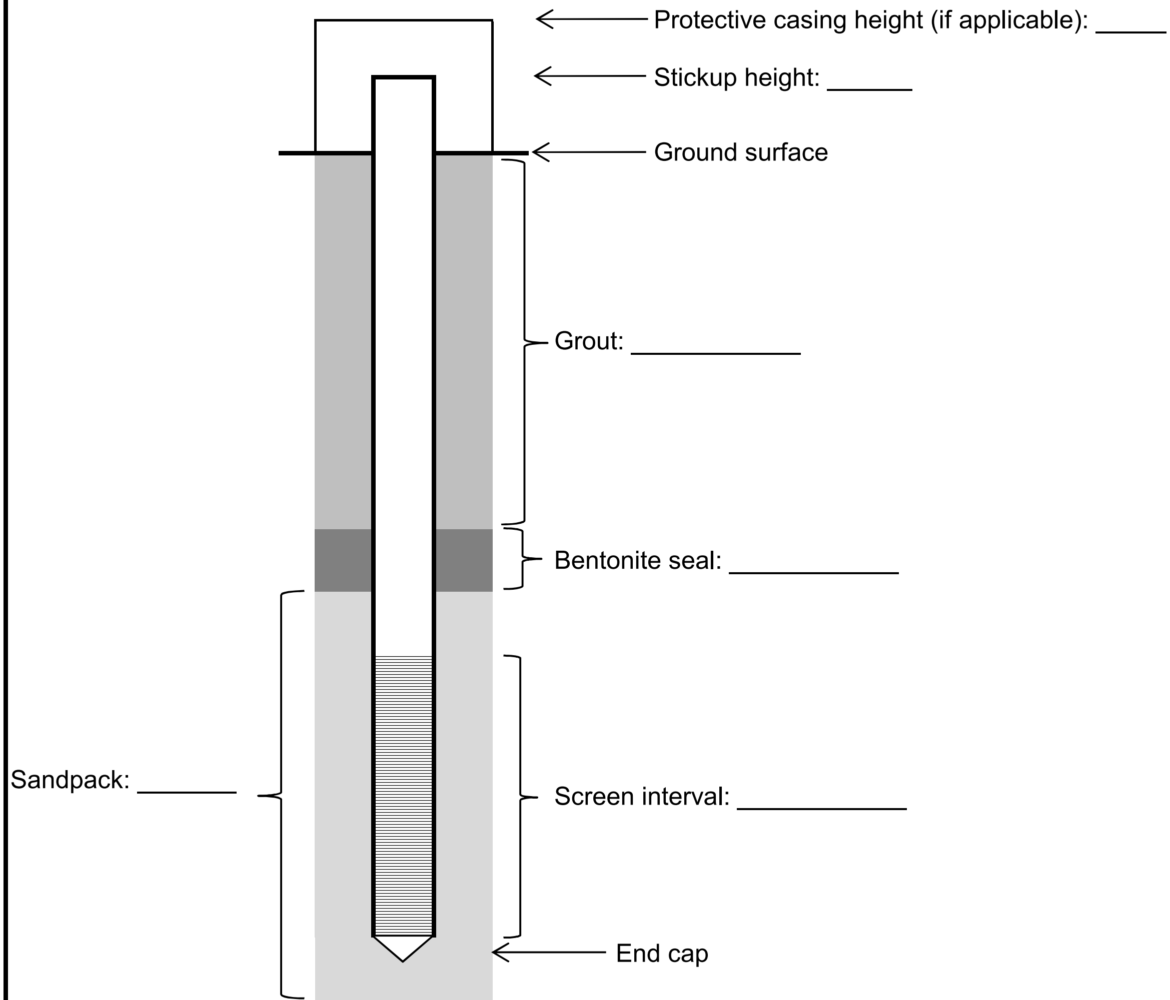
ERM

DEPTH (FT)	RUN			LITHO DEPTH (FT)		DESCRIPTION										PID (ppb)	LAB SAMPLE COLLECTION
	TOP (FT)	BOT (FT)	REC (IN)	TOP	BOT	COLOR	PRIMARY	RQD DESCR.	FIELD STRENGTH	TEXTURE	STRUCTURE TYPE	STRUCTURE ANGLE	DECOMPOSITION	DISINTEGRATION	FRACTURES		

MONITORING WELL CONSTRUCTION LOG (SINGLE SCREEN)
Location:

Project Name: ______________________ Logged By: ____________
Project Number: ______________________ Contractor: ____________
Client: ______________________ Driller: ____________
Start Date and Time: ______________________ Drilling Method: ____________
End Date and Time: ______________________ Boring Diameter: ____________
Weather: Boring Depth:

ERM



RISER & SCREEN
Type: ______________________
Schedule: ______________________
Diameter: ______________________
Screen Slot Size (in): ______________________

GROUND SURFACE COMPLETION
Type: ______________________
Other info (padlock added, etc): ______________________
____

GROUT & BENTONITE
Grout Type: ______________________
Hydration Details: ______________________
Bentonite Type: ______________________
Hydration Details:

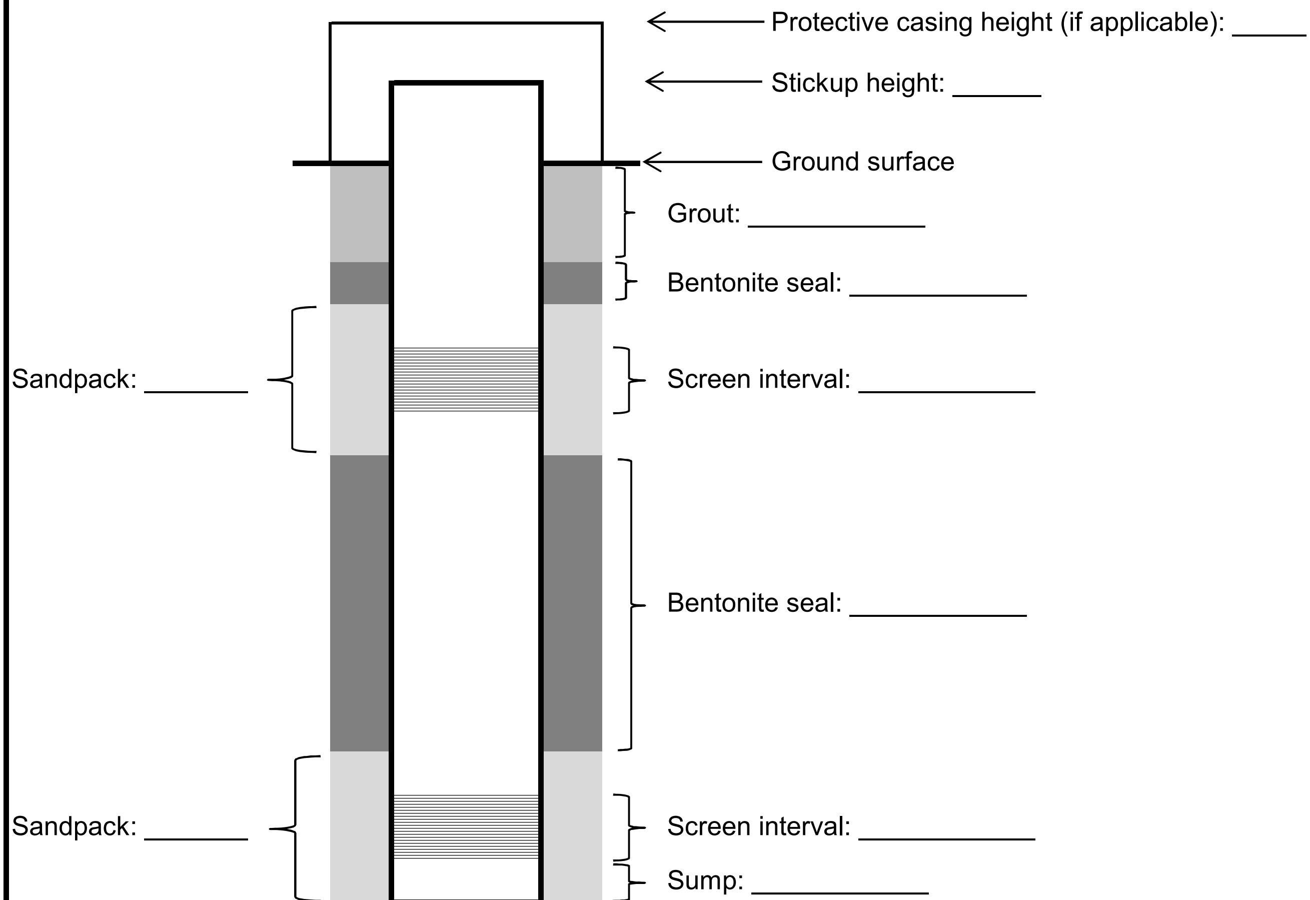
SANDPACK
Type: ______________________

OTHER NOTES ______________________

MONITORING WELL CONSTRUCTION LOG (MULTI-LEVEL - 2 SCREENS)
Location:

Project Name:	Logged By:
Project Number:	Contractor:
Client:	Driller:
Start Date and Time:	Drilling Method:
End Date and Time:	Boring Diameter:
Weather:	Boring Depth:

ERM



RISER & SCREEN
Type:
Schedule:
Diameter:
Screen Slot Size (in):

GROUND SURFACE COMPLETION
Type:
Other info (padlock added, etc):

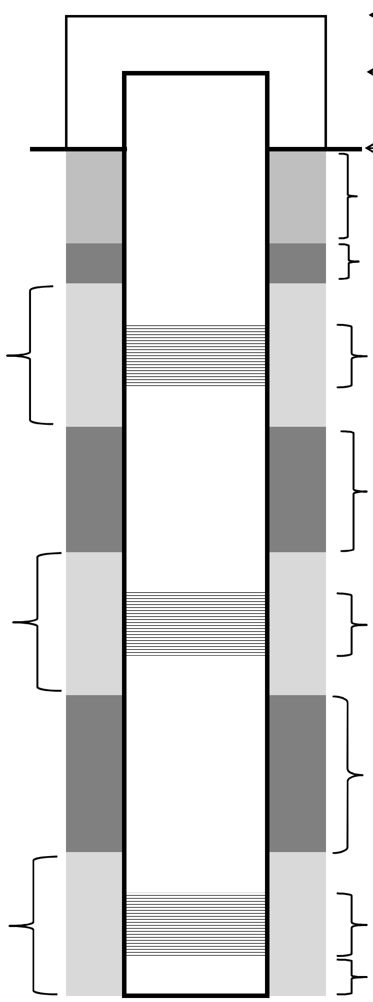
GROUT & BENTONITE
Grout Type:
Hydration Details:
Bentonite Type:
Hydration Details:

SANDPACK
Type:

OTHER NOTES

MONITORING WELL CONSTRUCTION LOG (MULTI-LEVEL - 3 SCREENS)
Location:

Project Name: ______________________ Logged By: ____________
Project Number: ______________________ Contractor: ____________
Client: ______________________ Driller: ____________
Start Date and Time: ______________________ Drilling Method: ____________
End Date and Time: ______________________ Boring Diameter: ____________
Weather: Boring Depth:



RISER & SCREEN
Type: ______________________
Schedule: ______________________
Diameter: ______________________
Screen Slot Size (in): ______________________

GROUND SURFACE COMPLETION
Type: ______________________
Other info (padlock added, etc): ______________________

GROUT & BENTONITE
Grout Type: ______________________
Hydration Details: ______________________
Bentonite Type: ______________________
Hydration Details:

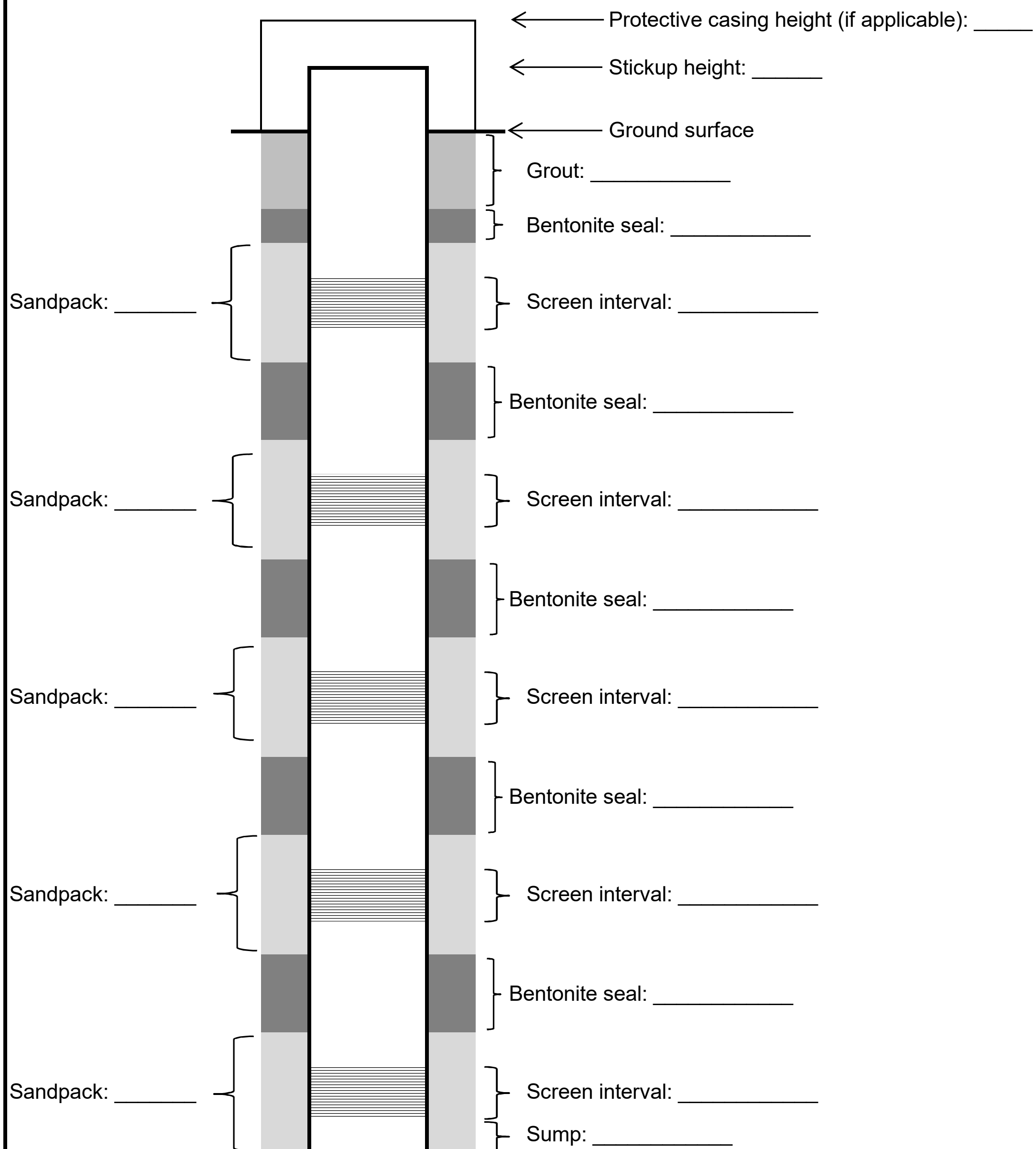
SANDPACK
Type: ______________________

OTHER NOTES ______________________

MONITORING WELL CONSTRUCTION LOG (MULTI-LEVEL - 5 SCREENS)
Location:

Project Name: ______________________ Logged By: __________
Project Number: ______________________ Contractor: __________
Client: ______________________ Driller: __________
Start Date and Time: ______________________ Drilling Method: __________
End Date and Time: ______________________ Boring Diameter: __________
Weather: Boring Depth:

ERM



RISER & SCREEN
Type: ______________________
Schedule: ______________________
Diameter: ______________________
Screen Slot Size (in): ______________________

GROUND SURFACE COMPLETION
Type: ______________________
Other info (padlock added, etc): ______________________

GROUT & BENTONITE
Grout Type: ______________________
Hydration Details: ______________________
Bentonite Type: ______________________
Hydration Details:

SANDPACK
Type: ______________________

OTHER NOTES ______________________

WELL DEVELOPMENT LOG

Page ___ of ___

Project Name: ______________________
Well ID: ______________________
Sampler Name: ______________________
Total Depth: ______________________
Initial Depth to Water: ______________________
Well Diameter and Casing Type: ______________________
Minimum Volume to Be Removed: ______________________
Total Volume Removed: ______________________

Date: ______________________
Weather: ______________________
Purge Start Time: ______________________
Purge End Time: ______________________
Pump Intake Depth: ______________________
Well Condition: ______________________

Equipment Info (model, serial number, etc)
Water Level Meter: ______________________
Pump Type: ______________________
Water Quality Meter: ______________________
Other Equipment: ______________________
Tubing Type: ______________________
Other Notes or Observations: ______________________

Time	Depth to Water	Volume Purged (gallons)	Well Volume(s) Removed	Turbidity (FNU)	Notes (color, odor, etc)

TRANSDUCER AND SLUG TEST FORMS

PRESSURE TRANSDUCER DEPLOYMENT FORM

Project Name: ______________________
Personnel: ______________________
Date: ______________________
Weather: ______________________

Equipment Info (model, serial number, etc)
Water Level Meter: ______________________
Transducer: ______________________
Other Equipment: ______________________

Other Notes or Observations: ______________________

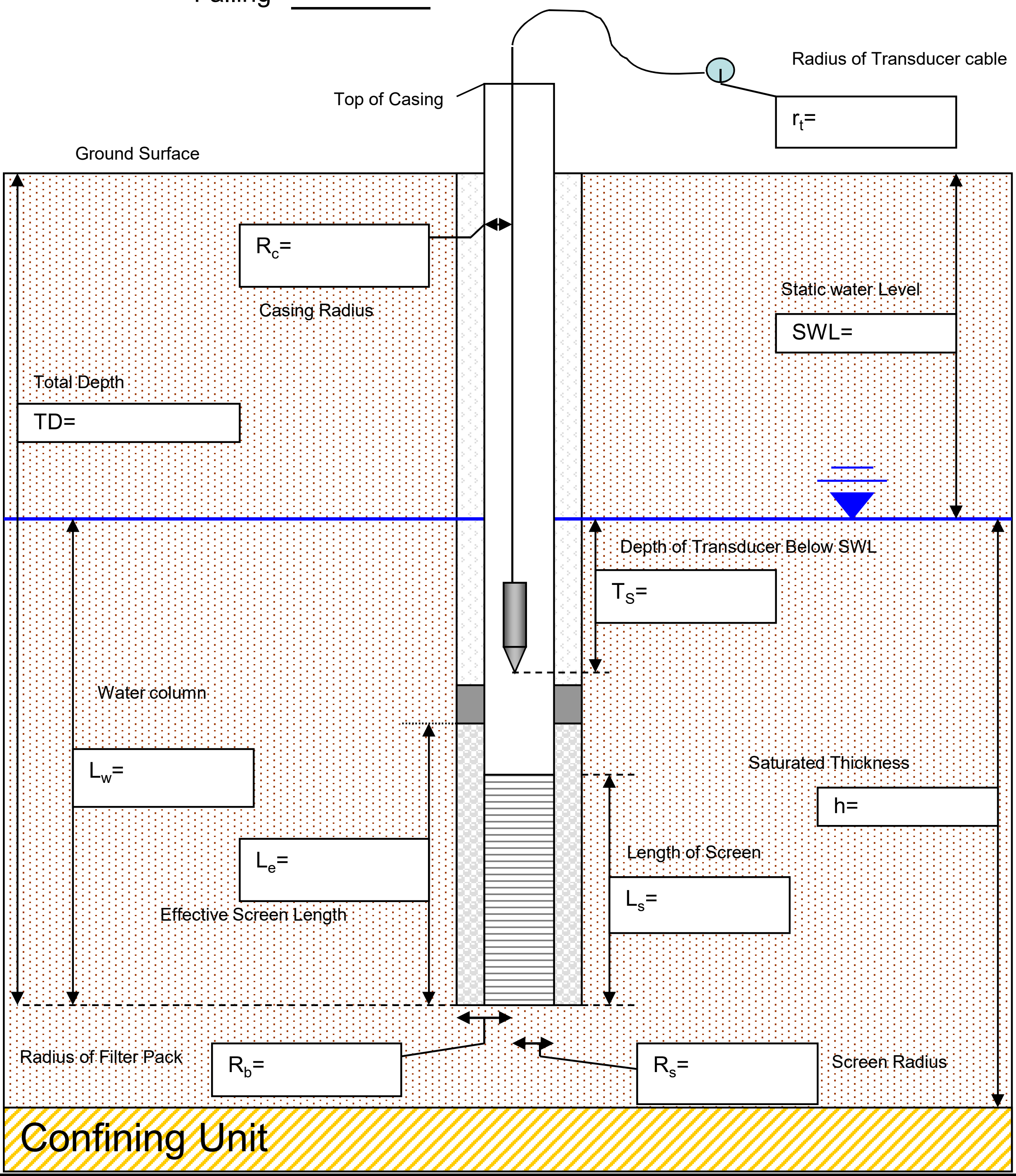
					Deployment			Retrieval			
Well ID	Transducer Serial Number	Program Start Date and Time	Recording Interval	Deployment Depth (ft BTOC)	Date	Time	Depth to Water (ft BTOC)	Date	Time	Depth to Water (ft BTOC)	Notes

Notes:
ft BTOC = feet below top of casing

PNEUMATIC SLUG TEST LOG

Project Name: ____________________ Date: ____________
Personnel: ____________________ Weather: ____________
Location: ____________________ Page: ______ of ______

Test Type: Rising ________
Falling ________



PNEUMATIC SLUG TEST LOG

Location: ____________________ Page: ______ of ______

Number of Tests: ________ Data File Name: ________________ Data File Location: ________________

Input Pressure: ________ Pressure Transducer SN: ______________ r_t: ______

Test: ________ T_S Baseline: __________ Pressure Reading: ______________

H_o: __________ Test Start ______ Test End ________

Test: ________ T_S Baseline: __________ Pressure Reading: ______________

H_o: __________ Test Start ______ Test End ________

Test: ________ T_S Baseline: __________ Pressure Reading: ______________

H_o: __________ Test Start ______ Test End ________

Notes:

H_o Initial change in head at instant the slug test is started

r_t Radius of transducer cable

T_S Depth of transducer below static water level

Additional Notes, Observations:

Theoretical Change in Head - 2.307 feet = 1 psi					
(Feet)	**(psi)**	**(Feet)**	**(psi)**	**(Feet)**	**(psi)**
0.50	**0.22**	**1.50**	**0.65**	**2.50**	**1.08**
0.75	**0.33**	**1.75**	**0.76**	**2.75**	**1.19**
1.00	**0.43**	**2.00**	**0.87**	**3.00**	**1.30**
1.25	**0.54**	**2.25**	**0.98**	**3.25**	**1.41**

Well Parameters Required for Calculating Hydraulic Conductivity	
L_e	Effective screen length, including the sand pack
L_s	True screen length
L_w	Length of water column in Well (TD-SWL)
R_s	Screen radius
R_b	Radius of filter Pack or borehole
R_c	Casing radius
r_t	Radius of the transducer cable
T_s	Depth the transducer is submerged below the SWL
SWL	Static water level
TD	Total depth of well/screen from reference point
h	Saturated thickness of aquifer
H_o	Initial head change at instant the slug test is started.
Aquifer Type	Confined or unconfined

VAPOR INTRUSION FORMS

Environmental Resources Management
One Beacon Street, 5th Floor
Boston, MA 02108

BUILDING SURVEY AND CHEMICAL INVENTORY

Preparer's name: ________________ Date: ____________________

Preparer's affiliation: ______________ Phone #: _________________

Site Name: _________________ **Project #:** _______________

Part I – Occupants/Property Owners

Occupant Address: ___________

Occupant Contact: _________ Owner / Renter / other: ______

Contact's Phone: home _____________ work _______________ cell __________

# of occupants in space: Children under age 13 ___ Children age 13-18 ____

Adults_______

Property Owner Address (if different): _______________________

Property Owner Contact: ______ Owner / Renter / other: ______

Contact's Phone: home _________ work _______________ cell __________

# of occupants in building(total):Children under age 13 __ Children age 13-18 ___
Adults ______________

Part II – Building Characteristics

Building type: residential / multi-family residential / office / strip mall / commercial / industrial

Describe building: ____ Year constructed: _________

Sensitive population: day care / nursing home / hospital / school / other (specify): ________________

Number of floors below grade: _______ (full basement / crawl space / slab on grade)

Environmental Resources Management
One Beacon Street, 5th Floor
Boston, MA 02108

Number of floors at or above grade: ______

Depth of basement below grade surface: ______ ft.   Basement size: _______ ft^2

Basement floor construction: concrete / dirt / floating / stone / other (specify): _________________

Foundation walls: poured concrete / cinder blocks / stone / other (specify) ________________

Basement sump present? *Yes / No*   Sump pump? *Yes / No*   Water in sump? *Yes / No*

Groundwater on floor? *Yes / No*

Type of heating system (circle all that apply):

hot air circulation	hot air radiation	wood	steam radiation heat
pump	hot water radiation	kerosene heater	electric baseboard

other (specify): ________________________

Type of ventilation system (circle all that apply):

central air conditioning	mechanical fans	bathroom ventilation fans
individual air conditioning units	kitchen range hood fan	outside air intake

other (specify): _________________

Type of fuel utilized (circle all that apply):

Natural gas / electric / fuel oil / wood / coal / solar / kerosene

Describe duct work if any (include supply and cold air return ductwork, and its current condition where visible, including whether there is a cold air return and the tightness of duct joints)

____
____
____
____
____

Provide a general description of activities in the space. Include commercial activities of business by floor or general use of each floor of each residence.

____
____
____
____
____

Are the basement walls or floor sealed with waterproof paint or epoxy coatings? *Yes / No*

Is there a whole house fan? *Yes / No*

Septic system? *Yes / Yes (but not used) / No*

Irrigation/private well? *Yes / Yes (but not used) / No*

Type of ground cover outside of building: grass / concrete / asphalt / other (specify)

Existing subsurface depressurization (radon) system in place? *Yes / No* *active / passive*

Sub-slab vapor/moisture barrier in place? *Yes / No*
Type of barrier: ______________

Part III - Outside Contaminant Sources

Other stationary sources nearby (gas stations, emission stacks, etc.): ______________________________

Heavy vehicular traffic nearby (or other mobile sources): ___________________________

Part IV – Indoor Contaminant Sources (if Indoor Air sampling is occurring)

Identify all potential indoor sources found in the building (including attached garages), the location of the source (floor and room), and whether the item was removed from the building 48 hours prior to indoor air sampling event. Any ventilation implemented after removal of the items should be completed at least 24 hours prior to the commencement of the indoor air sampling event. Use either of the two tables below as appropriate.

Potential Sources	Location(s)	Removed (Yes / No / NA)
Gasoline storage cans		
Gas-powered equipment		
Kerosene storage cans		
Paints / thinners / strippers		
Cleaning solvents		
Oven cleaners		
Carpet / upholstery cleaners		
Other house cleaning products		
Moth balls		
Polishes / waxes		
Insecticides		
Furniture / floor polish		
Nail polish / polish remover		
Hairspray		
Cologne / perfume		
Air fresheners		
Fuel tank (inside building)		
Wood stove or fireplace		
New furniture / upholstery		
New carpeting / flooring		
Hobbies - glues, paints, etc.		

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Boston, MA 02108

List specific products found that have the potential to affect indoor air quality (if indoor air samples are to be collected). Do not open a container to determine the contents or to take a field instrument reading. If field measurements are collected they will be from around the closed container only.

Location	Product Description	Size (units)	Chemical Ingredients	Field Instrument Reading (units)	Removed? Y/N

* Describe the condition of the product containers as Unopened (UO), Used (U), or Deteriorated (D)

** Photographs of the front and back of product containers can replace the handwritten list of chemical ingredients. However, the photographs must be of good quality and ingredient labels must be legible

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Part V – Miscellaneous Items

Do any occupants of the building smoke? *Yes / No* How often? _______________

Last time someone smoked in the building? ____________ hours / days ago

Does the building have an attached garage directly connected to living space? *Yes / No*

If so, is a car usually parked in the garage? *Yes / No*

Are gas-powered equipment or cans of gasoline/fuels stored in the garage? *Yes / No*

Do the occupants of the building have their clothes dry cleaned? *Yes / No*

If yes, how often? weekly / monthly / 3-4 times a year

Do any of the occupants use solvents in work? *Yes / No*

If yes, what types of solvents are used? ____

If yes, are their clothes washed at work? *Yes / No*

Have any pesticides/herbicides been applied around the building or in the yard? *Yes* / No

If so, when and which chemicals? ____

Has there ever been a fire in the building? *Yes / No* If yes, when? _____________

Has painting or staining been done in the building in the last 6 months? *Yes / No*

If yes, when __________________ and where? ____________________________

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Part VI – Sampling Information

Sample Technician: ________________________________ Phone number: ( ) _______ - __________

Company: ____

Sample Type (check all that apply): Indoor Air / Sub-Slab / Near Slab Soil Gas / Exterior Soil Gas

Sample locations (floor, room):

SAMPLING DATA – See Air sampling Data Sheet

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Boston, MA 02108

-

Drawing of Sample Location(s) in Building

Type of field instrument used (include summary of results): ______________________________________

Part VII - Meteorological Conditions

Was there significant precipitation within 12 hours prior to (or during) the sampling event? *Yes / No*

Describe the general weather conditions: ____

____

Part VIII – General Observations

Provide any information that may be pertinent to the sampling event and may assist in the data interpretation process.

____
____
____

Environmental Resources Management

Indoor Air/Outdoor Ambient Air Sampling Form

Project #:
Project Name:
Location:

Sample Location:		**Collector Name(s):**	
Address:			
PID Meter Used: (Model, Serial #)		**Date:**	

Sample ID:

Duplicate Sample? (Y/N): **Duplicate Sample ID:**

Type of sample (circle one): INDOOR AIR AMBIENT AIR

Photograph description:	

Summa® Information:

Canister Serial Number:		Flow Controller ID Number:	
Start Date/Time:		Stop Date/Time:	
Start Pressure: (inches Hg) [1]		Stop Pressure: (inches Hg) [2]	

Other Sampling Information:

Story/Level		Ground Surface (pavement, flooring)		Distance from Building (if applicable)	
Room (if applicable)		Potential Vapor Pathways Observed?		Distance to nearest Roadway (ft.)	
Indoor Air Temp (ºF)	ºF	Noticeable Odor?		Outside Barometric Pressure ("Hg or mb)	
Intake Height Above Ground Level (ft.)					"Hg

Field Screening Data[3]

Location in Building	Date	Time	PID Reading	Oxygen	Carbon Dioxide	Methane	Notes

Interim Monitoring

Reading #1:	Time:	Summa Vacuum ("Hg):		Noticeable Odor?	
Reading #2:	Time:	Summa Vacuum ("Hg):		Noticeable Odor?	
Reading #3:	Time:	Summa Vacuum ("Hg):		Noticeable Odor?	
Reading #4:	Time:	Summa Vacuum ("Hg):		Noticeable Odor?	
Reading #5:	Time:	Summa Vacuum ("Hg):		Noticeable Odor?	

Other information collected (e.g., Sketch of Sample Location, other readings, etc):

Comments:

1 - Verify pressure did not decrease noticeably from laboratory reported value.

2- Canister should have between 3 and 5 inHg vacuum left at the end of the sampling period.

3 - Field screening may be collected at multiple points inside and outside the building. At least one screening measurement should be recorded near the IA/OA sampling location.

If conducting both indoor air and sub-slab soil gas sampling, all indoor air sampling must be completed and canisters closed before soil gas sampling can be started.

Environmental Resources Management

Short-term Radon Monitoring Field Form
Indoor/Outdoor Air

Project #:	
Project Name:	
Location:	
Weather:	

Sample Location:		**Collector Name(s):**	
Address:			
Radon Meter Used: (Model, Serial #)	Durridge RAD7	**Date:**	
Calibration Date:			

Type of sample (circle one): INDOOR AIR AMBIENT AIR

Building Conditions:

Date/time building was closed:		Windows closed? (Y/N)	
HVAC system: heating, cooling, or off		Doors closed? (Y/N)	
HVAC system set temperature (ºF)		Estimated number of times door opened	

If building unable to be closed, describe general use during sampling:

Other Sampling Information:

Story/Level		Briefly describe/sketch position of meter in room:	
Room (if applicable)			
Indoor Air Temp (ºF)	ºF		
Intake Height Above Ground Level (ft.)			

Meter Purge Time (min 5 minutes)

Purge Location:	(outside building preferred)	Purge Total Time (min):	
Purge Start Time:		Purge End Time:	
Initial relative humidity:			
Initial temperature:		Initial battery voltage:	

Meter Operation

Drying Unit Type:		Drying Unit Number:	
2-Day test Start Time:		End Time:	
Final relative humidity:			
Final temperature:		Final battery voltage:	

Post-Sample Purge Time (min 10 minutes)

Purge Location:	(outside building preferred)	Purge Total Time (min):	
Purge Start Time:		Purge End Time:	

REPLACE CAPS ON DRYING TUBE AFTER SAMPLING

PRINT DATA RESULTS IF POSSIBLE IN FIELD AND UPLOAD DATA TO PROJECT FILE AT THE END OF SAMPLING

Comments:

Environmental Resources Management

Long-term Radon Monitoring Field Form
Indoor/Outdoor Air

Project #:	
Project Name:	
Location:	
Weather:	

Sample Location:		**Collector Name(s):**	
Address:			
Chamber Used: (Model, Serial #)	E-perm S-chamber	**Date:**	
Electret Used: (Model, Serial #)	E-perm LT electret	**Date:**	
Laboratory providing electret:			

Sample ID:		
Duplicate Sample? (Y/N):		**Duplicate Sample ID:**
Type of sample (circle one):	INDOOR AIR	AMBIENT AIR
Photograph description:		

Other Sampling Information:

Story/Level		Briefly describe/sketch position of meter in room:	
Room (if applicable)			
Indoor Air Temp (ºF)	ºF		
Intake Height Above Ground Level (ft.)			

Electret Test Start:

Initial electret voltage:		Signage posted (y/n):	
Chamber Condition:		Free of dust/debris (y/n):	
Sample Start Time:		Chamber fully opened (y/n):	

Electret Test End:

Sample End Date:		Sample End Time:	
Chamber Condition:		Chamber still fully opened (y/n):	

ENSURE THAT CHAMBER IS FULLY CLOSED AT END OF TEST

Comments:

Environmental Resources Management

Vapor Probe Construction Form

Project #:
Project Name:
Location:
Weather:

Location ID:		Installer Name(s):	
Address:			
PID Meter Used: (Model, Serial #)		Date:	

Type of sample (circle one): SUB-SLAB SOIL GAS EXTERIOR SOIL GAS NEAR-SLAB SOIL GAS

Is probe part of a nested well? Y/N

Construction Information (for sub-slab probes assume Vapor Pin® installation unless otherwise noted)

		Probe Construction Sketch (Sketch not needed for sub-slab probes using Vapor Pins®)
Boring Diameter:		
Probe Depth:		
Probe Diameter (i.e., tubing diam)		
Screen Length		
Sand Interval:		
Dry Bentonite Interval		
Hydrated Bentonite Interval		
Hydraulic Cement internal		
Surface Completion Type		
Surface Type (pavement, flooring, asphalt, grass, concrete)		
Slab thickness (if applicable)		

Water Dam Completed and Passed (sub-slab only)?[3]	Time:		Comments:	
Shut-in test passed before the following? (Mark all applicable with vac held and time held)	Pneumatic Testing?		Purge?	

Seal Testing (nested probes only)

Test #	Depth of Probe 1	Depth of Probe 2	Flow/Vacuum at Probe 1	Vacuum at Probe 2

All Probes in Nest passed Seal Test? Y/N

Pneumatic Testing (if applicable)

Start Time:		Pump Flow Rate (L/min)	Elapsed Time (min)	Well Head Vacuum (in H2O)

If no pnuematic testing, qualitative gas permeability completed (Y/N) Syringe plunger pulls back easily? Tedlar bag fills easily?

Purge (If applicagle. May be combined with helium leak test and/or field screening. Purge sub-slab soil gas into tedlar bag and transfer outside)

Calculated One Purge Volume =	Three Purge Volumes =		Final Purged Volume =
Purge Rate:	Purge Start Time:		
Purge Total Time (min):	Purge End Time:		

Helium Leak Test (if applicable)	~He in Shroud:		ppm	% calc:
	~He from point (via tedlar bag, syringe or similar):		ppm	Passed? Y/N

Field Screening Data

Tedlar bag or downhole?	Time	PID Reading (ppm or ppb)	Oxygen (%)	Carbon Dioxide (%)	Methane (% in air)	Notes (vol purged if from tedlar bag)

Differential Pressure Readings:	Min (in-H2O):	Max (in-H2O):	Total Time (min):

Environmental Resources Management

Radon Soil Gas Monitoring Field Form

Project #:	
Project Name:	
Location:	
Weather:	

Sample Location:		**Collector Name(s):**	
Address:			
Radon Meter Used: (Model, Serial #)	Durridge RAD7	**Date:**	
Calibration Date:			

Type of sample (circle one):	Soil Gas	Subslab Vapor

Vapor Sampling Port Conditions (Refer to Soil Vapor S

Vapor Sampling Port intact (y/n):		Vapor Sampling Port sealed (y/n):	

Notes

Meter Purge Time (min 5 minutes)

Purge Location:	(away from soil gas probe)	Purge Total Time (min):	
Purge Start Time:		Purge End Time:	
Initial relative humidity:			
Initial temperature:		Initial battery voltage:	

Meter Operation

Drying Unit Type:			Drying Unit Number:	
"sniff" test Start Time:				
	Test Time	Radon Reading	Test Time	Radon Reading
	0:05		0:20	
	0:10		0:25	
	0:15		0:30	

If stabilization not achieved (<10% change in radon activity and standard deviation <10% of radon activity):

Auto Mode Start Time:		Normal Mode Start Time:	

End of Test

Test End Time:		Final relative humidity:	
Final temperature:		Final battery voltage:	

Post-Sample Purge Time (min 10 minutes)

Purge Location:	(away from soil gas)	Purge Total Time (min):	
Purge Start Time:		Purge End Time:	

REPLACE CAPS ON DRYING TUBE AFTER SAMPLING

PRINT DATA RESULTS IF POSSIBLE IN FIELD AND UPLOAD DATA TO PROJECT FILE AT THE END OF SAMPLING

Comments:

Environmental Resources Management

Soil Gas Sampling Form

Project #:	
Project Name:	
Location:	
Weather:	

Sample Location:		**Collector Name(s):**	
Address:			
PID Meter Used: (Model, Serial #)		**Date:**	

Sample ID:

Duplicate Sample? (Y/N): **Duplicate Sample ID:** Is probe part of a nested well? Y/N

Type of sample (circle one): SUB-SLAB SOIL GAS EXTERIOR SOIL GAS NEAR-SLAB SOIL GAS

Photograph description:	

Summa® Information:

Canister Serial Number:		Flow Controller ID Number:	
Start Date/Time:		Stop Date/Time:	
Start Pressure: (inches Hg) [1]		Stop Pressure: (inches Hg) [2]	

Other Sampling Information:

Room (if applicable)		Surface Type (pavement, flooring, asphalt, grass, concrete)		Depth of Vapor Probe (bgs)	
Indoor Air Temp (ºF)	ºF	Slab thickness (if applicable)		Distance from Building (if applicable)	
Outside Barometric Pressure ("Hg or mb)	"Hg	Potential Vapor Pathways Observed?		Distance to nearest Roadway (ft.)	
Water Dam Completed and Passed (sub-slab only)?[3]		Time:		Comments:	
Shut-in test passed before the following? (Mark all applicable with vac held and time held)		Pneumatic Testing?		Purge?	Sampling?

Pneumatic Testing (if applicable)

Start Time:		Pump Flow Rate (L/min)	Elapsed Time (min)	Well Head Vacuum (in H2O)

If no pnuematic testing, qualitative gas permeability completed (Y/N) Syringe plunger pulls back easily? Tedlar bag fills easily? Summa canister fills easily?

Purge (may be combined with helium leak test and/or field screening)[3]

Calculated One Purge Volume =	Three Purge Volumes =		Final Purged Volume =
Purge Rate:	Purge Start Time:		
Purge Total Time (min):	Purge End Time:		

Helium Leak Test (if applicable)	~He in Shroud:		ppm	% calc:
	~He from point (via tedlar bag, syringe or similar):		ppm	Passed? Y/N

Field Screening Data

Tedlar bag or downhole?	Time	PID Reading (ppm or ppb)	Oxygen (%)	Carbon Dioxide (%)	Methane (% in air)	Notes (vol purged if from tedlar bag)

Differential Pressure Readings:	Min (in-H2O):	Max (in-H2O):	Total Time (min):

Other information collected (e.g., Sketch of Sample Location, other readings, liquid tracers?, etc):

Comments:

1 - Verify pressure did not decrease noticeably from laboratory reported value.

2 - Canister should have between 3 and 5 inHg vacuum left at the end of the sampling period.

3 - For sub-slab points, leave water dam in place through purging and through sampling if possible.

4 - If conducting a purge of soil gas inside a building, release purged air outside or capture purged air in tedlar bag and then release outside.
If conducting both indoor air and sub-slab soil gas sampling, all indoor air sampling must be completed and canisters closed before soil gas sampling can be started.

CALIBRATION FORMS

CALIBRATION LOG FOR WATER QUALITY METER

Project Name: ____________ Date: ____________________ Time (start): ______________ Water Quality Meter Model: ________
Field Technician: ____________ Weather: ____________________ Time (finish): ______________ Water Quality Meter Serial Number: ________
Notes: ____

Parameter	Action	Barometric Pressure (mmHg)			Temperature (°C)	Pre-Cal Reading	Post-Cal Reading	Pass?		Comments
DO (saturated air)	Calibrate daily							Yes	No	
Parameter	**Action**	**Standard Lot #**	**Standard Expiration Date**	**Value of Standard**	**Temperature (°C)**	**Pre-Cal Reading**	**Post-Cal Reading**	**Pass?**		**Comments**
pH (7)	Calibrate daily							Yes	No	
pH (4)	Calibrate daily							Yes	No	
pH (10)	Calibrate daily							Yes	No	
ORP (mV)	Calibrate daily							Yes	No	
Specific Conductivity (µS/cm)	Calibrate daily							Yes	No	
Parameter	**Action**	**Standard Lot #**	**Standard Expiration Date**	**Value of Standard**	**Temperature (°C)**	**Pre-Cal Reading**	**Post-Cal Reading**	**Pass?**		**Comments**
Turbidity (0 FNU)	Check calibration daily							Yes	No	
	Calibrate							Yes	No	
Turbidity (124 FNU)	Check calibration daily							Yes	No	
	Calibrate							Yes	No	

Notes:

Turbidity will be checked on a daily basis. Acceptance criteria are within 10% of the standard.

All other parameters will be calibrated on a daily basis.

CALIBRATION LOG FOR PHOTOIONIZATION DETECTOR

Project Name: ____________ Date: ____________________ Time (start): ______________ PID Model: ___________________

Field Technician: ____________ Weather: ____________________ Time (finish): ______________ PID Serial Number: ___________________

Notes: ____

	Action	Barometric Pressure (mmHg)	Temperature (°C)	Pre-Cal Reading	Post-Cal Reading	Pass?		Comments
Fresh Air (0.0 ppm)	Calibrate daily					Yes	No	
Isobutylene Gas (100 ppm)	Calibrate daily					Yes	No	

LABORATORY CHAIN OF CUSTODY FORMS

Air - Chain of Custody Record & Analytical Service Request

2655 Park Center Drive, Suite A
Simi Valley, California 93065
Phone (805) 526-7161
Fax (805) 526-7270

Requested Turnaround Time in Business Days (Surcharges) please circle 1 Day (100%) 2 Day (75%) 3 Day (50%) 4 Day (35%) 5 Day (25%) 10 Day-Standard	ALS Project No.
	ALS Contact:

Company Name & Address (Reporting Information)	Project Name
	Project Number
Project Manager	P.O. # / Billing Information
Phone / Fax	
Email Address for Result Reporting	Sampler (Print & Sign)

Client Sample ID	Laboratory ID Number	Date Collected	Time Collected	Canister ID (Bar code # - AC, SC, etc.)	Flow Controller ID (Bar code #- FC #)	Canister Start Pressure "Hg	Canister End Pressure "Hg/psig	Sample Volume	Analysis Method		**Comments** e.g. Actual Preservative or specific instructions

Report Tier Levels - please select

Tier I - Results (Default if not specified) _____
Tier II (Results + QC Summaries) _____
Tier III (Results + QC & Calibration Summaries) _____
Tier IV (Data Validation Package) 10% Surcharge _____

EDD required Yes / No
Type: ________________ Units:__________

Chain of Custody Seal: (Circle)
INTACT BROKEN ABSENT

Project Requirements (MRLs, QAPP)

Relinquished by: (Signature)	Date:	Time:	Received by: (Signature)	Date:	Time:
Relinquished by: (Signature)	Date:	Time:	Received by: (Signature)	Date:	Time:

Cooler / Blank Temperature ____°C

Pace Analytical®
www.pacelabs.com

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Page: of

Section A **Required** Client Information:		**Section B** **Required** Project Information:	**Section C** Invoice Information:
Company:		Report To:	Attention:
Address:		Copy To:	Company Name:
			Address:
Email To:		Purchase Order No.:	Pace Quote Reference:
Phone:	Fax:	Project Name:	Pace Project Manager:
Requested Due Date/TAT:		Project Number:	Pace Profile #:

REGULATORY AGENCY

☐ NPDES ☐ GROUND WATER ☐ DRINKING WATER

☐ UST ☐ RCRA ☐ OTHER ____________

Site Location

STATE: ____________

Section D
Required Client Information

SAMPLE ID
(A-Z, 0-9 / ,-)
Sample IDs MUST BE UNIQUE

Matrix Codes

MATRIX	CODE
Drinking Water	DW
Water	WT
Waste Water	WW
Product	P
Soil/Solid	SL
Oil	OL
Wipe	WP
Air	AR
Tissue	TS
Other	OT

Requested Analysis Filtered (Y/N)

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED: COMPOSITE START DATE	COLLECTED: COMPOSITE START TIME	COLLECTED: COMPOSITE END/GRAB DATE	COLLECTED: COMPOSITE END/GRAB TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Y/N ➞ Analysis Test ➞												Residual Chlorine (Y/N)	Pace Project No./ Lab I.D.
1																															
2																															
3																															
4																															
5																															
6																															
7																															
8																															
9																															
10																															
11																															
12																															

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME	SAMPLE CONDITIONS			
							Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER:

SIGNATURE of SAMPLER: **DATE Signed (MM/DD/YY):**

*Important Note: By signing this form you are accepting Pace's NET 30 day payment terms and agreeing to late charges of 1.5% per month for any invoices not paid within 30 days.

APPENDIX C SUBCONTRACTOR STANDARD OPERATING PROCEDURES AND SPECIALIZED EQUIPMENT USER MANUALS

VAPOR INTRUSION STANDARD OPERATING PROCEDURES AND USER MANUALS

RAD7

Electronic Radon Detector

User Manual

Owner: ______________________________

Serial #: _______________

SERVICE RECORD

Date:	Service:

It is recommended that the RAD7 be returned to DURRIDGE Company annually for recalibration.

DURRIDGE
Radon Capture & Analytics

WARNING

Opening the cover of this instrument is likely to expose dangerous voltages. Disconnect the instrument from all voltage sources while it is being opened. Due to battery power, the instrument may still be dangerous.

Using this instrument in a manner not specified by the manufacturer may impair the protection provided by the instrument.

TABLE OF CONTENTS

INTRODUCTION

The RAD7 is a highly versatile instrument that can form the basis of a comprehensive radon measurement system. It may be used in many different modes for different purposes. This manual adopts a progressive approach, in which there is, first, a simple, step-by-step description of how to get readings for a) real-time monitoring, and b) sniffing. Next comes a more detailed description of the many features of the instrument and how to access them. The rest of the manual covers a whole range of topics, in somewhat arbitrary order. We recommend that, as soon as possible, you read the entire text, just so that you will have an idea of what there is. While you can start to make good measurements on the first day of ownership of the RAD7, it can take years to master the subtleties of radon and thoron behavior, and to appreciate the full capabilities of the instrument.

We have tried to make the manual easy to use, with a useful table of contents. Please let us know how well we have succeeded. If there are some topics inadequately covered, please tell us. We will issue updates from time to time.

Points of special note

The RAD7 is a rugged and long-lasting piece of equipment. There are many units still in daily use that were sold ten years ago or more. However, it is a sophisticated, precision electronic device, and it is not hermetically sealed, so please treat it with respect. Please do not allow water, other liquids or dirt to get into the machine. If using it somewhere where it may get splashed, damaged, or exposed to rain, please protect it. See Chapter 4.8.1.

The batteries are lead-acid technology, like a car's. If left in a discharged state they will lose capacity. After running the RAD7 on its batteries please recharge them as soon as possible (by plugging in the unit). With careful use the batteries will last five years or more.

Finally, there is one security feature that is sometimes inadvertently set by an inexperienced, though authorized, user; namely the keypad lockout. If the keypad ceases to function, and all you see is `DURRIDGE RAD7` on the display, just do the following: Hold down the `[ENTER]` and two arrow keys until you hear a beep, release the three keys and immediately push `[MENU]`. You should then be rewarded by `>Test` on the display. If the tone was set to `OFF`, then you will not hear the beep, so hold the three keys down for three to four seconds, before releasing them and pushing `[MENU]`, - try hold-down times a little longer, or shorter, if, at first, you do not succeed.

Shipping and Contact Information

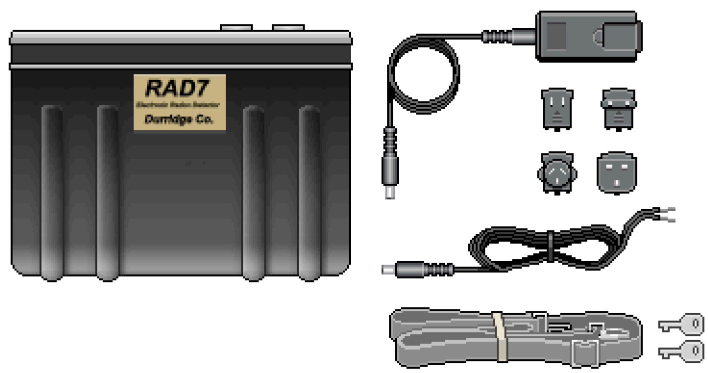
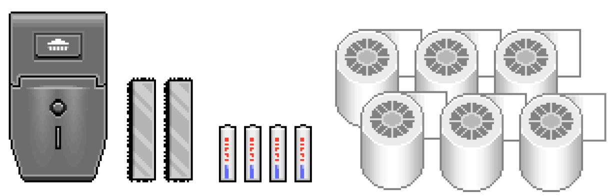
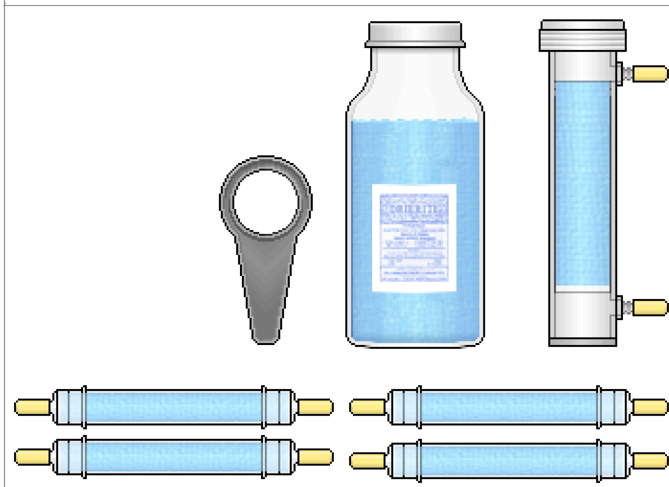
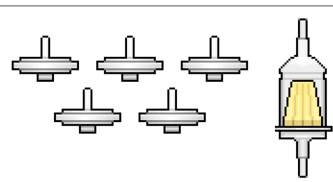
DURRIDGE U.S. Office	900 Technology Park Drive Billerica, MA 01821 USA Phone: (978)-667-9556 Fax: (978)-667-9557
DURRIDGE UK Office	Sheffield Technology Park Cooper Buildings, Arundel Street Sheffield S1 2NS, UK Phone: +44 (0)114 221 2003
Email	service@durridge.com
Web	www.durridge.com

1 GETTING STARTED: YOUR FIRST DAY WITH THE RAD7

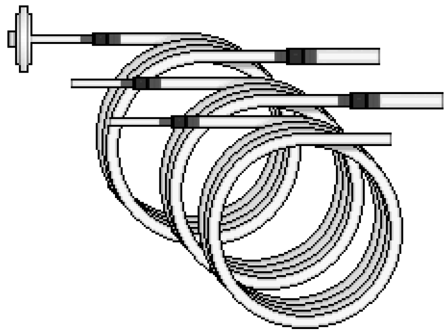
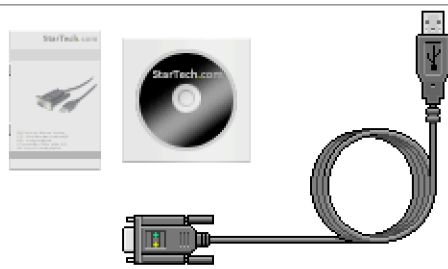
1.1 Unpacking

First make sure you have everything you are supposed to have. Take the materials out of the packing boxes and see if you have all the items shown in the diagram below, or on the packing list enclosed with the shipment. If anything is missing, please email DURRIDGE immediately or call us at (978) 667-9556.

RAD7 Packing List

	RAD7 and Case Accessories • RAD7 electronic radon detector • 12V adaptor w/ 4 plugs • 12V cord for custom applications • RAD7 Carrying Strap • Keys for RAD7 case
	RAD7 Printer Supplies • Wireless infrared printer • 4 AA alkaline batteries • 6 Rolls printer paper
	Drying Tubes and Desiccant • Gas drying unit • Opener tool for drying unit • 5 lbs desiccant •4 drying tubes
	RAD7 Filters • 5 RAD7 inlet filters • 1 Dust filter

RAD7 Packing List (Continued)

	Vinyl Tubing Set (3ft x 3) • From sample to drying tube • From drying tube to RAD7 inlet • From RAD7 outlet to exhaust
	USB/Serial Supplies • USB to serial adaptor cable • Adaptor cable documentation • Adaptor cable software driver CD
	RAD7 Documentation Binder • RAD7 User's Manual • Additional documentation • DURRIDGE Software USB Stick

1.2 General Safety Instructions

For your own safety and the proper operation of RAD7:

DO NOT spill liquids onto the machine.

DO NOT expose operating panel of machine to rain or any other excess moisture.

DO NOT allow liquid to be sucked into inlet tube.

If you intend to use the instrument in a harsh environment, give it some protection. Even just a transparent plastic bag enclosing the RAD7 (but not the air sampling tube) can protect it from splashing mud and water. Allowing the dry air from the RAD7 outlet to exhaust into the interior of the bag will keep the RAD7 in a clean and dry environment.

If liquid does get into the machine, please disconnect the power cord, turn off the power switch, and follow the instructions in Chapter 4.8.1, Harsh and Hazardous Environments: Splashing Water. It will be necessary to return the RAD7 to DURRIDGE for repair.

Do not use your RAD7 if the instrument is damaged or malfunctioning. Please call, or email, the DURRIDGE service department, who will advise what to do about the problem.

Replace a frayed or damaged power cord immediately. Electrical equipment may be hazardous if misused. Keep away from children.

Do not open or attempt to repair the machine. The detector has an internal high voltage supply that can generate more than 2,500V.

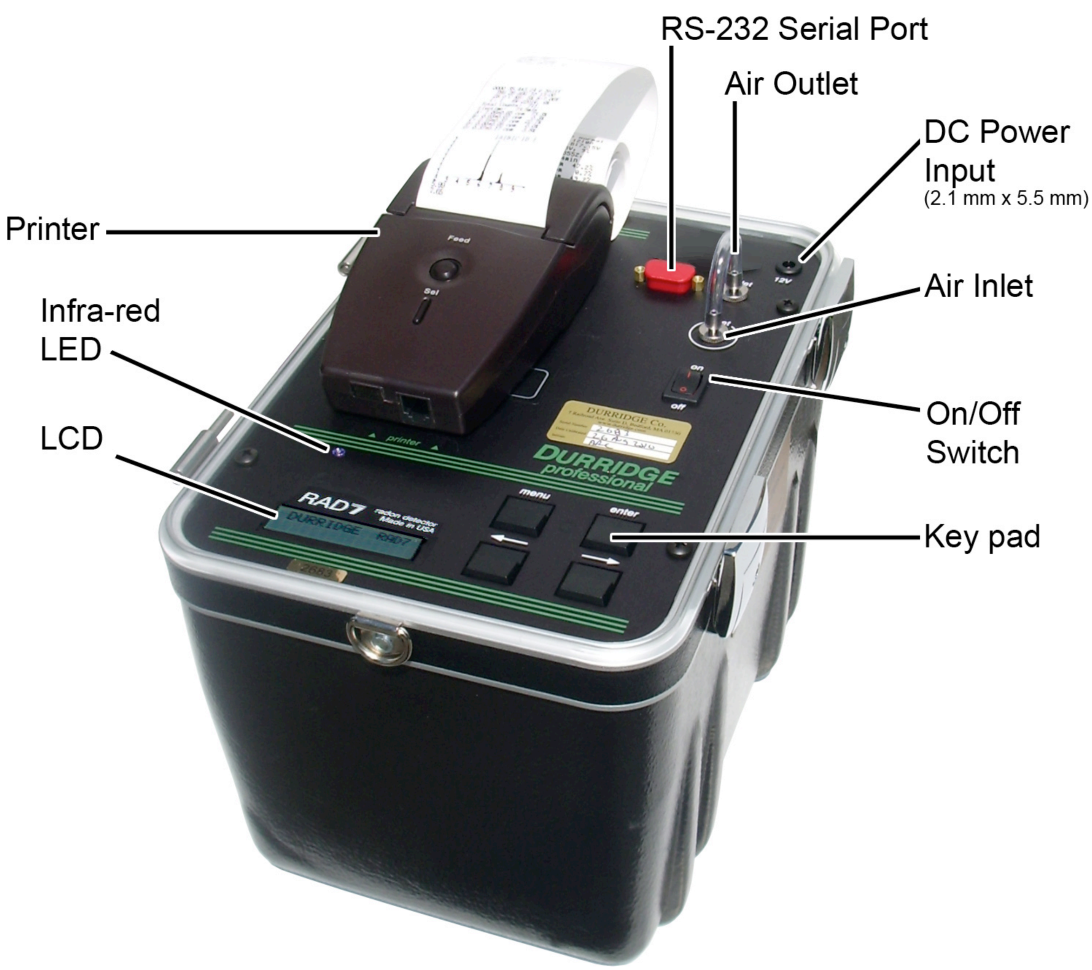
The batteries are Gates Monobloc type 0819-0012, 6V 2.5Ah. There are two installed in the instrument. They are not user replaceable.

1.2.1 Air Travel

The RAD7 is safe to take on an airplane either as carry-on or checked baggage. It is probably easiest, and least likely to cause problems, if it is put inside a suitcase, with clothes, and checked in.

Some airlines and some airline staff are concerned about lead-technology batteries, such as those in the RAD7. An MSDS sheet, issued by the battery manufacturer, is enclosed with the manual in the RAD7 documentation. A copy of that should be carried and presented when requested, when traveling with a RAD7 by air.

1.3 Taking a Look



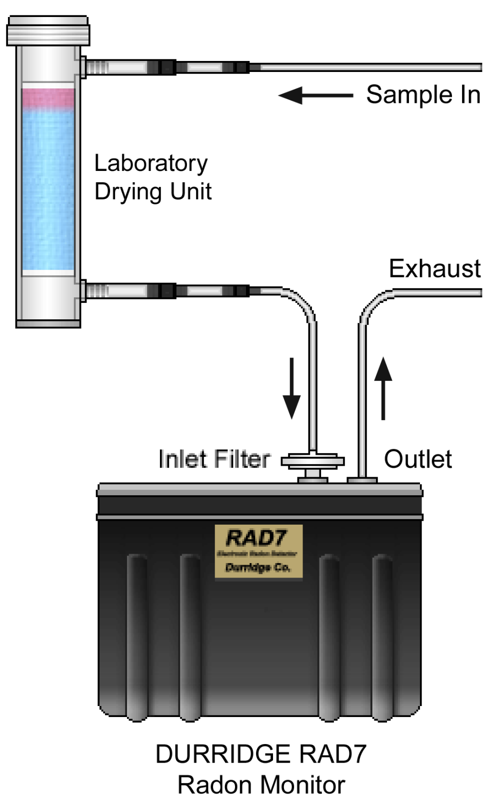
The RAD7 Professional Electronic Radon Detector

1.4 Starting a Two-day Test

You will need the RAD7 and power cord, the Laboratory Drying Unit (the large tube of desiccant, with a screw cap at one end), an inlet filter (one of the six small filters supplied), the piece of tubing with a 5/16" ID segment at one end and a ⅛" ID segment at the other and the printer.

On first starting up, you may need to set the clock for your time zone (See Setup Clock, Chapter 2.4.11). Switch on the RAD7, push `[MENU]`, then push `[➔]` twice. You will see Setup on the display. Push `[ENTER]`, then push `[➔]` ten times. You will see Setup Clock. Push `[ENTER]`. Use the arrow keys to adjust hours, minutes, seconds, day, month and year, pushing `[ENTER]` to confirm each setting. Now we are ready to continue.

RAD7 Normal Configuration



Attach the filter to the tubing (push it into the end with the insert).

Carefully remove both plastic caps from the Drying Unit (you will need them later, to reseal the unit). Attach the sleeved end of the tubing to the tube fitting, on the Drying Unit, farthest from the screw cap.

Attach the filter to the Inlet port of the RAD7. The air sampling system is now set up for the measurement. (See RAD7 Standard Configuration diagram at left.)

Plug in the RAD7 and switch on.

Push `[MENU]`, `[ENTER]`, then push `[➔]` four times. You should see on the LCD display: `Test Purge`.

Push `[ENTER]`. The pump should start.

Set up the printer (insert paper and batteries - see manual).

Place printer between green lines on face plate (See photo, Chapter 1.3).

After purging for some time (normally, at least five minutes), push `[MENU]`, and `[➔]` two times, you will see: Setup on the display.

Push `[ENTER]` twice, then push either arrow key repeatedly until you see:
Protocol: 2-Day on the display. Push `[ENTER]`.

With Setup on the display, push `[ENTER]`, then `[➔]` seven times, to see `>Setup Format` on the display. Push `[ENTER]` then use arrow keys to select `Format: Short`. Push `[ENTER]`.

Switch off the RAD7. Switch on the printer, now switch the RAD7 back on. The printer will print out something like the following:

```
DURRIDGE RAD7
Vers 3.1a   151208
Model 716
Serial 00512
Calib 21-MAY-17

Last used
   FRI 21-MAY-17  17:30

Current settings
   FRI 21-MAY-17  19:09
```

```
Protocol: 2-Day
Cycle: 01:00
Recycle: 48
Mode: Auto
Thoron: Off
Pump: Auto
Tone: Geiger
Format: Short
Units: pCi/L   °C
```

m) Push `[MENU]`, `[ENTER]`, `[➔]`. You should see on the LCD display: `>Test Start`

n) Push `[ENTER]`. The pump will start running. On the LCD display you will see something like:

```
0101        Live      Sniff
00:59:37              00001
```

You are now monitoring the radon level right where you are. Every hour, the printer will print out a reading something like this:

```
0102   2.69  " 0.73  p   Sniff
   FRI  21-MAY-13    19:41
   26.8 C   RH: 7%   B:7.06V
```

Where 0102 are the run (01) and cycle (02) numbers, 2.69 is the measured radon concentration, 0.73 is the two-sigma STATISTICAL uncertainty, p indicates the units (in this case pCi/L), and Sniff shows that, for this reading, only the Po-218 decays are being counted (after three hours, the mode changes automatically to Normal). The second line is clearly the date and time, while the third shows the temperature and humidity inside the measurement chamber, and the battery voltage. Medium and Long format settings print more information each cycle.

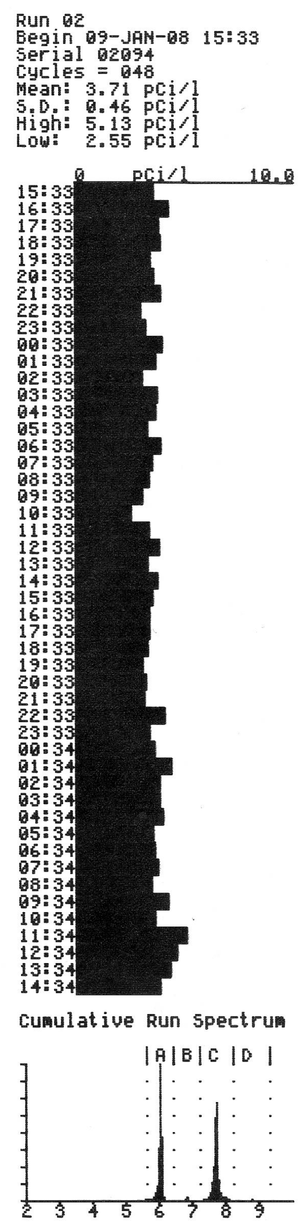
If you allow the RAD7 to complete a run, it will print out a summary of the entire run, including:

1. Date and time
2. Machine serial number
3. Average value for the test
4. Bar chart of the individual readings, and
5. Cumulative alpha energy spectrum.

In the example shown it may be seen that the average level was 3.71 pCi/L, or 137 Bq/m³.

To terminate the run early, you may switch off the RAD7. The data collected, to the end of the last completed cycle, is automatically stored in the RAD7 memory, and available for later display, printing or download to a PC. If you wish to store the last, incomplete cycle data as well, use Test Save before switching off the RAD7. When you do this, the end-of-run printout does not take place. The summary is stored in memory and may be printed at any time, except that the cumulative spectrum, which would have been printed out at the end of the run, is lost.

End-of-Run Printout



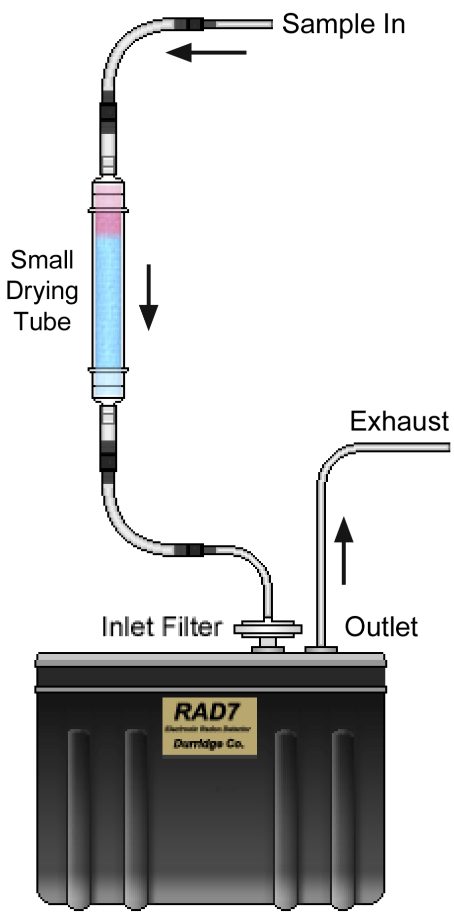
1.5 Starting a Sniff Test

Sniffing lets you make quick, qualitative surveys of radon and thoron levels. It may be used to search for radon entry points. There are some advantages in sniffing for both thoron and radon at the same time, (see Chapter 3.13.3), so that is the procedure described here.

You will need the same equipment as for the 2-day test, above, except that a small drying tube should be used, instead of the laboratory drying unit. Also, for portability, you may remove the external power from the RAD7, and run the RAD7 on its batteries.

If you have not already done so, set the clock, as described above.

RAD7 SNIFF Configuration



DURRIDGE RAD7
Radon Monitor

a) Attach the filter to the tubing (push it into the end with the ⅛" ID segment)

b) Carefully remove both plastic caps from the small drying tube (you will need them later, to reseal the unit). Attach the 5/16" ID end of the tubing to one end of the tube.

c) Attach the filter to the Inlet port of the RAD7. Make sure it is firmly fit onto the inlet. The air sampling system is now set up for the measurement. While testing, you can use the small drying tube as a wand, to collect your air sample from the location of interest.

d) Plug in the RAD7 and switch on.

e) Push `[MENU]`, `[ENTER]`, then push `[➔]` four times. You should see on the LCD display: Test Purge.

f) Push `[ENTER]`. The pump should start.

g) Set up the printer.

h) Place printer between green lines on the face plate (See photo, Chapter 1.3).

i) After purging for a few minutes push `[MENU]`, and `[➔]` two times, you will see: `>Setup` on the display.

j) Push `[ENTER]` twice, then push either arrow key repeatedly until you see: `Protocol: Thoron` on the display. Push `[ENTER]`. (See Chapter 2.4.5 for difference between Thoron and Sniff protocols).

k) With Setup on the display, push `[ENTER]`, then `[➔]` seven times, to see Setup Format on the display. Push `[ENTER]` then use arrow keys to select `Format: Short`. Push `[ENTER]`.

l) Switch off the RAD7. Switch on the printer, now switch the RAD7 back on. The printer will print out something like the following:

```
DURRIDGE RAD7
Vers 3.1a   151208
Model 716
Serial 00512
Calib 21-MAY-17

Last used
   WED 23-MAY-17  17:30

Current settings
   FRI 25-MAY-17  19:09

Protocol: Thoron
Cycle: 00:05
Recycle: 00
Mode: Sniff
Thoron: On
Pump: Auto
Tone: Geiger
Format: Short
Units: pCi/L   °C
```

m) Push [MENU], [ENTER], [➔]. You should see on the LCD display: >Test Start

n) Push [ENTER]. The pump will start running. On the LCD display you will see something like:

```
0201         Live     Sniff
00:04:37              00001
```

You are now sniffing for thoron and radon. Every five minutes, the printer will print out a reading something like this:

```
0203  2.69 ± 2.83 p  Sniff
      1.68 ± 2.15 p  Thoron
   FRI  21-MAY-17     19:41
   26.8 °C   RH: 7%   B:7.06V
```

Where 0203 are the run (02) and cycle (03) numbers, 2.69 is the measured radon concentration, 2.83 is the two-sigma STATISTICAL uncertainty, p indicates the units (in this case pCi/L), and Sniff shows that, for this reading, only the Po-218 decays are being counted. The second line is the measured thoron concentration and uncertainty. The third line is now the date and time, while the fourth shows the temperature and humidity inside the measurement chamber, and the battery voltage. Medium and Long format settings print more information each cycle.

Note that the Po-218 has a 3-minute half life. After moving to a new location, it will take about 15 minutes for the count rate to reach equilibrium with the new radon concentration. So not until after the third 5-minute cycle will the reading indicate the new level. However, the thoron daughter, Po-216, has a very short half life (150 ms), so the response of the RAD7 to thoron is virtually instantaneous. For thoron, the first 5-minute cycle is as good as any other.

Thoron will only be found very close to radon entry points. That, together with its fast response, makes thoron sniffing an excellent sleuth for radon entry points.

To terminate the run any time, you may switch off the RAD7. The data collected, of completed cycles, is stored in the RAD7 memory, and available for later display, printing or downloading to a computer.

2 BASICS OF RAD7 OPERATION

2.1 Introduction

2.1.1 The Keypad

The RAD7 is operated through a four-key menu-driven interface. These four keys allow you to look at the commands, select one, and then do it.

Menu Key

Press `[MENU]` and you see the menu prompt (>) and the word Test:

```
>Test
```

Arrow Keys

Press the forward and backward arrow keys to go through the available options. To advance quickly through the options, hold down the key so that it "auto-repeats."

The arrow keys allow you to move right and left through the various commands, looking for the action you want.

Enter Key

When you have decided on a certain menu option, you select it by pressing `[ENTER]`. The enter key tells the RAD7 that you have made your selection. You are telling it what you want it to do.

The enter key makes it happen.

2.1.2 Command List

The RAD7 command list has four command groups: Test, Data, Setup and Special. The Test group of commands controls the collection of new radon data. The Data group retrieves data from memory, outputs them, and gets rid of old, unwanted data. The Setup group prepares the RAD7 to operate according to your requirements. The Special group is a set of commands that are available when RADLINK, the remote control software, is loaded.

2.2 Test

The Test group of commands controls the collection of radon data and allows you to manipulate the current test (test-in-progress). You can start and stop data collection, save or clear the current test, or print the current test as it stands. (The Test commands do not allow access to stored data. You have to go to Data for that.)

2.2.1 Test Status

To see the status display, enter the Test Status command. Press `[MENU]`, `[ENTER]`, `[ENTER]`

On the LCD display, you will see:

```
0501          Idle      Sniff
00:30:00                00000
```

On the upper left, you see the current run number/cycle number (0501 - run 05, cycle 01.).

The middle shows the detector status (Idle or Live), and the upper right gives the current test mode (Sniff, Normal or Grab). (Note that in AUTO mode, the indication will change from Sniff to Normal after three hours of measurement.

Lower left shows the count-down timer (00:30:00 = 30 minutes) which counts down to zero when the detector is Live (i.e., a test is in progress). The lower right shows the total number of counts since the beginning of the current cycle.

The arrow keys may now be used to access additional status information.

Press `[➔]` once, and you will see something like this:

```
Last reading:

0409  1.80 " 0.74 p
```

The lower left is the run number (2 digits) and cycle number (2 digits) of the last completed cycle stored to memory.

The lower right is the radon reading and two-sigma statistical uncertainty, followed by “p”, indicating picoCuries/liter, or "b" for Becquerels/ cubic meter.

When a cycle ends, the information on this display is updated. If there have been no readings yet, the display will show

```
No readings yet.
```

Press [➔] once again, and now you will see something like this:

```
24.8°C      RH:3%
B: 6.36V    P:  00mA
```

Top left is the internal temperature. (To change from Celsius to Fahrenheit, see Chapter 2.4.9, Setup Units.)

Top right shows the internal Relative Humidity reading. When testing, maintain this value at 10% or less, by using the desiccant.

Bottom left is the battery voltage. This should range from about 6.00V to 7.10V. A discharged battery (less than 6.00) should be recharged as soon as possible. A fully charged battery will rest at 6.40 to 6.50 V. During a recharge, the voltage will eventually rise above 7.00 V. At no time should this read higher than 7.20V. In the lower right is the pump current. This number should vary from 00mA (pump off) to 80mA. When the pump is running with a light load, the current will range from 40-70mA. When the pump is running with a heavy load (clogged filter or blocked hose), the current will go to 90mA or higher. Pump currents above 90mA are considered a sign of trouble. Try changing the filters and check for blockage.

Press [➔] again, and you will see something like this:

```
HV:  2218V,  10%
L:   02        S:  0.21V
```

This is a display of diagnostic values. Ordinarily it will be of little interest to you.

The top line is the high voltage reading and duty cycle. The range of normal values is from 2000 to 2500V, and from 8% to 18%.

The lower left corner is the leakage current. At room temperature, this value will normally range from 0 to 10. Higher temperatures ordinarily cause this value to rise. Excessive leakage current will result in "noise" in the lower energy end of the spectrum, and will also cause broadening of the alpha peaks.

The lower right corner is the signal voltage from the analog circuit. This number should be "stable"; that is, fluctuations should be no more than " 0.05V from the average value.

Press [➔] yet again, and you will see something like this:

```
w  |  cpm   |  +/-   |  %tot
A  |  6.0   |  4.3   |  48.8
```

This is the display for the A window data. You may press [➔] to advance to B, C, D, etc.

The RAD7 records 8 windows (A - H) every time you make a measurement. They separate counts due to daughters of radon and thoron, and the background. Specific alpha particles end up in specific windows.

W: The window letter.

cpm: The counts per minute observed in the window.

+/-: The two-sigma statistical uncertainty of the cpm value, also in units of cpm.

%tot: The number of counts in the window as a percentage of the total counts in the spectrum. This tells you quickly where the majority of the counts are: In the 3-minute radon peak (window A), or the long-lived radon peak (window C), etc.

As always, you press the [MENU] key to exit this display and return to the start of the menu.

2.2.1a Quick Save-and-Restart

This function allows the user to end a sniff test, store it to memory, and start up a new sniff test, all using a single key. It operates only from the SNIFF mode.

From the status display (showing the countdown timer), press the `[ENTER]` key once. The display will show:

```
Save and restart
? Yes
```

Press the `[ENTER]` key once more to confirm your intention. To escape, push the `[MENU]` key or push an arrow key to select “No” and push `[ENTER]`.

2.2.2 Test Start and Test Stop

To start testing (or "counting"), after you have chosen the required setup, go to `>Test Start` by pressing `[MENU]`, `[ENTER]`, `[➔]`, and then `[ENTER]`. The display will indicate that counting has begun:

```
Start counting.
```

One second later, the Status display will appear with the countdown timer in motion:

```
0501        Live     Sniff
00:29:37             00001
```

When the countdown reaches zero, the RAD7 will automatically calculate the radon concentration, store (or "save") the counts to memory, and clear the counters to begin a new cycle.

To interrupt the measurement, go to `>Test Stop`

by pressing `[MENU]`, `[ENTER]`, `[➔]`, `[ENTER]`.

The display will respond:

```
Stop counting.
```

After one second, the display will go back to the top of the menu `>Test`.

You may wish to examine the Status display to verify that the status is Idle.

To resume testing from exactly the same point in the cycle where you stopped, select `>Test Start` as described above.

Note that Stop does not terminate the run, it is a pause. If you do not wish to resume testing from the same point, you should select either `>Test Save` or `>Test Clear` before continuing. This will terminate the suspended test, store it to memory (Save) or wipe it out (Clear), and clear the counters to begin a new run.

2.2.3 Test Save

The `>Test Save` command suspends counting and saves the suspended test (test-in-progress) to memory as if it had reached completion. Test Save completes the current run, so any subsequent test data will be stored as a new run. The display momentarily shows the run and cycle number in the form of `0101 Saved`. This command may be accessed whether the status is Live or Idle. It always leaves the status Idle.

You will find this command especially useful when you wish to move the instrument to another location without waiting for the countdown to reach zero, but without losing that last incomplete cycle. The calculated radon concentration from the incomplete cycle is still good.

2.2.4 Test Clear

The `>Test Clear` command causes counting to be suspended and the current run to be completed without saving the last (suspended) incomplete cycle. Subsequent test data will be stored as a new run. You must answer Yes to the question Are you sure? in order to activate this command.

This command may be accessed whether the status is Live or Idle. It always leaves the status Idle.

2.2.5 Test Purge

The `>Test Purge` command suspends counting and begins purging the detector. The pump begins running and the high voltage circuit turns off in order to clear the sample chamber of radon gas and daughters as quickly as possible. You must provide clean, desiccated, radon-free air to the inlet in order to push out any radon that was previously sampled. Outdoor air is usually adequate for this purpose.

As always, use the inlet filter and drying tube. Ten minutes is usually sufficient for bringing the background down after exposure to moderate amounts of radon.

In order to dry out the RAD7 without using up much desiccant, connect the hoses from the RAD7 to the drying unit, as a loop. When the pump runs, the same air will circulate repeatedly through the desiccant. This procedure will efficiently remove residual moisture from the RAD7. This does not introduce any fresh air, and so does not change the radon level in the instrument, but you can make a measurement of the background while it is set up in this configuration.

To end the purge, answer `Yes` to the question `Stop purge?` which appears on the display. Alternatively, you may push `[MENU]` to end the purge.

2.2.6 Test Lock

The `>Test Lock` command activates a RAD7 security feature to prevent people from tempering with the instrument while it is in use. While the RAD7 is locked, active measurements will continue uninterrupted, but the buttons on the keypad become unresponsive.

If you select `>Test Lock` and push `[ENTER]`, the keypad will lock and the LCD display will just show:

```
DURRIDGE RAD7
```

Nobody will be able to unlock the keypad, unless they know the secret.

Switching the unit off, while locked, will stop the measurement, but the keypad will still be locked when the RAD7 is switched on again.

To unlock the keypad, hold the `[ENTER]` and both arrow keys down, all together, for 3 - 4 seconds, or until the unit beeps, then release the three keys and push `[MENU]` immediately.

The Test Lock feature should be used whenever there is a risk that an unauthorized individual might tamper with the RAD7.

2.2.7 Test Sleep

The `>Test Sleep` command allows you to turn off most of the electronic circuits, with the power switch on, in order to conserve battery charge. A fully charged RAD7 should be able to "sleep" for about one week on batteries alone. Press the menu key to "wake up" the RAD7.

The Sleep function was particularly useful for older RAD7 models that did not have the Real Time Clock (RTC) and Non-Volatile Memory (NVRAM) options. New and upgraded instruments may be shut down completely, power switch off, without losing any stored data or clock.

2.2.8 Test Print

The `>Test Print` command calculates results for an incomplete or suspended test cycle and prints them according to the print format that is currently set.

Spectrum output is available by selecting `>Setup Format Long` beforehand.

If you wish to abort printing, press the `[MENU]` key. The run number and cycle number that ordinarily appear on printed data are replaced by 0000 to signify that the cycle is not completed.

2.2.9 Test Com

The `>Test Com` command outputs the results for an incomplete test cycle to the serial port.

If you wish to abort output, press the menu key. The run number and cycle number that ordinarily appear with the data are replaced by 0000 to signify that the cycle is not completed.

2.3 Data

The Data group of commands retrieves data from memory, displays it, prints it, reports it graphically, and outputs it to the serial port. The Data group also includes commands for managing memory. The memory will hold the data for 1,000 cycles, in up to 100 runs.

Many commands in the Data group require you to enter a two-digit run number after the command. The "default" run number (the one automatically set if you do nothing) is the run number of the last complete cycle of data stored. The arrow keys allow you to select any other run number.

2.3.1 Data Read

Select `>Data Read` followed by a two-digit run number, to examine radon readings from that particular run. For example, select `>Data Read 01` to examine readings from run number 01, the first test in memory.

You will see something like this:

```
0101  23.3 ± 1.54 p
  11:45     19–MAY–17
```

Line 1 is the run/cycle number followed by the radon concentration, two-sigma uncertainty, and unit indicator. This example shows:

Run 01, Cycle 01, 23.3 ± 1.54 pCi/L.

Line 2 is the time (24-hour military time) and date the reading was completed.

Press `[➔]` to advance to the next reading in memory; press the backward arrow to go back to the previous reading.

To quit examining data, press `[ENTER]` or `[MENU]`.

Note that large numbers are presented in shorthand notation. The symbol "K" stands for 1,000 and "M" stands for 1,000,000. For example, 33K2 stands for 33,200.

2.3.2 Data Print

To print out a run of data from memory, select `>Data Print` followed by the two-digit run number. For example, to print the data from run number 05, select `>Data Print 05`.

If the printer format has been set to Short, the following printout will be made for each cycle of the run:

```
0501  2.69 ± 2.83 p  Sniff
  FRI  21–MAY–17 19:41
  26.8 °C RH: 7% B:7.06V
```

Line 1 is the run/cycle number, the radon concentration, the two-sigma uncertainty, the units indicator (p=picoCuries per liter, B=Becquerels per cubic meter), and the mode indicator.

Line 2 is the date and time that the cycle was completed and stored to memory.

Line 3 is the temperature (in either "C" Celsius or "F" Fahrenheit), relative humidity (internal), and battery voltage at the time the cycle ended.

If the printer format has been set to Medium or Long, then you will see a printout like this for each cycle:

```
0501  2.69±2.83 p Sniff
  FRI  21–MAY–17 19:41
  26.8°C RH: 7% B:7.06V
  L: 1   HV:2218V, 9%
Total Counts:   42.
Livetime:   27.8min
A: 0.53±0.08 cpm    47.3%
B: 0.02±0.02 cpm     1.7%
C: 0.52±0.08 cpm    46.4%
D: 0.01±0.02 cpm     0.9%
O: 0.04±0.03 cpm     3.6%
```

Lines 1, 2, and 3 are the same as in Short format, as outlined above.

Line 4 indicates the Leakage Current, the High Voltage, and the High Voltage Duty Cycle.

Line 5 contains the total number of counts detected during the cycle.

Line 6 is the Live Time, the time that the detector was actively collecting data.

Lines 7 through 11 are the windows data for windows A, B, C, D, and O. (O is the consolidated window for "others", or counts that are in windows E, F, G, and H.)

Each line of windows data contains the window letter (A, B, C, etc.) followed by the window's counts per minute (cpm), two-sigma statistical uncertainty of the counts per minute, and percent of the total counts included within that window.

NOTE: The RAD7 does not store spectra from previous runs, so no spectra will print from memory even if the printer format is Long. If you need a spectrum, be sure you print it before advancing to the next test.

If no data are available to print, the RAD7 will beep and display `No tests stored`.

To abort a printout, press the menu key, then press the printer paper advance button.

2.3.3 Data Com

The RAD7 has an RS232 port that can transfer data to your computer. Status must be Idle.

To send a run of data to the serial port, select `>Data Com` followed by the two-digit run number. When ready, push `[ENTER]`. The following message will appear on the display as the data is sent:

```
Data transfer ...
```

When the data transfer finishes, the RAD7 will beep.

To enable your PC to receive data, appropriate software should be running. A terminal emulation program or DURRIDGE's CAPTURE software may be used. See Chapter 6 for more details on data communication. Table 6.3.3 contains information on parsing the content of the Data Com response.

2.3.4 Data Summary

To print a summary report and time graph of a run's data, select `>Data Summary` followed by the two-digit run number. The following information will be printed:

```
Run 31
Begin 01-Jun-17   12:49
Serial      00500
Cycles = 048
Mean: 0.77 pCi/l
S.D.: 0.27 pCi/l
High: 1.41 pCi/l
Low:  0.20 pCi/l
```

where:

Line 1 is the run number.

Line 2 shows the date and time of the first reading.

Line 3 is the serial number of the instrument.

Line 4 is the number of completed cycles in the run.

Line 5 is the arithmetic mean (or "average") of the radon concentrations recorded.

Line 6 is the standard deviation of the readings taken during the run.

Lines 7 and 8 are the highest and lowest radon concentrations.

Following Line 8 is a bar graph of radon concentration through time. Time-of-day is printed along the left-hand edge of the graph. If there is only one cycle of data, the bar graph will not print.

This printout procedure has been programmed into several protocols. When you choose one of the pre-programmed protocols, this report is printed out automatically at the end of the run, together with a cumulative spectrum.

2.3.5 Data Free

To determine the amount of free memory available for storing new radon readings, select `>Data Free`, and push `[ENTER]`.

For about two seconds, the display will look something like this:

```
910 cycles free.
```

The RAD7 can store up to 999 cycles of data. As the memory fills with data, the Data Free indicator decreases. If the Data Free indicator reaches 000, any subsequent attempt to store data to memory will result in a "memory full" error.

Keep your eye on this indicator to avoid embarrassment! When the amount of free memory gets uncomfortably low (i.e. 200 or less), consider deleting un-needed old data to open up space for new data. See Data Delete and Data Erase.

2.3.6 Data Delete

To delete an entire run of data, select `>Data Delete` followed by the two-digit run number. The display will prompt you for confirmation:

```
Delete run 31?
No
```

Press `[➔]` to find `Yes`, then press `[ENTER]` to delete the run's data from memory and free the space for new data. No other run's data will be affected.

After deletion of a run's data, any attempt to retrieve the data will result in a `No tests stored` message. The main purpose of the Data Delete command is to selectively free up memory space for new tests. Do not confuse Data Delete with Data Erase, which wipes out all runs of data from memory. See also Data Free, Data Renumber, and Data Erase.

2.3.7 Data Renumber

Select `>Data Renumber` to renumber remaining runs into consecutive order after deleting one or more runs. This allows you to free up run numbers for new runs to be added, which is necessary when the run number approaches 99.

Say you have used all 99 runs and you wish to clear out some space for new runs. Furthermore, you have decided that you no longer need the data from runs 01 to 10. Delete these runs using `Data Delete`. Now select `>Data Renumber` to renumber runs. Runs 11 to 99 become runs 01 to 89, leaving 90 to 99 free to take new data.

The Data Renumber command does not free up memory space, only run numbers. The 999 cycle memory limit remains whether or not all 99 runs have been used.

2.3.8 Data Erase

Select `>Data Erase` only if you wish to completely wipe all data from the entire RAD7 memory. Data Erase deletes all runs and resets the current run/cycle number to 0101.

Select `>Data Erase`. The RAD7 will ask for confirmation:

```
Erase all Tests?  No
```

Press `[➔]` to find `Yes`. Press `[ENTER]` to complete the erasure. Use with caution!

2.4 Setup

The Setup group of commands configures the RAD7 to perform tests according to your needs. The RAD7 remembers all Setup parameters when it is turned off, so access the Setup commands only to change parameters.

Setup includes a 1-step `>Setup Protocol` command to configure the most frequently used parameters (Cycle time, Recycle number, Mode setting, and Pump setting) according to preset "protocols". These standard preset protocols include (None), Sniff, 1-day, 2-day, Weeks (that is, indefinite), User (which lets you preset your own), Grab, Wat-40 and Wat250 (for use with the RAD H_2O), and Thoron.

The special command `>Setup SavUser` defines the user protocol according to the current parameter settings.

2.4.1 Setup Protocol

Select `>Setup Protocol` to automatically load in a group of predefined Setup parameters under one of the standardized protocols, or the User protocol. If you do not wish to select a protocol, you may abort the command by pressing the menu key, and no parameters will be changed.

Table 2.4.1 Preset protocols

	Cycle	Recycle	Mode	Thoron	Pump
Sniff	00:05	00	Sniff	Off	Auto
1-day	00:30	48	Auto	Off	Auto
2-day	01:00	48	Auto	Off	Auto
Weeks	02:00	00	Auto	Off	Auto
User	xxx	xxx	xxx	xxx	xxx
Grab	00:05	04	Sniff	Off	Grab
Wat-40	00:05	04	Wat-40	Off	Grab
Wat250	00:05	04	Wat250	Off	Grab
Thoron	00:05	00	Sniff	On	Auto

A Recycle number of 00 indicates indefinite test length. The test ends only if the operator intervenes, or if the RAD7 memory fills.

2.4.2 Setup Cycle

How long a test do you want, and how often do you want the RAD7 to take a reading (a cycle)? A typical radon test is made up of many cycles.

Select `>Setup Cycle` to adjust the Cycle time, or integration time, for a single radon reading. The Cycle time can be adjusted anywhere from two minutes to 24 hours. For continuous monitoring, the Cycle time is usually 30 minutes or longer. For radon sniffing, the Cycle time is usually 5 or 10 minutes. For thoron sniffing, the cycle time may be as little as 3 minutes.

Upon selection of `>Setup Cycle`, push `[ENTER]` and you will see something like this:

```
Cycle:    00:30
```

First, select the number of hours (00 to 23), and press `[ENTER]`. Then select the number of minutes (00 to 59) and press `[ENTER]`.

Remember that a run includes many cycles in sequence, and the total duration of the radon test is determined by the Cycle time multiplied by the number of cycles, or Recycle number. To adjust the Recycle number, use the `>Setup Recycle` command.

2.4.3 Setup Recycle

How long a test do you want, and how often do you want the RAD7 to take a reading (a cycle)? You determine the length of your test by choosing both the length and number of cycles. If you make a reading every 30 minutes, you will need 48 cycles to get a 24-hour test. In this case, 48 is the Recycle number.

Use `>Setup Recycle` to set the total number of cycles in a complete run. Multiply Cycle time by Recycle number to determine the total duration of the run.

Select `>Setup Recycle`. Push `[ENTER]`

and you will see something like this:

```
Recycle:   48
```

Use the arrow keys to change the Recycle number, and press `[ENTER]` to complete the selection. Recycle number may be set from 00 to 99.

If 00 is selected, then the number of cycles is assumed to be infinite. Select 00 if you want the RAD7 to collect data indefinitely, or to go beyond the 99th cycle. After the 99th cycle, the RAD7 will then simply start a new run, and continue collecting data. Data collection will stop only when the operator intervenes, or when the memory completely fills up.

2.4.4 Setup Mode

Select `>Setup Mode` to change the RAD7 mode of operation. Five modes are available: Sniff, Auto, Wat-40, Wat-250, and Normal.

SNIFF mode is used when you want to follow rapid changes of radon concentration. In SNIFF mode, the RAD7 achieves rapid response to changing radon levels by focusing on the 3-minute polonium-218 alpha peak, calculating the radon concentration on the basis of this peak alone.

In NORMAL mode, the RAD7 achieves higher statistical precision by counting both polonium-218 and polonium-214 alpha peaks.

AUTO mode automatically switches from SNIFF mode to NORMAL mode after three hours of continuous measurement. This allows time for the equilibrium of the longer-lived radon daughter isotopes. The earliest part of the run will have the benefit of the SNIFF mode's quick response, while the latter parts of the run will benefit from the NORMAL mode's superior statistical precision.

We recommend that the AUTO mode be used for all screening tests and any tests to measure the average concentration over a period of time. With the AUTO mode there is no need to throw away the first three hours of data, or to calculate adjustments to correct for disequilibrium. The mean concentration reported in the run summary should accurately reflect the actual mean. SNIFF mode should be used where the goal is to follow, and measure, rapid changes in the radon concentration.

Wat-40 and Wat250 make calculations of the radon concentration in 40 mL and 250 mL water samples, respectively. They require the RAD H_2O water accessory kit to aerate the water under the controlled conditions necessary for these calculations.

2.4.5 Setup Thoron

Select `>Setup Thoron`. Push `[ENTER]` and you will see:

```
Thoron:   Off
```

Use the arrow keys to toggle between On and Off, and press `[ENTER]` to complete the selection.

With Thoron On, the calculated thoron concentration will be printed during continuous data logging, or in subsequent printing of data. Also, if the pump is in AUTO mode, it will be directed to pump continuously during the thoron measurement.

Note that the thoron calculation assumes a standard setup for the measurement. A small drying tube, three feet of vinyl tubing, and the inlet filter, should be used. Typically, the small drying tube is held in the hand, and used as a wand. If the laboratory drying unit is used instead of the small drying tube, it creates additional sampling delay, which allows more of the thoron to decay before reaching the RAD7, reducing the sensitivity of the measurement to about half that of the standard setup.

The only difference between Sniff protocol and Thoron protocol is that this setting, 'Setup Thoron', is Off in Sniff protocol and On in Thoron protocol (See Setup Protocol, Chapter 2.4.1).

2.4.6 Setup Pump

Select `>Setup Pump` to change the Pump setting. Four settings are available: Auto, On, Grab, and Off.

When the pump is set to Auto, it will switch on and off according to a predetermined pattern that allows for sufficient sampling of air while conserving battery charge and pump wear. Specifically, the pump will switch on for five minutes at the beginning of each new test cycle, to ensure a good initial sample. The pump will then operate on a schedule of one minute on, four minutes off, and this pattern will repeat until the end of the cycle. However if at any point the humidity reaches 10% or higher during the off period, the pump will turn back on, running for at least one minute. If the humidity is under 10% after that minute, the pump will shut off and wait for four minutes, or until the humidity creeps back up to 10%.

When the pump is set to On, it will run continuously, whether the RAD7 is counting (Live) or not (Idle).

Grab initiates a standard grab sampling sequence at the beginning of a run. When you start a new run with the pump set to Grab, the pump will run for exactly five minutes. This is followed by a five-minute equilibrium delay, after which the counting period begins. The pump does not run at all during the counting period. As usual, you can determine the length of the count period by multiplying the cycle time by the recycle number. The total time to complete a test is the pump sample time (5 minutes) plus the delay period (5 minutes) plus the count period. Note that the Grab, Wat-40 and Wat250 protocols, under `>Setup Protocol`, above, all use this pump setting.

Off means the pump is always off.

Use Auto pump setting for routine radon testing. The RAD7 has been factory calibrated with the pump in this setting.

2.4.7 Setup Tone

Select `>Setup Tone` to choose the audible tone type. Three settings are available: Off, Chime, and Geiger. Off means the beeper remains quiet. Chime means the beeper will sound only at the end of a cycle, and is otherwise silent. Geiger means the beeper will emit a chirp whenever a particle is detected, much like the familiar Geiger counter. But unlike a Geiger counter, the pitch of the chirp depends on the energy of the alpha particle. A trained ear can distinguish "old" radon from "new" radon by the sound of the chirps. The thoron beep is the highest pitch. In the Geiger setting, anyone will recognize a radon "gusher" by the rapid-fire chirping the RAD7 produces.

2.4.8 Setup Format

Select `>Setup Format` to change the way data are printed out. Four settings are available: Short, Medium, Long, and Off.

Short causes the RAD7 to print results in an abbreviated form. Three lines of printed text contain a cycle's most important data: the run/cycle number, radon concentration and two-sigma uncertainty, units and mode, time and date, temperature, relative humidity (internal), and battery voltage.

Medium and Long printouts include seven additional lines of data: total counts, livetime, and counts per minute for five alpha energy windows. These seven lines are the raw data from which the radon concentrations shown in the first line of the printout are calculated.

The Long format, when printing from a test in progress (Live) includes a graph of the alpha energy spectrum. Since spectra cannot be saved to long-term memory, the spectrum will not be printed when retrieving past data.

Off means that no data will print out at the end of each cycle, but the summary and cumulative spectrum will print at the end of the run (if the printer is set up and switched on).

2.4.9 Setup Units

Select `>Setup Units` to change the measurement units with which the RAD7 reports radon concentration and temperature. First, enter the radon concentration unit (pCi/L = picoCuries per liter, Bq/m^3 = Becquerels per cubic meter, cpm = counts per minute, #cnts = number of raw counts). Next, enter the temperature unit (F = degrees Fahrenheit, C = degrees Celsius or Centigrade).

PicoCurie is the favored unit of radon activity in the U.S., while Becquerel is the favored unit in Europe and Canada. 1 pCi/L equals 37 Bq/m^3. "Counts per minute" is the direct output of the RAD7 while "number of raw counts" is the raw direct output. With livetime, mode, and calibration factor, one can convert from any of these units to any other, but it is usually easier to let the RAD7 do the work.

The choice is retroactive. Change the unit using the `>Setup Units` command, then print out the same data. Everything will print as before, but in the new units.

2.4.10 Setup Savuser

Select `>Setup SavUser` to program the special User protocol according to the present Setup parameters. You must answer Yes, and push `[ENTER]`, to confirm that you wish to change the User protocol. The purpose of this command is to give you an opportunity to customize a protocol according to a set of favorite parameters. Thereafter, it's a cinch to return to the same set of parameters; simply select `>Setup Protocol [➔] User`.

The User protocol has many possible applications. One RAD7 owner uses her instrument for 3-day screening tests. To make the setup easy, she programs the User protocol with the parameters for a 72-hour screening test. To do this, she first sets up all the parameters as she wants them. She enters 2 hour for the Cycle time, 36 for the Recycle number, Auto for the Mode setting, Off for thoron, and Auto for the Pump setting.

Finally, to program the User protocol with these values, she selects `>Setup SavUser` and answers Yes to the confirmation question. After that, she can easily return to the 72-hour protocol by selecting `>Setup, Protocol, User,` any time she wishes.

2.4.11 Setup Clock

Use `>Setup Clock` to change time zones, go in or out of daylight savings time, or to synchronize the RAD7 clock with another clock. The Real Time Clock (RTC) will maintain time-of-day and calendar date for as long as 10 years, and is accurate to within one minute per month at room temperature.

Select `>Setup Clock` to set the time and date of the RAD7 clock. You will see:

```
Time:   15:05:34
```

The time is listed with hours first, then minutes, then seconds. The arrow keys can be used to change each value. Holding an arrow key down will cause the number to change quickly. The cursor (blinking square) will start on the hour. Set the correct number with the arrow keys, then push `[ENTER]` to confirm. Do the same for the minutes and seconds.

Next you should see:

```
Date:  13-DEC-11
```

Dates are listed with the day of the month first, then the month, then the year. As with the RAD7 clock, the date is set by using the arrow keys to change each value. Press `[ENTER]` after each figure is set to move on to the next.

2.4.12 Setup Review

The `>Setup Review` command allows you to display and print a listing of the current instrument settings, including Date and Time, Protocol, CycleTime, Recycle, Mode, Thoron, Pump, Tone, Format and Units. Thus you can check that the instrument is set up properly, and confirm this, in hard copy, right on the data printout.

2.5 Special

The Special menu offers access to a selection of additional commands, provided by the RAD7's RADLINK remote control software. If for any reason RADLINK is not present, you will see the following when entering the Special menu:

```
Not installed.
Install?   No
```

Use the arrow keys to toggle between Yes and No. If you confirm Yes, the RAD7 will sit, waiting for a data string at the RS232 port. If necessary, DURRIDGE will complete this RADLINK installation process when the RAD7 is returned for calibration.

If RADLINK is installed, then `>Special` opens a menu of special commands available from the keypad of the RAD7. All the commands, both standard and special, will also be accessible from a remote PC, either directly, or by modem connection.

The following command set are those available with RADLINK versions 0252 and later. Earlier versions will have a subset of these.

2.5.1 Special Ident

Output the RAD7 identification sequence, including firmware version, hardware model number, unit serial number, and last calibration date.

The firmware version is expressed in the format `3.1a 151208`, with the "`3.1a`" representing the firmware version number, and the "`151208`" indicating the firmware release date (e.g. December 8, 2015). This is not to be confused with the RAD7's response to the Special Version command, which outputs the RADLINK version number as explained below.

2.5.2 Special SPrOn

Re-direct subsequent output from the infrared printer to the serial port. In other words, everything that would ordinarily be printed will shoot out the serial port, but nothing will be printed, even when you say "Print". One reason to use this might be to move the data very quickly into a computer without waiting for the (slow) infrared printer link. You can cancel the re-direction order and restore the use to the infrared printer with the "Special SPrOff" command. When you turn off the RAD7 and turn it on again, it always restores output to the infrared printer.

Note that the spectra that would be printed on the infrared printer are not sent to the serial port by Special SprOn.

2.5.3 Special SPrOff

Cancel the printer to serial port re-direction, so that output can go to the printer again.

2.5.4 Special SetBaud

Set the serial port bit rate. The following standard speeds are available: 300, 600, 1200, 2400, 4800, 9600, and 19,200 bps. The other communication settings are always 8 bit, no parity, and 1 stop bit. The RAD7 remembers the serial port speed when you power down. Note that at the highest serial speed settings the RAD7 may not be able to keep up with incoming character strings unless the characters are "paced". An "echo-wait" strategy will avoid this problem. Also note that the RAD7 recognizes XOFF/XON flow control protocol when sending data.

2.5.5 Special Status

Gives a snapshot of the RAD7 status page, including run and cycle numbers, countdown timer, last reading, temperature, humidity, and so on. This is basically the same information that you can get with "Test Status", but it gives the data in one shot and does not continue to update every second.

2.5.6 Special Start

Same as "Test Start" (see Chapter 2.2.2, Test Start), but does not go into a continuously updating status display.

2.5.7 Special Stop

Same as "Test Stop" (see Chapter 2.2.2 Test Stop).

2.5.8 Special Comspec

This command outputs the current test data in the same manner as the Test Com command, but it also provides the content of the alpha energy spectrum. The spectrum information is delivered as a column of either 200 or 300 numerical values, depending on the version of RADLINK installed on the RAD7. If an older version of RADLINK is installed, 200 values will be received, with each value representing the number of counts detected at a specific energy level during the current cycle. If a new version of RADLINK is installed, 300 values will be received, encompassing the entirety of the RAD7's most recent run. In the latter case the numerical values are encoded into a hexadecimal format. CAPTURE can parse either format to generate a visual spectrum histogram.

2.5.9 Special ComAll

Output the complete set of RAD7 test data (up to 1000 readings) to the serial port in comma delimited format. Each row of data represents one test cycle. See Table 6.3.3 for information on parsing the row content.

2.5.10 Special SPrAll

Output complete set of RAD7 test data (up to 1000 readings) to the serial port in standard, readable 24 column printer format, without affecting the infrared printer.

2.5.11 Special S-Load

Used to load special software into the RAD7 through the serial port.

2.5.12 Special Version

Output the RADLINK version number, which is a three digit integer. Each firmware version requires a specific RADLINK version: firmware version 2.5f uses RADLINK 253, firmware version 3.0f and 3.0g use RADLINK 301, and firmware version 3.1a uses RADLINK 311.

2.5.13 Special Model

Output the RAD7 hardware model number. Newer RAD7s have higher model numbers, due to changes in component designs. However all RAD7s with model numbers 711 and higher, with the same firmware, have the same functionality.

2.5.14 Special Serial

Output the RAD7 unit serial number.

2.5.15 Special Beep

The RAD7 gives an audible beep tone. Does not make any sound if the tone setting is "Off".

2.5.16 Special Relays

Access the RELAYS set of commands. At the end of every cycle, if the function is enabled, the RAD7 will set or reset two external relays according to the individually set thresholds and the measured radon level. The commands consist of 'relay1', 'relay2', 'enable', and 'disable'. Use the arrow keys to scroll between these commands. Relay1 permits the user to set a level, above which the RAD7 will turn on relay1, and below which it will turn the relay off. Relay2 does the same for the second relay. 'Enable' causes the function to go into effect. Note that the command to the relays is sent after the RAD7 has finished printing data at the end of the cycle. 'Disable' stops the RAD7 from sending any commands to the relays.

2.6 Infrared Printer

The RAD7 uses an infrared link to print to the supplied printer. Note that all references to the RAD7 printer in this manual apply to the Omniprint OM1000 printer and to the Chamjin I&C New Handy printer, model 700-BT. The most significant difference between these printers and the previously supplied, now obsolete HP 82240B printer is that the HP printer had to have external 12V power supplied in order to stay awake for more than 10 minutes between printouts. The newer printer models do not accept external power.

The printer should be placed on the RAD7 face plate, between the green lines as indicated. Because the print mechanism uses thermal technology, only thermal paper will work. Detailed instructions are provided in Appendix 1 at the end of this manual.

If the printer is placed in position and switched on before switching on the RAD7, it will print out identity information and a review of the setup, before the RAD7 goes to `>Test`. It is good practice to do this if the measurement data are to be printed out, because it automatically provides a header for the data printout, with instrument identity and setup as shown.

```
DURRIDGE RAD7
Vers 3.1a   151208
Model 716
Serial 00512
Calib 20-MAY-17
Last used
   FRI 21-MAY-17  17:30

Current settings
   FRI 21-MAY-17  19:09

Protocol: 2-Day
Cycle: 00:60
Recycle: 48
Mode: Auto
Thoron: Off
Pump: Auto
Tone: Geiger
Format: Short
Units: pCi/L   °C
```

At the end of every cycle, the printer will print the data of that cycle, according to the format setting. In short format, it prints:

```
0102   2.69 ± 0.73   p   Sniff
   FRI  21-MAY-17   19:41
   26.8 °C    RH: 7%    B:7.06V
```

With the run and cycle number, radon level, two-sigma uncertainty, units and mode in the top row, date and time in the second, and temperature, humidity and battery voltage in the third.

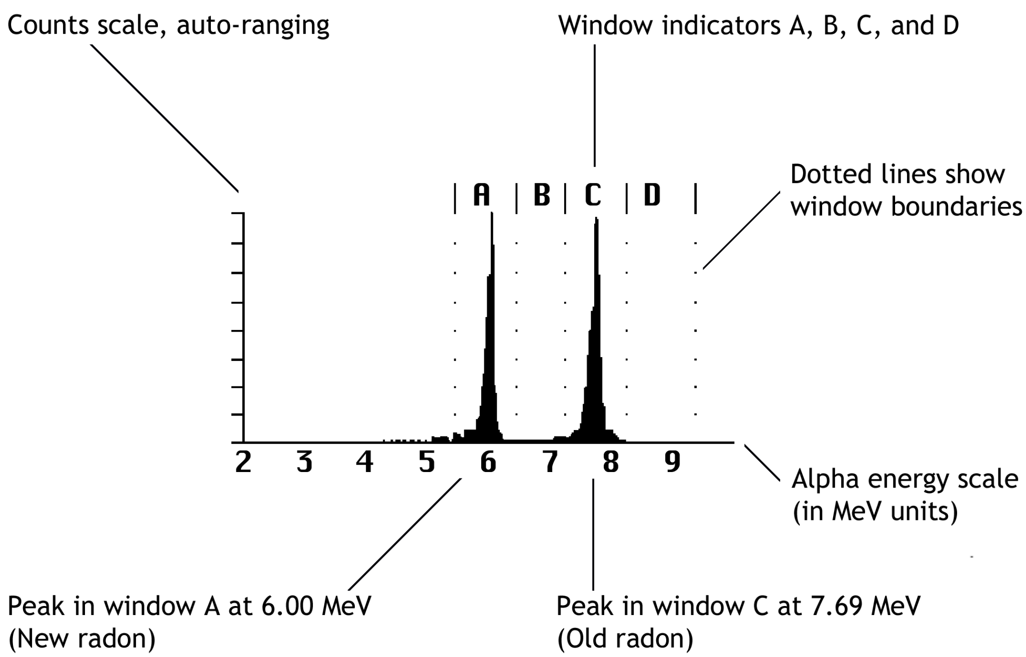
Medium format adds:

```
Total Counts:    357.
Livetime:   28.2 min
A: 5.74" 0.98 cpm 45.4%
B: 0.32" 0.29 cpm 2.5%
C: 6.13" 1.01 cpm 48.5%
D: 0.00" 0.14 cpm 0.0%
O: 0.46" 0.34 cpm 3.7%
```

Where the lifetime is the actual time spent waiting for an event, slightly less than the elapsed time. The windows, A, B, C, D, and all the rest, O (for "other"), correspond to the different alpha energies in the spectrum.

Long format adds, to the short and medium formats, a printed spectrum of the alpha energies, as shown on the following page.

At the end of a run, the printer will print a summary, see figure in Chapter 1.4. It will include an average of the radon concentrations, the high value, low value and standard deviation. These are followed by a bar chart, showing the variation of radon concentration from cycle to cycle throughout the run. Finally, it prints a cumulative spectrum, showing the distribution of energy of all the alpha decays counted during the run. This spectrum is very informative. It gives a good indication of the condition of the instrument and the quality of the measurement. It is a useful habit to look at the cumulative spectrum from time to time, just to be sure that it has not changed in character.



Alpha Energy Spectrum

3 BASICS OF RAD7 TECHNOLOGY: HOW IT WORKS

3.1 Introduction

This chapter deals with a number of fundamental facts concerning radon and thoron, their measurement in general and their measurement, specifically, with the RAD7. It is not necessary to master the underlying physics to become proficient in the use of the instrument, but some understanding of what is happening is helpful.

It is recommended that the user read the entire manual, including this chapter, on first acquiring the instrument, and then again after gaining some experience in the field.

3.2 Radon and Thoron Decay Chains

When the earth was formed, billions of years ago, there were probably many radioactive elements included in the mix of material that became the earth. Three, of interest, have survived to this day, namely uranium-235, uranium-238, and thorium-232. Each has a half life measured in billions of years, and each stands at the top of a natural radioactive decay chain.

A radioactive element is unstable. At some indeterminate moment, it will change to another element, emitting some form of radiation in the process. While it is impossible to predict exactly when the transformation of an individual atom will take place, we have a very good measure of the probability of decay, within a given time slot. If we started with a very large number of atoms of a radioactive element, we know quite precisely how long it would take before half those atoms had decayed (though we could not identify the decaying atoms individually, beforehand). This time interval is called the half-life of that particular element.

A natural radioactive transformation is accompanied by the emission of one or more of alpha, beta or gamma radiation. An alpha particle is the nucleus of a helium atom. It has two protons and two neutrons. Thus an 'alpha decay' will reduce the atomic number by two and reduce the atomic weight by four. A beta particle is an electron, with its negative charge. Thus a beta decay will increase the atomic number by one and leave the atomic weight unchanged. A gamma ray is just a packet of energy, so a gamma decay by itself would leave both the atomic number and atomic weight unchanged.

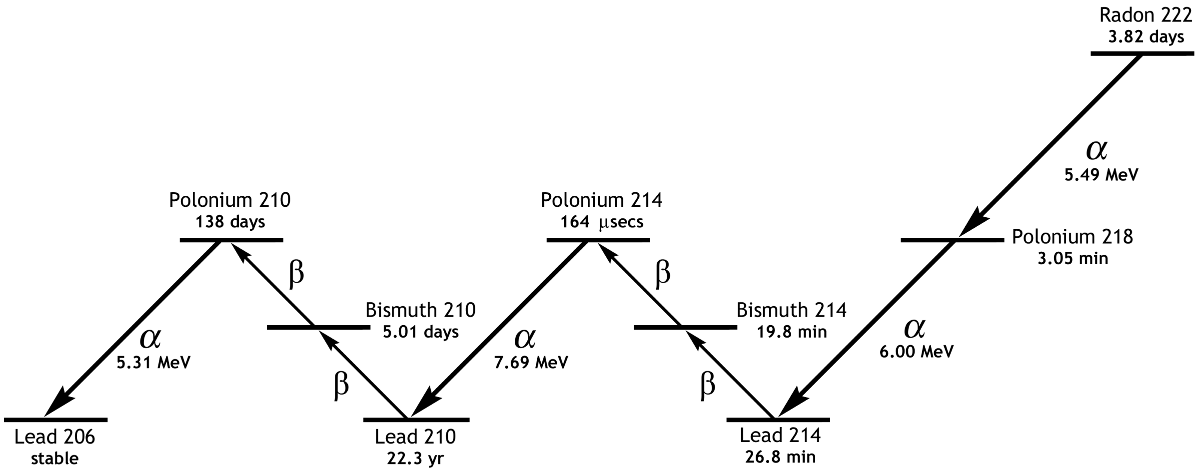
A decay chain is a series of distinct transformations. A uranium-235 nucleus goes through a series of 11 transformations to become stable lead-207. A thorium-232 nucleus goes through 10 transformations to become stable lead-208. And a uranium-238 nucleus goes through 14 transformations to become stable lead-206.

All three of these natural decay chains include isotopes of radon. Radon-219, or "actinon", is a link in the uranium-235 chain. You will probably never encounter actinon in indoor air, due to its scarcity and short half-life. Radon-220, or "thoron", is part of the thorium-232 decay chain. You will sometimes encounter thoron in indoor air, particularly near radon entry points, and, more often, in soil gas. Radon-222, or familiar "radon", is part of the uranium-238 decay chain. You will almost always be able to detect radon-222 in indoor air, outdoor air, and soil gas.

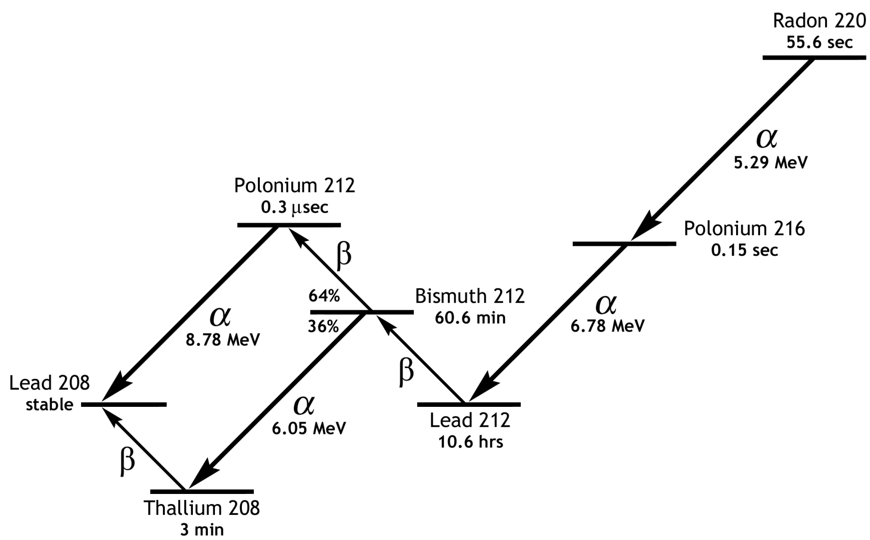
The radon isotope is the first element, in each of the decay chains, that is not a metal. It is, in fact, an inert, or "noble", gas. So it can escape any chemical compound its parent (radium) was in, and diffuse into the air.

To focus on these inert gases, the thoron and radon decay chains, shown below, are those parts of the thorium-232 and uranium-238 decay chains that include just these radioactive gases and their short-lived progeny.

It may be noted that only alpha decays change the atomic weight, and then only in steps of four. Thus the atomic weights of all the members of the radon-220, thoron, decay chain are divisible by four, while none of the radon-222 are.



Radon Decay Chain



Thoron Decay Chain

3.2.1 Radon-222 (Radon)

Every nucleus of radon-222 eventually decays through the sequence polonium-218, lead-214, bismuth-214, polonium-214, and lead-210. With each transformation along this path the nucleus emits characteristic radiations: alpha particles, beta particles, or gamma rays, or combinations of these. The RAD7 was designed to detect alpha particles only, so we will emphasize alpha radiation .

Radon-222 is an inert gaseous alpha-emitter that does not stick to or react with any materials. It has a half-life of 3.82 days. A particular radon nucleus may decay at any time, but it is most likely to decay between now and 8 days (two half-lives) from now. When the radon nucleus decays, it releases an alpha particle with 5.49 MeV of energy, and the nucleus transforms to polonium-218. The polonium nucleus can never go back to radon again. Polonium atoms are metals and tend to stick to surfaces they come in contact with, e.g., a dust particle in the air, or a wall, or the inside of your lung!

Polonium-218 nuclei have a short half-life, only 3.05 minutes, which means that most of them will decay within 6 minutes of their formation. The average polonium-218 nucleus lives for only 4.40 minutes before it decays (1.443 times the half-life gives the mean life). Like radon, polonium-218 emits an alpha particle when it decays, but with an energy of 6.00 MeV rather than radon's 5.49 MeV.

When polonium-218 decays, it transforms to lead-214, also a radioactive solid. But lead-214 has a half-life of 26.8 minutes, and it emits beta radiation rather than alpha radiation. When lead-214 decays, it becomes bismuth-214, also a radioactive solid and a beta emitter. Bismuth-214 has a half-life of 19.8 minutes, and transforms to polonium-214 when it decays.

Polonium-214 is a bit different. It has a half-life of only 164 microseconds (0.000164 seconds) and it emits a 7.69 MeV alpha particle when it decays. When polonium-214 decays, it becomes lead-210, which has a half-life of 22.3 years. This means that an average lead-210 nucleus takes 1.443 times 22.3 years, or 32.2 years, to decay. Because of its long half-life, we usually ignore lead-210 as a factor in radon measurement, though it adversely affects the background of some instruments (not the RAD7).

Lead-210 eventually undergoes beta decay to Bismuth-210 which quickly (5 days half-life) undergoes a further beta decay to Polonium-210. Polonium-210 has a half-life of 138 days and decays with a 5.30 MeV alpha particle to Lead-206, which is stable. The 5.30 MeV alpha particle from Polonium-210 creates unwanted background in most radon monitors, but not in the RAD7.

3.2.2 Radon-220 (Thoron)

Similarly to radon-222, every radon-220 (thoron) nucleus eventually decays through a sequence of 5 transformations to Lead-208. The main distinction is the very different half lives involved.

Thoron has a half life of only 55.6 seconds. It emits a 6.29 MeV alpha particle and transforms to polonium-216, which in turn has only a 0.15 second half-life before emitting a 6.78 MeV alpha particle and transforming to Lead-212.

Lead-212 hangs around for a long time, with a half-life of 10.6 hours. It transforms by beta decay to bismuth-212, which, in turn, has a half life of 60.6 min.

Bismuth-212 has a 2:1 split, with two thirds transforming by beta decay to polonium-212 and one third transforming by 6.05 MeV alpha decay to thallium-208. The polonium-212 decays immediately to lead-208, emitting an 8.78 MeV alpha particle in the process, while the thallium-208, with a half-life of 3 min, undergoes a beta decay to the same destination, lead-208.

3.3 Continuous Monitors

There are several types of continuous radon monitors on the market. Nearly all of these are designed to detect alpha radiation, but not beta or gamma radiation. Why? Because it is very difficult to build a portable detector of beta or gamma radiation that has both low background and high sensitivity.

Three types of alpha particle detectors are presently used in electronic radon monitors:

1. Scintillation cells or "Lucas cells"
2. Ion chambers
3. Solid state alpha detectors.

Each of these types has advantages and disadvantages relative to the others. All of these types can be used for low background alpha particle counting.

The DURRIDGE RAD7 uses a solid state alpha detector. A solid state detector is a semiconductor material (usually silicon) that converts alpha radiation directly to an electrical signal. One important advantage of solid state devices is ruggedness. Another advantage is the ability to electronically determine the energy of each alpha particle. This makes it possible to tell exactly which isotope (polonium-218, polonium-214, etc.) produced the radiation, so that you can immediately distinguish old radon from new radon, radon from thoron, and signal from noise. This technique, known as alpha spectrometry, is a tremendous advantage in sniffing, or grab-sampling, applications. Very few instruments other than the RAD7 are able to do this.

A distinction should be made between true, real-time continuous monitors, and other instruments and devices. With a continuous monitor, you are able to observe the variation of radon level during the period of the measurement. This can sometimes show big swings in radon concentration and may allow you to infer the presence of processes influencing the level. For good data, it is important that there be sufficient counts to provide statistically precise readings. Devices which give just a single, average reading, or whose precision is inadequate except after a long measurement time, are not, in this sense, continuous monitors.

Another important parameter is background. This is the reading given by the instrument when there is no radon in the air sample. For low level continuous monitoring, it is necessary that the background be extremely low and stable. Because of the high quality alpha detector, and unique, real-time spectral analysis, the RAD7 background is vanishingly small, and is immune to the buildup of lead-210, which plagues other instruments.

3.4 Sniffers

Sniffing means taking quick, spot readings. Thus you can get a rough idea of the radon level, without waiting for a full, 48-hour, EPA protocol test. The technique is often used to locate radon entry points in a building.

Any fast-response, continuous radon monitor, with a pump, can be used for sniffing. However, there are some factors to consider: One is the rate of recovery after exposure to high radon levels. When the sniffer finds a radon gusher, the whole radon decay chain builds up inside the instrument, and the various daughters become well populated. If the sniffer now moves to a low level region, it will take many hours for the lead/bismuth/polonium-214 daughters to decay away. In the RAD7 this doesn't matter, because, in SNIFF mode, it looks only at the polonium-218 decays, and ignores the polonium-214 decays left over from previous sniffs. The polonium-218 has a three-minute half life, so the RAD7, sniffing for radon, has a 15 minute response time to both sudden increases and sudden decreases in level.

Unique to the RAD7 is the ability to sniff for thoron. Polonium-216 has a 150 ms half life, so the instrument response is virtually instantaneous. The only delay is the time required to put the air sample into the measurement chamber, which is about 45 seconds.

Another factor, when sniffing, is the vulnerability (of other instruments) to lead-210 buildup. Only with the RAD7 can you continue to sample high levels, without having to worry about increasing the background.

3.5 Working Level

Radon concentrations are determined by measuring the radioactivity of the radon or by measuring the radioactivity of the radon decay products. Instruments that measure radon decay products in the air are called "working level" monitors. Working level monitors sample air through a fine filter and then analyze the filter for radioactivity. The radon progeny are metal and they stick to the filter and are counted by a working level instrument. Radon-222, an inert gas, passes through the filter, so it is not counted in such an instrument. Therefore, a working level instrument measures the radon progeny concentration (polonium-218, etc.), in the air, but not the radon gas concentration.

The RAD7, on the other hand, measures radon gas concentration. Radon daughters do not have any effect on the measurement. The RAD7 pulls samples of air through a fine inlet filter, which excludes the progeny, into a chamber for analysis. The radon in the RAD7 chamber decays, producing detectable alpha emitting progeny, particularly the polonium isotopes. Though the RAD7 detects progeny radiation internally, the only measurement it makes is of radon gas concentration.

In short, the RAD7 does not measure radon daughter concentrations (working levels), only radon gas concentrations.

3.6 RAD7 Solid-State Detector

The RAD7 's internal sample cell is a 0.7 liter hemisphere, coated on the inside with an electrical conductor. A solid-state, Ion-implanted, Planar, Silicon alpha detector is at the center of the hemisphere. The high voltage power circuit charges the inside conductor to a potential of 2000 to 2500V, relative to the detector, creating an electric field throughout the volume of the cell. The electric field propels positively charged particles onto the detector.

A radon-222 nucleus that decays within the cell leaves its transformed nucleus, polonium-218, as a positively charged ion. The electric field within the cell drives this positively charged ion to the detector, to which it sticks. When the short-lived polonium-218 nucleus decays upon the detector's active surface, its alpha particle has a 50% probability of entering the detector and producing an electrical signal proportional in strength to the energy of the alpha particle. Subsequent decays of the same nucleus produce beta particles, which are not detected, or alpha particles of different energy. Different isotopes have different alpha energies, and produce different strength signals in the detector.

The RAD7 amplifies, filters, and sorts the signals according to their strength. In SNIFF mode, the RAD7 uses only the polonium-218 signal to determine radon concentration, and the polonium-216 signal to determine thoron concentration, ignoring the subsequent and longer-lived radon daughters. In this way, the RAD7 achieves fast response to changes in radon concentration, and fast recovery from high concentrations.

3.6.1 RAD7 Calibration and Data Correction

The RAD7 depends on calibration to determine the radon and thoron concentrations it measures. Built into the RAD7 firmware are three sensitivities:

1. Sniff sensitivity, counting only 218-Po for fast response.
2. Normal sensitivity, counting both 218-Po and 214-Po decays for higher precision.
3. Thoron sensitivity, counting 216-Po decays for thoron.

In calibration, the RAD7 is exposed to a known concentration of radon (or thoron) and the count rates are measured. Your radon calibration certificate gives the two radon sensitivities.

For thoron calibration, a separate calibration letter gives the calibrated thoron sensitivity. If thoron calibration is not conducted, the thoron sensitivity is estimated to be half the radon Sniff sensitivity, which is usually a reasonable estimate. In either case, when making a thoron measurement the RAD7 has to be set up and used in Thoron Protocol for the thoron reading to be valid.

In addition to the bare count rates in the three windows, there are various corrections and calculations that may be applied to calculate more precise radon and thoron concentrations. Some of these corrections are made automatically by the RAD7 itself. Others are optionally applied using DURRIDGE's CAPTURE software, after the data has been downloaded onto your computer.

The RAD7's internal corrections and calculations are:

a. Spill from window C into window B. This is important when measuring thoron in the presence of radon-222. The DURRIDGE calibration system has no thoron in the sample air and it is therefore easy, during calibration, to measure the spill and calculate it as a fraction of the count rate in window C.

b. Bi-212 alpha decays occurring in the A window. This is important when measuring low radon concentrations in the presence of high thoron. The Bi-212 count rate is approximately half the Po-212 count rate, whose decays are in the D window. So, again, it is easy to measure the Po-212 count rate and use it to determine the Bi-212 count rate and consequently the correction to be applied to the 218-Po count rate in window A.

c. In WAT-40 and WAT250 protocols (used when recording RAD H_2O data), the RAD7 calculates the radon concentration of a water sample based on the radon concentration in the air loop. A known calibration factor is applied to achieve the necessary conversion.

After RAD7 data has been downloaded onto a computer, the DURRIDGE CAPTURE software can perform additional calculations and corrections:

a. B window to A window spill correction. This is important when measuring low radon levels in the presence of high thoron.

b. Humidity correction. This is essential if the desiccant becomes completely hydrated during a measurement.

c. Radon-in-water calculation. With the optional RAD AQUA and Radon-in-Water Probe, the equilibrium ratio between the radon concentration in the water and that of the air entering the RAD7 is a function of the temperature at the air/water interface. CAPTURE can be given the necessary temperature information via a data file produced by a temperature logger, or it can use the air temperature as measured by the RAD7, or it can be given a single temperature value. This temperature information is then used along with the radon-in-air readings to calculate the radon concentration of the water.

d. Meaningful thoron threshold: The spill from window C to window B produces counts that must be deducted from the B count rate before the thoron concentration can be determined, but those spill counts have statistical uncertainty. That means that a count rate in B that is slightly above the calculated spill from C may, in fact, be merely a statistical variation of the spill rather than actual thoron. The spill, therefore, increases the uncertainty in the thoron reading. CAPTURE calculates a 'meaningful thoron threshold', taking into account the statistical uncertainty in the spill, and will display this threshold on the graph if so instructed.

e. Forced Sniff mode: For long-term measurements, the RAD7 is normally put in Auto mode, in which the measurement starts in Sniff mode so as to achieve a fast initial response, before automatically switching to Normal mode after three hours, when the 214-Po decays have nearly reached equilibrium with the radon concentration. This assumes that the radon concentration is steady. If it appears that rapid changes in radon concentration were taking place, the user can, in CAPTURE, force the graph to display the data as if the RAD7 stayed in Sniff mode throughout the measurement, and thus see the rapid changes with a measurement time constant of just 12 minutes.

3.7 RAD7 Spectrum

The RAD7 spectrum is a scale of alpha energies from 0 to 10 MeV. Of particular interest are the radon and thoron daughters that produce alpha particles in the range of 6 to 9 MeV.

When the radon and thoron daughters, deposited on the surface of the detector, decay, they emit alpha particles of characteristic energy directly into the solid state detector. The detector produces an electrical signal. Electronic circuits amplify and condition the signal, then convert it to digital form. The RAD7 's microprocessor picks up the signal and stores it in a special place in its memory according to the energy of the particle. The accumulations of many signals results in a spectrum.

The RAD7 divides the spectrum's 0 to 10 MeV energy scale into a series of 200 individual counters, each representing a 0.05 MeV channel. Whenever the RAD7 detects an alpha particle, it increments one of these 200 counters by one. Every so often, the RAD7 manipulates, condenses, prints out and stores data to long-term memory. Then it resets all 200 counters to zero, and begins the process anew.

The idealized spectrum of a 6.00 MeV alpha emitter looks like a single needle-thin spike at exactly 6.00 MeV.

Although the RAD7 approaches this ideal, the actual spectrum shows a broadened peak centered at or near 6.00 MeV with a characteristic "tail" that stretches into lower energy channels. Electronic noise in the detector and amplifier causes the peaks to widen, while alpha particles that enter the detector at glancing angles cause the tail. Higher than normal operating temperatures tend to increase electronic noise, and so increase the width of the peaks.

A combination of different alpha emitters appears on the spectrum as a series of different peaks. For example, a combination of equal amounts of Po218 and Po214 (as would occur in the case of radon daughter equilibrium) appears as twin alpha peaks. One peak (Po218) is centered at 6.00 MeV, while the other (Po214) is centered at 7.69 MeV.

The second example spectrum, shown in Chapter 3.13, is the characteristic signature of radon at equilibrium with its alpha emitting daughters. We would expect to see a spectrum like this after several hours at a constant radon level. The 5.49 MeV alpha particle directly emitted by radon-222 does not appear on the RAD7 spectrum, because it was created in the air, not on the surface of the detector. The radon-222 atom is inert and electrically neutral, and cannot be attracted to the solid state detector. Only after it decays to polonium-218 does the atom become positively charged and is thus driven to the detector surface.

The RAD7 spectrum shows radon daughters, but not radon itself. Do not confuse the RAD7's spectrum with that of a working level instrument. The alpha peaks may appear the same, but the RAD7 is really measuring radon gas, not working level.

3.8 Windows

The RAD7 groups the spectrum's 200 channels into 8 separate "windows" or energy ranges. Window A, for example, covers the energy range of 5.40 to 6.40 MeV. So window A includes the 6.00 MeV alpha particle from polonium-218. The first step toward converting raw spectral data to radon measurement is to add up all the counts in each window and divide by the detector "livetime" or duration of active data collection. The RAD7 microprocessor does this task and stores the results to memory in this form. You can recall and print window data from past measurements. The RAD7 adds windows E, F, G, and H together to form window O (for "other") before storing the data to memory. Spectrum printouts clearly mark windows A, B, C, and D with dotted lines.

Each window's function:

A. Radon Sniffer Mode counts. The total counts of alpha particles from the 3-minute, 6.00 MeV, Po218 decay.

B. Thoron 1 Window. The total counts in the region of the 0.15 second, 6.78 MeV decay of Po216. This window lies between windows A and C of the radon groups and may have some counts from spill-over from adjacent windows.

C. Radon Po214 counts. The total counts of the 7.69 MeV alpha particles from the decay of the great-great granddaughter of radon, which has an effective half-life of nearly an hour.

D. Thoron 2 Window. The total counts in the region of the effective 8.78 MeV decay of Po212, which has a half-life of about 10 hours.

E. High Energy Window. A diagnostics window that normally has close to zero counts. If the counts in this window are a large fraction of the counts in A or B or C or D, the RAD7 is probably not working properly.

F. Low Noise counts. A diagnostics window that gives the total counts in the first 10 channels. The count rate in Window F is a measure of the noise in the system. The counts may be high if the RAD7 is operated at very high temperatures.

G. Medium Noise counts. A diagnostics window that gives the total count in the region around channels 30 to 40. Window G normally has few counts, even when Window F shows a high count rate.

H. High Noise or Po210 Window. The total counts in the region of the 5.31 MeV alpha particle due to Po210 (polonium-210), the grand-daughter of Pb210 (lead-210). Since lead-210 (22 year half-life) results from the decay of the radon progeny we measure, this isotope will build up on the detector's sensitive surface through sustained measurement of very high radon concentrations, or many years of normal use. This window is not used in calculating radon levels, so the RAD7 will function well even with this isotope present, and the background will not be affected.

O. Composite window for "Others". The RAD7 groups windows E, F, G, and H together to form the composite window O. Window O catches all the counts that did not go into the major windows A, B, C, and D. If window O consistently receives more than 30% of the total counts, you should inspect the spectrum printout for signs of trouble.

3.9 Isotope Equilibrium

Take a RAD7 that is completely clean, with no radon or daughters inside. What does the detector see? Close to nothing. Less than one alpha count per hour, due to unavoidable contamination of the materials of the instrument's construction. That is the instrument's intrinsic background. It is ignored by most people as of no consequence. Intrinsic background may add 0.01 pCi/L to a typical measurement, far below the radon concentration of outdoor air (usually 0.10 to 1.00 pCi/L).

Now introduce some radon into the RAD7. What do you see? At first, maybe nothing. But within a few minutes, you begin to get counts in the A window. The RAD7 chirps merrily with each count. That's polonium-218, a result of the decay of radon-222 within the RAD7 sample chamber.

For the first 5 minutes or so, the count rate increases, then begins to approach a steady level. After about 10 minutes, we say that the polonium-218 daughter has reached close to equilibrium with the radon-222 parent.

Equilibrium is when the activity of the daughter stabilizes, neither increasing or decreasing. At this point, nearly all of the counts land in window A, and you see a single peak in the spectrum printout.

But the total count rate is still increasing, more slowly now. You begin to see counts appear in window C. Just a few, but more and more of them over the course of the next hour or two. After 3 hours or so, we reach full equilibrium, when the activities of all the daughters stabilize. Now the spectrum shows the characteristic twin peaks: polonium-218 in window A and polonium-214 in window C. The peaks are of almost identical size.

Now flush the RAD7 with fresh, radon-free air. The count rate in window A immediately begins to drop, just as fast as it rose when you first put the radon in. Without radon inside the RAD7, there is no source to replace the polonium-218 that decays. So the polonium-218 disappears with its characteristic half-life of 3.05 minutes.

After 3.05 minutes, the count rate in window A is half of what it was before. After 6.10 minutes, the count rate is half of that, or one-quarter of what it was before. You get the picture. After 10 minutes, there are hardly any counts at all in window A. Not so for window C, however. The spectrum still shows a single strong peak in window C.

The peak in Window C takes hours to disappear. After half an hour, the count rate in window C has not even halved. Polonium-214 may have a very short half-life, but its parents, lead-214 and bismuth-214, certainly don't. One has a half-life of 26.8 minutes, and the other has a half-life of 19.8 minutes. And they are sequential, which makes matters worse.

After you completely remove the radon, it may be a good 3 or more hours before the counts really die down in window C. We call window C the "old radon" window, since it represents counts from radon that was present in the RAD7 an hour or more before.

The effects of time in windows B and D, is similar, but much more pronounced. There is no delay in the RAD7 to polonium-216, so the count rate in window B is always in equilibrium with the thoron gas in the measurement chamber. In contrast, there is a 10-hour half life in the decay chain down to polonium-212, so it will take days for window D to reach equilibrium. Window D is, therefore, not counted when sniffing for thoron.

Note however, that for every 66 counts in window D, there will be 34 counts in window A. This is because of the two-way split from Bismuth-212. So, in calculating radon concentration, the RAD7 corrects the counts in window A for any thoron daughters that show in window D.

3.10 Modes: Sniff and Auto

"Old" radon daughters can be a real pain in the neck if you can't tell them apart from "new" radon. Most radon monitors don't help you at all here, but the RAD7 does. Waiting around for equilibrium is also a trial if it means sitting around for more than 2 hours. It is possible to calculate your way out of that problem, but the "old" radon always comes back to bite you. With the RAD7, the solution is simple and painless. Put the RAD7 in SNIFF mode.

SNIFF mode means that the RAD7 calculates radon concentration from the data in window A only. It ignores window C. Now the instrument responds to changes almost instantaneously. Hit a "hot spot?" No problem. In SNIFF mode, you can purge the sample chamber and, in 10 minutes, you're ready to measure low levels again with reasonable accuracy. You can move from point to point in minutes, looking for radon entry points in foundation cracks or test holes.

For continuous monitoring in one location over many hours, NORMAL mode is the way to go. NORMAL mode means that the RAD7 uses both radon peaks, A and C, to calculate concentration. With double the count rate, you increase the precision of the measurement. In indoor environments, the radon concentrations rarely fluctuate quickly enough to justify using SNIFF mode for continuous monitoring.

The best of both worlds is provided by AUTO mode. Here, the RAD7 starts a test run in SNIFF mode, and then, after three hours, switches automatically to NORMAL mode. In this way, the first few cycles give readings without any bias from either "old" radon daughters left on the detector, or the slow build-up to reach equilibrium in window C, while the rest of the readings benefit from the higher precision given by twice the number of counts in each cycle.

For real-time monitoring, you are always better off to leave the mode in AUTO. The RAD7 is up to speed quickly, and is not influenced by old measurements. The final average of the run is therefore more accurate and more reliable.

CAPTURE can read a data file and force SNIFF mode presentation of the data, allowing the user to change the setting retrospectively.

Thus if, on looking at data taken in NORMAL mode, there is what appears to be a rapid change in radon concentration, changing to forced SNIFF mode presentation in CAPTURE will permit another look at the changes with better time resolution.

3.11 Background

"Background" in a radon detector refers to spurious counts that occur even in the absence of radon. Background can arise from the properties of the instrument or its components, other forms of radiation in the instrument's environment, or contamination of the instrument.

The RAD7's design makes it much less susceptible to background than other radon monitors, but one should still be aware of background in the RAD7 to avoid mistakes. The following list gives possible sources of background in the RAD7:

3.11.1 Short-lived Radon and Thoron Daughters

These are by far the most important components to background in the RAD7. Radon and thoron daughters that normally build up on the RAD7's solid state alpha detector continue to produce alpha counts for some time after the radon and thoron gases have been removed from the instrument. These lingering daughters can greatly confuse the result when you try to measure a low radon sample immediately after a high radon sample.

Many radon detectors require that you wait for the daughters to decay away (about three hours) before counting another sample. With the RAD7, however, you can go from high to low concentrations in a matter of minutes by counting in SNIFF mode, since the RAD7 distinguishes the different alpha-emitting daughters by their alpha energy. The resulting measurement responds with a 3.05 minute half-life. Thus, 10 minutes after the radon has been removed from the instrument, the background will have been reduced by more than 90% and you can count a new sample.

Thoron daughters are worse behaved than radon daughters. One thoron daughter, Lead-212, has a half-life of 10.6 hours, so that, with other radon monitors, if you build up huge amounts of this daughter, you may have to wait one to two days before using your radon instrument again. The RAD7's ability to distinguish daughters by their alpha energy almost always makes it possible to continue working.

3.11.2 Adsorbed Radon Gas

Radon atoms can adsorb on or absorb into internal surfaces of the RAD7, on the inside of tubing or on desiccant granules. This radon can stay behind after you purge the instrument, then desorb (or out-gas) from these surfaces and enter the sample cell volume. This effect is ordinarily negligible since only a small fraction of the radon ever becomes adsorbed. But at very high radon concentrations (over 1000 pCi/L), even a small fraction can be significant, and you can expect to see some lingering radon after purging the instrument.

The best solution is to purge for 10 minutes every few hours until the count rate goes down. Even in the worst possible case, the radon must decay with a 3.82 day half-life, so you will eventually be able to use the instrument again.

3.11.3 Intrinsic Background

Due to very low concentrations of alpha emitting contaminants in the materials of the RAD7's construction, you can expect to get as much as one count every two hours (0.009 cpm) without any radon present. This count rate, corresponding to about 0.02 pCi/L, is low enough to neglect when doing routine indoor radon work. But for very low-leveled outdoor radon levels, or special clean room applications, this background may be significant. With painstaking technique, and long-term monitoring, it can be measured. Very low level readings can then be corrected for background, bringing the detection threshold of the instrument down below 0.02 pCi/L.

3.11.4 Long-lived Radon Daughters

After many years of use at elevated radon levels, your RAD7's detector will accumulate lead-210, an isotope with a 22-year half-life. Though Lead-210 is itself a beta emitter, one of its daughters is polonium-210, which produces a 5.3 MeV alpha particle. The RAD7 is able to distinguish this isotope by its energy, and exclude it from all calculations. We do not expect lead-210 buildup to contribute significantly to background in the RAD7, even after years of use.

3.11.5 Contamination by Radon, or Thoron, Producing Solids

If radon- or thoron-producing solids, such as radium-226 or thorium-228, become trapped in inlet hoses or filters, they may emanate radon or thoron gas that will be carried through the filters and into the instrument. Certain dusty soils may contain enough of these isotopes to make this scenario possible. If you suspect this kind of contamination, please call DURRIDGE. We would like to discuss your experience with you and help you solve your problem.

3.11.6 Other Alpha Emitters

As long as you filter the incoming air stream, there is little or no possibility for contamination of the instrument with other alpha emitters. Virtually all solids will be stopped by the inlet filters. The only naturally-occurring alpha-emitting gas other than radon and thoron is radon-219, or "actinon." Actinon, which has a very short half-life (less than four seconds), results from the decay of naturally-occurring uranium-235. But since uranium-235 is so much less abundant than uranium-238 (the ancestor of radon-222), we do not expect to ever see actinon in significant quantities apart from even more significant quantities of radon.

3.11.7 Beta and Gamma Emitters

The RAD7's solid state alpha particle detector is almost completely insensitive to beta or gamma radiation, so there will be no interference from beta-emitting gases or from gamma radiation fields. The most likely effect of high levels of beta or gamma radiation will probably be an increase in detector leakage current and increased alpha peak width. Typical environmental levels of beta and gamma emitters have absolutely no effect on the RAD7.

3.12 Precision & Accuracy

3.12.1 Dry operation

"Precision" means exactness of measurement with regard to reliability, consistency and repeatability. "Accuracy" means exactness of measurement with regard to conformity to a measurement standard. An accurate instrument is necessarily precise, but a precise instrument can be inaccurate (due to mis-calibration, for example).

As long as the operator follows consistent procedures, counting statistics will dominate the RAD7's precision. Environmental factors have proven to be much less significant over normal ranges of operation. Aside from precision, the most important factor in RAD7 accuracy is calibration.

DURRIDGE calibrates all instruments to a set of four "master" instrument with a calibration precision of about 1%. The master instruments have been calibrated by way of inter-comparison with secondary standard radon chambers designed by the U.S. EPA. We estimate the accuracy of the master instrument to be within 4%, based on inter-comparison results. We estimate the overall calibration accuracy of your RAD7 to be better than 5%. We look forward to new developments in calibration standardization and traceability, which we expect will help improve calibration accuracy.

The table on the following page summarizes the precision of the RAD7 according to the contribution of counting statistics. Counting statistics depend on sensitivity (calibration factor) and background count rate. The RAD7's intrinsic, or "fixed," background count rate is so low as to be a negligible contributor to precision, for the range of radon concentrations covered by the table. Environmental and other factors may affect precision by as much as 2%. The uncertainty values reported by the RAD7 are estimates of precision based on counting statistics alone, and are two-sigma values, as are the values in the table on the following page.

Table: 3.12 Typical RAD7 precision based on counting statistics only.

NORMAL mode with sensitivity 0.500 cpm/(pCi/L). Table values are two-sigma uncertainty (or 95% confidence interval) in units of pCi/L (percent).

	1 pCi/L	4 pCi/L	20 pCi/L	100 pCi/L
1 hr	0.37 (37%)	0.73 (18%)	1.64 (8.2%)	3.65 (3.7%)
2 hr	0.26 (26%)	0.52 (13%)	1.15 (5.8%)	2.58 (2.6%)
6 hr	0.15 (15%)	0.30 (7.4%)	0.67 (3.4%)	1.49 (1.5%)
24 hr	0.07 (7.4%)	0.15 (3.8%)	0.33 (1.7%)	0.74 (0.7%)
48 hr	0.05 (5.3%)	0.10 (2.6%)	0.23 (1.2%)	0.53 (0.5%)
72 hr	0.04 (4.3%)	0.09 (2.1%)	0.19 (1.0%)	0.43 (0.4%)

3.12.2 Humidity Correction

Much of the superior functionality of the RAD7 is a result of the high-precision real-time spectral analysis it performs. The high resolution of the energy spectrum is obtained by precipitating the radon daughters, formed by the decay of radon, right onto the active surface of the alpha detector. The high sensitivity of the RAD7 is a result of the large collecting volume of the measurement chamber. The combination of a precipitation process and large collecting volume means that humidity inside the measurement chamber will affect the sensitivity of the instrument. The affect is a function of the absolute humidity; specifically, ions in the presence of water vapor will attract water molecules, as they are polar, until a cluster of 6 - 10 water molecules gathers around each of them. These cluster molecules move more slowly in the electrostatic field and thus there is more time for the 218-Po atoms to become neutralized en route to the detector surface, and therefore lost. So with high humidity the sensitivity of the instrument drops. In addition the high voltage (2,200V) that maintains the electrostatic field is from a high impedance source. Excessive humidity inside the chamber makes it more difficult to maintain the high insulation resistance necessary.

At normal room temperature and with good desiccant in the air sample path, the humidity in the measurement chamber at the start of a measurement will quickly be brought down below 10% RH and will eventually settle below 6%. In these conditions the collection has maximum efficiency and there is no humidity correction required. Should the desiccant expire and/or should the operating temperature rise well above normal room temperature, the absolute humidity may become significant and a humidity correction may be required to compensate for the drop in sensitivity.

While high humidity reduces the sensitivity of a RAD7, CAPTURE offers an automatic correction of the data, bringing readings back close to dry values. Please note, however, that the precision will be degraded, compared with readings taken in dry conditions. See Chapter 6.

3.12.3 Concentration Uncertainties

Obtaining accurate readings of a low radon concentrations often requires long cycle times, because when there are zero or very few counts within a given timeframe, the statistical uncertainty is proportionately high. Radioactive decays obey Poisson statistics, where the standard deviation (one-sigma) is the square root of the count. However, at very low counts Poisson statistics underestimates the uncertainty. To compensate, the RAD7 defines sigma as 1 + SQR(N+1), where N is the number of counts. Thus when there are no counts, instead of reporting a nonsensical zero uncertainty, the RAD7 reports an uncertainty value based on a two-sigma, 95% confidence interval, equivalent to +/- 4 counts for a cycle in which zero counts were recorded.

Typically, an average count rate of 0.2 cpm (i.e. one count in five minutes) would indicate a radon concentration of about 36 Bq/m^3, but sigma would be 1 + SQR(N + 1) or 2.4 counts, and the reported two-sigma value would be 4.8 counts. Thus after 5 minutes, the uncertainty would be reported as 0.96 cpm, or +/- 173 Bq/m^3.

Large uncertainty values are often the product of the fact that it is impossible to measure low radon concentrations quickly. Greater certainty can be achieved by increasing the cycle time and/or by averaging multiple cycles. In Sniff mode, 218-Po (which has a 3.05 min half life) takes more than 10 minutes to reach equilibrium with the radon concentration in the RAD7 chamber. Note that in Sniff protocol, which uses 5-minute cycles, it is important not possible to start averaging the readings to reduce uncertainty only after the first two cycles.

It is possible to measure radon and thoron concentrations simultaneously, but since their requirements are sufficiently different, it may be desirable to optimize the measurement first for one gas and then for the other.

For radon, it is advisable to select SNIFF protocol and then change the cycle time to 10 minutes. After starting a run, the first reading can be ignored, with only the second and subsequent readings being used. As more readings are recorded, more precise concentrations will be obtainable.

Occasionally, a concentration uncertainty greater than the base value may be reported, e.g. 0.00 +/- 83.1 Bq/m^3. Such values are typical for cycles containing zero counts. This should not be taken to suggest that a negative concentration may have occurred. The RAD7 does not report different positive and negative uncertainties, and it is expected that the user will recognize that the negative uncertainty can never be greater than the base value of the reading.

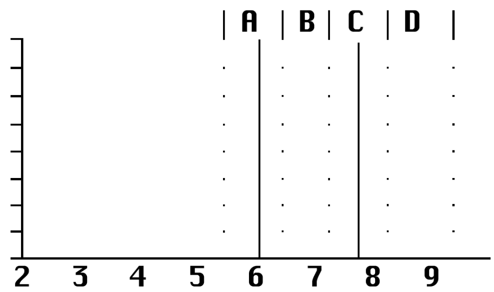
3.13 Spectrum Examples

3.13.1 Operational Radon Spectra

A. Idealized radon in equilibrium

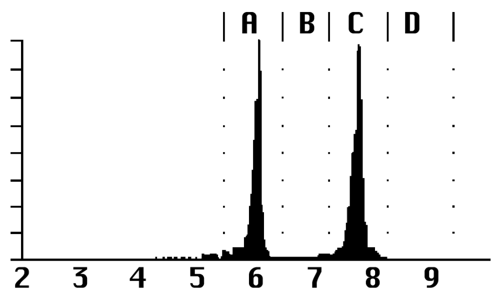
This is what you would see if both the detector and electronics reached theoretical perfection. At full equilibrium, both peaks are at the same height.

A	6.00 MeV	Po218
C	7.69 MeV	Po214



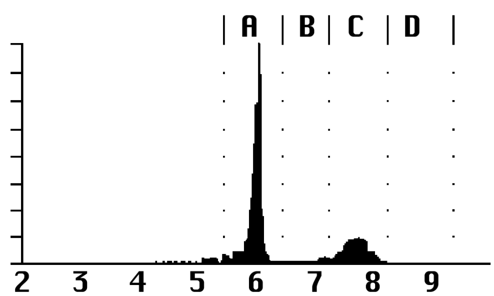
B. Radon in full equilibrium

After more than three hours at a constant radon level. The count rate in window C is about the same as in window A.



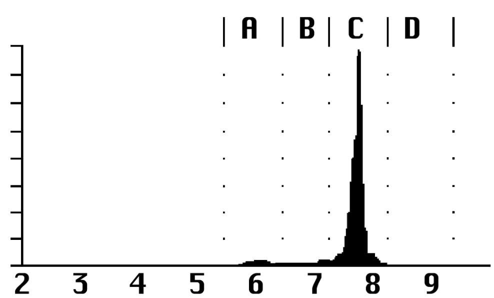
C. New radon

The RAD7 spectrum after less than one hour of exposure to radon. The peak in window C is just beginning to grow in, but its count rate is still much less than in window A.

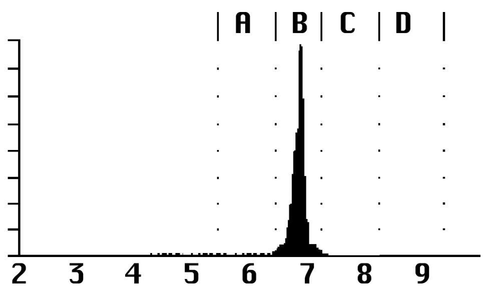


D. Old radon

The RAD7 spectrum after purging the instrument with radon-free air for more than 10 minutes, following exposure to radon.



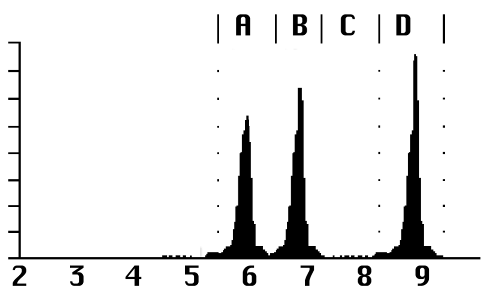
3.13.2 Thoron Spectra



A. New thoron

The RAD7 spectrum while continuously sampling thoron laden air

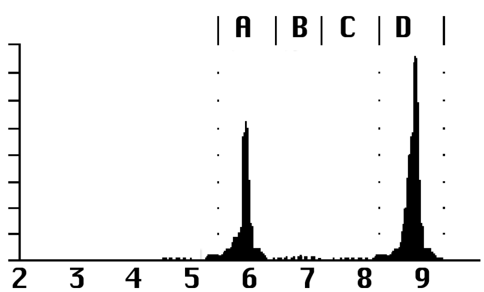
B 6.78 MeV Po216



B. Thoron in equilibrium

The spectrum after continuously sampling thoron laden air for more than 12 hours. The count rate in window A should be about half the count rate in window D

A	6.05 MeV	Bi212
B	6.78 MeV	Po216
D	8.78 MeV	Po212



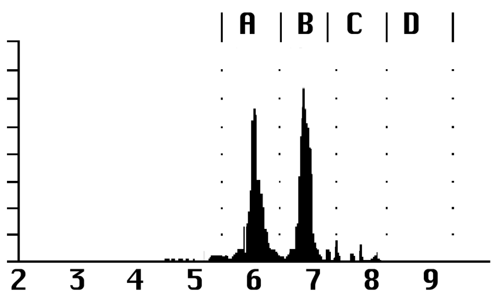
C. Old thoron

The spectrum after discontinuing a lengthy sampling of thoron laden air. The thoron peak, B, disappears immediately. The remaining two peaks decay together with a 10.6 hour half-life. The count rate in window A should be about half the count rate in window D.

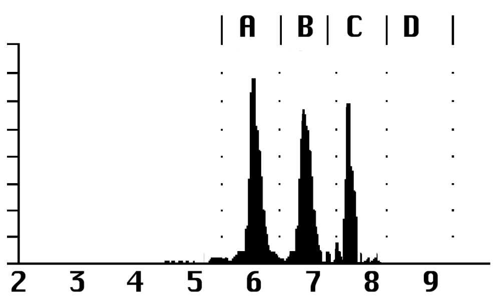
3.13.3 Combination Spectra

Radon and thoron spectra can add together to form combination spectra. Peaks in window B and/or D come from thoron, while a peak in window C comes from radon. The peak in window A is usually entirely from radon, but if there is a peak in window D, then there will a contribution of about half the D count rate to the peak in window A.

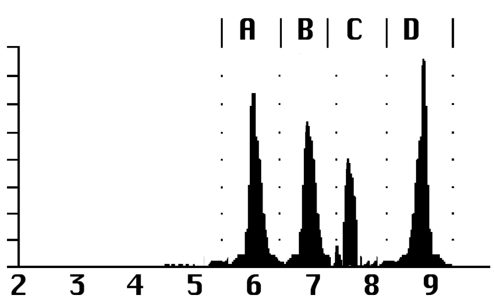
The RAD7 takes this into account, and always adjusts the window A count rate to correct for the Bi212 count, before calculating the radon concentration. The spectra below have comparable amounts of radon and thoron, but you will usually see one of the two much stronger than the other.



A. New radon with new thoron.



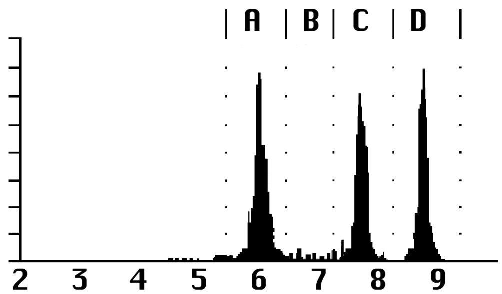
B. Equilibrium radon with new thoron



C. Equilibrium radon with equilibrium thoron.

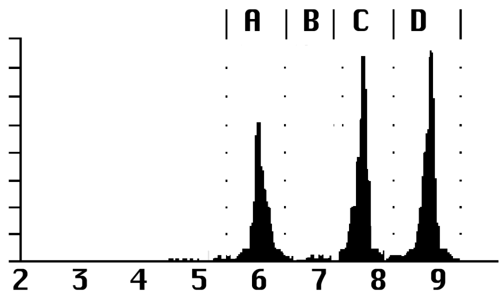
The count rate in window A is roughly the rate of window C plus half the rate of window D.

A	6.00 MeV	Po218
	+6.05 MeV	Bi212
B	6.78 MeV	Po216
C	7.69 MeV	Po214
D	8.78 MeV	Po212



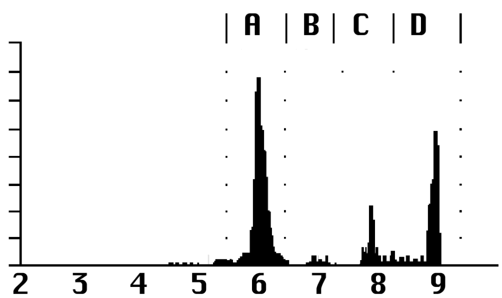
D. Equilibrium radon with old thoron

The count rate of A is roughly the rate of window C plus half the rate of window D.



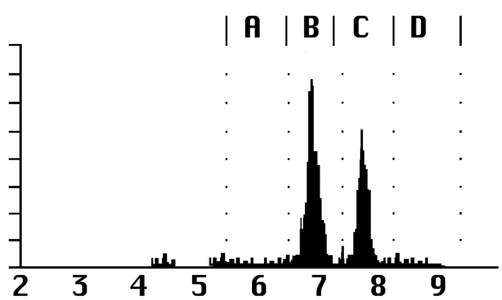
E. Old radon with old thoron.

The count rate in window A is no more than about half the count rate of window D.



F. New radon with old thoron.

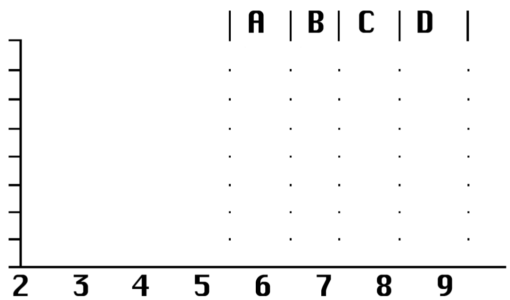
Looks like an old thoron spectrum, but the count rate of window A is significantly more than half the count rate of window D.



G. New thoron with old radon.

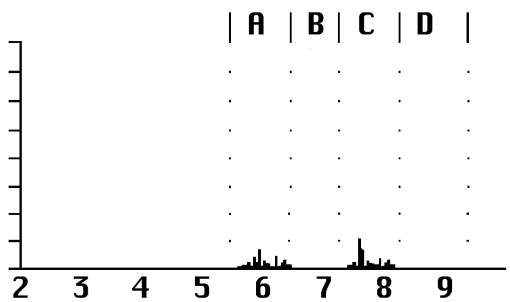
3.13.4 Pathological Spectra

If any of the following occur, and an external cause is not identified, the user should contact DURRIDGE immediately.



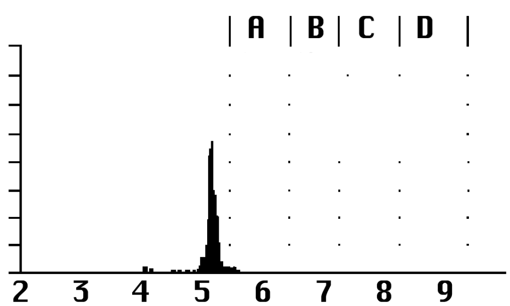
A. No counts.

Try a longer counting time. If there is not a single count in an hour, that is clear indication of instrument malfunction.



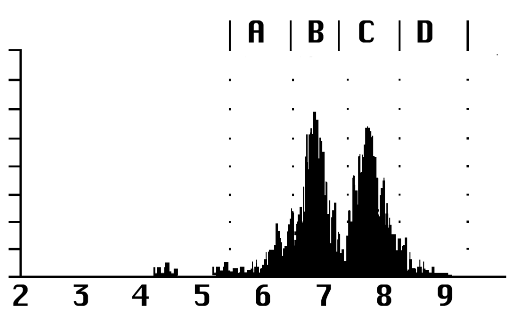
B. Few counts.

Normal for low radon levels and short counting times. Abnormally low counts could be caused by disruption of the air flow, or by malfunction in the high voltage circuit.



C. Lead-210/polonium-210.

A persistent peak at 5.3 MeV will develop from many years of regular use, or from sustained exposure to very high radon levels. It results from the buildup of lead-210 on the detector surface. Lead-210 has a 22 year half-life. It is not a problem for the RAD7 because the peak is outside window A, and thus does not contribute to the background.

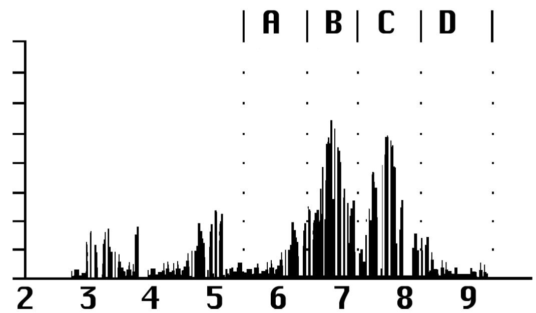


D. Wide alpha peaks.

Typically caused by electronic noise in the system. May be associated with vibration, with high operating temperature, or with degradation of the surface barrier detectors used in older model RAD7's, built prior to 1996.

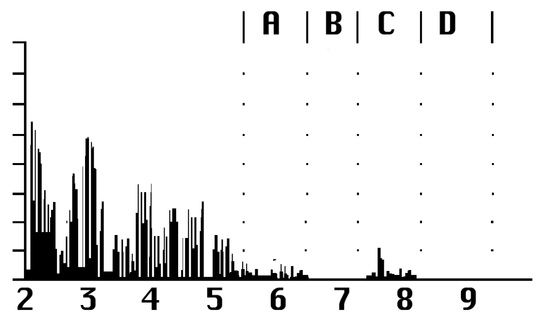
E. Smeared spectrum.

Alpha peaks cannot be discerned by the eye. Severe electronic noise.



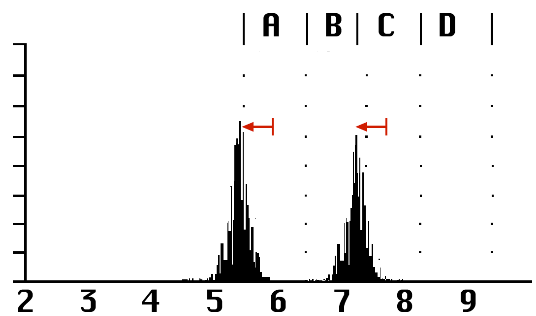
F. Low energy noise.

Independent of radon or thoron, such electronic noise may be intermittent or be associated with vibration.



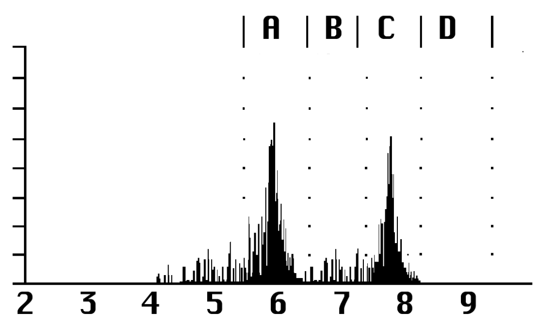
G. Shifted peaks.

Peaks appear normal, but are shifted in position. Shows a malfunction of the RAD7, which should be returned to DURRIDGE for service without delay.



H. Heavy tails on alpha peaks.

The peaks are narrow, but have unusually thick tails. This may be caused by electronic noise, or by malfunction of the alpha detector.



4 USING THE RAD7: MEASURING RADON AND THORON IN AIR

4.1 Introduction

The different ways of using the RAD7 may be arranged in six categories:

(a) continuous monitoring of radon in air

(b) sniffing for radon and/or thoron

(c) testing air grab samples

(d) measuring radon in water

(e) testing soil gas

(f) measuring radon and thoron emissions from objects and surfaces.

While all six are discussed below, it is primarily categories (a) and (d) that require standard operating procedures. The other applications tend to be more interactive, and individuals will develop protocols which work best for them. This chapter focuses on using the RAD7 to measure radon and thoron in air, without the user of special hardware accessories. Chapter 5 introduces applications involving the optional RAD AQUA, RAD H_2O, and other DURRIDGE accessories.

4.2 Continuous Monitoring

4.2.1 Preparation

The RAD7 batteries should be fully charged so that, even if there is a power cut, the test will be completed. Similarly, there should be more than sufficient active desiccant in the Laboratory Drying Unit.

For an EPA protocol test, the house should be fully closed from 12 hours before the start of the test. This means that ALL doors and windows should be shut tight. No air exchange system, or ventilation fans, may be running.

In winter it is not difficult to satisfy this requirement. Continued operation of the furnace is permitted. Closed house conditions are usually maintained anyway, to save heating costs. Doors may be opened momentarily, for access, but should otherwise remain closed during the test.

In summer it may be impossible to satisfy the requirement, without the residents moving out for the duration of the test. If doors and windows are left open, it can nullify the test, except that if there is a radon problem under these conditions, then there will be a greater problem under closed house conditions.

Air conditioning often includes some fresh air ventilation, which dilutes the radon. Even if there is no ventilation, the cold air in the house will want to sink, increasing pressure in the basement, and thus reducing any flow of soil gas into the house. So air conditioning in the summer will tend to lower the radon level in the house.

For further detailed information, see the EPA "Indoor Radon and Radon Decay Product Measurement Device Protocols" publication, EPA 402-R-92-004, or view it at http://www.epa.gov/radon/pubs/devprot1.html

4.2.2 Purging

For the RAD7 to be all set to go, ready to start a test, it should be purged for at least five minutes beforehand. This may be done in the car, en route to the test site.

Locate an inlet filter, a piece of tubing with a sleeve at one end and small tube at the other, and the laboratory drying unit. Connect the filter to the tubing: It should be a tight fit into the small diameter section. Remove the plastic caps from the drying unit and push the sleeved end of the tubing onto the tube connector, on the drying unit, farthest from the metal screw cap. Now attach the filter to the inlet of the RAD7.

Switch on the RAD7, push `[MENU]`, `[ENTER]`, [➔] four times, to see `>Test Purge` on the display, then push `[ENTER]`. The pump will start. The display will show Stop purge? No. Leave the unit purging for five minutes, or longer. When you are ready to start the test, the easiest way to stop purging is to push the Menu key, or switch off the instrument.

4.2.3 Test Location

In general, the test should be conducted in the "lowest area in the house that is used, or could be adapted for use, as a living area". This would include a full-height basement, but not a crawl space.

Place the RAD7 near the center of the room, about 3 - 4 feet above the floor. Avoid walls, vents, fireplaces, windows, draft, and direct sunlight.

Where possible, connect DC power to the RAD7, to conserve and recharge the batteries.

The air intake will be the connector of the drying unit without any tubing attached (nearest the end with the metal screw cap), or the far end of the tube if one is attached to this connector. Make sure the air intake is at least 30 inches (75 cm) above the floor, and away from the walls.

Once set up in location, let the RAD7 continue to purge until ready to start the test.

4.2.4 Test Protocol

In any location there is often a diurnal variation of radon level. It is preferable, therefore, that the test period be an exact number of whole days. The EPA protocols require an average taken over at least two days. The RAD7 gives time resolution as well. A choice must be made, therefore, of the cycle time and the number of cycles (recycle). For 24-hour and 48-hour tests, the RAD7 has preset protocols which will make the choice for you. You can always change the choices (even in the middle of a test!), and, if you wish, save your preferences as the user protocol. You may, for instance, prefer to conduct 3-day tests, and, perhaps, use 24 cycles, each 3 hours long. The longer the test, the greater the precision of the result.

For a 24-hour or 48-hour test, using the preset protocol, before starting the test, go to `>Setup Protocol` and choose `1-day` or `2-day`, and then push `[ENTER]`. You need, also, to decide whether to leave the tone Off, Chime, or Geiger, and whether to have short, medium or long format of printouts at the end of each cycle, and set the parameters accordingly.

For very long term monitoring, use the Weeks protocol. This sets the RAD7 to run indefinitely, with 2-hour cycles. The internal memory capacity, of 1,000 cycles, will last nearly 12 weeks. If data is periodically downloaded to a PC, and erased from the RAD7, there is no limit to the measurement duration. With the laboratory drying unit used to dry the sampled air, the desiccant will have to be replaced every 7 to 14 days, depending on the humidity. The RAD7 needs external power for indefinite operation, but can survive, without loss of data, an interruption of power lasting up to 50 hours, or more, depending on the condition of the batteries.

For any other measurement period, you will need to set the parameters yourself. The cycle time, times the number of recycles, gives the duration of the total measurement. In almost every case, for continuous monitoring, choose `[Mode Auto]`, `[Thoron Off]`, and `[Pump Auto]`.

Once the RAD7 switches (after three hours) to NORMAL mode, the counts are included from Window C, which come from Po-214 atoms. These were once radon atoms, that entered the measurement chamber as much as an hour or more beforehand. Therefore, in NORMAL mode, the RAD7 is averaging the radon concentration from less than 20 minutes ago (Po-218) with the radon concentration from less than three hours ago (Po-214). So, for a long test in NORMAL mode, the cycle time should be set to one hour, or more.

Where there is a requirement for a fast response and detailed time resolution, the cycle time may be set as short as half an hour, or even 20 minutes, but the Mode should then be set to Sniff, not Auto. Note however, that counting only Window A, and for such short periods, the number of counts per cycle will be less than for longer cycles in NORMAL mode, and so the individual readings will have more scatter. Note also that short cycle times will fill up the memory more quickly (the capacity is 1,000 cycles), use up the desiccant more quickly, and, if the printer is being used, produce more printout.

4.2.5 To Print Or Not To Print

It is not necessary to run the printer during a measurement as all data, except for the detailed spectra, are stored at the end of every cycle, and are available for printing or downloading to a PC at any time. Furthermore, with no printer and the keypad locked, it is impossible for any unauthorized snooper to read the radon concentration during the run. On the other hand, use of the printer gives a convenient and informative hard copy of the results. For routine continuous monitoring, it is usual to set the printer format to short (`Setup`, `Format`, `Short`, `[ENTER]`).

Place the printer on the face plate and switch on. Switch the RAD7 off, then on again. Information about the RAD7, and the setup, will print out. Data will be printed at the end of every cycle, and a summary, bar chart and cumulative spectrum will print at the end of the run.

4.2.6 Running the Test

When everything is ready, start the test (`Test`, `Start`, `[ENTER]`). The pump will start running and the LCD display will go to the first status window.

The house should remain in closed condition for the duration of the run. At any time, the status windows can be viewed. The relative humidity, temperature and battery voltage are all parameters that are worth observing. Rising relative humidity may indicate that the desiccant is exhausted, or that there is a leak in the sample path. The temperature reading gives a base for future reference, see below. A dropping battery voltage may indicate that the power is not connected.

4.2.7 Security and Quality Control

For a good measurement, it is essential that the RAD7 (or any measurement device, for that matter) remain in its place, and the house remain closed, throughout the run.

Anti-tampering tapes are available for the windows and doors. A soft, plastic adhesive, such as Blue-Tack, HOLDIT or Tac'N Stik, under the RAD7, will stick better the first time than in subsequent placings. An experienced hand can tell if the RAD7 has been moved. But perhaps the best anti-tampering defense is the data itself. With the time resolution in the data provided by the RAD7, anomalies are clearly revealed. A sudden change in radon concentration and in air temperature, during the measurement, is a strong indication of tampering, either by moving the instrument, or by opening windows. The RAD7's keypad lock feature prevents tamperers from looking at the data, or interfering with the measurement. (See Section 2.2.6, Test Lock.)

A detailed and systematic quality control protocol must be established by any user seeking certification. This should include a description of the measurement process, and the steps taken to ensure that the readings are reproducible.

The RAD7 is too accurate for any procedure in the field to be able to verify that it is working within specifications. However it is a good practice to compare the RAD7 readings with some other device, such as a passive charcoal collector. The two devices should be placed close together, with the RAD7 sampling point near to, but not touching, the charcoal collector. The tests should occur during the same time period. The charcoal reading may then be compared with the RAD7 mean for the period. Remember, however, that some charcoal devices, and labs, may give readings which are in error by as much as 25%. If the RAD7 and the charcoal device differ by more than 10%, repeat the comparison as soon as possible, preferably with a different charcoal device, from a different lab. Look at the RAD7 cumulative spectrum, printed out at the end of a run, to see if it appears normal. If the RAD7 mean is consistently, significantly different from the readings of other devices in side-by-side tests, or if the spectrum looks abnormal, please call , or email, DURRIDGE for advice. In any case, we recommend that the RAD7 be returned to DURRIDGE Company, for recalibration, annually.

An excellent test of RAD7 quality is to examine the cumulative spectrum printed at the end of every run. If the spectrum looks normal, and the humidity, temperature, and battery voltage are acceptable, the RAD7 is most likely fine.

4.2.8 Finishing the Run

Even if no printout has been made at the end of every cycle, it is still useful to have a printout at the end of the run. If the RAD7 can be accessed before the run is finished, simply place the printer in position on the face plate and switch it on. After the last cycle is completed, the RAD7 will print the run summary, including the mean value, the bar chart of all the readings, and the cumulative spectrum. If the instrument cannot be accessed before the end of the run, the summary can be printed out later, but without the cumulative spectrum.

Switch off the printer and the RAD7. Disconnect the tubing from the desiccant and replace the plastic caps over the hose connectors. If the caps have been lost, a single piece of tubing may be attached between the two connectors, thus providing a seal to keep the desiccant dry.

Remove the inlet filter from the RAD7. It is good practice to leave the inlet filter attached to the plastic tubing. Replace the short piece of tubing connecting the inlet to the outlet. Putting the jumper between the inlet and outlet keeps the internal space of the instrument sealed and thus dry, while still allowing air flow should the pump start running.

When moving the RAD7, please treat it with respect. It is rugged, but it is still an electronic instrument. Please avoid hard knocks and very harsh environments.

4.2.9 Examining the Data

In addition to the printout, data may be examined on the LCD, during or after a run. The records may also be downloaded to a PC, where they are then available for creating graphs and tables for printed reports.

On reviewing a set of data, first check that the relative humidity in the instrument stayed below 10% throughout the measurement. If it rose above 10%, it suggests that the desiccant was either removed, or became depleted. The RAD7 reads low if the internal RH rises above 10%. The temperature during the measurement should remain fairly steady. Sudden changes of temperature in the record suggest that either the windows were opened, or the RAD7 was moved to a different location.

If the house was not properly closed up until the measurement was started, you may expect to see a rising radon concentration during the first few hours of the run. If that is the case, any very low, early readings should be discarded in the calculation of the mean value for the house. That would mean manual calculation of the average, from the good readings. EPA protocols require at least 48 hours of continuous good data. If the house was not closed up beforehand, a 3-day test could satisfy the EPA requirement.

If the air sampling point was changed for a while, or some windows opened, during the run, you may expect to see a change in air temperature, and change in radon concentration, during that period. Simultaneous changes of these two parameters is an indicator of tampering.

4.2.10 Very Short Term Monitoring

Some home inspectors choose to use the RAD7 for a short-term test, just during the home inspection. This means that they have full control over the test, and they can take the RAD7 with them, when they leave, on completion of the home inspection.

They close up the house, set up the RAD7 in the basement, choose a half-hour cycle time and a total run length (recycles) of, typically, four or five cycles. At the end of the run, the RAD7 prints out a bar chart of the increasing radon concentration, at half-hour intervals. The data gives the Home Inspector, and his client, a good indication of the radon situation. Adding 50% to the final half-hour reading gives an estimate of what would be the average radon level, for closed house conditions. If, during those two hours of the test, the radon concentration climbs towards, or over, the 4 pCi/L mark, then they can be confident that, with a full 2-day EPA protocol test the result would surely exceed the 4 pCi/L action level.

4.3 Sniffing

4.3.1 Why Sniff?

There are two main reasons for sniffing. One is to obtain a quick, spot reading of radon concentration, as a simpler substitute for grab sampling, and the other is to locate radon entry points. For each application, the method will be slightly different.

4.3.2 Locating Radon Entry Points

There is a very good chance that thoron will be present in the soil gas entering the building. It will, however, be detectable only close to the entry points. Thoron, therefore, if it is in the soil gas, can be considered as a tracer for fresh radon gas. Sniffing to locate radon entry points may, therefore, be focused on detecting thoron, if it is there, to speed, and simplify, the process. The same procedure will also give radon concentrations, provided that the sampling point is kept at one spot for at least 15 minutes.

4.3.3 Preparation

Detailed instructions are given in Chapter 1.5. Choose Thoron in the Setup Protocol menu, and set the Tone to Geiger. Employ a small drying tube and, preferably, just a yard of tubing to the inlet filter.

4.3.4 Purging

While it is always good practice to purge the instrument before using it, there is less necessity before sniffing. In SNIFF protocol, the pump runs continuously, so the air sample will be flushed through every minute or two, and the measurement chamber will quickly dry out, even if the relative humidity starts above 10%.

To bring the humidity in the instrument down without wasting desiccant, the RAD7 outlet may be connected to the open end of the drying tube, making a closed loop, during the purge cycle.

After detecting high concentrations of radon and/or thoron, it is good practice to purge the instrument immediately after use.

4.3.5 Running the Test

With the RAD7 strap over one shoulder, holding the small drying tube as a wand, start the test. The first status window will be displayed in the LCD. Push the right arrow five times, to reach the B window status screen. This will show the cpm for thoron. You may also listen to the beeps, which have a different pitch for different windows. Thoron has a high-pitched beep.

Floor/wall, wall/wall and split-level seams are common locations for radon entry points. So are sumps, wells, beam pockets and utility conduits, entering the building from below ground level. It is useful, before starting the sweep, to have a sketch map of the area, with the likely culprits marked, on which to write down the readings. While making this sketch map, the RAD7 can be taking a benchmark radon measurement in the center of the room. Take at least four 5-minute-cycle readings. Later radon readings, at likely entry points, can then be compared with this benchmark.

To start the sweep, hold the small drying tube as a wand, with the open end either in, or as close as possible to, the most likely radon entry point. Keep it there for at least five minutes. If the thoron count, in window B, during this time, exceeds 2 cpm, say, then you know a) that you were right in your suspicion, and that you are, indeed, close to a radon entry point, and b) that thoron is present in the soil gas, so you can concentrate on thoron for the rest of the survey. Move the wand a foot or so in any direction to see if the window B cpm changes appreciably, in the next cycle.

If there are few or no counts in window B, then either the location is not a radon entry point, or there is no appreciable thoron in the soil gas. You must, then, keep the wand in that position for another 10 minutes, or until the counts in window A start to rise rapidly. If, after fifteen minutes, there are still only a few counts in window A, and the radon concentration, displayed at the end of the third 5-minute cycle, is still very low, then you can be confident that the position is not a radon entry point. On the other hand, a high radon concentration, without thoron, does not necessarily indicate a radon entry point if the whole basement is high. In either case, you need to note the reading on your sketch map, and move to another likely point to repeat the process, first looking for thoron.

If no thoron is found at any time, then the map of radon concentrations, will help to identify entry points. Once thoron has been detected, the whole search is made much easier. Reset the cycle time to two minutes. Spend one complete cycle at each suspected radon entry point, observing the counts in window B, or listening for the characteristic thoron beeps. You will quickly determine the location and relative strengths of the radon entry points, from the cpm in window B, for the different locations. Note that, in this procedure, you must ignore the counts in window A, because they refer to radon that entered the measurement chamber as much as 10 minutes previous to the observed counts.

Even if thoron is present at some points, there is still a possibility that there may be a radon entry point showing little or no thoron. This could occur if the path taken by the soil gas was very long, or the flow was slow. Conduit for a utility service, or a path up a hidden shaft in a wall, could delay the entry of the soil gas by several minutes. Each minute's delay halves the concentration of thoron.

4.3.6 Drilled Sampling Points

Some mitigators drill a number of test holes through the concrete slab, to sniff the soil gas beneath and to test the communication between different areas of the slab. They then install the suction points of the mitigation system where the sub-slab radon readings are highest. This approach is complementary to the search for actual radon entry points, as described above. Both methods are likely to result in a similar, final configuration of the mitigation system, though locating the entry points can also indicate where additional sealing is required.

4.3.7 Spot Readings

A spot reading may be accepted only as a rough indicator of the radon level at any location. This is not only because a short-term reading is less precise, but also because it does not average out the fluctuations in radon level through a typical day. The EPA protocol calls for a measurement to cover at least two days. Quite often, the indoor radon concentration tends to be higher in the early morning, after a cold night, and lower at the end of a warm day.

Furthermore, the radon concentration, typically, takes hours to recover from open doors and windows so, unless the house was closed up tight for many hours beforehand, the spot-reading radon level will be significantly lower than an average, taken over several days, in closed house conditions.

For this spot reading, the sampling point should be away from walls and floor. Thoron is not an issue in this measurement, so the larger, laboratory drying unit may be used, instead of a small drying tube. The cycle time may be left at five minutes. At least four, better six, cycles should be taken, of which the first two should be ignored. Alternatively, increase the cycle time to 10 minutes, or more, and ignore the first reading.

To measure a radon level of 4 pCi/L, with a standard deviation of no more than 10%, needs a run of one hour (six cycles of ten minutes, say).

4.4 Grab Sampling

4.4.1 Applicability

The ability of the RAD7 to "grab" a collected sample is useful when it is not possible to take the RAD7 to the location to be tested, or when the RAD7 is pre-occupied with continuous monitoring and will not be available until later. The Grab functionality is also useful when many samples must be gathered from different rooms of a building within a short timeframe.

However, if the RAD7 is available and can be taken to the test location, then data quality is much improved by a) monitoring the radon level over an extended period of time, such as 1-day, or, if that is not a possibility, b) making a short-term measurement such as described in Chapter 4.2.10, or else just sniffing for a spot reading, as described above.

Grab samples have the same shortcomings as spot readings. The radon concentration 'grabbed' is not representative of the EPA average level at the sampling location The precision of the reading is also limited by the short time for counting.

4.4.2 Preparation

It is important that the RAD7 be well dried out prior to accepting the grab sample. First, purge the unit with fresh, dry air for five minutes. Then connect the laboratory drying unit in a closed loop with the RAD7 so that air from the outlet passes through the desiccant and back into the inlet. Note that air should always flow the same way through the desiccant. Purge for ten minutes then check the relative humidity (push `[MENU]` `[ENTER]` `[ENTER]`, then `[➔]` `[➔]`). If the RH is not below 8%, repeat the process. Keep the pump running until ready to take the grab sample.

4.4.3 Protocol

Choose the `Setup`, `Protocol`, `Grab` menu selection, and push `[ENTER]`. This will set up all the measurement parameters correctly. For the printout, choose `Setup, Format, Short`.

4.4.4 Taking the Sample

If the RAD7 is at the location, simply start the test (`[MENU]` `[ENTER]` `[➔]` `[ENTER]`). Alternatively, samples may be taken in tedlar air sampling bags. Samples of at least five liters are required.. Any sampling pump may be used. Even the RAD7 could be used as a sampling pump, but remember to purge the instrument of old air first. These bagged samples may be connected to the RAD7 and analyzed later. Make sure there is active desiccant and the inlet filter in place, between the sample bag and the RAD7.

4.4.5 Analysis

With the grab sample source connected to the RAD7, start the test (`[MENU]` `[ENTER]` `[➔]` `[ENTER]`). The pump will run for five minutes, flushing the measurement chamber, and then stop. The RAD7 will wait for five more minutes, and then count for four 5-minute cycles. At the end of the run, the RAD7 will print out a summary, including the average radon concentration, a bar chart of the four cycles counted, and a cumulative spectrum. The measurement process takes 30 minutes. If the analysis is made more than an hour after the sample was taken, a correction must be applied for the decay of radon in the sample.

4.5 Thoron Measurement

4.5.1 Thoron and Radon

Thoron is an isotope of the element radon having an atomic mass of 220, so it is also known as radon-220. The word "radon" without a mass number almost always refers to radon-222. Thoron and radon have very similar properties. They are both chemically inert radioactive gases that occur naturally from the decay of radioactive elements in soils and minerals. Both thoron and radon are members of decay chains, or long sequences of radioactive decay.

While radon results from the decay of natural uranium, thoron results from the decay of natural thorium. Both uranium and thorium are commonly found in soils and minerals, sometimes separately, sometimes together. The radioactive gases radon and thoron that are produced in these soils and minerals can diffuse out of the material and travel long distances before they themselves decay. Both radon and thoron decay into radioactive decay products, or progeny, of polonium, lead, and bismuth before finally reaching stable forms as lead.

Thoron and radon and their respective progeny differ very significantly in their half-lives and in the energies of their radiations. While radon has a half-life of nearly 4 days, thoron has a half-life of only 55 seconds. Since thoron is so short lived, it cannot travel as far from its source as radon can before it decays. It is commonly observed that compared to that of radon gas, a much smaller fraction of the thoron gas in soil ever reaches the interior of a building. Even so, thoron can still be a hazard since its progeny include lead-212 which has a half-life of 10.6 hours, more than long enough to accumulate to significant levels in breathable air.

4.5.2 Thoron Measurement Issues

Many difficulties impede the accurate measurement of thoron gas. The presence of radon gas (often found together with thoron) can interfere with a measurement. The short half-life of thoron gas makes some aspects of the measurement easier, but makes sampling method a critical issue. Thoron concentration can vary greatly through a space, depending on the speed and direction of air movement as well as turbulence. The position of the sample intake can strongly affect the results.

In many instruments, radon and thoron interfere with each other. Generally speaking, it is difficult to measure one isotope accurately in the presence of the other. But compared to other instruments, the RAD7 is much less susceptible to radon-thoron interference due to its ability to distinguish the isotopes by their unique alpha particle energies. The RAD7 separates radon and thoron signals and counts the two isotopes at the same time with little interference from one to the other.

Some issues of concern in measuring radon do not apply to thoron. The short half-lives of thoron (55 seconds) and its first decay product (Po-216 - 0.15 seconds) mean that thoron measurements can be made quickly and in rapid succession, since there is little concern with growth and decay delays. The RAD7 responds virtually instantly to the presence of thoron; its time constant for response to thoron is less than 1 minute. The chief limit on the thoron response speed is the pump's ability to fill the internal cell. And the RAD7 clears just as rapidly when you purge the instrument with thoron-free air. In fact, you need not purge the instrument at all as thoron's short half-life ensures that it will be gone in a few minutes.

In thoron measurement the sample pump must run in a continuous fashion, at a steady consistent flow rate. If the flow rate of the sampling pump changes, then the RAD7 thoron result will also change. Flow rate affects the amount of thoron in the internal cell, since a significant fraction of the thoron decays in the sample intake system as well as within the instrument. For the most accurate thoron measurements we recommend that you use a consistent sample intake system (always use the same hose and filter arrangement) and pay special attention to air flow rate. Be sure the filters, hoses, and RAD7 inlet and outlet ports remain free from obstruction. It is recommended that the RAD7 be plugged into an external power supply and that its batteries be fully charged so that the battery voltage remains steady at close to 7V. This will ensure a high and consistent air flow rate, providing the optimal thoron sensitivity. Use a flow meter (rotameter or "floating ball" type) to check that the flow remains consistent. Note that the flow rate affects the thoron reading, but not radon due to its much longer half-life.

The RAD7 measures thoron concentration in the air at the point of sample intake. Since thoron varies from place to place depending on the motion of the air, the instrument operator may find it necessary to make measurements in several locations to properly assess a thoron situation. Fortunately, rapid-fire thoron measurements are very easy to do with the RAD7.

4.5.3 Calculation and Interference Correction

The RAD7 calculates thoron concentration on the basis of the count rate in spectrum window B which is centered on the 6.78 MeV alpha line of Po-216, the first decay product of thoron gas. To further avoid interference from radon, the RAD7 applies a correction to the thoron count rate to compensate for a small percentage of "spillover" from window C.

If the spill from window C to window B is too great relative to the base amount in window B, it becomes impossible to calculate thoron concentrations with sufficient certainty. This situation can be avoided by purging the RAD7 with fresh air and waiting with the unit turned off for two hours prior to testing for thoron. This provides enough time for the peak in window C to decay to one tenth of its original value.

The RAD7 calculates radon concentration from the count rate in window A (SNIFF mode) or windows A plus C (NORMAL mode). The RAD7 compensates for interference from the long-lived progeny of thoron (10.6 hours) by applying a correction to the radon count rate in both SNIFF and NORMAL modes. The correction is based on a fixed fraction of the count rate in the D window (around the 8.78 MeV peak of Po-212) which predicts the amount of thoron progeny activity in the A window (due to the 6.05 and 6.09 MeV peaks of Bi-212). Note that the uncertainty figures given with each reading include the effect of these corrections.

4.5.4 Avoiding Longer Lived Decay Products

Although the RAD7 now corrects for the buildup of the long-lived thoron progeny (10.6 hour), we recommend that you avoid unnecessary exposure of the instrument to high levels of thoron for long periods of time. The presence of these long-lived progeny can make low level radon measurements somewhat less accurate than would otherwise be possible. But if you err, the 10.6 hour half-life of the thoron progeny makes for a temporary inconvenience of a few days at worst.

4.5.5 Decay Correction, Flow Rate, and Thoron Calibration

As discussed above, thoron's rapid decay causes the intake path and the air flow rate to become important factors in calibration. The RAD7 factory calibration for thoron is based on a standard RAD7 inlet filter, a standard 3-foot long, 3/16 inch inner diameter vinyl hose, and a standard small (6 inch) drying tube. Deviation from this arrangement can change your thoron results. For example, if you were to use a very long hose for thoron sampling, then the sample might decay significantly before it ever reached the instrument inlet. The same thing would happen if you substituted the small drying tube with the full-sized laboratory drying unit. In that case, the thoron reading should be multiplied by a factor of approximately 2.0. Additionally, if you were to use a non-recommended inlet filter, the flow might be restricted enough to greatly lower the result.

4.5.6 Calculating Sample Decay

The thoron concentration at the inlet of the RAD7, C1, can be expressed mathematically as

$$C1 = C0 * \exp(-L * V1 / q)$$

where C0 is the original sample concentration, V1 is the volume of the sample tube + drying tube + filter (around 50 mL), q is the flow rate (around 650 mL/min), and L is the decay constant for thoron (.756 /min). A typical value for C1/C0 is then

$$C1/C0 = \exp(-.756 * 50 / 650) = 0.943 = 94.3\%$$

This is the number DURRIDGE assumes in the factory calibration. Adding a few extra feet of hose will not matter much (about 0.5% per foot), but if we were to use a 100 foot hose instead (V1 is around 580 mL) then the same calculation would give 0.509 or 50.9%, a significant reduction from 94.3%!

4.5.7 Calculating Internal Cell Concentration

The sample decays slightly in going from the RAD7 inlet to the internal cell, due to internal hose and filter volumes. This decay can be calculated in a similar fashion to the above, giving the internal cell inlet concentration, C2, about 95.5% of C1. Within the RAD7 internal cell, the equilibrium thoron concentration, C3, will be determined by the following formula:

$$C3 = C2 / (1 + L * V2 / q)$$

where L and q are as above, and V2 is the volume of the internal cell (around 750 mL). Typical values then give C3/C2 as

$$C3/C2 = 1/(1+.756 * 750/650) = .534 = 53.4\%$$

Multiplying this result by the sample decay factors calculated above, we obtain an overall concentration in the internal cell of 48.1% of the original sample. Recognizing the uncertainty of several of the inputs to these formulas, particularly the flow rate, we will round the overall result to 50%.

4.5.8 Internal Cell Thoron Sensitivity Calibration

Preliminary investigations have shown that the RAD7's internal cell thoron sensitivity in cpm/(pCi/L) is identical to its radon SNIFF mode sensitivity, to within 25%. We have no reason to expect any sizable difference between the thoron and radon SNIFF mode sensitivity values, so we are presently assuming that the two values are indeed nearly equal, and claim an uncalibrated thoron precision of +/- 30%.

With calibration against a thoron standard assessed by gamma spectrometry we are able to state the thoron sensitivity with much higher certainty. This thoron calibration is offered as an option and for this we claim an overall accuracy of +/- 20%. Otherwise we estimate the overall thoron sensitivity to be 50% of the radon Sniff sensitivity to account for sample decay in the intake and internal cell. The RAD7 has a typical radon Sniff sensitivity of 0.25 cpm/(pCi/L), so we estimate the typical thoron sensitivity to be around 0.125 cpm/(pCi/L).

4.5.9 Setting up a Thoron Measurement

Sniffing for thoron is much the same as sniffing for radon, except it tends to be a little faster. If you are just "prospecting", you probably will not be very interested in getting the most accurate results possible, so technique is not critical. But if you are trying to make an accurate measurement, technique is of great importance.

For accurate thoron measurement, always use the same sample taking arrangement. Keep the sample tubing short: no more than 6 feet (2 meters) total length. Use one of the small drying tubes supplied with the instrument, positioned vertically and filled with fresh (blue) desiccant. Always use an inlet filter, free from flow restrictions or clogs.

Avoid obstructing the intake of the sample tube.

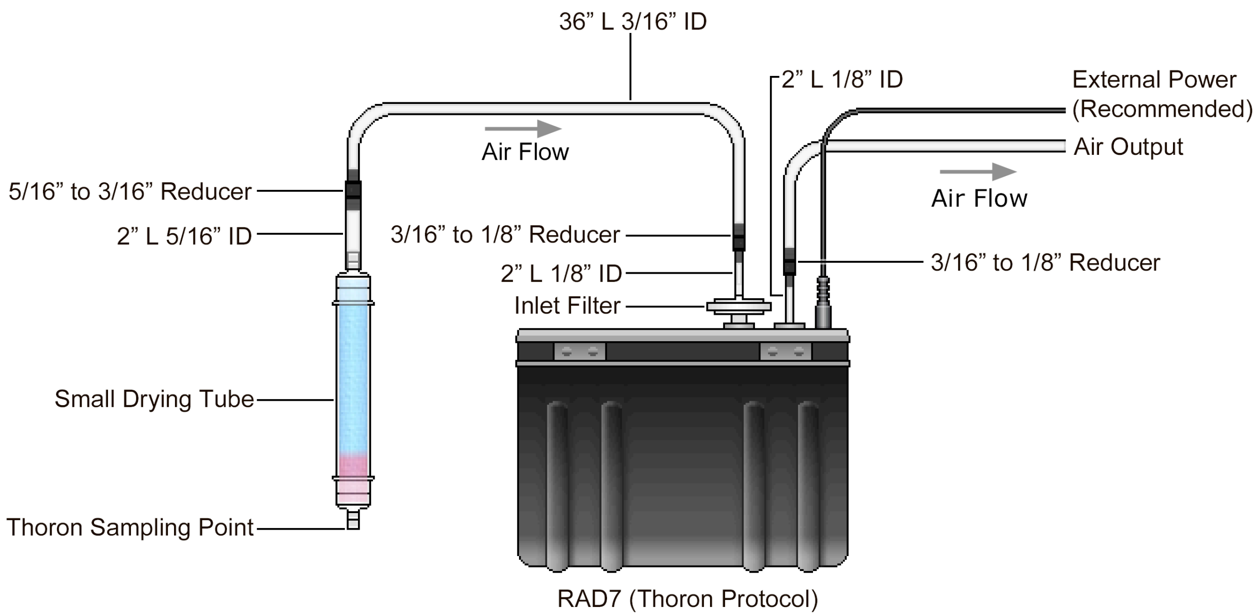
If possible, keep the RAD7 plugged in and its battery charged for optimal pump operation. The recommended configuration is pictured below. For the most accurate results, check the flow rate with a flow gauge to be sure it is consistent from measurement to measurement. Use the RAD7's Setup Protocol command to choose Thoron protocol for a 5 minute repeating cycle. Be sure the instrument has been "dried out" before making a measurement. Position the sample tube intake and start the test.

4.5.10 Thoron Mode

Thoron mode causes the RAD7 to print both thoron and radon concentrations (in pCi/L or Bq/m^3) in continuous data logging or in subsequent printing of data. Thoron mode also directs the automatic pump setting to continuous pump operation to assure a fresh sample.

The setup parameter "Setup Thoron" allows you to select Thoron mode On/Off, for configuring a particular test to perform thoron readings.

The protocol "Protocol: Thoron" provides a standard test for sniffing both radon and thoron in 5 minute cycles.



Recommended RAD7 Thoron Configuration

4.5.11 Thoron Measurements in Standard Radon Mode

When the RAD7 is configured to perform a standard radon measurement, it will detect both radon and thoron, but the thoron readings will be unreliable because most of the thoron will have decayed before it ever reached the RAD7's measurement chamber. This is because a standard radon measurement typically involves a larger drying unit and a lower average airflow rate than is stipulated for thoron measurements. However even under these unfavorable conditions it is often possible to apply adjustments to the reported thoron readings to determine the actual thoron concentration.

When the RAD7 is configured for measuring radon, a full-sized laboratory drying unit is typically used. Each cycle begins with five minutes of continuous pump activity, and then the pump typically operates for one minute in five for the remainder of the cycle. The thoron sensitivity will be about half normal (because of the laboratory drying unit) for the first five minutes, when the pump is running, and then close to 1% of normal for the rest of the cycle, due to the reduced pump activity. If the cycle is T minutes, the average thoron sensitivity will be:

(2.5 + 0.01*(T-5)) / T * Thoron Sensitivity

That means the thoron reading should be multiplied by the following factor:

T / (2.5 + 0.01*(T-5)).

Using this logic, if T is 30 minutes, then the scale factor will be around 10 or 11 times.

When RAD7 data is graphed in CAPTURE, thoron data will not be viewable on the graph by default unless the software detects that the RAD7 was configured optimally for the measurement of thoron. However thoron data can always be graphed by overruling CAPTURE's objections. More details are available in the CAPTURE user's manual.

4.6 Managing Background

A major concern in radon testing is background. The RAD7 has a number of features that help to keep short and long-term background under control. These are discussed in Chapter 3.11. Following a few simple rules will help to keep background to a minimum.

Short term background is activity left in the detector after the air sample has been flushed from the measurement chamber. The higher the radon concentration and the longer the sample is held in the cell, the more daughter activity it leaves behind. So, to avoid background, when you see high radon readings, finish your measurement, and purge the sample cell promptly. Take the instrument somewhere with little radon, such as outdoors. Make sure the drying tube is connected, and select `>Test Purge`. Let the RAD7 purge for 5 to 10 minutes, or longer if the sample was exceptionally "hot".

The two alpha peaks decay at different rates. The polonium-218 peak, in window A, decays with a 3.05 minute half-life. So in 10 minutes it will be down to about one-tenth of its original count rate. The peak in window C, however, will take over two hours to get down to one-tenth its count rate.

Rather than wait around for hours, you can start the next radon test in SNIFF mode, which ignores window C. In fact, the preset, one and two-day, monitoring protocols, in the RAD7, use AUTO mode, which starts a measurement in SNIFF mode and automatically changes to NORMAL mode after three hours. This takes care of all but extreme exposure to very high radon.

You can always measure the short-term background, with 5-minute SNIFF mode tests. Run a few to see that the background is low.

4.7 Airflow Rate Limits

When the RAD7's pump is set to OFF (`Setup, Pump, Off [ENTER]`), it is permissible to use an external pump device, such as the DRYSTIK, which may provide a higher or lower airflow rate than the RAD7's built-in pump. However certain flow rate limits should be observed.

High flow rates are useful for thoron measurement and for fast response RAD AQUA monitoring of radon and thoron in water. Low flow rates are useful for continuous soil gas monitoring and for sampling gases, such as stack gases, that need significant conditioning.

4.7.1 Maximum Airflow Rate

The maximum recommended airflow rate is 2.5L/minute. Beyond that rate the RAD7's sensitivity will eventually drop, because the very fast movement of air interferes with the electrostatic precipitation process. Airflow rates approaching the 2.5L/min limit are suitable for measuring thoron, which must be brought into the RAD7 swiftly due to its rapid decay.

If the RAD7 has been specifically calibrated for thoron however, the specified thoron sensitivity will remain in effect only when the RAD7 is configured exactly as instructed on the Thoron Calibration Certificate. Generally this entails operating the RAD7 in Thoron Protocol, causing its internal pump to run continuously, producing an airflow rate of about 800 mL/min.

4.7.2 Minimum Airflow Rate

If the RAD7's cycle time exceeds 5 minutes and its internal pump is set to Auto, the pump normally runs continuously to dry out the RAD7 until the RH drops below 10%. After that the pump runs for 5 minutes at the start of every cycle to put an entirely fresh sample into the measurement chamber, and thereafter for one minute in every five, to keep the air sample fresh. Therefore the typical average flow rate is less than 0.2L/min. For certain applications lower airflow rates may be preferred. To determine the minimum acceptable airflow rate, consider the following parameters:

a) The distance from the sample source to the RAD7 (very slow flow rates may allow significant radioactive decay of the radon before it reaches the RAD7).

b) Whether thoron is being measured (with a one-minute half life, sample decay during acquisition is significant).

c) The required response speed of the RAD7 (a low flow rate may cause an unacceptably long time to change the sample in the measurement chamber).

d) The radioactive decay during residence in the RAD7's measurement chamber.

Regarding point c), the amount of time it takes to change the measurement sample should be short compared to the required response time.

Regarding point d), the radon sample in the measurement chamber should have nearly the same concentration as the radon at the sampling point, to within a small fraction of the acceptable uncertainty. Ideally less than 1% of the original sample concentration will be lost to radioactive decay before the measurement occurs. This requires that the transit time from the sampling point plus the time that radon remains in the RAD7's chamber is less than one hour. The RAD7 has a volume of less than 1L, so a flow rate of 1L/hour, or 0.016L/min is sufficient to satisfy the residence criterion, but the response time to a step change in radon concentration at the sampling point would then be about 1 hour. For a 15min response time, the flow rate would have to be at least five times greater, or 0.08L/min.

The 3min half life of 218-Po limits the radon response time to a little less than 15 minutes, so there is little benefit in a flow rate greater than 0.1L/min unless the source is far away or thoron is being measured.

4.8 Harsh and Hazardous Environments

4.8.1 Splashing Water

Extra care should be taken to prevent water from splashing onto the RAD7 face plate or entering the instrument through the RAD7 inlet. Either situation can cause malfunctions and corrosion. If the RAD7 is to be operated in a harsh environment, such as a cave or mine, where water may splash around, the RAD7 may be protected in two ways:

a) A thin plastic film may be stretched over the face plate and down the sides of the case. It can be pushed down around the hose connectors and plugs can be pushed into data and power sockets, pushing the plastic film down around the pins. The result is to make the instrument almost waterproof.

b) The RAD7 can be enclosed in a large transparent plastic bag with the opening gathered, and held with an elastic band, around the incoming air-sample tubing.

c) The dry air from the RAD7 outlet may be exhausted to the interior of the bag, ensuring that the operating environment is clean and dry.

If water ever enters the RAD7, immediate steps should be taken to minimize the impact on the instrument. For detailed instruction see Section 8.4, Water Catastrophe.

4.8.2 Dusty Environment

Dust may contaminate the desiccant and cause elevated radon background due to radon emitted by trace amounts of radium deposited in the desiccant by the contaminating dust. To prevent this, a dust filter should be attached to the tubing at the sampling point, upstream of everything.

A suitable dust filter is supplied with every RAD7. The filter should be replaced when it becomes soiled. Replacements may be purchased from a car-parts supplier as 1960's VW Beetle in-line gasoline filters, part number 803-201-511C, or FRAM G4164, or from DURRIDGE Company.

Please note that any restriction to air flow, including a plugged dust filter, upstream of a passive DRYSTIK will reduce the effectiveness of the DRYSTIK. In a dusty environment, with a dust filter in place, an Active DRYSTIK will continue to work well even if the dust filter becomes partially blocked.

4.8.3 Radiation Hazard

If the RAD7 is to be placed in a location that is hazardous to the health of individuals, remote communication may be established through either a wireless Bluetooth connection or a local wireless network. For details please see Chapter 6, and the Long Distance Connectivity section of the CAPTURE user's manual. (The CAPTURE manual is available from within the program's Help Menu, as well as from the DURRIDGE website.)

5 USING RAD7 ACCESSORIES: TESTING SOIL AND WATER

5.1 Introduction

With the addition of various accessories offered by DURRIDGE, the RAD7 can acquire the ability to detect radon in water samples, flowing water, soil gas, hard and soft surfaces, and collected objects. These applications and the accessories required for each are described below.

The accessories discussed here are not included with the RAD7. For full details on the usage of a given accessory, please see its user manual. All product manuals are available in print form, and on the DURRIDGE website (www.durridge.com) in PDF format.

The RAD H_2O Accessory

5.2 Radon in Water

5.2.1 The RAD H_2O and Big Bottle Systems

The RAD H_2O is an accessory for the RAD7 that enables you to measure collected water samples to detect radon with high accuracy over a wide range of concentrations, obtaining your reading within an hour of taking the sample. It is particularly suited for well water testing, where immediate results are often required.

The RAD H_2O uses a standard, pre-calibrated degassing system and pre-set protocols, built into the RAD7, which give a direct reading of the radon concentration in the water sample itself. The method is in fact a special variation of the grab sampling method described in the previous chapter.

The most widely supported sample sizes are 40 mL and 250 mL, as these correspond to the RAD7's built-in Wat-40 and Wat250 protocols. Large water samples of up to 2.5L may be sampled using a separate product, the Big Bottle System, in which radon concentrations are calculated using the provided CAPTURE software for Windows and macOS.

The RAD H_2O and Big Bottle System manuals contain further information on these products.

The RAD AQUA Accessory

5.2.2 The RAD AQUA Accessory

The RAD AQUA accessory handles the continuous monitoring of radon in water, offering accurate results in as little as half an hour. Applications for the RAD AQUA include testing water from running faucets and water being pumped from the bottom of a lake. In addition to its rapid response time, the RAD AQUA offers a high degree of sensitivity.

The RAD AQUA functions by bringing air into equilibrium with water passing through an exchanger in a closed loop. During this process, the RAD7 is set to operate in continuous mode, as described in Chapter 4.2.

Since the equilibrium ratio of radon in air to radon in water is affected by temperature, a temperature probe is used to collect water temperature data, and DURRIDGE CAPTURE software for Windows and macOS later accesses the RAD7 data and the water temperature data and calculates the final radon in water readings.

Users are encouraged to refer to the RAD AQUA manual for further details.

5.2.3 The WATER PROBE Accessory

The Water Probe is used to collect radon samples from large bodies of water. The probe consists of a semi-permeable membrane tube mounted on an open wire frame. The tube is placed in a closed loop with the RAD7.

When the probe is lowered into water, radon passes through the membrane until the radon concentration of the air in the loop is in equilibrium with that of the water. As with the RAD AQUA, the RAD7 data and water temperature data are collected simultaneously and accessed by CAPTURE to determine the final result.

As compared to the RAD AQUA, the Water Probe takes longer to make a spot measurement. However it does not require a pump, so power requirements are reduced.

5.3 Soil Gas Sampling

5.3.1 Application

The radon concentration in the soil gas surrounding a house is one of many parameters that impact radon health risk. The construction of the house, the porosity of the soil, the height of the water table, and several other factors are all important. Even if there is no radon in the surrounding soil, the house may still be at risk if it has a well in the basement, or is built on rock, over a fissure. Regardless, it is often of interest to determine the radon concentration in soil gas.

Thoron is usually associated with radon in the soil. When measuring soil gas, it is therefore particularly useful to determine the thoron content as well as the radon content. Should there be significant thoron, it may be used as a tracer, to find radon entry points inside the house. See Chapter 4.3.2 for details.

5.3.2 The Soil Gas Probe Accessory

The cost and complexity of a soil gas probe increases with the depth to which it can be inserted. A variety of probes are available from DURRIDGE, the simplest of which will penetrate to a depth of 3 feet.

5.3.3 Soil Gas Probe Preparation

For full details on using a soil gas probe, please refer to the appropriate user's manual found at the DURRIDGE website (www.durridge.com). The basic procedure can be summarized as follows.

Insert the soil probe. Make sure that there is a reasonable seal between the probe shaft and the surrounding soil, so that ambient air does not descend around the probe and dilute the soil gas sample.

Between the probe and the RAD7, connect the included water trap (which could be just a jar with two air-tight hose connectors in the lid). Then connect the laboratory drying unit, and the inlet filter. A water trap is included in the package when the DURRIDGE soil gas probe is purchased.

Set the protocol to Sniff. Soil gas is normally so high in radon that it is not necessary to use long cycle times to gain precision. Five minute cycle times are sufficient.

5.3.4 Running the Test

Start the test. (`Test, Start, [ENTER]`). On the LCD screen you will see the first status window. Push the right arrow twice and the screen will display the temperature, relative humidity, battery voltage and pump current. Pay particular attention to the relative humidity and pump current. The humidity should gradually drop down to below 10%, and stay there.

If the pump current starts to rise much above 100 mA, it suggests that the soil is not porous, in which case it may be that a good soil gas sample cannot be drawn, no matter how powerful the pump is. With the RAD7 pump current above 100 mA, the air flow rate will be significantly reduced from the nominal 1L/min. This will not affect the radon reading, but will reduce the effective sensitivity to thoron, as more of the thoron will decay en route to the RAD7. If desired, an additional pump may be used, but it should be placed upstream of the RAD7, so that the RAD7 is operating at normal pressure. In fact, with an external sampling pump in use, the RAD7 pump can even be switched off altogether.

5.3.5 Interpreting the Data

As with any Sniff test, the first two 5-minute cycles should be ignored. The next one or two cycles should be averaged, to arrive at the radon concentration of the soil gas.

For thoron, some estimate has to be made of the time taken for the sample, after it has left the soil, to reach the RAD7. This requires an estimate of the volume of the sample path, including the probe, water trap, tubing and drying unit, and an estimate, or measurement, of the flow rate. For example, if the total volume of the sample path is 2L, and the flow rate is 0.5L/min, then the sample delay is about 4 minutes. If the thoron decays by half every minute, then after four minutes the concentration will be just 1/16th of the concentration in the ground. So, the thoron concentration measured by the RAD7 would be multiplied by 16.

5.4 Emission Measurements

5.4.1 Application

With its internal pump, sealed sample path, and inlet and outlet connectors, the RAD7 is well suited to the measurement of radon emissions from objects and surfaces. Furthermore, the ability to count only the polonium-218 decays means that dynamic measurements are clean, and not complicated by long-half-life events.

5.4.2 Open Loop Configuration

Emissions may be sampled from collected objects using DURRIDGE's Bulk Emission Chamber. It is also possible to analyze emissions from soft or hard surfaces, with the aid of a DURRIDGE Surface Emission Chamber, which consists of a plate-like enclosure capable of forming a tight seal around the surface in question. In both cases the RAD7 draws air from within the enclosed space, through the desiccant and inlet filter, and into the measurement chamber. The air may then be returned to the enclosure from the RAD7 outlet, to form a closed loop. Alternatively, in an open loop configuration the air being drawn from the enclosure may be replaced with 'zero' air from a cylinder, or with ambient air, which should have a low but known radon concentration.

With the open loop configuration, a steady and known flow rate must be established. If a cylinder of 'zero' air, or nitrogen, is used, then the RAD7's internal pump may be set to Off, and a pressure reduction valve and needle valve may be used to control the flow rate. With ambient air, the RAD7's internal pump may be set to On, for a continuous flow. In both cases, a flow meter is required. Once a steady state has been achieved, a long-term measurement may be made. The rate of emission will equal the increase in radon concentration times the flow rate. The precision will depend on the radon concentration and the duration of the measurement.

5.4.3 Closed Loop Configuration

In a closed-loop configuration, the system is first purged, then sealed. Next the radon concentration within the loop is monitored in SNIFF mode, with short, e.g. 15 min., cycle times, for a few hours. It is necessary to know the total volume of the closed-loop system. For this purpose the volume inside the RAD7 may be taken as 800 mL. The initial rate of increase in radon concentration (neglecting the first 15-min cycle), multiplied by the volume, gives the rate of radon emission. A reduction in the slope, as the radon level builds up, may be due to leaks in the system, or to a reduction in the net emission.

DURRIDGE's CAPTURE software can be used to view a graph slope line and inspect the change in radon concentration over time. The line should be set to begin after the initial response delay and before any observable drop from either leakage or decay. CAPTURE will express the slope of the line in the units of your choice.

5.4.4 Very Low Emission Rates

Very low emission rates can be measured by placing the sample in an airtight container with sealable inlet and outlet valves, and allowing the ingrowth of radon to occur over at least a week (after which the ingrowth must be calculated) and preferably a month or more (after which the ingrowth may be assumed to have reached equilibrium). The container is then connected to the RAD7 in a closed loop. The valves are opened and the RAD7 measures the radon concentration. The concentration rises as the radon is distributed around the loop. Eventually the concentration will settle to a slowly decreasing value.

5.4.5 Bulk Emissions

The DURRIDGE Bulk Emission Chamber is an airtight box with two well separated hose connectors. The material to be tested is placed in the chamber, which is then connected to the laboratory drying unit, and thence to the inlet filter on the RAD7. The other box connector has tubing attached, which is either connected to the RAD7 outlet for closed-loop operation, or to a cylinder of zero gas or ambient air.

Note that bulk emissions are affected by pressure fluctuations and by temperature and humidity. All these parameters can and should be controlled in both the closed-loop and open-loop configurations. Radon emission is also dependent on the grain size of loose materials, and the porosity of any bulk material.

In addition to radon, thoron can also be measured in the Bulk Emission Chamber. In the open loop mode, a correction is required for the decay of the thoron during the time between its emission and measurement in the RAD7. In closed loop mode, another correction must be made for the portion of thoron that gets fed back to the enclosure. Note that for thoron, both the closed loop and open loop modes are steady-state measurements.

5.4.6 Surface Emission

DURRIDGE offers two surface emission chambers, one for solid hard surfaces, and another for soft soil surfaces. Each consists of an circular plate which is sealed against the surface under investigation. The Solid Surface Emission Chamber accomplishes this using a rubber seal, while the Soil Surface Emission Chamber uses a penetrating metal rim.

The measurement procedure is similar to that of the Bulk Emission Chamber described above. Once the total emission rate within the enclosure has been calculated, it may be divided by the area of the surface within the sealed boundary, to determine the emission per unit area.

The Bulk Emission Chamber

The Surface Emission Chamber

5.5 Supporting Accessories

5.5.1 Overview

DURRIDGE offers additional RAD7 accessories which improve the accuracy of radon and thoron reporting by optimizing operating conditions.

The RAD7 is able to detect radon in concentrations of up to 20,000 pCi/L (750,000 Bq/m^3). For applications involving higher concentrations of radon, DURRIDGE offers the Range Extender, a device which removes 90% of the radon from the air sample entering the RAD7, giving the instrument the ability to operate in conditions under which it would otherwise be unable to cope. A final concentration figure is attained by multiplying the reported result by ten.

Another limitation of the RAD7 is that it loses reporting accuracy under high humidity conditions. The use of desiccant ensures that the air entering the RAD7 inlet is not too humid, but since desiccant is expended quickly when exposed to very moist air, DURRIDGE offers the DRYSTIK, an instrument which removes moisture from the air entering the RAD7 without removing the radon itself. The premium DRYSTIK model is capable of reducing the humidity of a typical air sample to 4% in under 20 minutes, greatly prolonging the life of the desiccant, or eliminating the need for it altogether.

The Range Extender and DRYSTIK are described in more detail below. For full documentation on each, please refer to the Range Extender and DRYSTIK user manuals, available in PDF format at the DURRIDGE Website (www.durridge.com).

5.5.2 The Range Extender

The Range Extender mixes fresh air with the air being sampled, reducing the concentration of radon entering the RAD7 by a factor of ten. This greatly increases the instrument's effective range.

The Range Extender consists of two parallel capillary tubes joined at one end to an outlet hose connector. Fresh air is fed to the input of one tube while the incident radon sample is fed to the other. A differential pressure sensor across the two tube inputs, with a needle valve for adjustment, is used to ensure that both capillary tubes have the same pressure drop across them. With this system the radon concentration delivered to the RAD7 is reduced by an order of magnitude, regardless of the strength and flow velocity of the RAD7's internal pump. The RAD7 pump can cycle on and off without affecting the reduction factor.

The Range Extender can be used for the measurement of very high radon concentrations in air, in soil gas, and in water. It can also be used with any other instrument that has its own pump, for any gas. If used to extend the range of thoron measurement, care must be taken to assess and correct for the additional decay of the thoron due to sample acquisition delay.

The Range Extender

5.5.3 The DRYSTIK

The DRYSTIK reduces the humidity of the air entering the RAD7 by transferring moisture from the sample about to enter the RAD7 to the air being pumped out of the instrument. As the air enters the desiccant in the drying unit (which is not included with the DRYSTIK) on its way to the RAD7, it will have already lost most of its moisture, greatly extending the life of the desiccant in the drying unit. In certain cases the need for desiccant is eliminated altogether.

The DRYSTIK has at its heart a Nafion humidity exchanger with diaphragm pump, fixed and variable flow limiters, and a built-in Duty Cycle Controller. These are all contained in a compact, portable enclosure. The DRYSTIK's pump compresses the sample air inside the membrane tubing, initiating the transfer of water molecules to the outer purge flow, drying the incoming air as it moves through the device.

The DRYSTIK is available in three variants, based on the length of Nafion tubing used. The premium 144-ADS model is capable of bringing the relative humidity of air flowing at 0.15L/min down below 10% in less than four hours, and maintaining the RH below 6% indefinitely without any desiccant. This allows a RAD7 to operate under optimum conditions with the highest sensitivity and lowest operating cost. At a higher flow rate of 1.2 L/min, the DRYSTIK can bring the RH down below 12%, which is sufficient for enhanced-sensitivity thoron measurement.

For soil gas measurement, the DRYSTIK provides a high flow capability, supporting the detection of short-lived thoron. For radon, the ability to lower the flow with the built-in Duty Cycle Controller means that continuous soil gas readings may be made indefinitely, without any risk of fresh air diluting the soil gas sample by diffusing from the surface down to the extraction point. Given its versatility, the DRYSTIK is effective for a wide range of applications.

The DRYSTIK (Model ADS-3R)

6 COMPUTER CONNECTIVITY

6.1 Computer Connectivity Basics

The RAD7's built-in serial port allows you to transfer radon data to your computer and to communicate with the device remotely in real time. DURRIDGE provides a free software utility for Windows and macOS called CAPTURE, which makes it easy to perform these actions, as well as to monitor the RAD7's status, graph radon and thoron data, apply corrections to account for environmental factors, and export the results for analysis in a spreadsheet program or other software.

It is also possible to use a terminal emulator program to interface with the RAD7, and to write your own RAD7 communications software using the protocol documented later in this chapter.

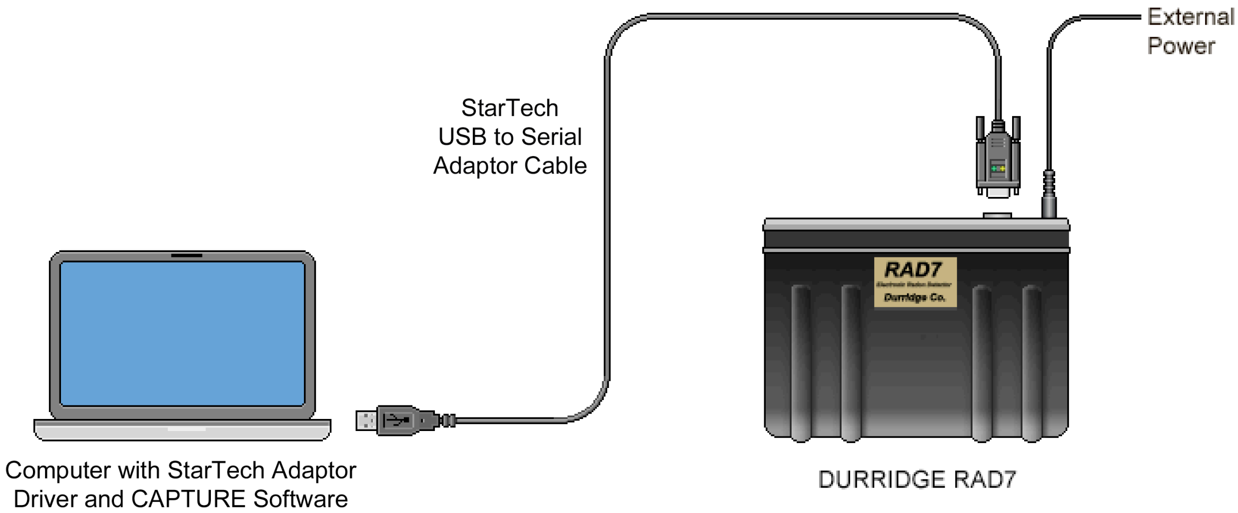
An overview of the CAPTURE software is provided in Section 6.2, and the full program documentation is available at www.durridge.com/capturehelp/. This documentation is also accessible from within the CAPTURE application, using the Help menu. For troubleshooting RAD7 detection problems in CAPTURE, please refer to the program documentation or to Section 8.7, CAPTURE RAD7 Detection Failure, in this manual.

Following the section on CAPTURE, the remainder of this chapter contains technical information which will be of interest to advanced users who intend to communicate with the RAD7 via a terminal window and those who wish to write their own software for communicating with the RAD7.

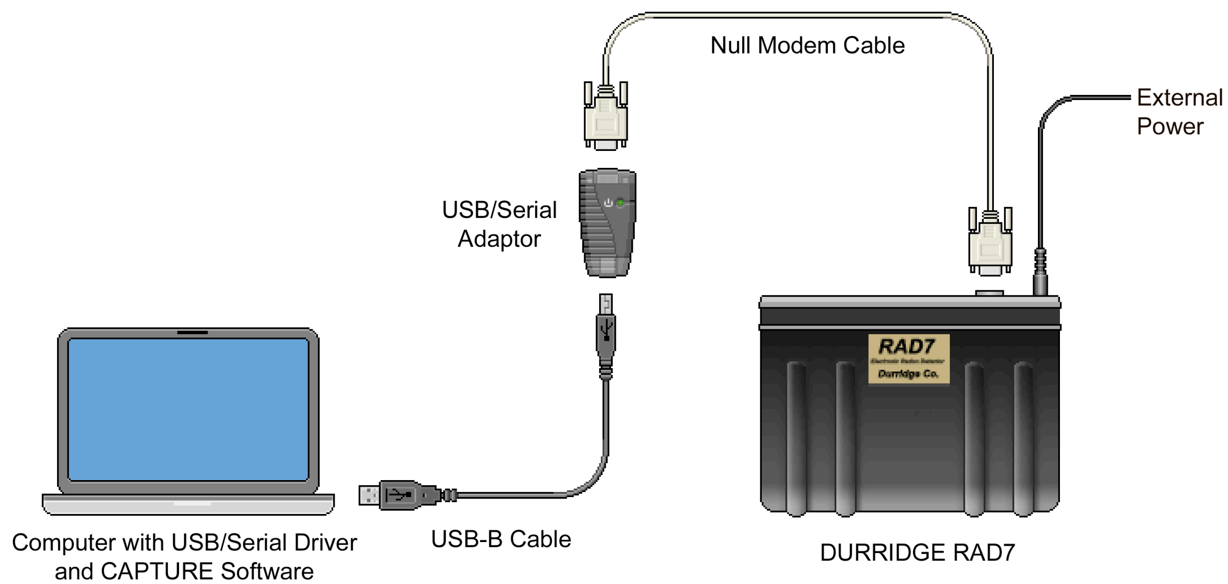
6.1.1 Connecting the RAD7 to the Computer

On most systems the RAD7 should be connected to the computer using the included USB to Serial adaptor, and it will be necessary to install the included adaptor driver software. If your computer has a physical serial port however, it is possible to instead use an RS232 DB9 female to female null modem cable to connect the RAD7 directly to the computer, without the need for adaptors or drivers.

The diagrams on the next page show how to connect the RAD7 to a computer using two different kinds of USB to Serial adaptors: the StarTech adaptor (top), and the Keyspan adaptor (bottom).



Connecting the RAD7 to a Computer with the StarTech Adaptor



Connecting the RAD7 to a Computer with the KeySpan Adaptor

It is recommended that the RAD7 remain plugged into external power to prevent its battery from dying while it is connected to the computer.

For connecting more than one RAD7 to a computer, it is possible to use several USB to serial adaptors simultaneously, with each plugged into a USB port on the computer (it is not advisable to plug multiple adaptors into a single USB hub.) Alternatively, a multi-port USB to serial adaptor may be purchased.

6.2 CAPTURE Software

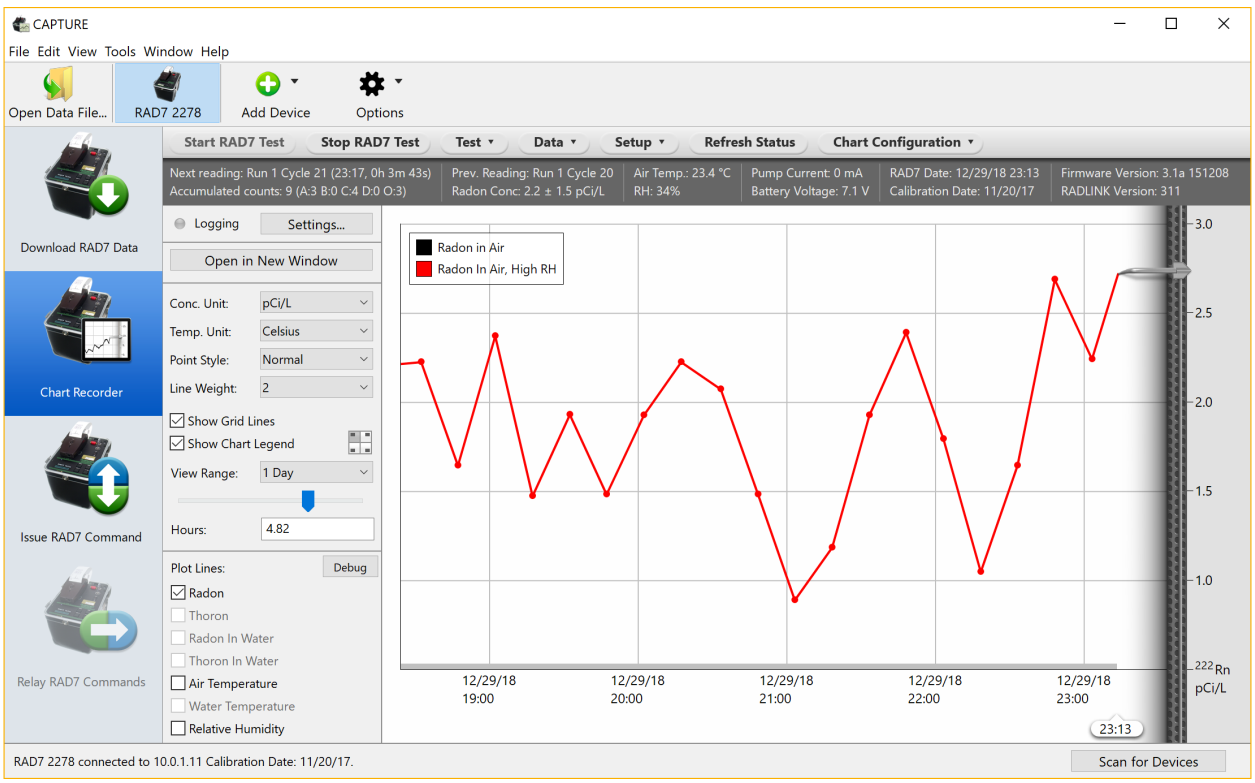
CAPTURE is intended to simplify the transfer of data from the RAD7 to a computer. It also provides a wealth of graphing and data analysis options, and offers the ability to export data to other programs for further review. The software is available for Windows and macOS.

This section serves as a brief introduction to the CAPTURE software.

6.2.1 CAPTURE Installation

The latest version of the CAPTURE software may be downloaded from the DURRIDGE website (www.durridge.com/capture). Download the appropriate version of the software for Windows or macOS. In Windows an installer program will install the necessary components and place shortcuts in the Start Menu and on the desktop, if desired. To install CAPTURE for the Macintosh, open the downloaded .dmg disk image file and drag the CAPTURE application into the Applications folder or to the location of your choice.

Next connect the RAD7 to the computer using the provided adaptor cable as described in Section 6.1.



CAPTURE Software running on Windows

6.2.2 Feature Summary

CAPTURE's capabilities fall into three main categories: downloading RAD7 data, graphing and analysis, and real-time RAD7 monitoring. An overview of each is described below.

6.2.3 Downloading RAD7 Data

CAPTURE's original and primary function is to download RAD7 data. Once connected to a RAD7, the program can download all of the device's data, or a particular data run. For a more complete record set, supplementary output containing thoron concentration records may also be obtained. When a download operation is complete, the results are saved to disk in the format of the user's choice.

In addition to being able to download data from RAD7s connected directly to the computer, CAPTURE can obtain data from more remote RAD7s connected via bluetooth, a local network, or remote desktop software.

6.2.4 Graphing and Analysis

Once RAD7 data has been downloaded and saved to disk, it may be displayed as a graph. CAPTURE's Graph Window allows for the display of radon, thoron, temperature, and humidity data. Navigation controls make it possible to select the data points within a specific date range and zoom in to that region for a closer look.

Accompanying the graph display is a statistics panel showing information about the point nearest to the cursor and the points within the selected region, as well as the points comprising the entire data set.

A synthesized spectrum display appears in another panel, providing an indication of the changes that occur within the RAD7 as a testing session progresses.

RAD7 Profiles based on device calibration data may be applied to graphs to improve the accuracy of the data shown. Data points may also be corrected for temperature, humidity, and other variables. Any problematic data records will be examined by CAPTURE's comprehensive error catching system and reported to the user.

CAPTURE supports the exporting of both raw RAD7 data and more complete error-corrected RAD7 data in a number of formats, for use in spreadsheets and other analysis tools. Summary reports may also be generated, providing general overviews of the collected data.

6.2.5 Real-Time RAD7 Monitoring

CAPTURE is capable of monitoring multiple local and remote RAD7s simultaneously in a Chart Recorder, displaying status details and plotting radon concentrations in real time as they are recorded. A statistics panel is automatically refreshed as new information arrives.

In addition to being able to track the state of each connected RAD7, it is also possible to issue menu commands, performing such tasks as starting and stopping tests and setting the device protocol. Nearly all of the functionality of the RAD7's physical controls is accessible from within CAPTURE's graphical interface.

As stated above, it is suggested that users examine the complete CAPTURE documentation, which is available from the www.durridge.com/capturehelp/, and from within the program's Help menu. If CAPTURE fails to detect a connected RAD7, troubleshooting solutions can be found in Section 8.7 in this manual.

6.3 RAD7 Communication Protocol

6.3.1 Communication Requirements

Although DURRIDGE's CAPTURE software for Windows and macOS provides a complete solution for downloading RAD7 data and issuing RAD7 commands, it may be desirable to communicate with the device using a terminal window, or with custom communication tools designed to fulfill specific needs.

The RADLINK firmware, installed standard with every RAD7 sold, enables the RAD7 to respond to commands issued through its serial port. With RADLINK installed, all of the commands available through the RAD7 keypad will also be available via the serial port. From a computer you may, for example, change the RAD7's operating parameters, complete a test, and then download the accumulated data.

6.3.2 RAD7 Command Format

The format of commands issued to the RAD7 serial port generally match, as closely as possible, the format of the commands available to the user at the RAD7 keypad. For example, the command to change the cycle time to 1 hour is "`SETUP CYCLE 01:00`". The command to turn off the audio beeper is `"SETUP TONE OFF"`. The command to send over the data from run number 3 in comma-delimited form is `"DATA COM 3"`. (This particular command is described further in Chapter 6.3.3, Parsing RAD7 Data.)

Besides the ordinary RAD7 commands, additional commands have been implemented via RADLINK which add functionality and in some cases substitute for other commands. These commands all start with the word "SPECIAL". One such command is `"SPECIAL STATUS"`, which gives information about the current status of the instrument. It is like `"TEST STATUS"`, but does not continue to update the information every second; instead, it returns control to the user.

The third standard ASCII character, ETX, functions as a remote "menu" key that can be used to interrupt certain RAD7 activities and prepare it to accept a new command. The RAD7 replies with a prompt, the greater-than character ">", that tells you it is ready for a new command. When using a terminal emulator program, you will always type commands at the prompt.

All commands must be followed by a carriage return (the thirteenth standard ASCII character), denoted here as `<CR>`. No command will be activated until the `<CR>` goes through. Once you have typed a command, always end with a carriage return keystroke. This key may be marked "Enter" or "Return" on your keyboard.

If the RAD7 cannot understand your command, for example if you typed words in the wrong order or misspelled something, it will respond with

```
?ERROR
```

followed by a list of acceptable command words The case of the command does not matter, nor does the numeric format of numbers. In the last example, `"data com 03"`, `"Data Com  3"`, and `"dAtA coM 03.00"` all work equally well.

6.3.3 Parsing RAD7 Data

Stored RAD7 data can be obtained through the "`Data Com ##`" command. Specify the run number in the command line and finish with a carriage return. Alternatively, issue "`Special ComAll`" to download all runs from the RAD7.

Each cycle produces a record containing 23 fields. Carriage-return line-feeds separate the records, and within each record, commas separate the fields. Fields may have leading zeros, extra space characters, trailing decimals, etc., which may need to be trimmed. When the RAD7 responds to a Data Com or Special ComAll command, each line returned represents a different cycle. Here is an example of a single line:

```
009,99,10,29,04,18,4823.,337.8,45.4,
2.9,46.6,0.3, 2201,14, 23.7, 5, 7,
7.09, 00, 125, 28.32743, .8500846,
255<CRLF>
```

The meaning of each of these values is described in the table on the next page.

Table 6.3.3 RAD7 Data Record Content

ID	Field Name	Notes
1	Record Number	Ranges from 001 to 999
2	Year	2 digit value
3	Month	2 digit value
4	Day	2 digit value
5	Hour	2 digit value
6	Minute	2 digit value
7	Total Counts	Integer indicating total counts recorded during test
8	Live Time	Expressed in minutes
9	Percent of total counts in win. A	These 4 windows will not always add up to 100% since counts can come into channels below or above these windows.
10	Percent of total counts in win. B	
11	Percent of total counts in win. C	
12	Percent of total counts in win. D	
13	High Voltage Level	Ranges from 2200V to 2300V
14	High Voltage Duty Cycle	Ranges from 0-100%; typically 10-20%
15	Temperature	Measured in °C or °F depending on RAD7 setup
16	Relative humidity of sampled air	Should be kept below 10% for most accurate test
17	Leakage Current	Ranges from 0 to 255. Above 20 is cause for concern.
18	Battery Voltage	Below 6.00V is a discharged battery. Does not affect accuracy of test but indicates need for recharge.
19	Pump Current	Ranges from 0-260mA. Typically 40-80mA; Above 100mA possible clogged filter or obstruction.
20	Flags Byte	This is a number between 0 and 255 which represents one data byte consisting of eight individual bits: Bits 0 and 1 indicate the pump state: either Off (0,0), On (0,1), Timed (1,0), or Grab (1,1). Bit 2 is not defined. Bit 3 indicates whether Thoron is On, in which case the thoron reading appears on the end-of-cycle printout. Bits 4 and 5 indicate the measurement type: either Radon in Air (0,0), Wat-40 (1,0), or WAT250 (1,1). Bit 6 indicates whether the RAD7 is in Auto mode, meaning it changes from SNIFF to NORMAL after the first 3 hours. Bit 7 indicates whether the RAD7 is in SNIFF mode.
21	Radon concentration	Expressed in pCi/L, Bq/m^3, cpm, or # counts, depending on the units the RAD7 has been set to use.
22	Radon concentration uncertainty	The two-sigma uncertainty of the radon concentration, expressed in the same units as the base value.
23	Units Byte	This is a number between 0 and 255 which represents one data byte consisting of eight individual bits: Bits 0 and 1 indicate the concentration unit: either Bq/m^3 (0,1), pCi/L (1,1), counts per minute (0,0), or total number of counts (1,0). Bit 2 through Bit 6 are not defined. Bit 7 indicates the temperature unit used on printer output, either Celsius (1) or Fahrenheit (0).

6.3.4 Terminal Emulator Tips

If you are using a terminal emulator application to interact with the RAD7, you can gain access to additional functionality by making sure the terminal has been set up to give ANSI standard escape codes for the function keys and cursor control keys. Set the terminal for either ANSI, VT-52, or VT-100 mode to get these functions. The function keys F1, F2, F3, and F4 act as a remote RAD7 keypad, corresponding to the RAD7 keys `[MENU]`, `[ENTER]`, `[←]`, and `[→]`. The Control-C character also acts as the remote `[MENU]` key (ETX). The backspace/delete key on your keyboard allows you to correct misspelled commands before the carriage return. If this key does not work, then Control-H may handle the same function.

6.4 Serial Port Specifications

6.4.1 Communication Protocol

The RAD7 serial port follows RS-232C convention for signal levels. Positive voltage (+3V to +15V) indicates logic state 0 (SPACE), while negative voltage (-3V to -15V) indicates logic state 1 (MARK).

The connector pin-out follows the IBM PC convention for the 9 pin serial port. The handshaking lines (DTR, DSR, RTS, and CTS) are not fully implemented, and should be considered non-functional (NF), but X-on/X-off flow control can be used.

Table 6.4.1a Serial Port Pin Assignments

Pin	Function	Comment
1	Carrier Detect (CD)	NF
2	Receive Data (RD)	
3	Transmit Data (TD)	
4	Data Terminal Ready (DTR)	NF
5	Signal Ground (SG)	
6	Data Set Ready (DSR)	NF
7	Request To Send (RTS)	NF
8	Clear To Send (CTS)	NF
9	Ring Indicator (RI)	NF

The RAD7 serial port implements two-way communication at 300, 600, 1200, 2400, 4800, 9600, and 19200 bits per second (baud); these speeds are available through the 'Special' commands of the RADLINK remote control package. The default speed is 1200 bps.

If a terminal emulator or custom software application is used, communication should be conducted at a data rate not exceeding 9600 baud. This will significantly reduce the risk of characters being dropped from sent commands.

Table 6.4.1b Communication Parameters

Default Rate	1200 bps
Maximum Rate	19200 bps
Recommended Rate	9600 bps
Data Bits	8 bits
Parity Bit	None
Stop Bits	1 bit

The RADLINK remote control software resides in the RAD7's non-volatile memory (NVRAM), but its presence does not decrease the amount of memory available for storing radon data.

6.4.2 Extending the RS-232 Range

The simple, direct serial port to serial port connection has a range limited to around 50 feet (15 meters) by the RS-232-C standard. Options for extending this range include RS-232 line boosters, current-loop and other types of interface converters, short-haul modems, and leased-line modems.

You may use standard data modems to communicate over the telephone system to one or more remote RAD7 monitors, so that when you want to get some data or start a new run, just "dial up" the instrument of your choice. The modem should be Hayes compatible and should be set to auto-answer.

The CAPTURE user's manual contains a section titled Long Distance Communication, detailing several strategies for communicating with distant RAD7s that are fully supported by CAPTURE. These include the transmission of commends via Bluetooth, local area networks, and more.

7 MAINTENANCE

If the RAD7 is treated with respect, the only maintenance required is its regular recalibration. For this, it should be returned to DURRIDGE Company, who will check the health of the instrument, and who will incorporate the new calibration factors in the instrument firmware.

If the instrument is to be used in a harsh environment, where water and/or mud may be splashed on the face plate, the RAD7 should be put in a box or large transparent plastic bag. The air input may be brought into the container by a plastic tube from the sampling point. The air outlet should be left in the container, so that the RAD7 becomes surrounded by clean and dry air.

7.1 Accessories - Usage and Care

7.1.1 Desiccant

Two sizes of desiccant tubes are supplied. In the NORMAL mode, use the large 2" diameter tube (laboratory drying unit). This unit will last for days under continuous operation at high humidity before it needs regeneration.

When used as a Sniffer, the small desiccant tube is recommended. It will last for several hours before replacement or refilling of the tube is necessary. To regenerate the desiccant, the granules should be removed from the tube and spread evenly in a thin layer on a metal or Pyrex glass tray. Heat at about 200°C (400°F) for at least two hours or until granules turn uniformly blue. Allow the desiccant to cool in a closed, but not airtight, container before refilling the acrylic laboratory drying unit or small drying tube.

The following sections provide insight into how long the desiccant will last in various scenarios.

7.1.2 Laboratory Drying Unit

The column holds approximately 500 grams of Drierite desiccant. This desiccant can adsorb at least 10% of its weight in water, so the water capacity of the column is at least 50 grams. The RAD7 pump develops a flow rate of about 1L/min. With the RAD7 set for continuous monitoring with timed pump operation, the pump operates 20 to 30% of the time. We will assume an average flow rate of 0.3 liters per minute.

The following table shows the expected lifetime of a charge of desiccant in the Laboratory Drying Unit under various temperature and humidity conditions.

Table 7.1.2 Laboratory Drying Unit Life

RH	Deg. C	Deg. F	Column Life
30%	20	68	23.1 Days
30%	35	95	9.8 Days
50%	20	68	13.3 Days
50%	25	77	10.0 Days
90%	10	50	13.7 Days
90%	15	59	10.0 Days
90%	20	68	7.4 Days
90%	25	77	5.5 Days
90%	30	86	4.2 Days

7.1.3 Small Drying Tube

The small drying tubes each contain 30 grams of Drierite desiccant. The water capacity of each tube is 3 grams. We will assume that the RAD7 pump operates continuously, for an average flow rate of 1L/min. The following table shows the expected lifetime of a small drying tube under a variety of temperature and humidity conditions.

Table 7.1.3 Small Drying Tube Life

RH	Deg. C	Deg. F	Tube Life
30%	20	68	10 Hours
30%	35	95	4.2 Hours
50%	20	68	5.7 Hours
50%	25	77	4.3 Hours
90%	10	50	5.9 Hours
90%	15	59	4.3 Hours
90%	20	68	3.2 Hours
90%	25	77	2.4 Hours
90%	30	86	1.8 Hours

7.1.4 Cascading Drying Tubes

To extend the time before desiccant depletion, you may cascade several drying tubes in series. Two factors limit the number of drying tubes you can use. First, each additional drying tube or column adds a small amount of resistance to the air flow, so the pump will have to work a little harder. But the resistance added by a drying tube is much less than the resistance of the inlet filter, so you should be able to cascade several without severely restricting the air flow. Second, each additional tube adds a time lag between sample intake and instrument response.

For continuous monitoring, a 10- to 20-minute lag may be perfectly acceptable, but for sniffing it may not be. You can conservatively estimate the time lag by taking four times the volume of the drying system and dividing it by the average flow rate. Consider a continuous monitor application using a laboratory drying column (with an internal air volume of approximately 400 mL) with the pump in timed operation, giving an average flow rate of 0.2 liters per minute. Four times the volume divided by the flow rate gives 8 minutes for the estimated lag time. This would be perfectly acceptable for continuous monitoring. For radon sniffing, you will usually use the small drying tubes (with internal air volume of 23.7 mL), which create negligible delays of less than a minute, even at low flow rates. You can cascade several small drying tubes without trouble.

Do not cascade drying tubes when sniffing for thoron, since thoron's 56-second half-life necessitates that you keep delays to an absolute minimum. For thoron sniffing, use a single small drying tube, and set the pump for continuous (on) operation. Keep hose length to 6 feet (1.8 meter) or less.

7.1.5 Filters

Inlet filters are supplied that fit the metal inlet fitting (male Luer type). These filters block ultra fine dust particles and all radon daughters from entering the RAD7 test chamber.

The filters are manufactured in various pore sizes by several companies, including Millipore and SRI. We favor pore sizes of 1.0 microns or less; pore sizes as small as 0.4 microns can be used with the RAD7 pump.

The filter should be replaced when it has become noticeably discolored or has clogged enough to impede the flow of air. If you cannot suck air easily through the filter yourself, it's time to change the filter.

When you operate the RAD7 in construction areas or basements, dust can quickly build up in sampling hoses, drying tubes, and inlet filters. This dust will slowly clog the filter, restrict air flow, and create strain on the pump. You will have to replace the inlet filter. To greatly slow the buildup of dust, we recommend that you attach a "prefilter" to the intake of the sampling hose, to prevent coarse dust particles from entering. Then, the inlet filter will remove the ultra-fine dust particles that pass through the prefilter and drying system.

We find that automotive gasoline filters can serve as convenient and inexpensive prefilters. A particular filter, intended for Volkswagens, is a small, disposable, clear-plastic capsule containing a pleated paper filter. This filter effectively removes most dust from the air stream, greatly extending the life of the inlet filter. You can buy this type of filter in almost any auto parts store for around $3.

7.1.6 Batteries

Your RAD7 has enough battery capacity to go for two to three days without any external power source. Electronic circuits control the charging and discharging of the battery, avoiding overcharge or destructive discharge. If you maintain the batteries according to the following directions, you can expect to get two to five years of heavy service from them.

Keep the batteries fully charged as much as possible. Try to recharge promptly after use. The RAD7 batteries charge whenever the unit has DC power. With the power cord plugged in and the RAD7 measuring radon, the batteries will charge slowly. Full recharge takes about 48 hours.

With the power cord plugged in and the RAD7 in fast charge mode (not measuring radon), the batteries will charge more quickly. Full recharge takes about 24 hours. The battery voltage indicator on the display (go to Status Window 1) will reach 7.10 to 7.20V when the batteries are fully charged and the power cord is still plugged in.

If the batteries are deeply discharged, to the threshold of battery damage, an electronic circuit will completely disconnect them to avoid further discharge. The circuit will then not allow battery operation until they are completely recharged. If this occurs, you may still be able to operate the RAD7 from DC power until the batteries recharge. Expect the recharge to take 48 hours.

Never store the RAD7 without first recharging the batteries. If you intend to store the RAD7 for a long period of time, you must recharge the batteries at least every four months, as they can be damaged by self-discharge on the shelf. Otherwise, you may have to replace the batteries before you can use your instrument again.

Battery voltage can be read from the Status display, and appears on printed output. A fully charged battery will rest at 6.40 to 6.50V. As the battery discharges, its voltage drops steadily to 6V. If the battery voltage ever goes below 6.00V, it is fully discharged and should be recharged as soon as possible. As the battery charges, its voltage rises steadily until it goes above 7V. Consider the battery fully charged if it charges at or above 7V.

7.1.7 Real-time Clock and Non-volatile Memory

The RAD7's Real-Time-Clock (RTC) and Non-Volatile Memory unit (NVRAM) allows the RAD7 operator to switch power off without losing data or disrupting the clock time and date. These functions are powered by a lithium cell with an expected lifetime of ten years.

7.1.8 Printer and Adapter

Infrared printer documentation is provided in Appendix A at the end of this manual. It is important to familiarize yourself with its operation, and to be aware that the printer operates through an infrared optical link and should be positioned on the top of the RAD7 to match the data link on the detector. The printer runs on its own batteries.

7.2 RAD7 Operating ranges

Parameter	Minimum Value	Maximum Value
Temperature	0°C (32°F)	45°C (113°F)
Relative Humidity, external *(Must be non-condensing)*	0%	100%
Relative Humidity, internal	0%	10%
Battery Voltage	6.00V	7.20V
Pump Current *(pump off)*	0mA	10mA
Pump Current *(pump on)*	30mA	90mA
High Voltage	2100V	2400V
HV Duty Cycle	8%	20%
Leakage Current *(room temp.)*	0	20
Leakage Current *(max. temp.)*	5	80
Signal voltage level	0.15V	0.30V

Table 7.2 RAD7 Operating Ranges

7.3 Service and Repair

7.3.1 Calibration

DURRIDGE maintains a professional radon calibration facility that includes a controlled, standard source of radon gas, and a controlled-temperature environmental chamber. All RAD7 alignment and calibration is done here, as well as basic testing and quality assurance. We determine calibration factors by direct comparison to "master" RAD7s, which were themselves compared with EPA and DOE instruments, and which have participated in international inter-comparisons of radon instrumentation. The calibration accuracy is independently verified by direct determination of the radon chamber level from the calibrated activity and emission of the standard radon source. In addition, we periodically intercompare with other radon chambers. We generally achieve a reproducibility of better than 2% with our standard RAD7 calibration. Overall calibration accuracy is in the range of 5%.

The U.S. EPA recommends that continuous radon monitors such as the RAD7 be calibrated at least once per year, and DURRIDGE agrees. DURRIDGE's standard RAD7 calibration procedure requires 10 days from the receipt of the instrument. As a preliminary to recalibration, we give every RAD7 an inspection and test its critical parts. If additional service is required, this may delay the return of the instrument.

At present, only DURRIDGE can make adjustments to your instrument's alignment and calibration factors. If you determine, on the basis of an independent intercomparison (e.g., another calibration chamber) that you would like to adjust your RAD7's calibration by a known amount, we can generally perform this service and send back your instrument within one day. Requested calibration adjustments of more than 10% are considered highly unusual and require the written permission of the instrument's owner.

7.3.2 Repair

If you discover that your RAD7 is malfunctioning, we recommend that you first call DURRIDGE and talk to a technician. A surprising number of minor "disasters" can be avoided by long-distance consultation. The next step, if consultation fails, is usually to send your instrument in for evaluation and repair. Please send any documentation of the problem that you might have (notes, printouts, etc.) and a short description of the problem. This information may be emailed to us at service@durridge.com. Be sure that you put your name and contact information on the note. Within 48 hours of our receipt of the instrument, we will call you to give a diagnosis.

Bear in mind that RAD7 repairs involve a re-calibration of the instrument, which takes time. If you need a RAD7 during the repair time we may be able to provide a loaner instrument.

7.3.3 Shipping

1. You can send us your RAD7 at any time to either one of our Calibration facilities (USA and UK), listed below (**see important, specific instructions for each below**).
2. We need the RAD7 in house for 10 days, so the total time a RAD7 will be away from your facility will be 10 days plus the time the RAD7 spends in transit. If additional service or repair is required, this may delay the return of the instrument.
3. When sending your RAD7, please send the instrument only, without the cables and accessories. Pack the instrument upright in a box with one-inch (2.2cm) padding all around. A 14x14x14in (or 36x36x36cm) box is suitable. Pack the box well, and seal it carefully. Please include your contact info with the package.
4. International customers must be very careful, to avoid substantial extra shipping charges and delays, both for shipping to the nearest calibration facility, and for its subsequent return.

5. Commercial Invoice check-list

- [ ] For your courier or freight forwarder, you will need to provide a **Commercial Invoice**.
- [ ] Please write only in English on the commercial invoice.
- [ ] Please use the following description for the RAD7: "RAD7 Electronic Radon Detector, returned to manufacturer for service". Please also include this description on the air waybill (AWB).
- [ ] Insured value US$2,490.
- [ ] Please state on the invoice that the instrument is MADE IN USA and that it is being "**returned to the manufacturer temporarily for repair and recalibration**".
- [ ] Please use the HS (Commodity) code 9030.10.00.
- [ ] Please mark the box with the serial number of the RAD7 (as the RMA – Return Merchandise Authorization).
- [ ] Please add the phone number of the Calibration facility you choose, in case the Customs Office wants to call us.
- [ ] Next, you must ensure that your courier (i.e. UPS, FedEX) or freight forwarder will **deliver the package to our door**. The formal "INCOTERM" for this is "DDP", which means "Delivered Duty Paid."
- [ ] We will not pay or be responsible for USA or UK import duties, or Customs clearance charges. Your shipper must be told this when you arrange your shipment.
- [ ] It is important to make sure you prepare all the documentation you need to reimport the goods back into your country without being charged.
- [ ] **For the Return to you:** unless you instruct us otherwise, we will return your RAD7 via the same shipping method you used to deliver it to us, Freight Collect. DURRIDGE can pay for the return shipment CPT ("Carriage Paid To") to you, but our cost will be invoiced to you before shipment.

If we can help further, please email us at service@durridge.com.

Specific info for SHIPPING TO OUR USA FACILITY (from outside the USA):

DURRIDGE Company, Inc.
900 Technology Park Drive
Billerica, MA 01821-2812, USA
Phone: +1 (978) 667-9556
Fax: +1 (978) 667-9557

Declaration Form

There needs to be documentation proving that the instrument was previously imported into your country, otherwise you may be charged import duties when the instrument is returned to your country.

Please fill out the **declaration form** provided at http://durridge.com/services/rad7-calibration/. Attach the completed declaration form to the commercial invoice. If the invoice is scanned and submitted electronically, please scan the declaration form and submit it electronically as well.

Specific info for SHIPPING TO OUR UK FACILITY:

DURRIDGE UK Ltd.
Sheffield Technology Park
Cooper Buildings
Arundel Street
Sheffield S1 2NS, UK
Phone: +44 (0)114 221 2003

For Customers inside the EU:

No special paperwork is required for shipping within the EU Customs Union.

For Customers Outside the EU:

Please complete the checklist in the above section. It is very important to include the HS (Commodity) code 9030.10.00, otherwise import duty may be charged at the UK border, for which you will be liable. Please also include our EORI number GB219670885000. Please ensure that you make the necessary arrangements with the Customs authority in your territory for the return of your instruments. There may be special procedures for temporary exports. For example, you may need to provide documentary evidence that the instrument was previously imported into your country, to avoid being charged import duty again.

7.3.4 Upgrades

Whenever you send your RAD7 in for repair or calibration, you have the option of having the latest available software installed. Most RAD7s can be upgraded to the latest hardware configuration as well. You will be informed periodically of whatever new features are available for your RAD7. Please advise us if you want to have an upgrade made. We intend to keep our RAD7 customers happy by keeping their instruments up-to-date and state-of-the-art.

7.4 RAD7 Quality Assurance

While the annual inspection and calibration, carried out by DURRIDGE Company, is the most effective quality assurance, and the prime requirement of EPA, there are other tests and observations that may be made that will give assurance of good performance throughout the year.

7.4.1 Spectrum

At least once a month, the spectrum printed by the IR printer should be observed. The cumulative spectrum, printed at the end of a run, has the most data points and is, therefore, the most useful for this purpose. All that is required is that the printer be placed on the face plate at the end of a 1-day or 2-day run. It doesn't matter what format is chosen, the summary printed at the end of the run will conclude with a cumulative spectrum, after the bar chart.

Alternatively, the RAD7 will print a spectrum at the end of every cycle if the format is set to LONG. However, this will include only the counts during that cycle. For the spectrum to be useful it should have at least 100 counts. There should be clearly defined peaks and little or no noise across the spectrum. The peaks should be located in the middle of the windows. A clean spectrum is indicative of an instrument in perfect working order, and hence of reliable and accurate readings.

7.4.2 Spill Factor (C Window to B Window)

Due to the occasional alpha particle emitted, from a polonium atom on the detector surface, at grazing incidence to the surface, there is always a small, low-energy tail to the peaks. This may be observed in the printed spectra. There is thus a spill of 214-Po counts from window C into window B. It is normally around 1% to 1.5% in a current production RAD7. The actual value is measured during the calibration process and the spill factor used to compensate for this phenomenon when measuring thoron in the presence of radon.

If the detector becomes contaminated in use, or either electronic or detector failure causes noise in the system, thus making the low-energy tail thicker, or the peaks broader, then this spill factor will increase.

The C Window to B Window spill factor value can be calculated from any reading, provided that it is known for sure that there was no thoron in the chamber. The percentage of counts in windows B and C is given in fields 10 and 11 of each record in memory (see Chapter 6.3.3). The spill factor is simply the ratio of the values in those two fields.

It is recommended that the C to B spill factor be noted every month. Any sudden change is cause for further study of the instrument, and an examination of the spectrum.

8 TROUBLESHOOTING

8.1 LCD Display

8.1.1 Blank Display

If the unit is switched on, the most likely cause of a blank display is discharged batteries. Please see Chapter 7.1.6.

Make sure the RAD7 is properly plugged in to an external power source and is switched on.

If the instrument has been run on the batteries and not recharged, or if it has been left untouched for a lengthy period, the batteries may be completely flat. In that case, the instrument should be left plugged in and switched on for many hours, preferably 24 hours or more. If this fails to restore the display, the RAD7 should be returned to DURRIDGE Company for service.

8.1.2 Frozen Display

If the display shows "DURRIDGE RAD7" and does not respond to key strokes, the keypad has been locked. Hold down the ENTER and two arrow keys until you hear a beep, release the three keys and immediately push MENU. You should then be rewarded by "Test" on the display. If the tone was set to OFF, then you will not hear the beep, so hold the three keys down for three to four seconds, before releasing them and pushing MENU, - try hold-down times a little longer, or shorter, if at first you do not succeed. Please refer to Section 2.2.6.

8.1.3 Incomplete Or Garbage Characters

Incomplete or garbage characters may indicate a faulty LCD display. Please return RAD7 to DURRIDGE Company for service.

8.2 Readings

8.2.1 No Counts

The total number of counts so far in any cycle is displayed in the bottom righthand corner of Status Window 1. If, near the end of a cycle, there are no counts, or less than 10, say, it probably means the cycle length is too short. Increase the cycle length to increase the number of counts in a cycle and to improve the precision of the individual readings (`>Setup Cycle`, `HH.MM [ENTER]`).

If, with a cycle time of one hour or more, the total count near the end of a cycle continues to be zero and it is known that there is radon in the sample, then either the sample path is blocked or there is a fault with the RAD7 and it should be returned to DURRIDGE Company. Check that air is flowing using any of the following measures:

a) Feel the air exiting the outlet when the pump is running.

b) Stop the outlet of the RAD7 and feel the buildup of pressure.

c) Clamp the sample input tubing, hear the change in pump sound and see the change in pump current (third status window).

d) Feel the suction at the sampling point.

8.2.2 Excessive Uncertainty In Reading

If the uncertainty in the reading is greater than the base concentration value or if there is a large scatter in the readings, the cycle length is too short for the radon concentration being measured.

Increase the cycle time to reduce the scatter. Four times the cycle time will produce half the scatter and half the uncertainty. For past data, use CAPTURE to graph the data and use "Smoothing" to smooth out the statistical scatter in the data.

8.2.3 Run/Cycle Number 0000

A Run/Cycle number of `0000` indicates that the RAD7's memory is full. Download the RAD7's contents to a computer using CAPTURE. Then erase the RAD7 data using `>Data Erase`. The memory will be emptied and the data structure reset.

8.3 Relative Humidity high

Relative humidity (displayed in the third status window) normally starts high unless the instrument has been well purged just before starting the run. Depending on how long it has been since the last measurement, it may take an hour or more of measurement to bring the relative humidity down to below 10%.

If it takes too long to bring down the relative humidity, check the following:

a) The desiccant is used up. Replace it.

b) The desiccant insufficiently regenerated. Follow the instructions in Chapter 7.1.1.

c) There is a leak in the drying unit. Clean the O-ring and seating before replacing the desiccant. Be sure to draw the air sample from the end furthest from the screw cap.

d) There is a leak in the connection to RAD7.

e) There is a blockage in the air path. Squeeze the inlet tubing and note any change in the sound of the pump. Feel for suction at the sampling point.

If none of the above succeed in lowering the relative humidity, there may be a problem with the humidity sensor. Measure the relative humidity of the air leaving the RAD7. If no humidity sensor is available, another RAD7, if one is available, would do. The two RAD7s can be connected in series. Set the downstream RAD7 pump to OFF (Setup, Pump, Off [ENTER]). If the downstream RAD7 reads a lower relative humidity than the upstream one, then the upstream humidity sensor is wrong and should be replaced. Return the RAD7 to DURRIDGE Company for service.

If none of these solutions are applicable, measurements made at high humidity can be corrected automatically using CAPTURE. See Chapter 3.12.2.

8.4 Water Catastrophe

If water ever enters the RAD7, or if the RAD7 ever goes swimming in the water, it will probably cease to operate and immediate steps should be taken to minimize the impact on the instrument. Keep the RAD7 upright. This will prevent water from touching the detector, which is close to the face plate at the top of the dome. Put a piece of tubing on the RAD7 outlet with the other end in a sink. Use the RAD7 pump if it still works or, otherwise, an external pump into the inlet, to blow air through the instrument. When water ceases to be blown out of the outlet, put desiccant upstream of the RAD7 to dry out the air path. When the air path is fully dry (after dry air has been blown through it for approximately one hour), remove the face plate from the case, empty the water out of the case and blow dry the case and the RAD7 electronics.

Once there is no visible water in or on the instrument, it can be put in an oven at 50°C for a few hours to dry out completely. Additionally, desiccated air can be passed through the air path until the air leaving the RAD7 drops below 10% RH. After this treatment further corrosion will be prevented, and the RAD7 will boot once more and you can use the internal RH sensor to measure how dry the air path is. At this point the instrument should be returned to DURRIDGE for service.

8.5 Battery Voltage Low

Keep the RAD7 plugged into external power and switched on until the battery voltage (Status Window 3) recovers to about 7.1V. The RAD7 may safely be left charging all night.

8.6 Pathological Values and Error Messages

A Bad Offset Voltage error message, a 100% duty cycle, or leakage (L) above 15 (Status Window 4) all indicate faults in the RAD7, which should be returned to DURRIDGE Company without delay.

8.7 CAPTURE RAD7 Detection Failure

If DURRIDGE's CAPTURE software is unable to detect a connected RAD7, the following steps should be taken. Note that comprehensive instructions for troubleshooting a RAD7 detection failure and other CAPTURE problems can be found in the CAPTURE documentation available at the DURRIDGE website, and from the CAPTURE Help Menu.

1. Make sure you are using the latest version of CAPTURE. The software can be downloaded free of charge from the Durridge website.
2. Make sure your computer is running a supported operating system. The supported operating systems are listed in the System Requirements section of the CAPTURE documentation.
3. Make sure the RAD7 is powered On, and that the RAD7's battery is charged or charging.
4. Make sure the RAD7 is connected to the computer properly. If the computer has a built-in serial port, simply use a null modem cable (DB9 female to female). If a StarTech USB to serial adaptor cable is being used, connect the USB end of the adaptor cable to the computer, and the serial end of the cable to the RAD7. If a Keyspan USB to serial adaptor is being used, connect the adaptor to the computer and to the RAD7 using a USB-B cable and a null modem cable, respectively. Be aware that null modem cables have 9 holes at each end; standard serial cables are not supported, nor are "gender bender" adaptors that convert one end of a serial cable from male to female.
5. If you are using a serial to USB adaptor, make sure the appropriate adaptor driver is installed on your computer. Drivers for the adaptor included with the RAD7 are available on the Durridge website. Additionally, RAD7s come with a Durridge USB Stick containing the appropriate drivers for each operating system.
6. Make sure the RAD7 has RADLINK installed. (To verify that it is installed, use the keypad to navigate to the `>Special` menu, and press `[ENTER]`. If `>Special Ident` appears, then RADLINK is installed correctly.) If RADLINK is not installed, use CAPTURE to install it. See the RADLINK Operations Section of the CAPTURE manual for detailed instructions. Note that it is possible to download data from a RAD7 that does not have RADLINK installed: use the Manual Download procedure described in the Basic CAPTURE Functionality section of the CAPTURE manual.
7. If the RAD7 is not detected when connected to a particular USB port, try connecting it to a different USB port on the computer.
8. Make sure your computer is not running anti-virus software or any program that could interfere with CAPTURE. This includes any other software that communicates using serial ports.
9. Using the RAD7's keypad, select `>Special, SetBaud, [ENTER]` to change its baud rate, switching between `9600` and `19200`. Performing keypad commands such as this may help the RAD7 to "wake up".
10. Make sure the RAD7's baud rate is not set any lower than 1200. CAPTURE does not support baud rates of 300 or 600. The recommended baud rate is 9600.
11. After performing the above checks, if the RAD7 is still not recognized, try restarting the RAD7 and your computer. If another computer is available, try to connect on the other one.

Additionally, it can be helpful to determine whether the problem lies with the RAD7 or with the computer. This requires connecting a different serial device that is known to work, such as a modem or other instrument. Using a terminal emulation program such as Durridge Terminal or TerraTerm, attempt to communicate with the device. If communication is successful, then it is likely that there is a problem with the RAD7. If communication is unsuccessful, then it is more likely to be a problem with the computer.

Appendix 1: WIRELESS INFRARED PRINTER

A1.1 Infrared Printer Description

A1.1.1 General Printer Information

A portable wireless printer is provided as a standard accessory with the RAD7. It uses infrared technology to communicate with the instrument using the Infrared Data Association (IrDA) standard, or HP protocol.

The printer is designed around a patented easy-loading paper mechanism, which consists of a main cavity into which a paper roll is dropped for loading. The thermal print head is at the front of the cavity and a rubber roller is attached to the lid of the mechanism. When the lid is closed, the paper is pinched between the rubber roller and the print-head to give a close alignment and a consistent pressure.

A1.1.2 Printer Features

- Wireless printing
- IrDA standard or HP protocol
- Small size
- Quiet, and fast printing
- Direct line thermal printing
- Easy loading paper
- Easy maintenance and head cleaning
- User settable parameters using external buttons
- Self-test function

A1.1.3 Power Switch

The Power switch, located on the left side of the printer, is used to turn the unit ON and OFF.

A1.1.4 Indicator LEDs

The Power LED (Green) glows steadily when the printer is turned ON.

The Error LED (Red) flashes once-per-second when the printer is out of paper; the buffer is full; or when the print head temperature exceeds 140°F (60°C). This LED will also flash one time when the printer is placed into its set-up mode (refer to Section Set-Up Mode).

A1.1.5 Push Buttons

FEED Button:

Momentarily press the FEED button to advance the paper. Press and hold down to feed paper continuously.

This button in conjunction with the ON/OFF switch is used to start the printer's self test function (refer to the Self Test section).

When the printer is in its set-up mode, this button is used to modify the selected printer parameter (refer to the Set-Up Mode section).

SEL Button:

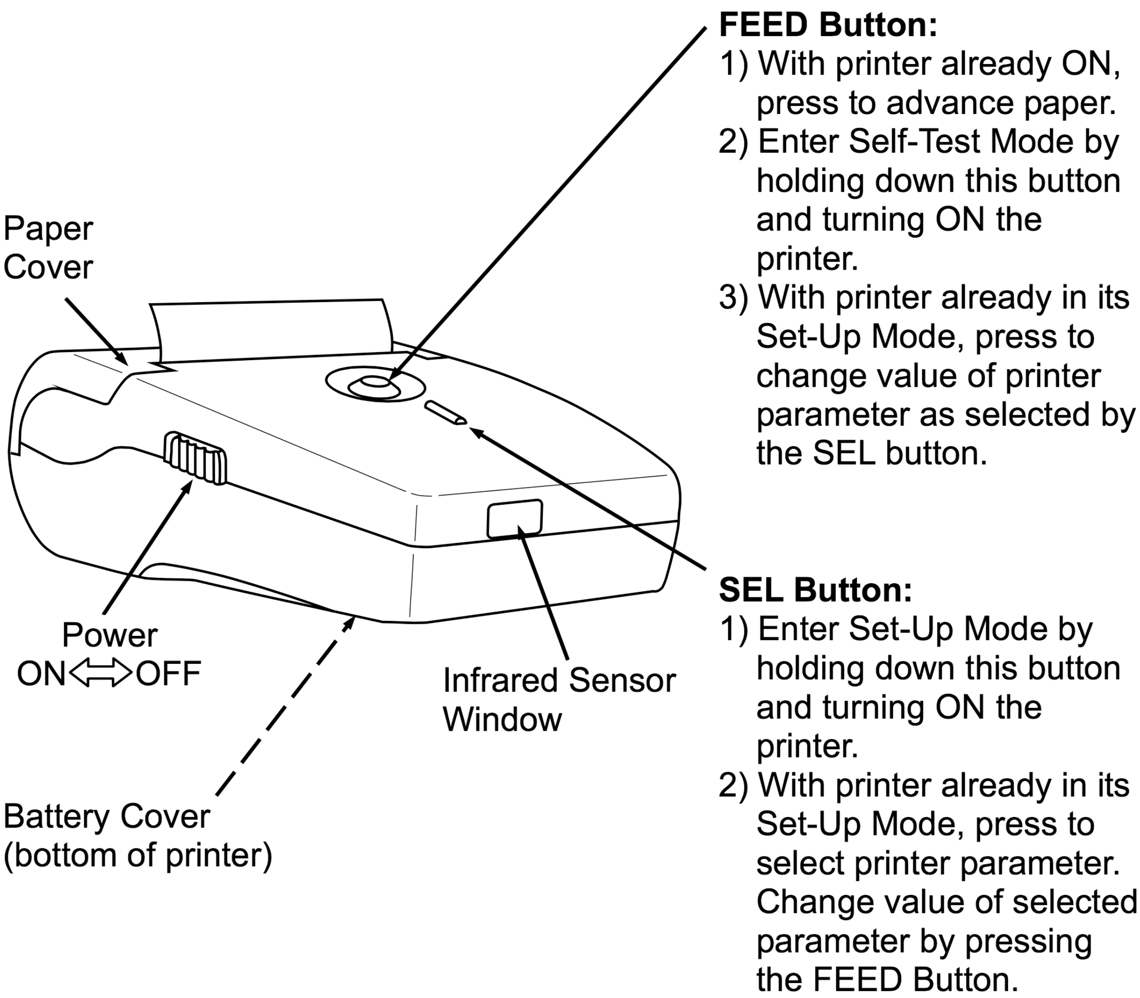
Used in conjunction with the ON/OFF switch to place the printer into its set-up mode (refer to the Set-Up Mode section).

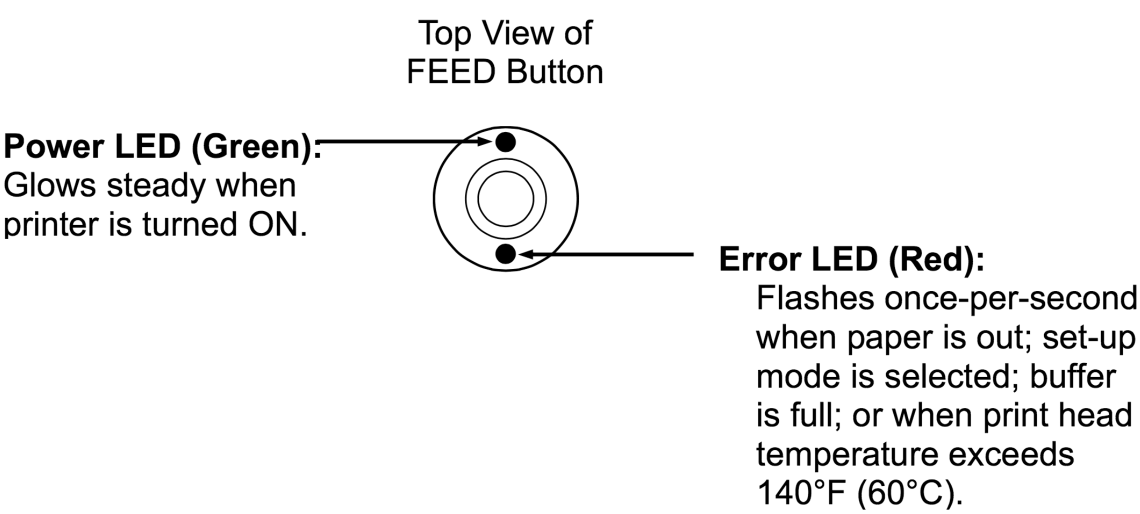
With the printer in its set-up mode, use this button to select the desired printer parameter.

A1.1.6 Sensors

Paper Out: When the paper roll runs out, the printer is disabled to prevent damage to the print head. This condition is indicated by the Error LED flashing red.

Infrared Sensor: Located at the front of the printer, this sensor receives the infrared output of an external instrument.





Infrared Printer Component Locations and Functions

A1.2 Infrared Printer Operation

A1.2.1 Precautions

To ensure the proper operation of the printer and prevent the possibility of voiding the warranty, be sure to observe the following precautions:

- Avoid dirty or dusty locations, or those with excessive heat or humidity
- Choose a stable level surface to place the printer
- Use only alkaline batteries
- Use only the appropriate thermal paper

A1.2.2 Self-Test

The self-test mode checks the printer's control circuit functions, setup parameters, software version, and printer quality.

Before running the self test, make sure there is sufficient paper to run the test (18" [46 cm]); the paper cover is closed; and that the printer is switched OFF.

With the printer initially switched OFF, press and hold down the FEED pushbutton, and then switch ON the printer to begin the test. Note: The test can be aborted by switching OFF the printer.

The following typical information is printed, followed by the printer's complete character set:

```
Version:      x.xx
Data bit:     8 bit
Parity:       None
Baud rate:    9600bps
Handshaking:  DTR
Country:      U.S.A.
Print Mode:   Text (upright)
Paper:        Normal paper
Density:      100%
IrDA:         IrDA-SIR
Buffer Size:  7000Byte
Head volt:    6.0V
Head temp.:   25°C
```

A1.2.3 Setup Mode

The printer has been set up at the factory with the following default parameters:

```
Baud rate:    9600bps
Handshaking:  DTR
Country:      U.S.A.
Print Mode:   Text (upright)
Paper:        Normal paper
Density:      100%
IrDA:         IrDA-SIR
```

If necessary, the default parameters can be changed as follows:

1. With the printer initially switched OFF, press and hold down the SEL pushbutton; and then switch ON the printer.
2. The printer now goes into its set-up mode as indicated by the red LED flashing. At this time all of the printer's current parameter settings are printed, followed by the first parameter that can be modified.

   Note that if no button is pressed within 15 seconds, the set-up mode is automatically terminated without changing the original parameters.
3. IrDA is the first parameter printed. Pressing the FEED button causes the value of that parameter to change in the sequence shown in the following table.

Table A1.2.3 Sel and Feed Functions

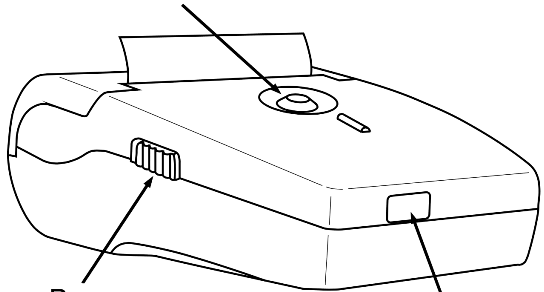
SEL Button	FEED Button
Baud Rate	300-115,200 bps
Handshaking	DTR, X-on/X-off
Country	U.S.A., Korea, Cyrillic, Denmark2, Norway, Japanese, Spain, Italy, Sweden, Denmark1, U.K., Germany, France
Print Mode	Text (upright), Data (inverted)
Paper	Normal Paper, Reprint Paper
Density	50-150% in 5% steps
IrDA	IrDA-Off, IrDA-SIR, HP-Ir

4. Press the SEL button to print the next parameter, and then use the FEED button to change that parameter to the desired value.
5. Repeat Step 4 as necessary to change all desired parameters.
6. Once all parameters have been set, press and hold down the SEL button, and then press the FEED button to save the new settings; after which the message "Data Keeping, Setting mode END !!" should be printed.

A1.2.4 Using the Printer

Turn the printer ON and observe that the Power LED should glow green. Align the printer's infrared sensor to the infrared output of the RAD7. The printer should not be more than 18 inches (45 cm) away from the instrument, at an angle of no more than 30 degrees. Issue a RAD7 command such as Data Print to initiate printing.

If the printer does not print, or if random characters are printed, check that the baud rate and communication protocol (IrDA-SIR or HP-Ir) settings of the printer is set to the correct value.



Using the Wireless Infrared Printer

A1.3 Infrared Printer Maintenance

A1.3.1 Battery Installation

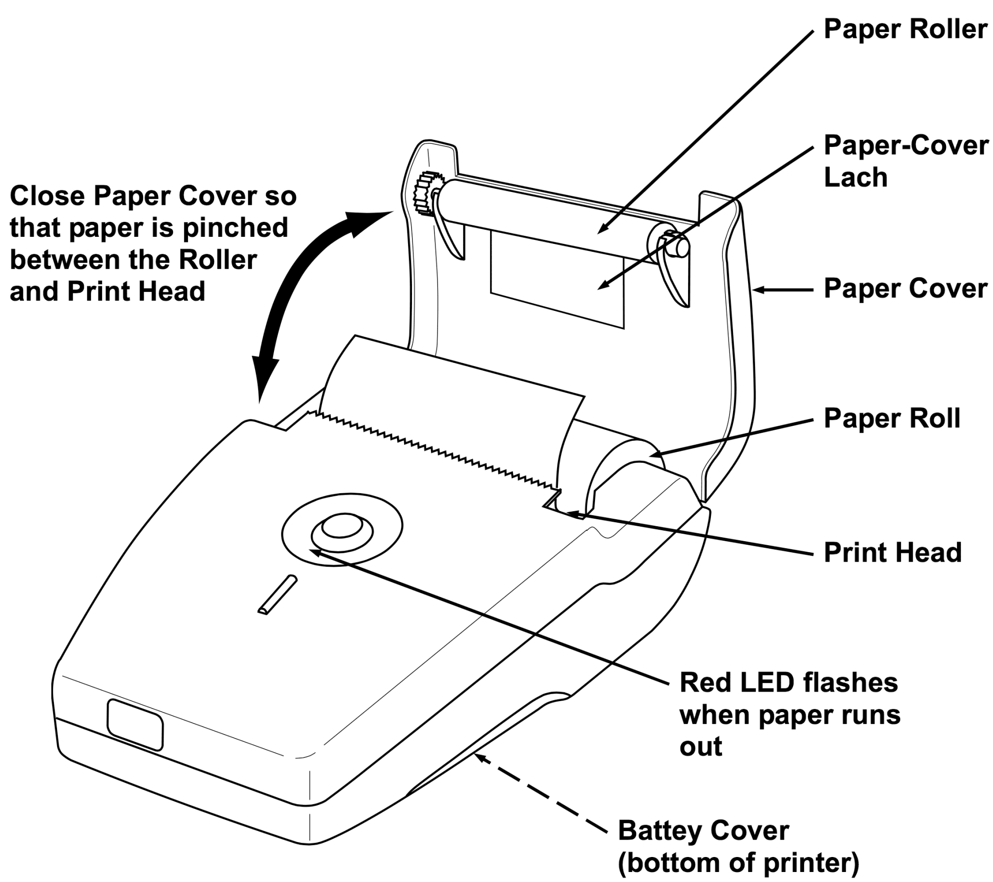
The printer requires four AA alkaline batteries. To install or replace the batteries, first turn the printer OFF. Next, unlatch and remove the battery cover. Remove any old batteries and dispose of them properly. Then insert four new AA alkaline batteries, observing the polarity marked inside the batteries, observing the polarity marked inside the battery compartment. Finally, replace the battery cover.

A1.3.2 Paper Installation

When the printer runs out of paper as indicated by the front panel red LED flashing, install a new paper roll as follows:

1. Lift up paper cover latch, and then open paper cover as illustrated on the following page.
2. Remove spent paper core and dispose it it.
3. Drop in a new paper roll so that it will rotate in the direction shown in the illustration.
4. Close the paper cover so that the paper is pinched between the roller and the print head. Remove any slack by pulling out about 1⁄2 inch of paper from printer.

Note: If there was unprinted data in the memory when the infrared printer runs out of paper, and the printer was not shut OFF, then the printer will automatically print the remaining data 5 seconds after closing the paper cover.



Wireless Infrared Printer Maintenance

A1.3.3 Cleaning the Printer

External surfaces of the printer may be kept clean by simply wiping with a damp cloth. Do not use any solvents that may attack the plastic case. Be sure that the inside surfaces are kept dry at all times.

A1.3.4 Cleaning the Print Head

To maintain a good print quality, it is recommended that the print head be cleaned at least once a year or up to once a month if the printer is used heavily. The print head should be cleaned immediately, however, if the print becomes visibly fainter due to contamination of the print head. The cleaning procedure requires isopropyl alcohol and cotton swabs, and should be completed as follows:

1. Switch the printer OFF, and allow the print head to cool before cleaning, otherwise damage to the print head may occur.
2. Open the paper cover and remove paper roll.
3. Using a cotton swab dampened with alcohol, wipe the heating dots of the print head. Be careful not to touch the heating dots with your fingers.
4. Allow the alcohol to dry.
5. Reload the paper and close the paper cover.

A1.4 Wireless Infrared Printer Specifications

The following table contains the physical and technical specifications for the infrared printer.

Printing Method	Direct thermal
Number of Columns	32, 48 columns, 384 dots/line
Character Size	0.06 x 0.12 in. (1.5 x 3.0 mm)
Line Pitch	0.1 in (4.0 mm)
Paper Width	2.25 in. (57.5 mm)
Interface	IrDA and Serial (RS-232C)
Protocol	IrDA-SIR, HP-Ir, IrDA-Off
International Characters	U.S.A., France, U.K., Denmark, Sweden, Italy, Spain, Japan, Norway, Korea
Buffer	7 kB
Baud Rate	300-115,200 bps, IrDA: 9,600-115,200 bps
Power	4 AA Alkaline Batteries
Weight with batteries	0.8 lb. (0.4 kg)
Dimensions	3.2” W x 5.6” L x 1.6” H (81 x 142 x 41mm)

Table A1.4 Infrared Printer Specifications

Appendix 2: RAD7 Specifications

Specifications for the RAD7 exceed those of all radon gas monitors made in North America, as well as those in its price range world-wide. This is a partial list of specifications that make the RAD7 so highly regarded in the field.

Table A2.1 Functional Specifications

Modes of Operation	• SNIFF Rapid response and rapid recovery radon measurement • NORMAL High sensitivity radon measurement • AUTO Automatic switch from SNIFF to NORMAL after three hours • THORON Radon and thoron measured simultaneously and independently • GRAB Analysis of air "grabbed" from a discrete sample • WAT Automatic analysis of water samples with optional RAD H_2O accessory
Measurements	• Radon in air measurement with Sniff protocol for quick, spot reading • Thoron protocol for searching for radon entry points • Radon in air 1-day, 2-day or weeks protocol for long term measurement • Radon in water samples with optional RAD H_2O and Big Bottle RAD H_2O kits • Continuous radon in water testing with optional RAD AQUA and Water Probe • Radon in soil gas with optional Soil Gas Probe and DRYSTIK • Radon emission from soil and hard surfaces with optional accessory • Bulk radon emission from bulk materials and objects with optional accessory
Data Storage	1,000 records, each with 23 fields of data Log of printer output also stored
Sample Pumping	Built-in pump draws sample from chosen sampling point Flow rate typically 800 mL/min
Print Output	Short, Medium, or Long format data printed after each cycle Run summary printed at end of run, including averages and spectrum
PC Connectivity	RS232 serial port, full remote control implemented in CAPTURE Software Optional serial to Bluetooth adaptor for wireless PC connectivity
Audio Output	• GEIGER Tone beeps for radon and thoron counts • CHIME Chime only at the end of each cycle, otherwise silent • OFF No sound
Tamper Resistance	TEST LOCK command locks keypad to secure against tampering

Table A2.2 Technical Specifications

Principle of Operation	Electrostatic collection of alpha-emitters with spectral analysis Passivated Ion-implanted Planar Silicon detector SNIFF mode counts polonium-218 decays NORMAL mode counts both polonium 218 and polonium 214 decays
Built-In Air Pump	Nominal 1L/min flow rate Inlet and outlet Luer connectors
Connectivity	RS-232 port up to 19,200 baud rate USB adaptor is included with every RAD7
Measurement Accuracy	+/-5% absolute accuracy, 0% - 100% RH
Nominal Sensitivity	SNIFF mode, 0.25 cpm/(pCi/L), 0.0067 cpm/(Bq/m^3) NORMAL mode, 0.5 cpm/(pCi/L), 0.013 cpm/(Bq/m^3)

Radon Concentration Range	0.1 - 20,000 pCi/L (4.0 - 750,000 Bq/m^3)
Intrinsic Background	0.005 pCi/L (0.2 Bq/m^3) or less, for the life of the instrument
Recovery Time	Residual activity in Sniff mode drops by factor of 1,000 in 30 minutes
Operating Ranges	Temperature: 32° - 113°F (0° - 45°C) Humidity: 0% - 100%, non-condensing
Cycle Range	User controllable number of cycles, from 1 to 99 to unlimited, per run User controllable cycle time, from 2 minutes to 24 hours
CAPTURE Software	• Compatible with Microsoft Windows 7 through 10, and macOS • Automatic RAD7 connection and data download • Graphs radon, thoron, temperature and humidity over time • Automatic humidity correction • Statistical analysis tools track concentration averages and uncertainties • Chart Recorder mode provides real-time RAD7 status monitoring • Control RAD7 operations from computer via direct or remote connection • Automatic calculation and display of radon in water with optional accessories • Automatic combination of data from multiple RAD7s

Table A2.3 Physical Specifications

Dimensions	11.5" x 8.5" x 11" (29.5 cm x 21.5 cm x 27.9 cm)
Weight	9.6 pounds (4.35 kg)
LCD Display Output	2 line x 16 character, alpha-numeric display
Case Material	High density polyethylene
Infrared Printer	Omniprint OM1000 Wireless Infrared Printer included
Power Supply	11-15V DC (12V nominal) @ 1.25A, center pin positive, or included internal EnerSys sealed lead acid rechargeable battery pack (6V nominal, 30Wh, 5Ah)
Battery Longevity	24 hours in SNIFF mode; 72 hours in Monitor mode

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Note: DURRIDGE frequently updates its product manuals with new information. The latest version of this manual can be downloaded in PDF format from the following location: www.durridge.com/support/product-manuals/

Revision 2019-05-21

Standard Operating Procedure
Leak Testing the VAPOR PIN®
Via Water Dam

Updated July 14, 2020

Scope:

The operating procedure describes the methodology to test a VAPOR PIN® or equivalent sub-slab sampling device for leakage of indoor air.

Purpose:

The purpose of this procedure is to assess the potential for indoor air to leak past the VAPOR PIN ® and dilute the sub-slab soil gas sample.

Equipment Needed:

- VAPOR PIN® water dam
- Play-Dough or VOC free modeling clay
- distilled water
- VAPOR PIN® and associated sample tubing.

Procedure:

1) Drill a 5/8" diameter hole in the concrete slab and install the VAPOR PIN® as per the Standard Operating Procedure (SOP).

2) Clean the slab within a 2-inch radius of the VAPOR PIN® to remove dust. Avoid wetting the concrete or wait until the concrete is dry before proceeding and avoid cleaning with VOC-containing substances. A whisk broom or shop vacuum is recommended. Any remaining dust can be picked up with a piece of scrap Play-Dough or modeling clay.

3) Roll a 1-inch diameter ball of Play-Doh or modeling clay between your palms to form a "snake" approximately 7 inches long and press it against the end of the water dam. Push the water dam gently against the slab to form a seal with the concrete.

4) Attach the sample tubing to the top of the VAPOR PIN® and pour enough distilled water into the water dam to immerse base of the VAPOR PIN®, and if desired, the tubing connection at the top of the VAPOR PIN®.

5) Purge the sample point as required by the data quality objectives. Concrete will absorb some of the water, which is normal; however, if water is lost to the sub-slab, stop, remove the water from the water dam, and reposition the VAPOR PIN® to stop the leakage. Reseat the leak test equipment, if needed.

6) If the VAPOR PIN® is installed in the flush-mount configuration, the larger hole can be filled with water in place of the water dam and Play-Dough.

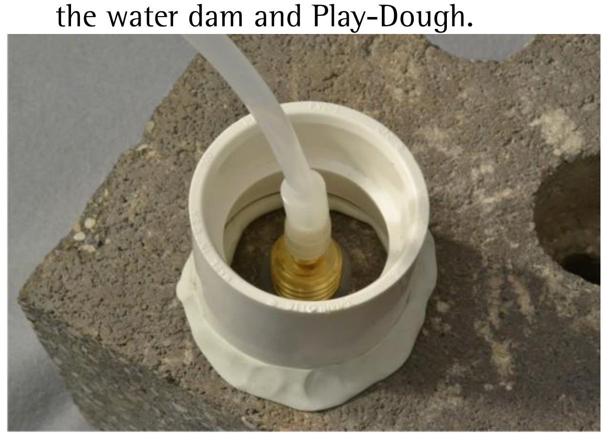


Figure 6. Water dam used for leak detection

Technical Procedure and Work Instructions for

Geophysical Logging - General Procedure

TP-1

Prepared by: David A. Renner Date: 7/6/15

Approved by: Nathan O. Davis Date: 7/6/15

CONTROL DOCUMENT No. TP1011409

Colog, Inc. Technical Procedure TP-1

Revision History

Revision Level	Issue Date	Change Summary
0.00	3/10/97	New procedure, issued as TP-13.
1.00	6/17/97	Changes to original draft, renamed to TP-1 from TP-Gen.
1.10	7/9/97	Minor grammatical corrections and clarification of deliverables. Procedural change with regard to depth system, cablehead checkouts.
1.11	7/28/97	Clarification of how “A.S.D.E.” is to be measured. Added
		procedure to include diagram of well construction.
1.12	3/12/98	Minor grammatical changes, added copyright protection.
1.20	2/5/99	Included revisions to incorporate the purchase of COLOG, Inc. by Layne GeoSciences, Inc.
1.21	2/3/00	Include revisions for name change Layne GeoSciences, Inc. to Layne Christensen Company
1.22	2/15/07	Tightened tolerance for depth check from 0.4% to 0.1%. Added 7-conductor cable to the Wireline Integrity Check.
1.23	5/4/07	Revised to include new logging acquisition systems and ASDE to 0.2%
1.24	1/14/09	Revised with new image of Logging Report form
1.30	7/6/15	Included revisions to incorporate the sale of the COLOG division of Layne Christensen Company to Colog, Inc.

Table of Contents

1.0 SCOPE

This document describes the general procedures for acquiring geophysical logging measurements for Colog, Inc. In addition to this document, detailed technical procedures also exist for each of the specific geophysical log measurements to be acquired.

1.1 Purpose

1.1.1 This procedure provides instructions for performing geophysical logging measurements, to assure the accuracy, validity, and applicability of the methods used.

1.1.2 This procedure further describes the components of geophysical logging systems common to all such measurements, and provides specific guidelines for calibration, standardization and performance verification of the equipment, and for data acceptance.

1.1.3 This procedure also describes the possible interactions between logging measurements and the considerations which shall be applied to ensure a minimal level of degradation of one log by a previously recorded measurement.

1.1.4 This procedure is intended to replace those sections of the Technical Procedures for the individual log measurements which are common to all measurements.

1.1.5 In applying this procedure to an individual measurement, the requirements of this procedure shall be superseded by those stipulated in the Technical Procedure applicable to that measurement.

1.1.6 This procedure does not include a description of the methods to be used in the analysis and synthesis of the results of geophysical logging.

1.1.7 Requirements for data tracking and the use of field notebooks and other documentary materials are addressed in the work plan for each individual project.

1.2 Applicability

This procedure applies to Colog, Inc. personnel who perform work referred to in paragraph 1.1

2.0 REFERENCES

2.1 Standard Guide for Planning and Conducting Borehole Geophysical Logging, ASTM Designation D5753-05, October, 2005.

2.2 Appropriate instrument manufacturer instruction manuals, and Colog, Inc. operational and procedures manuals.

2.3 Site specific Quality Assurance Plans (QAPs).

3.0 DEFINITIONS

Definitions shall be in accordance with ASTM D5753-05.

3.1 Logging is the process of recording one or more measurements as a function of depth in a borehole.

3.2 Wireline - Typically, a multistrand steel cable which connects the logging sonde at one end to the logging truck at the other. Provides a means to raise and lower the sonde in the borehole, and allows electronic communication and transmission of power between the sonde and the surface electronics.

3.3 Sonde or probe - Instrument package which is attached to the end of a wireline and lowered into a borehole to provide one or more measurements as a function of depth in the hole.

3.4 Surface electronics - Electronic equipment which provides control and may provide power to run a wireline log. The raw signals from the measurement device(s) may be translated to engineering values by this equipment. The surface electronics may also include a means of printing a hard copy display of the results of the log, and a means to digitally record the data.

3.5 Validation or Standardization - The process of verifying that a measurement is repeatable.

3.6 Calibration - The process used to adjust the raw signal of a logging instrument to measurable units via a known standard.

3.7 Checks - The process of demonstrating that a measurement is accurate.

3.8 Measurement device - A device which provides one or more measurements. A single sonde may include a number of measurement devices.

3.9 Wireline tension - the sum of the weight of a downhole probe and wireline, and the force applied due to motion of the probe. When the probe is stationary, this typically represents the weight of the equipment as suspended in the wellbore fluid. When running into the hole the tension is typically a bit lower than when stationary; when coming out it is typically greater. Tension provides a means of monitoring the motion of the tool thus providing an indication of points where the probe may get stuck.

3.10 Depth Measurement - Depth is measured with a pulse digital encoder which outputs a specific number of pulses for each rotation of a measure wheel of known circumference. The pulse frequency is translated to a logging speed which can be monitored and controlled by the Logging Engineer. The pulses are counted and normalized to provide depth measurements which are recorded by the surface recording equipment along with the data from the logging probe.

3.11 Personnel:

In addition to the Technical Program Director and other people identified by the client, the people specifically defined based on their responsibilities during the acquisition of geophysical logging measurements are:

3.11.1 Logging Engineer - Employee or designate of the company providing the measurement device who is responsible for overall operations and data quality.

The Logging Engineer typically monitors tool operations by watching surface displays, keeps track of field records, and ensures that acquired data are properly transported and archived.

The Logging Engineer is responsible for ensuring full compliance with this procedure and with the specific Technical Procedure for the measurement being made, and for ensuring that all assigned personnel are adequately trained and qualified to perform these activities.

3.11.2 Technician: Responsible for electrical and mechanical integrity of the logging sonde, the wireline, and the logging truck. The technician typically runs the wireline, monitors depths, and assists in general operations as required.

The Logging Engineer and the Technician may be the same person.

4.0 REQUIREMENTS

4.1 Prerequisites

4.1.1 The well site shall be prepared in a manner that provides adequate access to the well and a reasonably level surface on which to position the wireline truck.

The site shall have sufficient space available to perform all necessary procedures, including equipment and depth checks, in a safe and efficient manner.

4.1.2 The well should be drilled in a manner that permits the intended measurements to be recorded and interpreted in a meaningful way. Although Colog, Inc. may not have control over the drilling process, adjustments will be made to the logging program as necessary, to acquire the most accurate geophysical data as possible under the given well condition(s).

The Logging Engineer shall have access to all information necessary in order to acquire the best possible data for the given conditions. This includes the information necessary to complete the "Well Sketch" (Appendix 7.3) and the "Logging Report" form (Appendix 7.5) of this TP. It is the responsibility of the Project Director to provide this information to the logging engineer in order that the appropriate equipment is brought to the site. Additional information should be obtained from the driller on site if possible.

4.1.3 A general plan for all downhole measurements shall be established prior to drilling the first hole. This allows consideration in the drilling plan of factors affecting the measurements. Furthermore, it makes it possible to schedule operations in such a way as to prevent a situation in which one measurement damages the hole and prevents successful performance of subsequent measurements.

4.1.4 All calibration standards including but not limited to multi-meters, oscilloscopes, and measuring tapes shall be certified and referenced to ANSI standards if such standards exist. If these standards do not exist, the manufacturer's guidelines shall be followed.

4.1.5 All logging instruments shall be calibrated at the manufacturer, in the logging operator's shop, or in an applicable calibration facility. Calibration records shall be maintained by the logging contractor.

4.1.6 All equipment which is quality affecting shall be identified uniquely, and documentation and records pertaining to that equipment shall include the identification number.

4.2 Tools, Material, Equipment

4.2.1 Calibration

All quality affecting devices which provide data to be interpreted in a quantitative manner shall be calibrated. These calibrations shall be made prior to the first use on this project of such devices, whenever a quality affecting device is repaired for any reason, and if the Logging Engineer is concerned about the level of performance of the measurement device. Reasons for repair include but are not limited to 1) damage during operations, 2) field check or standardization failure.

4.2.1.1 Calibration records shall be maintained by Colog, Inc.

All measurement devices which require calibration shall also have standardization checks performed to verify their operation. These checks shall be made prior to and following each use of the measurement device, except if specifically detailed otherwise in the individual Technical Procedure.

4.2.2 Standardization (Validation)

All probes used for qualitative comparison of data obtained either at different times in the same well, or in different wells, or using different probes for the same measurement, shall have standardization checks performed to verify the repeatability of the measurements. Use of an external standard shall be deemed acceptable for validation.

4.2.2.1 Standardization using external standards: When using this approach, standards should be selected which cover the range of output values expected to be encountered in the logged boreholes if possible. Standardization checks should be made before and after logging each measurement, or as appropriate to the goals of the project (checks made daily or even weekly).

4.2.2.3 The conditions for acceptance using standardizations of each wireline log measurement shall be detailed in the appropriate Technical Procedure.

4.2.3 Calibrations and standardizations shall be conducted as detailed in the Technical Procedure for each measurement.

4.3 Precautions and Limits

All geophysical measurement devices are designed for operation within a specific range of conditions. These include but are not limited to temperature, wellbore size, rock type, fluid pressure, and fluid salinity. Furthermore, many devices deliver results which are dependent on these and other conditions.

4.3.1 The operating range of each measurement device shall be detailed in the Technical Procedure for that device.

4.3.2 Specifics of the factors affecting output results shall be detailed in the Technical Procedure for that device.

4.4 Acceptance Criteria

4.4.1 Acceptance shall be dependent on each device having met the criteria for calibration and validation.

4.4.2 Acceptance shall depend on an adequate level of repeatability for the repeat section of each log. The criteria for acceptance shall be spelled out in the TP for each log.

4.4.3 Acceptance shall require that the depth measurement be repeatable and the after survey depth error (A.S.D.E.) shall fall below a value of 0.2%, or 2 feet per 1000 feet of logged depth.

4.4.4 Acceptance shall require the approval of the results of each measurement by the Logging Engineer. The criteria employed shall be detailed in the Technical Procedure for each measurement.

5.0 DETAILED PROCEDURE

All operations shall be carried out in conformance with this procedure and with ASTM standards for the specific tool, if those standards exist. If such standards do not exist, the manufacturer's standard operating procedures (SOP's) shall be substituted, provided such procedures do not conflict with specific instructions in this or any other Technical Procedure. If a conflict arises, it shall be resolved by modification of this procedure and of the Technical Procedure for the specific measurement device, to incorporate the manufacturer's SOP's in a manner which does not degrade the quality or affect the ability to document the quality of the resulting data.

5.1 Prior to mobilization

5.1.1 If possible, determine hole size, the type of wellbore fluid and the fluid level, and select the optimum device(s) for use in each hole.

5.1.2 Examine other logs (if run), noting in particular conditions which may cause tool sticking or variations in data quality.

5.1.3 If logging sondes that include hazardous materials such as active nuclear sources are to be run, client must sign a written agreement addressing paragraph 8 of Colog's "Terms and Conditions".

5.1.4 If possible, discuss hole conditions with drillers.

5.1.5 Develop a preliminary logging plan, based on all available information.

5.1.6 Prepare a list of materials requirements for completion of the logging plan.

5.1.7 Calibrate all quality affecting measurement devices.

5.1.8 The depth measurement system shall be calibrated by running 100 feet of wireline out of the truck (measured with a measurement tape) and verifying that as the wireline is spooled off and back onto the drum the wireline depth counter reads the wireline length to an accuracy of 0.2 ft per 100 feet of wireline motion. Calibrate the depth measurement system as follows:

5.1.8.1 Set up the logging vehicle to perform a depth measurement system checkout (preferably as shown in Appendix 7.1). Mark the wireline with tape at some convenient reference point as shown in the figure. Be sure to keep tension on the wireline when marking the reference point. Set depth in the appropriate data acquisition program to 0.0 (***Note: If more than one program is to be used, a separate checkout form should be completed for each program).***

5.1.8.2 Run out 100 feet of wireline, measured using the digital output from the data acquisition program or panel mounted depth display

5.1.8.3 Measure length of wireline between the tape and the original reference position using a steel measurement tape. Be sure to hold tension on both the wireline and the measurement tape when making the measurement as shown in Appendix 7.1. The measured length should be within 0.2 feet of 100.

5.1.8.4 Spool wireline back to the original zero point (tape back at the reference point).

5.1.8.5 Determine the A.S.D.E. When the wireline is returned to the original zero point. The A.S.D.E. is equivalent to whatever is displayed in the acquisition software with the tape back at the original reference point. The A.S.D.E. may be positive or negative, and should always be reported in feet (if the acquisition program outputs depth in meters, simply convert the values to feet. The A.S.D.E. should be within ±0.2 feet of zero.

5.1.8.6 Alternately, a log of a designated borehole may be substituted for the wireline calibration. In implementing this procedure a log shall be used which repeatably identifies a measurement anomaly at a characteristic depth (for example, caliper will identify the depth of the bottom of casing, a known wellbore enlargement (washout), or a known change of bit size). The depth to the measurement anomaly should be at least 50' from ground level.

Comparison of the "calibration log" to previous logs of the same hole for purposes of depth calibration shall meet the same criteria for depth validation based on the expectation that depth errors shall not exceed 0.2 feet per 100 feet of measured depth.

5.1.9 Complete the "Depth Measurement System Checkout Form" (Appendix 7.2). Be sure to indicate the acquisition program being checked on the form.

5.2 On arrival

5.2.1 Calibration records for all equipment requiring calibration prior to arrival shall be made available to the client or designate upon request.

5.2.2 The truck should be situated on as level ground as possible adjacent to the ***well head.

Caution - Be sure to keep the well head covered during <u>all</u> surface operations (rig up, calibrations/checks, rig down) to prevent inadvertently dropping a foreign object down the hole.

5.2.3 The wireline shall be rigged for access to the wellbore in such a manner that wireline tension can be monitored to prevent endangering the wireline, the measurement sonde, or individuals on the site.

5.2.4 The site shall be inspected to mitigate any potential hazard to ensure the safety of all personnel.

5.2.5 All pertinent wellbore information shall be recorded on the front side of the "Logging Report" form shown in Appendix 7.5. Also, in the "Comments/Other Information" box, document (or draw a rough sketch) of the wellhead itself. Include the stick-up of the pipe (if any) and, if the zero point is on a reference other than the measure point (such as the knurl), document how the depth reference was determined. An example sketch is shown in Appendix 7.3.

5.2.6 The electrical integrity of the wireline shall be checked prior to each continuous logging operation. Typically, the cross-conductance (between individual conductors and between conductor and armor) is less than 10 nanoSiemens. Cable line resistance varies depending the type of logging cable being used. The results shall be recorded on the "Wireline Integrity Check" form (Appendix 7.4).

If more than one logging system is used, complete a separate form for each individual cable line. Indicate the cable line type on the form.

5.2.7 A detailed diagram of cable head dimensions shall be provided, in order to select appropriately sized "fishing tools" if necessary to remove a stuck tool from a wellbore (Appendix 7.7). Furthermore, diagrams for each specific logging probe shall be provided (in the individual Technical Procedures) which shall include the locations of each measurement point relative to a reference (usually, the top or bottom of the logging tool), as well as the diameters of each section of the tool.

5.3 <u>During logging</u>

All procedures detailed in the individual Technical Procedures for each measurement shall be adhered to.

5.3.1 Discuss borehole conditions with drillers.

5.3.2 Examine logs previously run in the same well (if available), noting in particular, conditions which could cause tool sticking or variations in data quality.

5.3.3 Logging sondes which include hazardous materials such as active nuclear sources shall be run only with the approval of the client (including signed agreement addressing paragraph 8 of Colog's "Terms and Conditions"), after verifying that conditions in the well are such that the risk of losing the tool is minimized. Conditions which shall prevent the use of such tools include but are not limited to (a) problems encountered with a previous tool, and (b) wellbore deviation which exceeds safe limits as determined by the Logging Engineer.

5.3.4 If possible, note depths of water table, surface casing, and total depth of well to compare with depths supplied by client.

5.3.5 Minimize the total time the probe is in the borehole, thus minimizing the risk of being stuck. Be particularly careful when the probe is sitting at the bottom of the hole as it is much more vulnerable to sticking.

5.3.6 Wireline tension and other relevant parameters shall be monitored while running into the hole to verify continued motion of the logging sonde.

5.3.6 A minimum 50 foot repeat section shall be recorded for all measurements (if appropriate for the particular measurement), as input to the acceptance criteria. Additional footage may be logged at client's request. Failure to meet the acceptance/ criteria shall require a re-logging of the entire interval which shall include a repeat interval. Measurements which do not normally require a repeat log are detailed in the individual Technical Procedures.

5.3.7 At the completion of each logging run, determine the After Survey Depth Error (A.S.D.E.) as shown in Appendix 7.8 and record it in the "Depth Error" box on the back of the "Logging Report" form next to last file recorded for the particular run.

5.3.7 All measurements shall be checked prior to and following their acquisition in the well (or as appropriate to the goals of the project) to ensure that they meet calibration standards established in the individual TP. The results shall be recorded on forms for each measurement detailed in the specific Technical Procedure. For measurements which are interpreted quantitatively, criteria for acceptance shall be detailed in the Technical Procedure for that measurement which utilize the results of such validations in a quantitative manner.

5.4 Prior to departure

5.4.1 If operations at the site revealed any deviation from the wellbore conditions recorded on arrival, or resulted in any change to those conditions, such changes shall be annotated on the "Logging Report" form (Appendix 7.5).

5.4.2 All equipment which has been exposed to potential contamination shall be cleaned prior to departure. Cleaning procedures shall be in compliance with established site-specific Health and Safety plans.

5.4.3 All quality assurance forms pertaining to all measurements obtained at the site shall be initialed and dated by the Logging Engineer.

5.5 Site Operational record

A record of operations at each site shall be maintained on the back side of the "Logging Report" form as shown in Appendix 7.5.

5.6 Measurement record

A record of each measurement shall be maintained on the back side of the "Logging Report" form as shown in Appendix 7.5.

6.0 RECORDS

The following records generated from the performance of activities under this procedure shall be maintained in accordance with the Project's records procedure, Reference 2.3. Although record keeping and documentation adds significantly to the time and effort required to obtain the data necessary to fulfill project objectives, the overriding concern of all persons associated with these operations shall be to fulfill the requirement for full and complete documentation of the measurements while the measurements are acquired.

6.1 Data records

Records of the data obtained from each measurement shall be produced as follows:

6.1.1 A paper copy of the log values shall be provided as described in ASTM D5753-95.

6.1.2 A digital record of the log shall be recorded for each measurement.

For most measurements, this record shall consist of space-delimited depth data gathers, one gather per line, as either:

A single file which includes both the raw data and translations of that data to engineering units accomplished using conversion factors established during pre-log validations.

(or)

Separate files of the raw and converted log data.

The conversion factors shall be recorded as stipulated in each individual Technical Procedure. Headers shall identify the depth and measurement columns, and the calibration values used to convert the raw data values to engineering units. The filename should designate the name of the well along with the unique run it correlates to.

Exceptions to this type of digital record are described in the individual Technical Procedures for each logging probe.

A backup copy of the digital record(s) shall be created and archived according to data handling procedures established for this project.

6.1.3 Digital record(s) of the pre- and post- log calibrations/checks shall be provided either as part of the digital record(s) of the log or as separate file(s).

6.1.4 Forms shall be completed as specified in this and the specific technical procedures so as to document conformance.

6.2 Exceptions

All exceptions shall be documented on the "Daily Log" form (Appendix 7.6) and verified by client's signature.

6.3 Field Modifications

A field modification is considered to be an exception.

6.3.1 Field modifications of these procedures shall be permitted only if: 1) the activity cannot be performed as defined in this Procedure and the normal change process would cause unreasonable delays, and 2) the modification would either not affect or would enhance the quality of the data, or 3) the modification would result in more efficient operations and would not degrade data quality or the ability to qualify the data. Of course, the Logging Engineer may modify any procedure at the request of the client (or client's representative); however, if the modification is quality affecting, client assumes full responsibility for the data.

6.3.2 Any field modification(s) shall be documented on a "Daily Log" form (Appendix 7.6). This documentation should describe the modification, the new procedure, the name(s) of the person(s) requesting and approving the change along with their signatures.

6.3.3 If the modification results in an improvement in the quality of the data this Procedure shall be modified to incorporate the change.

6.4 Deliverables

Deliverables shall be prepared and provided as detailed in Colog's original proposal or contract. The following shall also be provided upon client's request if applicable for the specific type of measurement being recorded.

6.4.1 A copy of all forms as detailed in this and the individual Technical Procedure for the specific measurement.

6.4.2 For logs which consist of one or more single measurements as a function of depth, a digital data file in ASCII format of the data described in 6.1.2.

6.4.3 A paper copy of the log data described in 6.1.1.

6.4.4 For logs which cannot be stored digitally as described in 6.3.2, the specific format shall be detailed in the controlling Technical Procedure.

7.0 APPENDICES

7.1 Example set up to perform depth measurement system checkout.

7.2 “Depth Measurement Checkout” Form

7.3 Example well sketch

7.4 “Wireline Integrity Check” Form

7.5 “Logging Report” Form

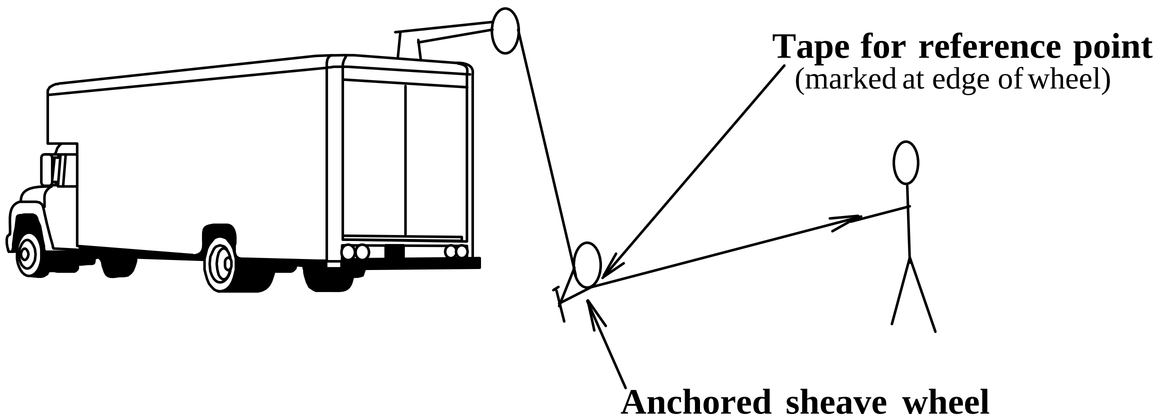
7.6 “Daily Log” Form

7.7 “Cablehead Diagrams”

7.8 After Survey Depth Error Calculation

Appendix 7.1

.


Tape for reference point
(marked at edge of wheel)
Anchored sheave wheel

Appendix-7.2

Depth Measurement System
Checkout Form

Engineer:______________ Location:______________ Unit No:___________

Data Acquisition Program or Type of Counter:____________________________

Depth Indicated in Acquisition Software ________________ Feet (Typically 100.0 ft)
________________ Meters (if applicable)

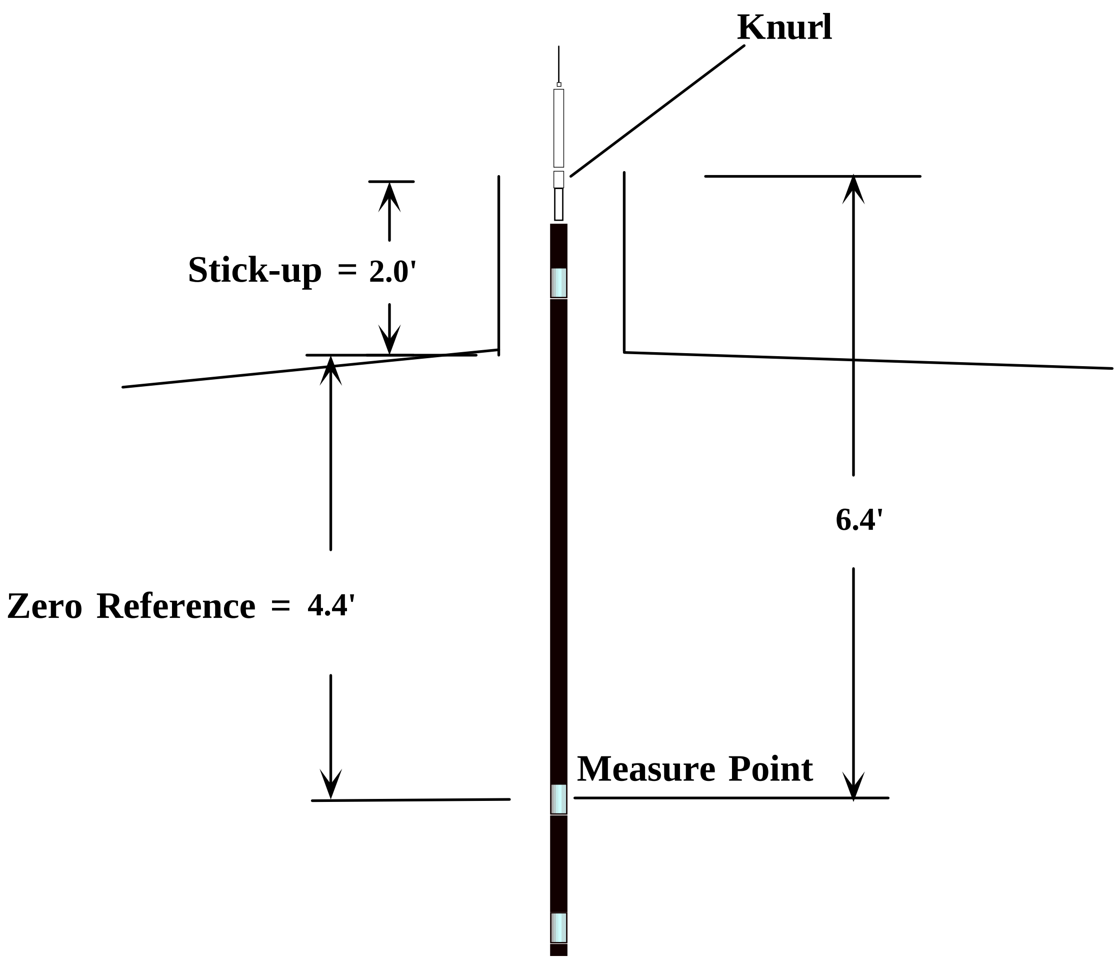
*Measured Length _______________ Feet (or reported length of characteristic feature)
_______________ Meters (if applicable)

Calculated Depth Error______________ Feet per 100'
After Survey Depth Error______________ Feet (Indicate if "+" or "-")

Date:_______________ Time:_______________

*Length measured with approved steel measuring tape only. If using a designated borehole (with repeatable anomaly) the anomaly depth must be verified by an alternate means such as: 1) Driller's strap (when comparing bottom of casing measurement), or 2) Depth verified by previously calibrated depth measurement system.

Appendix 7.3 Example Well Sketch



BOREHOLE GEOPHYSICAL STANDARD OPERATING PROCEDURES AND USER MANUALS

Wireline Integrity Check

Winch/Truck	
Date	
Time	
Location	
Well Designation	
Person Completing Form	

Type of Wireline: (Check One)   Length _______________ Feet

	Wireline Type	Conductor Resistance (Ohms/1000ft) @ 68° F
	1/8” Armored Single Conductor	25.3
	3/16” Armored Four Conductor	24.6
	3/16” Armored Single Conductor	12.5
	7/32” Armored Four Conductor	23.3
	¼” Armored Seven Conductor	26.0
	¼” Armored Coaxial Single Conductor	12.0
	¼” Armored Four Conductor	16.6

Line Resistance (Ohms)

Line 1________________

Line 2________________

Line 3________________

Line 4________________

Line 5________________

Line 6________________

Line 7________________

Armor________________

Cross Conductance (nS)							
	L1	L2	L3	L4	L5	L6	L7
L2		------	------	------	------	------	------
L3			------	------	------	------	------
L4				------	------	------	------
L5					------	------	------
L6						------	------
L7							------
Arm							

Appendix-7.5 “Logging Report” Form

COLOG
borehole geophysics / hydrophysics

LOGGING REPORT

Date ______
Page ______
Engineer ______

Computer ______ Matrix / RG ______ Truck Number ______ Radioactive Sources ______

Well Name ______ Project ______ Client ______

Location ______
State County Qtr. Sec. Section Twp Rge P.M. Other

Elevation ______ Depth Reference ______ Witness ______

Drilling Co. ______

Driller TD ______ COLOG TD ______

Bit Size 1 ______ from ______ to ______ Casing Size 1 ______ from ______ to ______
2 ______ ______ ______ 2 ______ ______ ______
3 ______ ______ ______ 3 ______ ______ ______

Comments and Information:

______
______
______
______
______
______

810 Quail Street, Suite E, Lakewood Colorado 80215
office.303.279.0171, fax.303.278.0135

Run No.	Tools	Speed ft/min Digitize Int.	Time Start Stop	Depth Start Stop	Depth Error	Digital File Name "tol" or "pb1" File Name	Remarks/Comments	Fluid Level
	Model: SN:							
	Module:							
	Model: SN:							
	Module:							
	Model: SN:							
	Module:							
	Model: SN:							
	Module:							
	Model: SN:							
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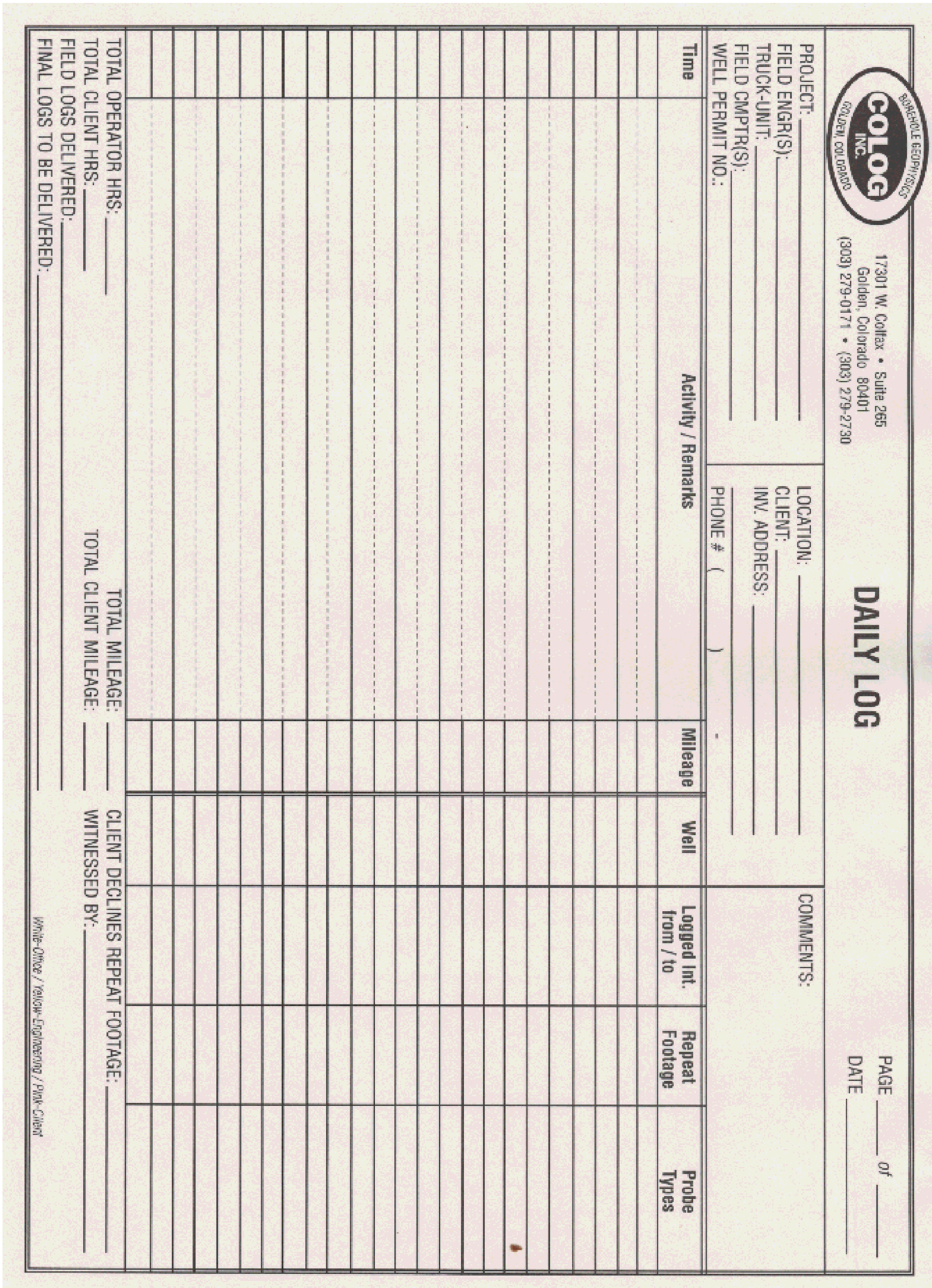
Comments and Information

Appendix-7.6 "Daily Log" Form



BOREHOLE GEOPHYSICS
COLOG INC.
GOLDEN, COLORADO

17301 W. Colfax • Suite 265
Golden, Colorado 80401
(303) 279-0171 • (303) 279-2730

DAILY LOG

PAGE ____ of ____
DATE ____

PROJECT: ____
FIELD ENGR(S): ____
TRUCK-UNIT: ____
FIELD CMPTR(S): ____
WELL PERMIT NO.: ____

LOCATION: ____
CLIENT: ____
INV. ADDRESS: ____
PHONE # ( ) -

COMMENTS:

Time	Activity / Remarks	Mileage	Well	Logged Int. from / to	Repeat Footage	Probe Types

TOTAL OPERATOR HRS: ____
TOTAL CLIENT HRS: ____
FIELD LOGS DELIVERED: ____
FINAL LOGS TO BE DELIVERED: ____

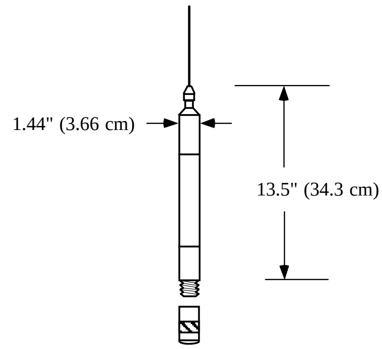
TOTAL MILEAGE: ____
TOTAL CLIENT MILEAGE: ____

CLIENT DECLINES REPEAT FOOTAGE: ____
WITNESSED BY: ____

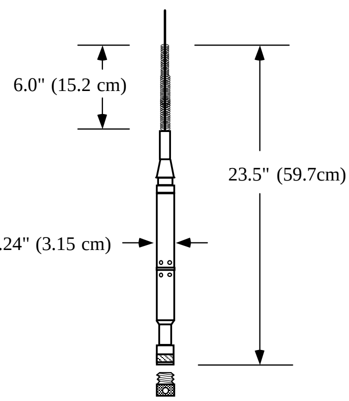
White-Office / Yellow-Engineering / Pink-Client

Appendix-7.7 Cablehead Diagrams

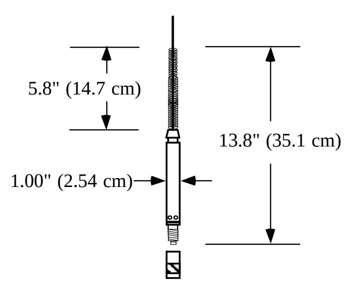
Laval Single Conductor
Cablehead



MSI Four Conductor
Cablehead

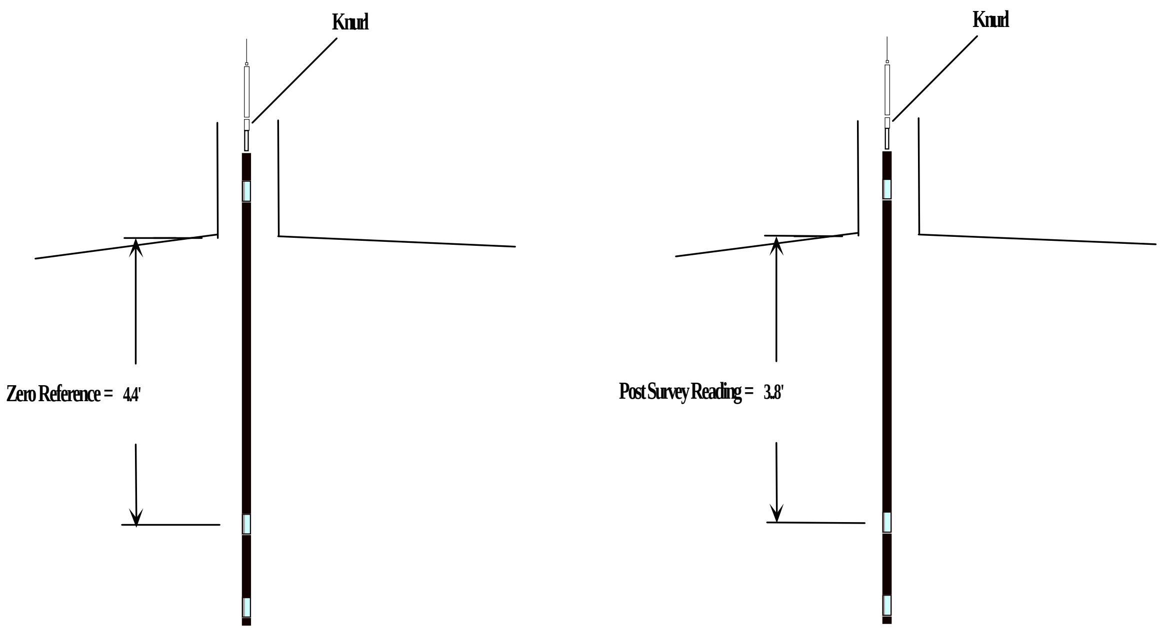


MSI Single Conductor
Cablehead



Appendix 7.8 Determination of After Survey Depth Error (A.S.D.E.)

Pre-Log Zero **Post Log Zero**



A.S.D.E. is determined by subtracting the zero reference depth (4.4’) from the depth indicated in the acquisition program (or depth counter) after the log survey is completed with the tool returned to the same reference point (3.8’). Therefore, in this example the A.S.D.E. is calculated as:

$$\textbf{A.S.D.E.} = (3.8 - 4.4) = -0.6 \text{ ft}$$

Note: In most cases, the tool is zeroed at the measure point, so the zero reference depth is 0.0 ft. In this case, the A.S.D.E. is equivalent to whatever is indicated on the digital output (or counter) for depth with the tool back at the zero reference point.

Javelin

Manual and Documentation

⚠ WARNING

Read this manual in its entirety before attempting to assemble or operate the Javelin instrument. Operation of the Javelin equipment by untrained or unqualified personnel can expose the operator and other persons to serious injury or death.

Magnets in the downhole probes create very strong magnetic field that are always present, even when no power is connected. Use caution when transporting the probes. Do not allow magnetic objects near the probes; magnetic objects and probes will be attracted and may become projectiles if not secured. Persons wearing any type of electronic medical device must not operate the system and should remain at least 2 meters (6 feet) away from all instrument components due to strong magnetic fields.

VISTACLARA INC.
21ST CENTURY GEOPHYSICS

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Mukilteo, WA, USA 98275
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support@vista-clara.com
www.vista-clara.com

Revision 2.3, April 2018

Published by Vista Clara, Inc.

12201 Cyrus Way, Suite 104,

Mukilteo, WA, USA 98275

Printed in the United States

Limited Warranty

Vista Clara Inc. guarantees the Javelin equipment and Javelin software for two years from the date of shipment when used according to our instructions, as described in the Javelin Manual and Documentation. Equipment or software which proves to be defective upon inspection by Vista Clara Inc. will be replaced or repaired free of charge, including freight and insurance charges to and from the customer. No allowance will be made for customer's labor or other expenses incurred by the customer in making exchanges, replacements or repairs. No equipment will be accepted for return without a return goods authorization. Any equipment failures due to accidents, accidental or intentional misuse of the equipment, damage caused by insufficient protection during transit, faulty installation, maintenance or repairs carried out by a person other than the vendor or his agent, or from alterations carried out without the Vista Clara's consent in writing, or normal wear and tear are excluded from the warranty. The Javelin equipment contains sensitive electronic instrumentation and must be handled with care at all times.

Limitations of Liability

Vista Clara Inc. expressly disclaims any liability whether in negligence, strict liability, or warranty for damage or injuries resulting from using, operating, servicing, maintaining, or failure of the equipment caused by not following Vista Clara's safety warnings, manuals, and training or because of the sole negligence of purchaser.

Limited License

The purchaser is granted a limited use license to use Vista Clara's technologies, including its proprietary processing and other software, for its own use only in order to operate the Javelin equipment and to process data collected by the Javelin equipment. Vista Clara retains ownership of the technologies. The purchaser is not authorized to make or provide copies of the software or sublicense the technologies to anyone else or to use the software for any other purpose.

Certification

See next page.

DECLARATION OF CONFORMITY

-2006/42/EC Machinery

-2006/95/EC Low Voltage

-2011/65/EC RoHS

-2004/108/EC EMC

-47 CFR/Part18 EMC

-2005 EN/60204/5th Machinery

Name of Manufacturer

Vista Clara, Inc.

Full postal address, including country of origin

12201 Cyrus Way, Suite 104,

Mukilteo, WA, USA 98275

United States of America

Description of Product

Instrument for the characterization of underground water

Name, type, model, and serial number

Type: Instrument

Model: Javelin

Supply: 220 V

Country of Origin: USA

Make: Vista Clara

Location: Mukilteo, Washington, USA

Reference: CD2009-07

European Normalized Standards Applied

EN 292-2:1991	Basic concepts, general principles for design – Technical principles and specifications
EN 60204-1:2005	Basic concepts, general principles for design – Technical principles and specifications
UL 61010-1:2008	Standard for Safety, Electrical Equipment for Measurement, Control, and Laboratory Use

ISO 14121	Safety of Machinery – Risk Assessment (formerly EN1050:1997)
ISO 3864	Safety colours and safety signs
NFPA 70-2008	National Electric Code
NFPA 79-2007	Electrical Standard for Industrial Machinery

Manufacturer

Place of issue	USA	Date of issue: January 31, 2010
Title of signatory	**Name**	**Signature**
President	David Walsh	________________________________

DECLARATION OF CONFORMITY

-2006/42/EC Machinery

-2006/95/EC Low Voltage

-2011/65/EC RoHS

-2004/108/EC EMC

-47 CFR/Part18 EMC

-2005 EN/60204/5th Machinery

Declaration

I declare that as the authorized representative, the above information in relation to the supply and manufacture of this product, is in conformity with the stated standards and other related documents following the provisions of the above Directives and their amendments.

Copies of the Technical File are kept by the authorized representative for inspection by enforcement authorities.

1. Warnings and Alerts

The following document contains important information regarding the safe and effective operation of your new Javelin system. Improper use of this system can result in physical damage to the instrument, personal injury, or even death.

It is essential that you read carefully through the entire Manual and Documentation (especially the Safety Information) before attempting to operate the system.

ymbols used in this Manual and Documentation have the following meanings.

DANGER	**DANGER:** Indicates a potentially hazardous situation which, if not avoided, will result in death or serious injury
WARNING	**WARNING:** Indicates a potentially hazardous situation or an unintended use which, if not avoided, could result in death or serious injury

	**CAUTION:** Indicates a potentially hazardous situation or an unintended use which, if not avoided, may result in minor or moderate injury and/or appreciable material, financial and environmental damage
	**MAGNETIC FIELD HAZARD:** Indicates a hazard associated with strong magnetic fields surrounding downhole probes.
	**ELECTRICAL HAZARD:** Indicates an electrical hazard associated with high-voltage power
	**LIFTING HAZARD:** Indicates a lifting hazard associated with the moving of heavy components
	**IMPORTANT:** Highlights important notes or instructions which must be closely followed for proper operation of equipment or software

2. Product Identification

Surface Station Serial No. : ***JSS-XXX***

Downhole Probe Serial No. : ***JP###-XXXX***

Reference Coil Serial No. : ***JREF-XXX***

(where XX = 01, 02, 03,…, nn)

3. Table of Contents

Contents

4. Introduction

Javelin is a magnetic resonance logging system. The tool can be used in open or PVC-cased boreholes to estimate formation properties including porosity and permeability.

Included in the Javelin system:

Primary Instrument Units:

Surface Station

Downhole Probe

Custom Downhole Cable

Cable Winch

Additional Components:

Tripod and Sheave Wheel

Connection Cables

Field Laptop Computer

Data Acquisition Card (some units)

Noise Reference Coil

Software:

Javelin NMR Logger Acquisition Software

Javelin Processing Software

Javelin Interpretation Software

Documentation:

Javelin Manual and Documentation (this document)

Components Not Included

Generator Power Source

General system specifications:

Operating Frequency: 240-500 kHz

5. Manual

Unpacking the System

Magnets in the downhole probes create very strong magnetic field that are always present, even when now power is connected. Use extreme caution when transporting the probes. Do not allow magnetic objects (such as steel) near the probes; magnetic objects and probes will be attracted and may become projectiles if not properly secured. Magnetic fields can cause damage to electronics and devices with magnetic encoding (e.g. hard drives and credit cards); keep all such objects away from probes.

The Javelin system is delivered in wooden crates or plastic to prevent damage during shipment. The plywood used in the wooden crates is heat-treated and has not been treated with any hazardous chemicals. The foam is 100% recyclable polyethylene foam. Although the shipping materials can be safely disposed or recycled, it is recommended that the purchaser retain the shipping crates and packaging to be used for future shipment or to protect the system during transport.

The downhole probes are encased in steel magnetic shielding tubes inside the wooden shipping crates or plastic cases. Before unpacking the probes, ensure that there are no unsecured magnetic objects or electronics nearby in the unpacking area. To unpack the probes, first remove wooden supports or removable foam lining and lift the steel shielding tubes from the crate. Next, remove the caps from the steel tubes (if present) and carefully slide the probe from the shielding tube.

The Javelin Surface Station and Cable Winch are very heavy. Four or more persons should be present to unpack the system and heavy system components should never be lifted alone. Units should be lifted using the belts or handle grips attached by the manufacturer. After unpacking the system, the purchaser should check all system components for signs of damage during shipping. If any dents, scrapes, or rattling noises are observed, the purchaser should not use the system and should immediately contact Vista Clara, Inc. to discuss repairs.

Component Specifications and Assembly

The Javelin system has three primary units: the Surface Station, the Downhole Probe, and the Winch with Custom Downhole Cable. Additional components include the Tripod, Connection Cables, Field Computer with Data Acquisition Card, and optional Reference Coil. The specifications, electrical requirements, and important safety features of each component are outlined in the following “Component Specifications and Assembly” section. At the end of this section, instructions for assembling the system are outlined.

Javelin Surface Station

The Javelin Surface Station controls and powers the downhole probe via the High Voltage (HV) Winch NMR Cable connection to the cable winch. The Surface Station also interfaces with the field computer through the data cable (USB or Express Card). If your system has a depth controller, it is located in the Top Panel of the Surface Station and controls the Winch through several cable connections. The surface station receives power from the generator via the Surface Station Main Power Cable. **REFER TO THE FRONT PANEL OF THE SURFACE STATION TO DETERMINE ELECTRICAL REQUIREMENTS (120V or 240V).**

WARNING The Surface Station produces high-voltage power. Never touch, connect, or disconnect the High-Voltage Winch NMR Cable when the system is powered on:

Specifications: **Electrical Requirements:**

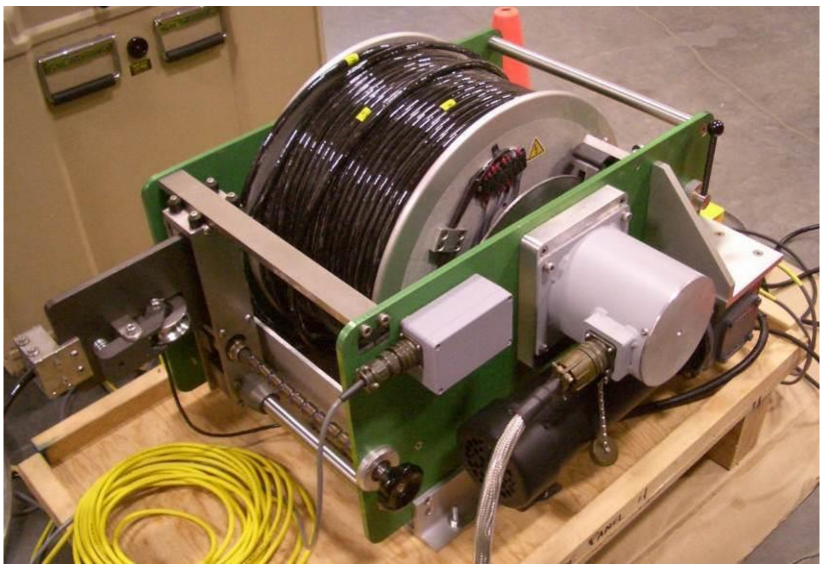
Weight: approximately 120 lb.	AC Line Requirements:
Dimensions: 34L X 29 W X 26 H in.	Varies by model:
Standby power consumption: 120 W	Generator Requirements:
Peak power consumption: 2400 W	3000 W

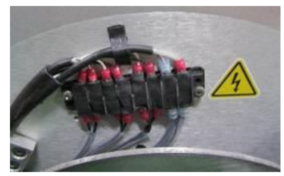
Cable Winch with Custom Cable

For all winches, refer to the winch manufacturer manual.

The cable winch stores, raises, and lowers the Custom Downhole Cable. The cable winch interfaces with the Surface Station via the HV Winch NMR Cable. The Cable Winch is powered by a generator or AC line power. REFER TO POWER INPUT ON THE WINCH TO DETERMINE ELECTRICAL REQUIREMENTS (120V OR 240 V).

WARNING The Cable Winch and cable carry high-voltage power. Do not allow water to splash or rain on the winch. Never allow water to contact the cable bridge located on side of the Cable Winch.





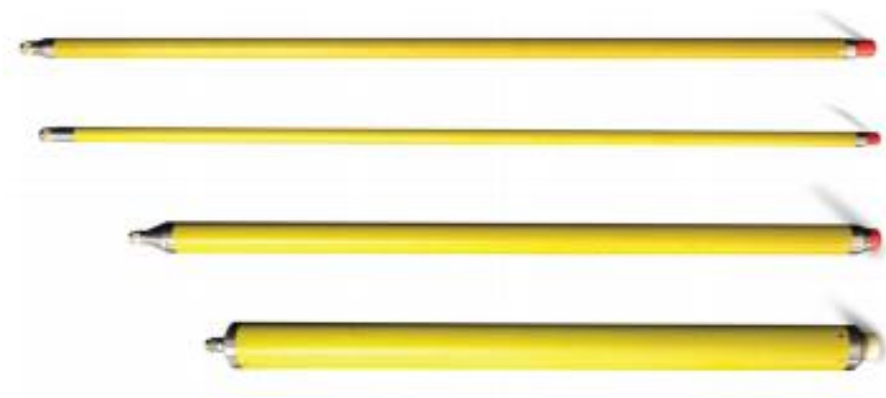
DO NOT ALLOW WATER TO CONTACT THE CABLE BRIDGE

Note: Newer models may have internal cable bridge (not shown.)

Specifications:	**Electrical Requirements:**
Weight: 300 lbs without cable (390 lbs with cable) Dimensions: approximately 40L X 28W X 20H in Refer to Mount Sopris manual for additional specifications.	AC Line Requirements: Varies by model: 120 V; 20 A; 60 Hz OR 240 V; 16 A; 50 Hz Downhole probe power provided by Surface Station via HV Winch NMR cable

Downhole Probe

The Downhole Probe collects NMR measurements of fluids in a Earth formation when lowered into a PVC-cased or open borehole. Permanent magnets in the probe project a static magnetic field into the formation. NMR signals are measured from within a thin cylindrical shell surrounding the probe using pulsed oscillating magnetic fields.



Specifications:	**Electrical Requirements:**
Weight and Dimensions vary by probe, refer to Table 1 in the Appendix	Power supplied by Surface Station via Custom Downhole Cable via HV Winch NMR Cable connection to Winch

⚠WARNING

Magnets in the downhole probes create very STRONG MAGNETIC FIELDS THAT ARE ALWAYS PRESENT, even when no power is connected. Use extreme caution when transporting the probes. Do not allow magnetic objects (such as steel) near the probes; magnetic objects and probes will be attracted and may become projectiles if not secured.

Persons wearing any type of electronic medical device such as a pacemaker must not operate the system and should remain at least 5 meters (15 feet) away from all instrument components due to strong magnetic fields.

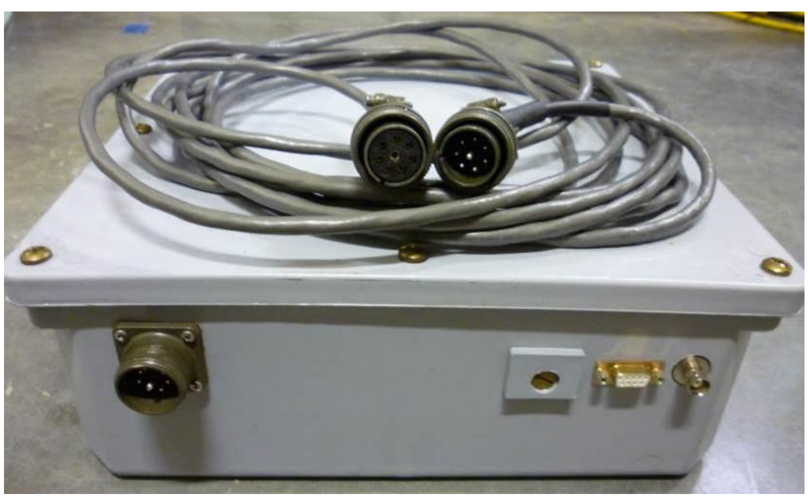
Additional Components

High Voltage Winch NMR Cable

The High Voltage Winch NMR Cable connects the Surface Station to the Cable Winch and carries high voltage power to the Downhole Cable and Probe

Optional Reference Coil

The optional reference coil box is used to cancel environmental noise encountered in very shallow investigations. The coil box is connected to the Surface Station via a custom keyed cable.



Tripod and Sheave Wheel

The Javelin system can be configured with a number different tripods. The Javelin system does have a custom sheave wheel. The Sheave wheel is appropriately sized at 11 inches diameter for the Javelin cable, which has a minimum bend radius of 5.5 inches. NEVER ATTEMPT TO USE A THIRD PARTY SHEAVE WHEEL FOR THE JAVELIN CABLE – THIS CAN DAMAGE THE CABLE IRREPARABLY.

National Instruments Data Express Card (Some systems)

Versions of the Javelin manufactured after 2015 interface with the computer through a USB. Older versions of the Javelin interface through a National Instruments Express Card. The National Instruments Data Express card fits into the Express Card reader on the Field Computer and interfaces with the Surface Station through the Express Card Data Cable.

Software and Software Installation Guide

General Software

The Basic Javelin Instrument includes three software programs:

1. **"Vista Clara NMR",** for acquiring Javelin NMR logging data.
2. **"Process Javelin Log",** for processing of raw Javelin logging data.
3. **"Interpret Javelin Log",** for automated interpretation of processed Javelin logging data.

A separate driver is required to enable communication with the depth encoder and must be installed separately.

The Javelin software is provided on a CD-ROM or USB thumb drive. All software should be installed before attempting to operate the Javelin instrument.

Calibration folders

Calibration folders provided with the Javelin system contain important acquisition and processing parameters specific to the Javelin model and downhole logging cable. A separate calibration folder is provided for each pairing of Javelin probe and downhole cable. These files should be carefully managed and protected to prevent changes to the file data or loss of the files. The user will be prompted by acquisition software to locate an appropriate calibration folder at the start of each logging survey.

It is important that the calibration files remain unchanged and that the user can easily select the proper calibration file when prompted by software. Use of an incorrect or corrupted calibration file will lead to improper acquisition and will render data collected unusable. Carefully maintain clear file and directory naming conventions for your calibration files.

6. Connection Guide

Before attempting to connect the Javelin System, read this section “Connection Guide” in its entirety. The following instructions describe how to properly and safely connect all the components of the Javelin system **without power**:

Never attempt to connect or disconnect any cable in the Javelin system when the system is powered on. Permanent damage to the Javelin System may occur if the system is powered on prior to completing connections or if any connections are adjusted while the system is powered.

DO NOT power on the Javelin system until all connections are completed. Powered operation is described in the "Operation" section.

CAUTION The surface station and cable winch are extremely heavy. Use at least four people to move the instrument components and lift with care.

1. Set up the tripod and Sheave Wheel:

Center the tripod over the logging hole. Stabilize the tripod so that it will not shift or tilt during logging.

Never attempt to use a sheave wheel with an outer diameter less than 10 inches. The logging cable can be permanently damaged if forced into tight bends.

2. Connect the Downhole Cable to the Downhole Probe:

WARNING Magnets in the downhole probes create very STRONG MAGNETIC FIELDS. Use extreme caution when handling and transporting the probes.

a) Unscrew and remove the protection cap from the logging head of the Downhole Probe. ***Check O-rings in Logging head and Protection Cap.*** O-rings should be present, well lubricated with silicone (non-conductive) grease, and free of any Dirt. If the O-ring is dirty no well lubricated follow the instructions for cleaning and lubricating the O-ring in "System Care". Store the cap in a dust-free bag in a secure place.

Note: Never attempt to unscrew the logging head from the probe; only unscrew the connection at the top of the probe.

Downhole Probe Logging Head

Downhole Probe Protection Cap

Inside Down Hole Probe Logging Head

Inside Downhole Probe Protection Cap

b) **Unscrew the protection cap from the end of the Downhole Logging Cable.** ***Check O-rings in Cable Head and Protection Cap.*** O-rings should be present, well lubricated with silicone (non-conductive) grease, and free of any Dirt. If the O-ring is dirty no well lubricated follow the instructions for cleaning and lubricating the O-ring in "System Care". Store the cap in a dust-free bag in a secure place.

Downhole Cable Logging Head

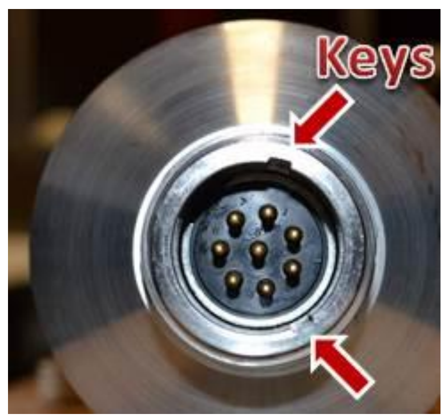
Cable Head Protection Cap

Inside Downhole Cable Logging Head

Inside Cable Head Protection Cap

c**) Connect the Downhole Cable to the Downhole Probe Logging Head**. As you insert the Downhole Cable end connector into the logging head connector, twist the connections so that the keys align; you will feel the connections dock and may hear a dull click. Ensure the connection keys are aligned before tightening the screw cap. Gently tighten the screw cap; hand tightening is sufficient; do not use tools to tighten.

Cable Logging Head



Downhole Probe Logging Head

Downhole Probe connected to Logging Cable

3. Connect Field Computer via Data Cable and Express Card or USB:

If your Javelin system has a USB connection, attach the USB cable between the surface station and computer. Otherwise if your system has a PXI connection, follow the instructions below:

a) Insert the Data Express Card into the field computer Express Card Reader and ensure that the data cable connection is secured in the Data Express Card.

b) Insert the Data Cable into the "PC" connection on the Surface Station and gently tighten the screw knobs.

Data Cable Connection and Data Express Card inserted into field computer

Data Cable Connection on Surface Station

4. Connect the Reference Coil to the Surface Station

a) Insert the female end of the Reference Cable into the port on the Reference Coil box and hand tighten the threaded connection.

b) Insert the male end of the Reference Cable into the "REF" port on the Surface Station and hand tighten the threaded connection.

Reference Channel Cable connection to Reference Coil box.

Reference Channel Cable connection to Surface Station.

5. Connect the High Voltage (HV) NMR Winch Cable between Winch and Surface Station

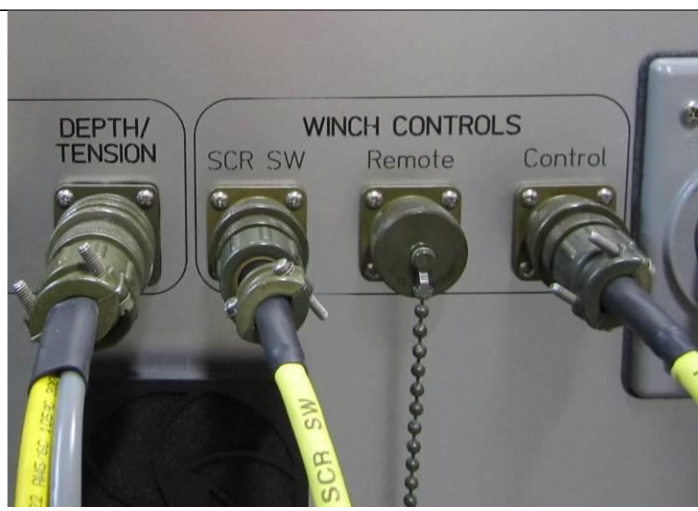
a) Insert the female end of the HV NMR Winch Cable into port on the right side of the Cable Winch and hand tighten the threaded connection.

b) Insert the male end of the HV NMR Winch Cable into the port labeled "WINCH CABLE" on the Surface Station and hand tighten the threaded connection.

 NMR Winch Cable connection to Cable Winch.	 NMR Winch Cable connection to Surface Station

6. Complete all other Winch/Encoder Connections

Complete all other connections from the outputs on the Surface Station Encoder or Winch. The number of connections will depend upon the winch and encoder type. Refer to the winch manufacturer manual for instructions on connecting the Cable Winch.



Connections from output of Surface Station to the Cable Winch

7. Connect power cables to the Surface Station and Cable Winch

Connect the AC power cable to the Javelin Surface Station <u>but do not yet supply power to the cable.</u> AC power requirements are specified on the front panel above the power cable port.

⚠WARNING

An appropriate power source must be used to power the surface station. Use of an incorrect power supply will cause permanent damage to the Javelin system. Surface station power requirements vary by model and are specified on the front panel.

The surface station and winch may have different voltage requirements.

 **Surface Station Configured for 120V AC Power**	 **Surface Station Configured for 240V AC Power**

8. Prepare all generator connections

If using a generator, adjust the generator power to the appropriate settings for the surface station (120V 60Hz or 240V 50Hz – varies by model). The winch may require a different voltage from the surface station. <u>If using a 240V generator for a 120V Javelin system, YOU MUST USE A STEP DOWN TRANSFORMER.</u> Plug the power cables for the surface station and for the winch into the generator power outputs but <u>do not yet power the generator.</u> Ground your generator according to the rules of your local jurisdiction.

EMERGENCY SHUTOFF PROCEDURE:

<u>If any electrical hazard arises or in case of any emergency, shut off power to the Javelin Surface Station by disconnecting the main power cable or by pressing the main power switch if the Surface Station is powered on.</u>

7. Disconnection Guide

The following instructions describe how to properly and safely shut down and disconnect all components of the Javelin system:

⚠WARNING

Never touch, connect, nor disconnect any cable when the system is powered on. Always power the system off before touching any connections. Disconnecting or reconnecting the downhole probe while the Surface Station is powered will cause permanent damage to the Javelin system.

1. Turn off the Surface Station:

Turn off the surface station by pressing the main power switch. You will see the green power light turn off and hear the cooling fans turn off.

Main Power Button on Javelin Surface Station

2. Power down the generator:

Turn off the generator and disconnect all power cables.

3. Power down and store the Field Computer:

Power down the Field computer and store it in a safe place.

4. Remove and Disconnect the Downhole Probe:

⚠WARNING

Magnets in the downhole probes create very STRONG MAGNETIC FIELDS. Use extreme caution when handling and transporting the probes.

a) Ensure that the field computer is powered down and stored at a safe distance before removing the Downhole Probe from the logging hole. Strong magnets on the downhole probe could damage the field computer if a safe distance is not maintained.

b) Remove the Downhole Probe from the logging hole and place probe on the ground. Do not attempt to remove the Cable from the Probe while the Probe is hanging or setting above the wellhead.

c) Disconnet the Downhole Cable from the Probe logging head by unscrewing the screw cap connection at the base of the cable. Do not attempt to unscrew the logging head assemply from the probe.

d) Store the probes in the steel packing tubes and cases for safe transport

Check that all O-rings are in place following disconnection. An O-ring should be located in the Cable Logging Head, Probe Logging Head, and in each protector cap.

Disconnect remaining cables and pack components:

Disconnect all remaining cables and store them in the cable case. Replace caps on all connection ports and close the surface station casing.

8. Operation

Overview of Nuclear Magnetic Resonance

The Javelin System directly detects the presence of groundwater utilizing a phenomenon known as proton nuclear magnetic resonance (NMR). Proton NMR is observed when protons spins associated with hydrogen atoms in groundwater are subjected to a perturbation in the background magnetic field. In a static magnetic field, B_0, the proton spins will preferentially align in the same direction as the field and so form a small magnetic moment. In the case of the Javelin system, the background field is created by magnets in the probe.

The spin magnetic moments associated groundwater can be excited from their equlibrium state by transmitting an radio-frequency RF pulse at a specifically tuned frequency. This pulse is generated by the probe and causes a portion of the spin magnetization to rotate perpendicular to the background field, into the so-called "transverse plane." In this excited state, the magnetization will then precess about the background field and generate an RF signal which has the same frequency as the transmitted pulse. This frequency is called the Larmor frequency, f_0, and it is proportional to the magnitude of the background magnetic field. For hydrogen in water, the Larmor frequency can be calculated as:

$$f_0 = 4258(Hz/Gauss) * B_0(Gauss).$$

A series of EM pulses are used to measure the transverse magnetization signal which decay as the spins return to their equilbrium state.

In the basic CPMG experiment, a series of RF pulses are transmitting in short-sucession. Between each pulse, an NMR spin echo is measured generating a so called "echo train". The time spacing between each pulse (also the duration between each echo signal is known as the "echo-time". The center frequency of the spin echo signal is the Larmor frequency. The intial amplitude of spin echo train is directly proportional number of proton spins being measured (i.e. the amount of water). The echo train exhibits a decay over time characterized by the decay time T_2 (typically between 1ms and 1s). The T_2 decay time provides information about the pore-scale environment of the spins and can be used to derive estimates of pore size and permeability.

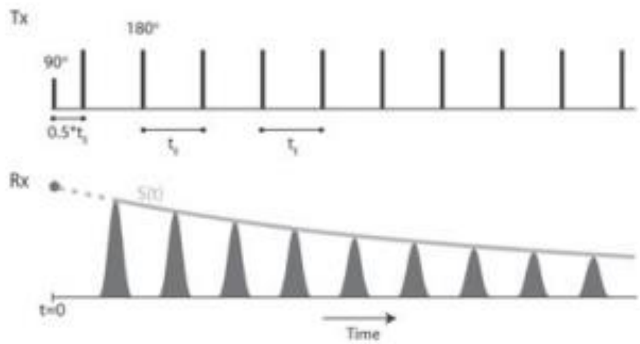


Figure 1. Schematic illustration of the CPMG pulse sequence showing timing of transmitted B_1 pulses in the top panel, and received NMR echo signals (dark gray) in the bottom panel. The lighter gray line represents the spin echo decay curve $S(t)$ with an initial amplitude proportional to water content and an exponential decay time T_2.

As the Javelin probe is lowered into the formation, multiple CPMG measurements are collected (or “stacked”) at each depth interval. After a series of measurements are collected at one depth interval, the probe is lowered and another series of measurements is collected to generate an NMR depth log used for interpretation.

Weather Planning

⚠WARNING

The Javelin Surface Station and Cable Winch are not approved for use in the rain! In case of rain, the Surface Station and Cable Winch must be kept covered and dry at all times.

Under no circumstances should the instrument be used if there is a chance of lightning.

The user is responsible for monitoring changing weather conditions and responding appropriately well before a danger becomes present. If weather changes and a storm becomes likely, seek shelter. The following preventative steps for protecting the Javlin system should be carried out only if conditions safely permit with the following priority:

(i) Turn off the system.

(ii) Disconnect cables and replace unit covers.

The user’s first reponisibility is for the safety of all field operators.

If lightning is nearby, abandon the sytem without regard to its currrent state and seek shelter immediately!

Survey Setup

WAIT: Do not power on the system until instructed to do so in the following section "Running the Javelin System". Powering on the system before properly connecting all components may cause permanent damage to the Javelin system.

1. Determine Survey Geometry

Prior to setting up a logging survey, determine a working geometry for the survey. Components and cable should be arranged in a manner that minimizes hazards. Ensure that the logging cable will not be disturbed by persons or vehicles; place orange safety cones in areas where potential hazards are identified.

2. Set up the tripod

Center the tripod and sheave wheel over the logging hole. Stabilize the tripod so that it will not shift or tilt during logging.

3. Connect all components and remove plastic casing covers.

Connect all components following the instructions in the section "Connection Guide." Remove the front and back plastic casing ends from the Javelin Surface Station enclosure. <u>It is critical that the both the from and back doors to the enclosure be removed to provide for adequate air circulation.</u>

Make sure to check all O-rings during connect. Replace, clean, and lubricate any O-rings if necccessary. Never attempt to operate probe with missing O-rings.

4. Set the downhole probe at the desired initial depth

Determine the desired starting depth and set the probe to the proper vertical location. It is good practice to reference all measurement depths based on the distance from the top of the well head to the top of the logging head (the end of the logging cable). This distance can be easily monitored by using the depth encoder (if available) or by observing the depth demarkations on the downhole cable and noting which demarkation is inline with the top of the well head. Keep in mind that there is a vertical offset between the logging head and the sensitive zone of each downhole probe; this distance differs between the various downhole probes as shown in Table 1 in the

Appendix. This vertical offset from the logging head is corrected in the processing software.

Running the Javelin System

1. Check connection of all hardware components but DO NOT power on the surface station.

Do not power on the system. Ensure that all components are properly connected as described in Section "Connection Guide" and check that all connections are hand tightened. Also ensure that the Data Cable and Express Card are connected to the field computer, but do not power on the computer yet.

2. Power on the generator.

Plug the surface station power cable into the generator and power on the generator. The extension cable to the generator should be connected to the 110V or 220V output, depending on the voltage of the Surface Station and Winch.

3. Power on the Javelin Surface Station.

Once all hardwater components are plugged in and the generator is running, power on the Surface Station by pressing the power switch. You will see the main power light illuminate and hear the cooling fans turn on.

Main Power Button on Javelin Surface Station

4. Check that the DC Power Supply reads 20V. Check that the red overtemp/overvoltage protection light is not illuminated (applicable only if your system has an OVP/OTP light).

If the system is in an operable state, the DC Power Supply will read 20V and the overtemp/overvoltage protection (OVT/OVP) light will not illuminate.

Sometimes when powering or cycling power on the Javelin Surface Station, the DC Power Supply will not initiate to 20V. If the DC Power Supply reads 0V, turn off the power supply using the black switch on the left of the panel, wait 10 seconds, and repower.

The system will warn of an overvoltage state if the generator output is set inappropriately – check that the generator is set to the right power output. The system will warn of an overtemperature state if the internal electronic temperature exceeds 60^{o}C. If the system is over temperature, move the Surface Station into a cooler area and allow the system to cool for at least 10 minutes after the OVP/OVP light delluminates.

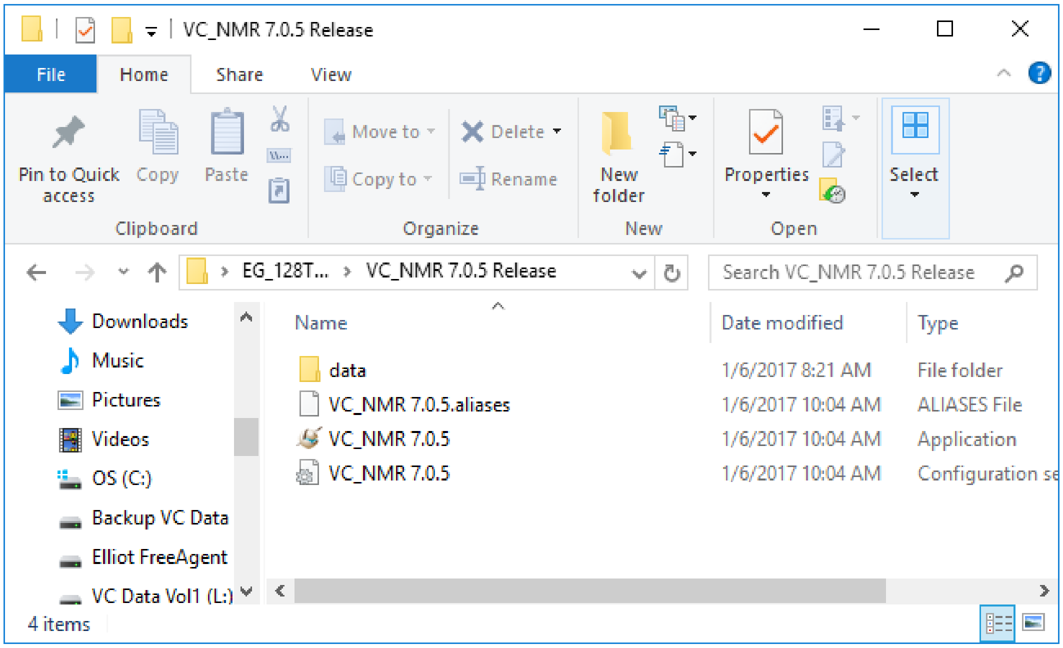
5. Power on the Field Computer.

For systems operating with a National Instruments Express Card, the Javelin Surface Station must be powered on and connected to the computer prior to powering the computer. If the computer is powered on prior to powering the Surface Station, the system will not establish communication.

Once the Surface Station is powered on, power on the field computer (note: some computers will power on automatically when the Surface Station is powered turned on). If the computer was turned on before the main power was turned on, the computer may not recognize the data acquisition express card; if this occurs, turn off the computer and reboot.

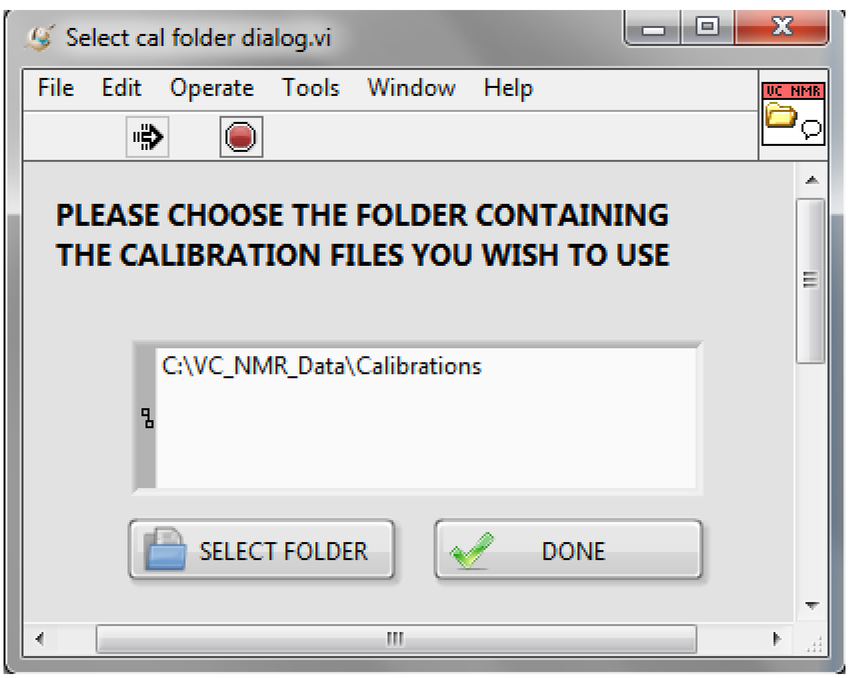
6. Open the Javelin Logging Software

The Javelin Logging Software is an execuatable contained in a folder with other helper files:



The Javelin Logger Software Folder

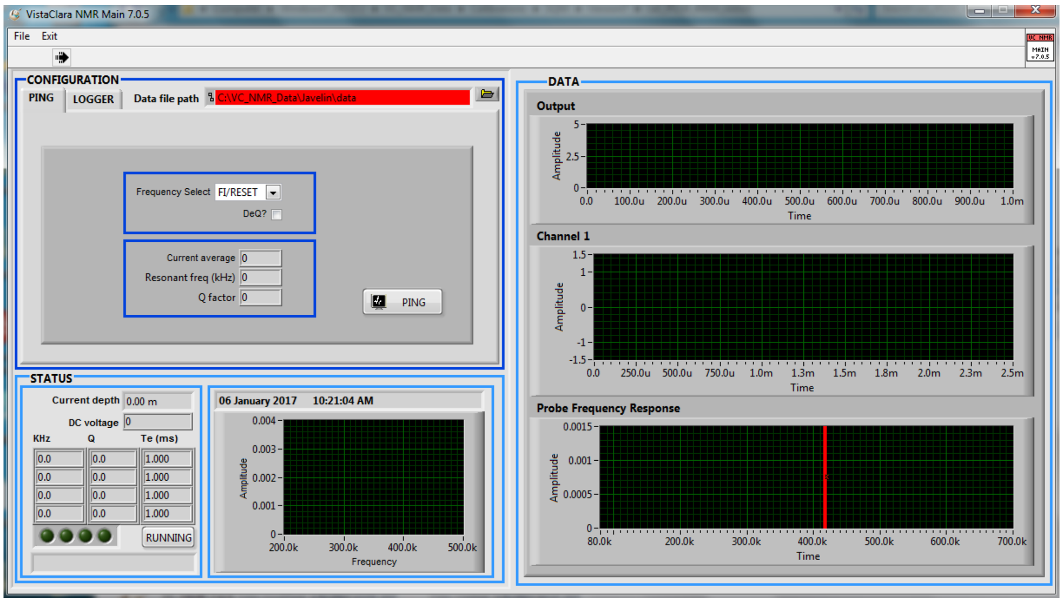
To launch the Javelin Acquisition software, open the executable named “VC_NMR 7” with the Vista Clara Icon. You will immediately be prompted to select a calibration folder.



The software is disabled until you select the calibration folder for your system configuration. A separate calibration folder should be provided for each surface station, winch, and probe combination. Click “Select Folder” and Navigate to the location of your calibration folder. Note that the folder will appear to be empty, but in fact contains a number of hidden files. With the correct folder highlighted, click select folder to choose the calibration folder. By default, calibration files should be stored in the following directory “C:\VC_NMR_Data\Calibrations”.

It is citical that the correct calibration folder be selected. Use of an incorrect calibration file will lead to improper acquisition and will render data collected unusable. Cafefully maintain clear file and directory naming conventions for your calibration files.

After selecting a calibration file, the Main Screen will appear and will launch into the “PING” tab.

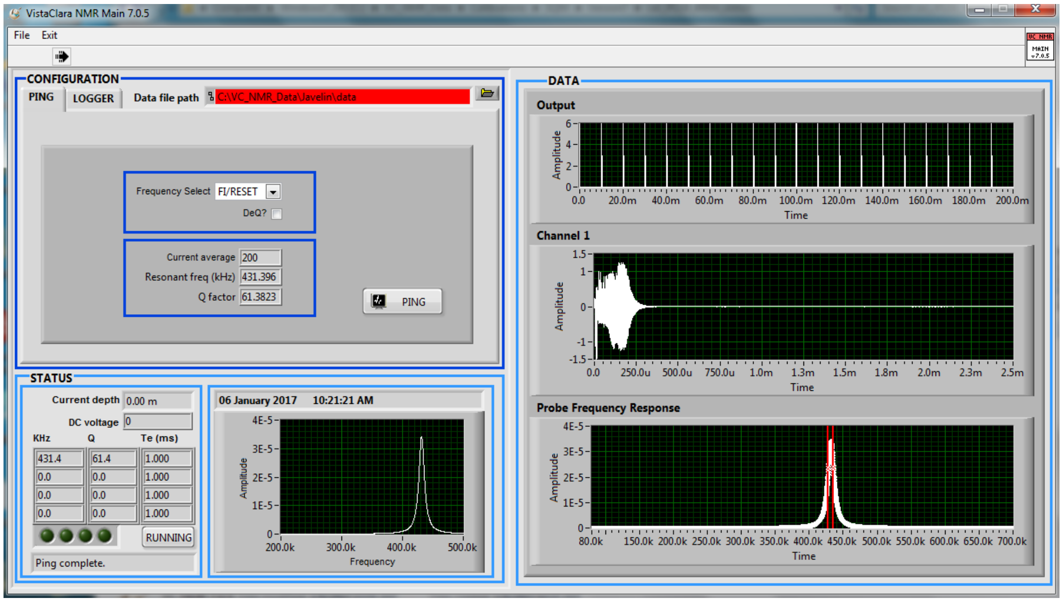


The NMR Launch Screen after selecting a calibration file

In order to proceed, the user must run a ping diagnostic of the system.

Diagnostic Ping

The Diagnostic Ping tests the response of the probe electronics, including the resonant coil response and the preamplifier function. The Ping should always be run prior to the Logger Software to ensure the electronics are funcitoning properly.



The diagnostic "Ping" software showing a normal response

To run the ping software, click "Ping" button in the lower right corner of the ping tab. A good ping response is shown in the example figure. The middle plot shows the time-domain ringdown response of the probe and the lower panel shows the frequency-domain rindown response. The time-domain response should appear as an quasi-exponential ringdown of energy to a low level of background noise. The frequency-domain response should appear as a gaussian peak centered around the known frequency tuning of the probe. In noisey conditions, burst of noise may be observed in the time domain or noisey frequency bands may be observed as spikes in the frequency domain. Thus, the ping also provides some indication of the noise level and expected data quality.

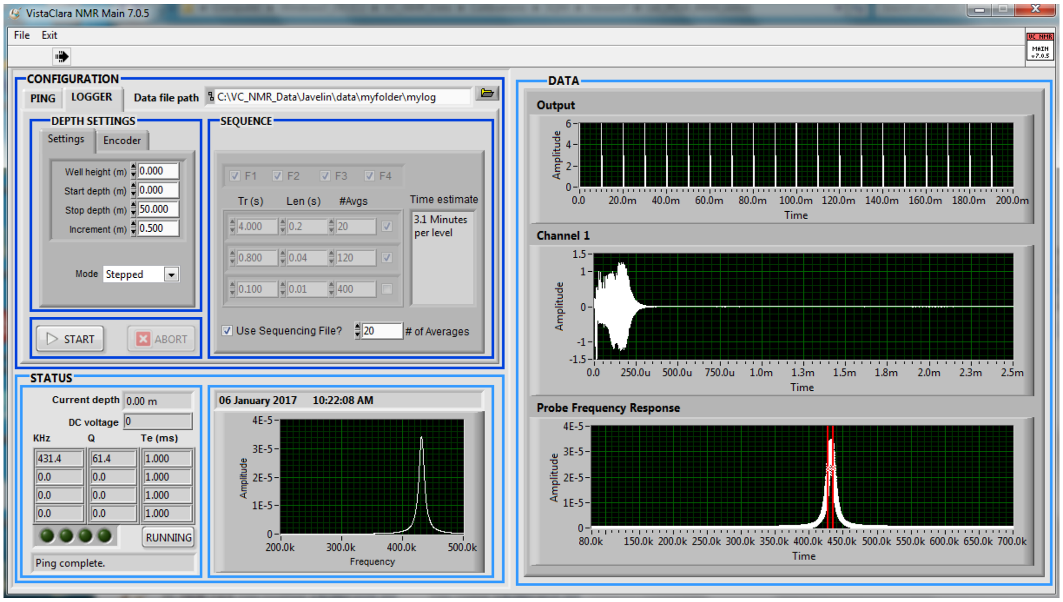
If an abnormal ringdown or resonant peak response appear, there may be a problem with the system. Power down the system and computer, recheck all connections, power on the system, check all indicator lights and rerun the ping. If the response still appears abnormal, contact Vista Clara.

The ping software also allows the user to test the ping response at different tuning frequencies. Before clicking or reclicking "Start" the user may change the Select Frequency field to a different frequency . F1/RESET will always be the highest frequency. F2, F3, and F4 will be seqeuentially lower frequencies. The location of the peak in the frequency domain should shift as the frequency is adjusted.

The ping must be run at least one time before the user will be allowed to start logging.

Javelin Logger

Upon clicking the "Logger" tab, the main NMR Logger window will open as shown below:



The Javelin NMR Logger data acquisition screen on start-up.

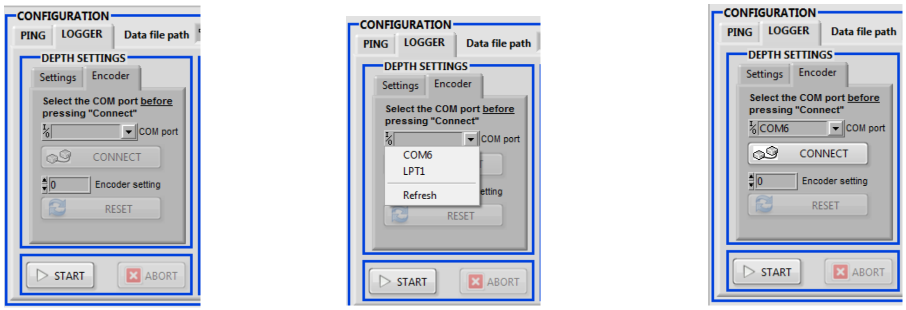
1. Select a data folder name

Enter a data folder name. A new folder must always be specified This is the folder in which all data from the current log will be written. You can type the folder name directly in the window or you can click the yellow folder button for a file navigation dialog box. Note that all files written to this folder will have the same name as the folder and suffices describing their order in the log. A separate file will be written for each depth level and for each acqusition type that is acquired at that depth.

You must specify a new folder that does not contain any Javelin data files. Otherwise the folder wil be colored red and you will not be able to proceed until you specify an empty folder.

2. Connect to the depth encoder

If your Javelin system includes a depth counter, you must connect to the depth encoder in order to adjust the reading on the counter. First, click the encoder tab under the Depth Settings window. Next, select the COM port to communicate with the encoder. If more than one COM port is listed, you can attempt to connect to each port successively. Select a COM port, then click, "CONNECT". If the connection is succesful, the "RESET" button will become active. If the connection is unsuccessful, you will receive an error – click continue and try to select a new COM port.



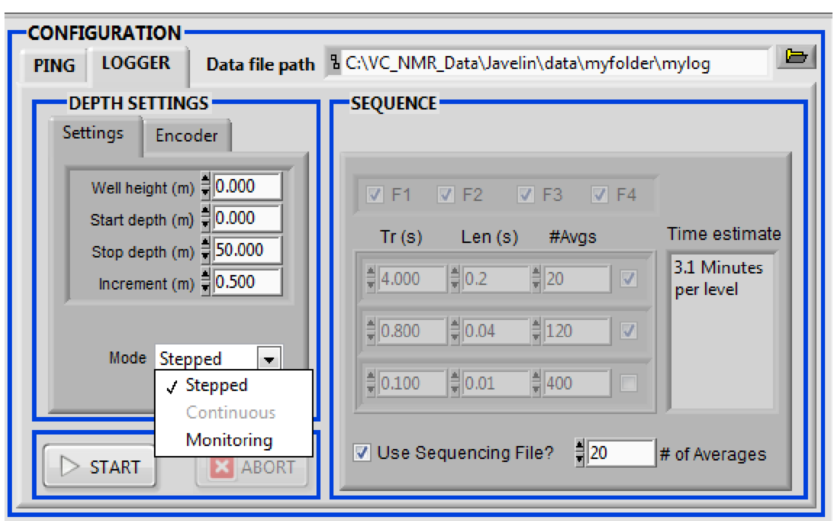
Navigating the depth encoder tab in the Depth Settings Window

Once the port is connected, you can zero the depth encoder or set it to a desired value, by entering an encoder setting and choosig "RESET". By convention, the "Zero Depth" for Javelin logging is the depth at which the cable head (top of probe) is aligned with physical zero datum (e.g. the top of the well casing). If you have a depth encoder, the encoder should be reset to 0m when the probe is positioned in the hole such that the top connection is aligned with the physical zero datum point (usually the top of the casing). If you are using a tape marked cable, the tape markings should read 0m at the cable head and should increase in 0.25m or 0.5m increments along the cable such that the reading aligned with the zero datum point will reflect the depth of the cable end down the hole.

To avoid bringing the cable head too close to the sheave wheel, it is suggested that the cable be marked at 1m. When setting the depth encoder, the cable should be positioned at the 1m mark and the value should be reset to 1m. This avoids lifting the probe too high and potentially bending the fragile cable head.

3. Choose a logging mode

Return to the "Settings" tab under Depth Settings. Three different modes are available: Stepped, Continuous, and Monitoring.



Navigating the Settings tab

In stepped mode, the probe is lowerd to a specified depth and is left in position for a specified period of time to average data. In this mode, the user specifies the start depth of the tool, the stop depth of the tool, and the increment in which the tool will be lowered. The user must then track the position of the tool by reading the depth counter values.

In continuous mode, the user does not enter start or stop values. Rather the depths are read into software from the depth encoder. The winch is set to a low speed to raise or lower the probe and data is collected as the probe is moving. Continuous mode is only available after the user has connected to the depth encoder.

Monitoring mode, is rarely used. In monitoring mode, the probe is left in a fixed poisition and the user can specify how many repeated measurements should be performed.

A) Stepped logging mode at fixed increments. To operate the software in this mode, selecte “Stepped”. The user must specify to the software what the “Start Depth”, “Stop Depth”, and “Depth Increment” that will be used for the current hole. The depth increment should be set to the nominal resolution for the probe being used (see Appendix table 1). A negative value for the depth increment should be used if logging up and a positive increment should be used for logging down. In this mode, the software will specify to the user what Depth the probe should be set to at each point in logging.

B) Continuous logging mode. This mode can be used for logging at a slow conitnuous speed without stops. To enable the continuous logging mode, select “Continuous.” Because the software reads from the depth encoder during continous logging, the encoder must be connected in order to enable the continous mode. In this mode many small files will be written for each small increment of depth as the probe moves. The number of averages (see below) should be set to a small value of 2.

3. Select the number of averages

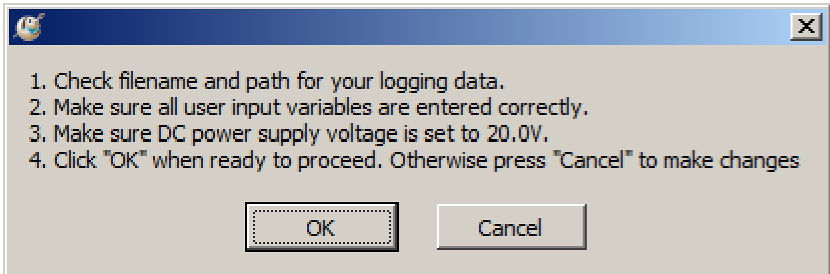
Here the user can specify how many averages are repeated at each depth level. Using a large number of averages will increase the data quality, but will decrease the rate of logging (m/hr). Using a small number of averages will allow for faster logging, but will results in lower data quality. The software will automatically update and display the total time that will be required for each measurement sequence.

5. Adjust advanced sequencing settings

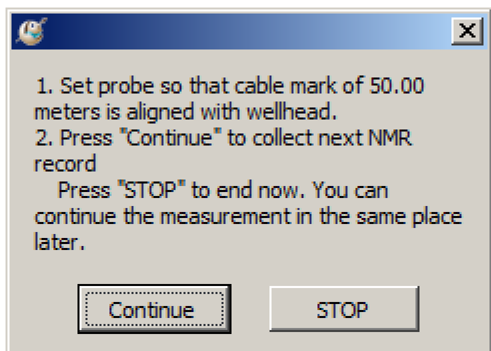
The sequence settings determine various parameters of the NMR scans that are acquired in a complete measurement sequence at each depth. The user can adjust advanced sequencing settings if desired. If the sequencing file in the calibration folder is already configured with appropriate advanced setttings, it is not necessary to adjust these settings. The adjustment of sequencing settings is described later.

6. Review all setting and click “START”

A second prompt will appear. Reminding the user to check all variables are correct and check the DC power supply has a voltage near 20V.

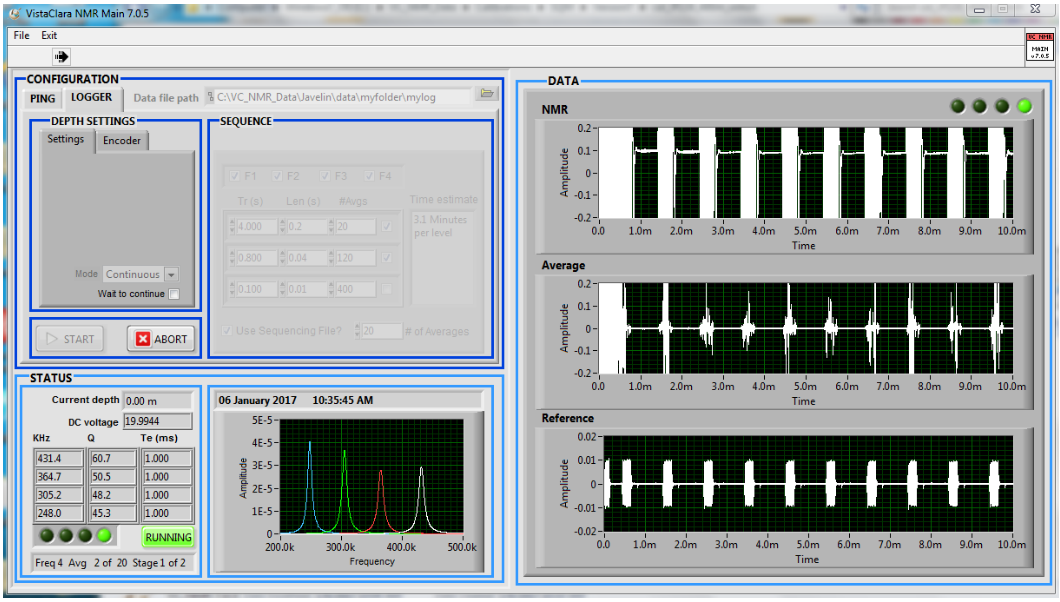


Check all values and click 'OK'. If you are running in continuous mode, the software will immediately start acquiring data. If you are running in stepped mode, the software will prompt the user to set the probe to the starting depth level and will begin once the user chooses continue.



7. Monitor Initial Data Collection

Before the system begins acquiring NMR measurements, a sequence of calibration ping measurements will be acquired. This process will take approximately 20 seconds. During this time, the panel will indicate that the ping is in progres. At the conclusion of the ping calibration, the bottom left window panel will display a curve representing the frequency response of the Javelin probe at the current measurement depth. The curve should appear as a bell curve centered at the probe tuning frequencies.



Logger Window While Acquiring Data

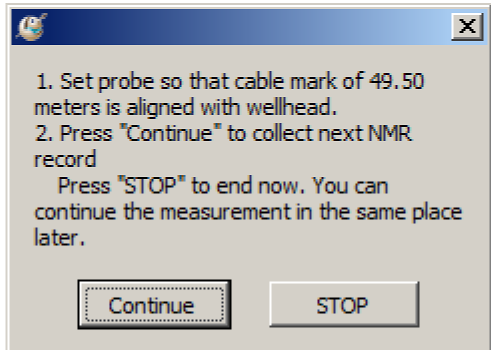
After the calibration sequence completes, the software will begin acquiring NMR CPMG measurement sequences. During each CPMG measurement sequence, the Javelin Probe transmits a series of RF pulses and measures the spin echo signals centered between the pulses. The top two right panels show the signals measured by the probe; the lower right panel shows the signals measured on the reference channel. The uppermost panel “NMR” shows results for each CPMG measurements; the middle panel “Average” shows averaged results for successive CPMG measurements. In the NMR plots, the user will observe a series of very high amplitude (off-scale) signals separated smaller high frequency signals. The off-scale signals are the individual RF pulses in the CPMG sequence. The lower amplidue signals between the RF pulses contain the NMR spin echo signals.

The progress of the measurement at a given depth level will be displayed in the top right status bar. The measurement sequencing at each depth is described later in the manual. As the measurement progresses, the time remaining at each depth level will count down in the right edge of the status bar “Left ## sec”.

For conditions of very high signal to noise, the user may directly observe the formation of echoes in the “NMR Time Average” window; the echo signals will have a rounded bell shape centered between the RF pulses. Under many conditions, however, the echo signals will not be readily identifiable until data processing is completed.

8A. Completing a log in stepped mode:

Once the specified number of averages has been collected at a given depth, the computer will produce a beeping sound and the user will be prompted to lower or raise the probe to the next measurement depth as shown in the figure below. Lower the probe to the specified measurement depth; then click the OK button. The system will then begin a new series of CPMG measurements at the new depth. At each depth the system will recalibrate before beging the CPMG measurements.



Note that for each depth interval, the program will write a new file with a number file suffix that increments from the start index. Continue to collect measurements, lowering the probe as prompted until the final series of measurements at the "Stop Depth" has been collected. You can also stop early by clicking STOP. Once the system has completed all measurements, exit the Javelin software by clicking the "EXIT" button. Depower and disconnect the system as described below.

8B. Completing a log in continuous mode:

Once acquisition has started, adjust the winch to move at the desired rate. The logging rate can be viewed by pressing the "display" button on the depth counter. A logging rate and number of averages should be selected such that a complete measurement sequence is completed wihtin the time requried for the probe to traverse 0.5 m or less.

When you have reached the desired stop depth, stop the winch. You can then force the software to stop by clicking the box named "Wait to continue". When the system is finished with the current measurement it will allow the user to choose to "STOP" measuring rather than continuing. Once the system has completed all measurements, exit the Javelin software by clicking the "EXIT" button. Depower and disconnect the system as described below.

Restarting logging following interruption

If logging is interrupted, it is suggested that a new data folder be used for the continued log. Make field notes of the log start and end depths. The logging data files can be combined after logging is complete using the program Total Commander.

Depowering the Javelin System

DO NOT disconnect any connections until after the Javelin system is completely depowered.

Once data collection has completed, exit the Javelin NMR Logger software and power off the computer. Next press the power button on the Javelin Surface Station to depower the system. Next power off the generator. Next unplug the surface station power cable from the generator. Before extracting the probe from the borehole, store the computer safely so that the computer is not damaged by proximity to the strong magnets in the Javelin Probe. Also ensure that all power is off before adjusting any connections.

After the Javelin Surface Station is depowered, the computer will lose communication with the Data Express Card. Before starting another set of logging measurements, the computer will have to be depowered and properly restarted as described above (after the Surface Station is powered).

To stop the data acquisition sequence in a non-emergency situation:

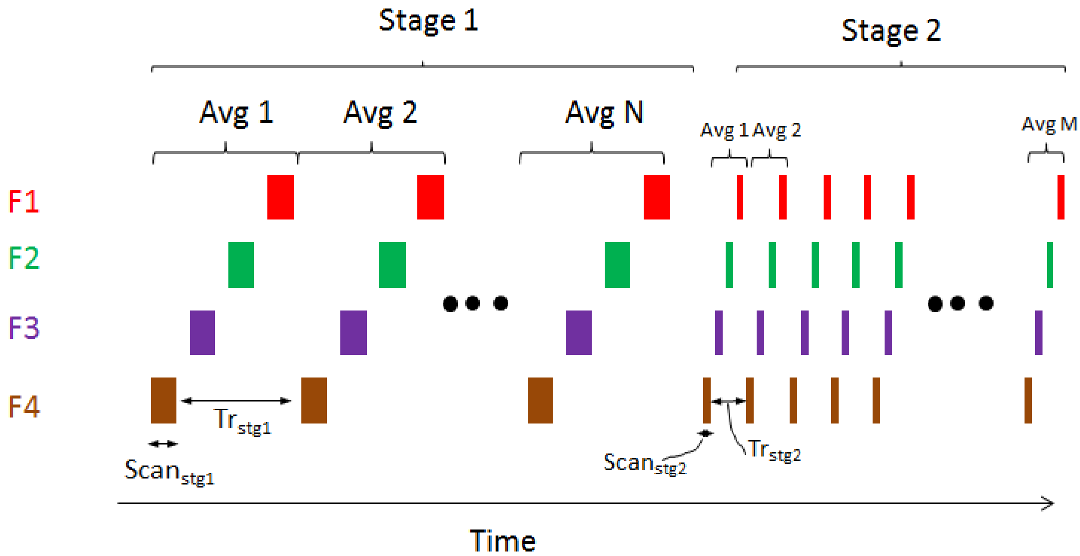
To interrupt data acquisition click the “Abort” button. You may need to click the “Abort” button a second time if using Burst mode.

To stop the data acquisition in an emergency situation:

To interrupt data acquisition in an emergency, immediately turn off the Javelin surface station by presssing the power button or unplugging the power cord. The winch can be stopped by depressing the red EMO switch.

Detail on Acquition Sequence Parameters

An example logging measurement sequence is shown below. At a given depth level, one or more stages of measurement are performed. The stages are comprised of scans at different frequencies (“F1”, “F2”…), and each scan is repeated to form multiple measurement averages. What differs between each stage is the time between each repeated measurement average (“Tr”) and the length of each measurement scan (“Scan”); also each stage may include a different number of averages. The practical importance of these sequence parameters is described briefly below.



An example sequencing setting showing the use of multiple measurment frequencies and multiple averaging stages.

-Frequency: The Javelin probes can operate at two or four different frequencies. Lower frequency measurements provide sensitivity at a maximum radial depth of investigation. The higher frequency measurements provide a radial depth of investigation slightly closer to the probe (by approximately 0.5-1 cm per freuency step). In general, it is advantageous to perform measurements at as many frequencies as possible to increase the amount of data acquired in a given time interval or logging speed.

-Tr: The recovery time controls the amount of time between sucessive CPMG measurement scans at a given measurement frequency. The value of Tr will determine how much time is allowed for water in the formation to recover between measurements. If Tr is set to a long value, all the water in the formation will recover between measurements and all water will be detected. If Tr is set to a short value, only the water with short relaxation times (fast recovery time) will be measured accurately and water with long relaxation times (slow recovery) will be muted. A Tr value of 10 will allow complete recovery for any type of water regardless of formation, but will yield a slower logging speed (long time between measurements). A Tr of 0.5 second will allow much faster logging and will allow complete recovery/detection of water in silty formations, but may result in underestimation of water in unexpected coarse layers. To

balance the advantages of long and short Tr values, data are often acquired in a multi-Tr mode as shown above: A few averages are acquried with a long Tr to accurately detect water in large pores with long T_2 and many more averages are acquired with short Tr to accurately detect and resolve water in small pores with short T_2 .

-Scan Length: The scan length is the length of each CPMG. As the value of Tr is decreased, the scan length must also be decreased so that the total measurement duty cycle does not exceed a recommended value. In general, the following equation should be satisfied to avoid errors:

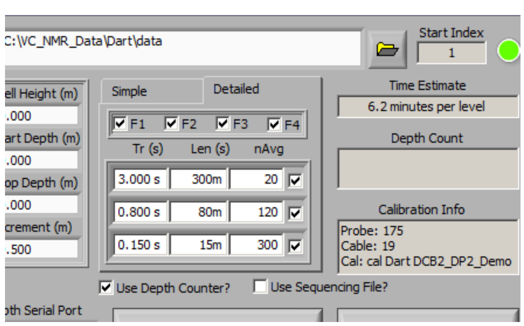
$$(\#frequencies)*(scan\_length) / Tr <= 0.2$$

- #Averages: The number of averages is the number of complete CPMG scans collected at each depth interval using the user specified Tr. Increasing this number will increase the signal to noise of the log but will also increase the total acquisition time. It is recommended that a larger number of averages be used for formations with low water content or for very shallow surveys which may be affected by cultural noise. A suggested value for #Averages is 50. Doubling the #Averages will double the survey time but will also increase the signal to noise ratio by a factor of approximately sqrt(2).

-Echo Spacing: The echo spacing is the time delay between transmitted refocusing pulses and is also the spacing between receive NMR spin echo signals. Using the shortest "default" echo spacing will provide higher signal to noise and will decrease the influence on diffusion on measured relaxation times. Only expert users should change the echo spacing from the default value. Refer to table Table 1 in the Appendix for a list of default echo spacings for a each probe.

Adjusting Sequence Parameters : The sequence parameters can be adjusted either by changing the sequenc file in the calibration folder. They can also be changed directly in the logging software by disabling use of the sequence file. It is suggested that if a new sequence will be used repeatedly (e.g. for a survey with many holes in a particular geology), the sequence file should be updated. If the sequence is being changed for only one log, it is best to adjust the sequence in the logging software.

To adjust the sequence parameters in the logging software, uncheck the "Use Sequence File Box". Unchecking this box will allow the user to access the parameters for multiple stages as shown below.



User access to multiple scan stages by deselecting "Use Sequence File?"

Here, the frequencies used in the measurment can be selected or delected on the top row. Fields for up to three stages are provided. For each stage (each row) the user can select the value of Tr, the scan length, and the number of averages. Each stage is enabled by checking the box at the right of the matrix. These values can also be set in the sequencing file as described later.

9. Data Processing

NOTE: The user may run the data processing software while the data acquisition software is running and is advised to do so to monitor data progress and quality.

Data processing and interpretation is accomplished using two separate pieces of software: 1) Javelin Processor and 2) Javelin Interpreter.

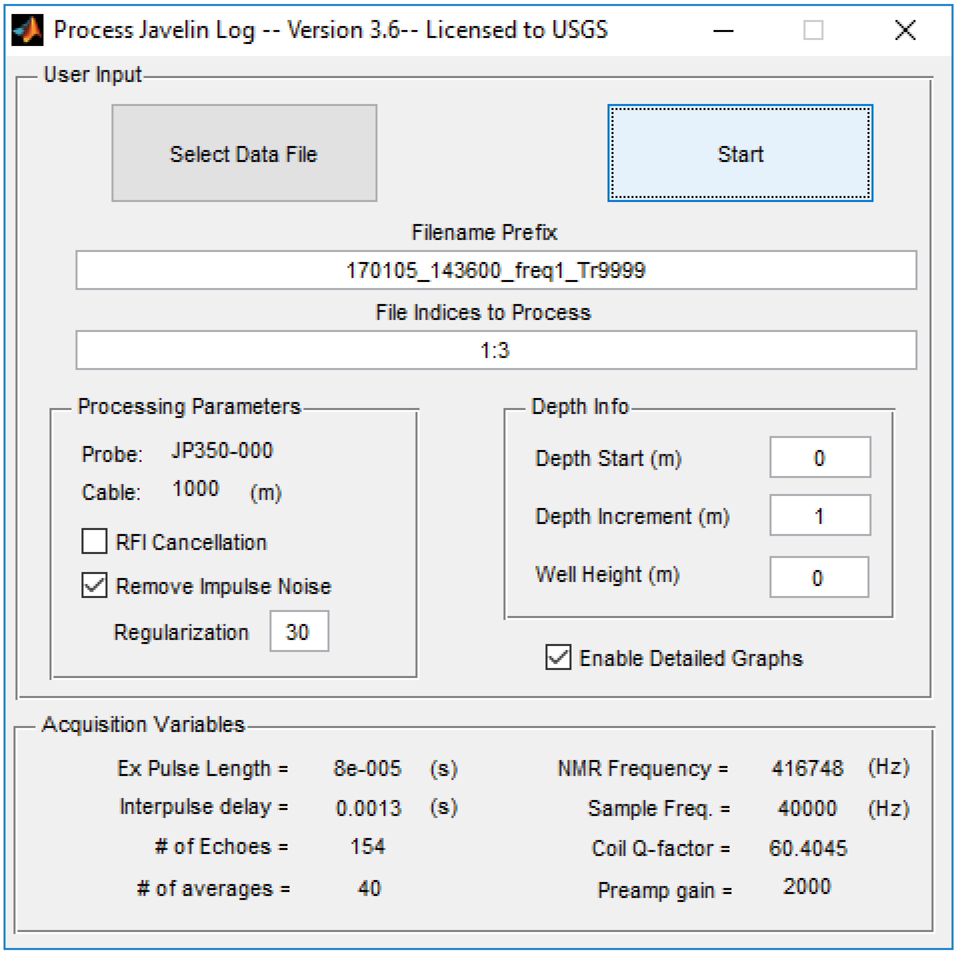
Javelin Processor Software

The Javelin Processor is used to perform basic signal processing steps and initial automated data interpretation, including:

- Extraction of spin echo signals in the time domain.
- Digital filtering of and water content scaling of echo signals.
- Noise cancellation and removal of impulse noise.
- Basic interpretation.

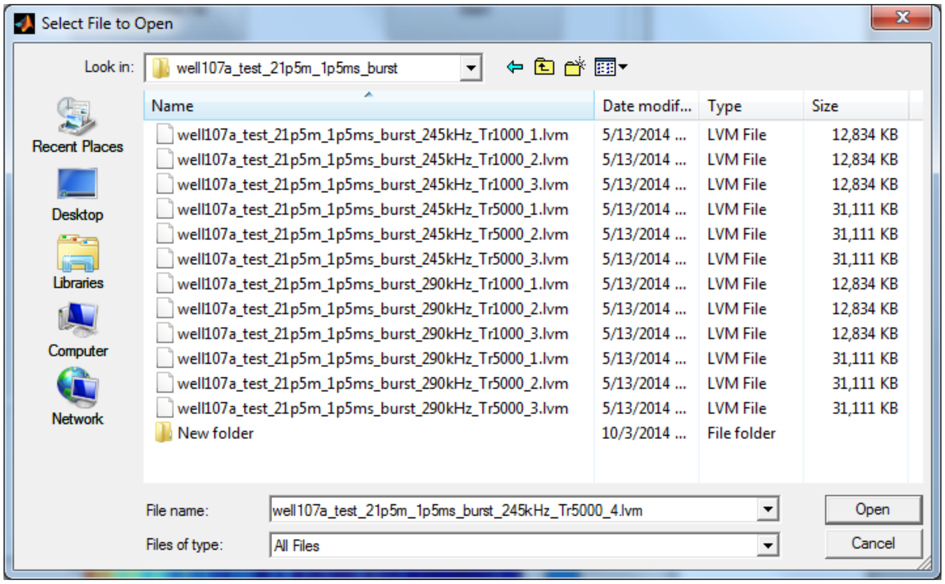
It is advisable to begin processing and examining your data with the Javelin Data Processing program as soon as you begin to accumulate data in the field. The Javelin NMR Logger program collects and saves separate data files for each logged depth interval, so as soon as the first depth interval of data is written to its file, you can use Javelin NMR Logger to open and process the file. This can be useful for initial evaluation purposes.

1. **Start the Javelin Log Processing Software.** Double click the icon for the Javelin Log Processing program. The startup screen should appear as shown in the screenshot below:



The Javelin Log Processing startup screen

2. **Click "Select Data File"** A file navigation window will appear as shown below. Navigate to the directory in which the logging files were written. You will see a series of files; a separate file exists for each frequency (specified as 245 or 290), each Tr (Short-Tr or Long-Tr, specified as TR###), and each depth (specified by the final _1, _2, extension). All depth and Trs will be processed together but data for different frequency must be processed separately. To process one frequency select any data file corresponding to that frequency. The program will automatically identify the filename prefix, and the other associated depth and Tr files in the directory.



File navigation window showing 3 depth files

3. **Enter processing variables.** Once the user identifies the logging filename, the program will automatically populate the processing variables using default values. In many cases, the user will not need to modify these variables, however a description of each variable is provided below:

   -*File Indices to Process:* Specifies which depth indices to process entered as list (e.g. "1, 2, 3, 4") or as a range (e.g. "1:4"). This variable is automatically set to the total range of indices found with the specified filename prefix. If the user is processing a dataset concurrent with acquisition, the last index should be eliminated since that file will not be completely written (e.g. change "1:6" to "1:5").

   -*Start Depth*: Specifies the start depth. This depth is read from the file header information and will reflect the same value entered in the Javelin NMR Logger program. As standard practice, this depth should be referenced as the depth from the top of the wellhead to the top of the logging head (end of the downhole cable).

   - *Depth Increment*: Specifies the depth increment between subsequent acquisitions. This variable is read from the file header information and will reflect the same value entered in the Javelin NMR Logger program.

   - *Well Height*: Specifies the height of the well head. This variable is read from the file header information and will reflect the same value entered in the Javelin NMR Logger program. As standard practice the well height should be measured as the vertical distance from the top of the well head to ground surface.

   - *Regularization Factor*: Specifies the regularization factor for the multi-exponential

T_2 inversion. The appropriate value for the regularization factor will depend upon the signal to noise of the dataset. Generally assigning a lower value to the regularization factor will force the inversion to fit the CPMG decay curve more precisely, but will result in a more spikey T_2 distribution that may be influenced by data noise. Assigning a higher value to the regularization factor will force the inversion to a smooth out peaks in the T_2 distribution, but the inversion will be less sensitive to data noise.

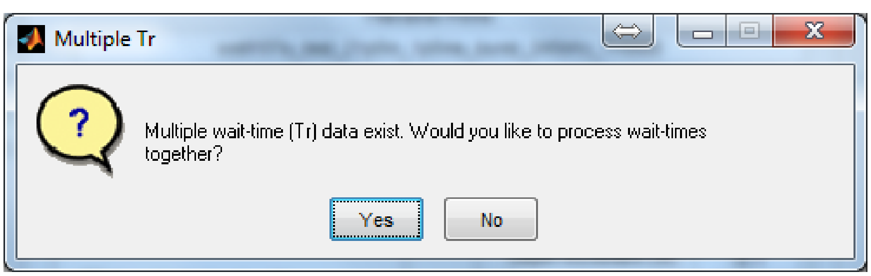
- *RFI Cancellation:* Selecting RFI cancellation will prompt the software to use automated noise cancellation based on a comparison of the noise on the reference channel and noise on the downhole probe. RFI Cancellation can be especially valuable when survey depths are shallow.

-*Remove Impulse Noise:* Selecting remove impulse noise will prompt the software to automatically identify and discard data records containing impulse noise above a certain threshold. Impulse noise is often associated with regional thunderstorms and can reduce the data quality if it is not removed from the raw data.

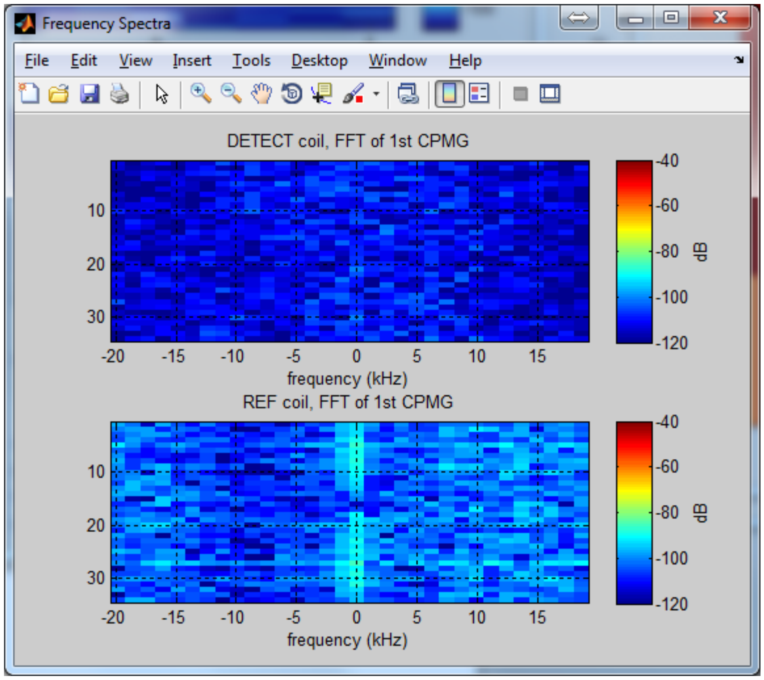
-*Specify Calibration File:* Calibration info will be read in automatically from the header information. If the user prefers to reenter calibration information for a different calibration file the user should select this checkbox; the user will be directed to select an appropriate calibration file.

-*Use Custom Depth Profile:* If the data were collected using a non-uniform depth sampling, the user can select this box and will be prompted to select a customized depth profile file. A customized depth profile file should be formatted as an ASCII text file. Each *i*th line of the file should contain the logging depth corresponding to the *i*th indexed file (i.e. the third line should correspond to the logging depth for the file *filename_3.lvm*. Only one depth should be listed on each line of the ASCII text file.

4. **Click "Start".** Upon clicking "Start" the software will look if there are dual-Tr data (i.e. multiple stages were used), and if detected will display the following prompt:

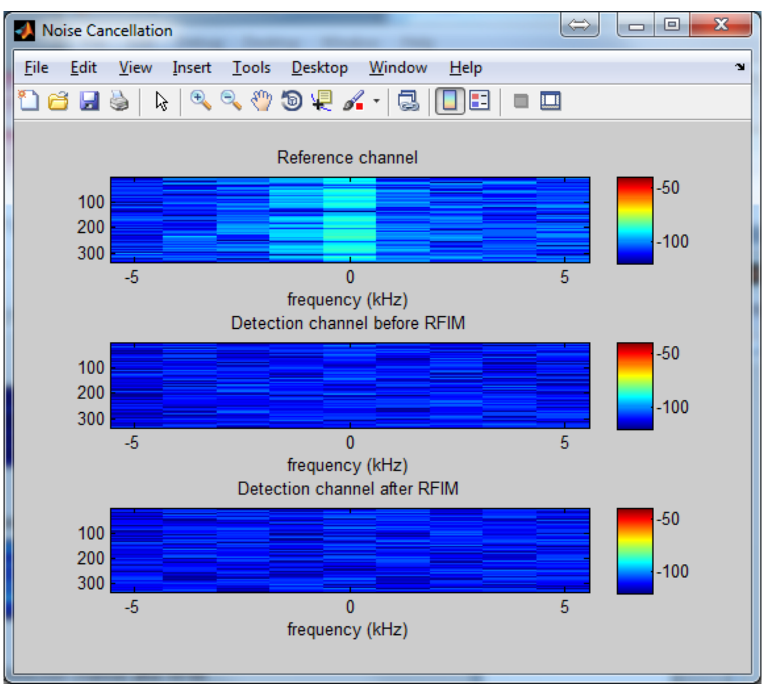


To incorporate the Burst and long Tr data (recommended) click 'Yes'. Once the processing begins, the files from each depth level are processed, and four windows are displayed for each file, as described below:



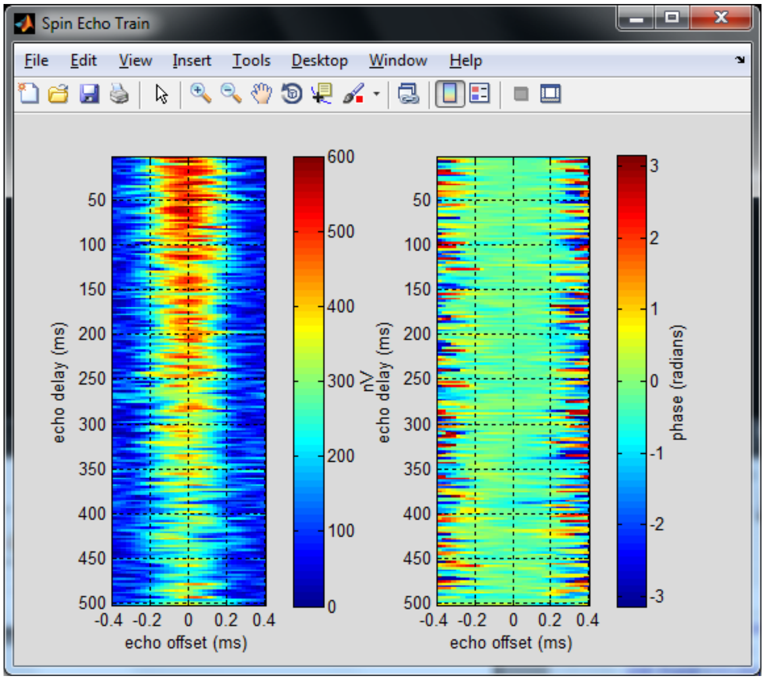
Javelin Log Processing: Frequency Spectra Window

This window displays the frequency spectra (referenced as an offset from the Larmor frequency) for the signal measured on the detection coil in the Downhole Probe and the signal measured on the reference channel for the first echo signal. In this case, the blue stripe which appears on the detection and reference coil at around -10kHz is environmental noise. The diffuse light blue patch centered at 0kHz in the detection coil is the NMR signal.



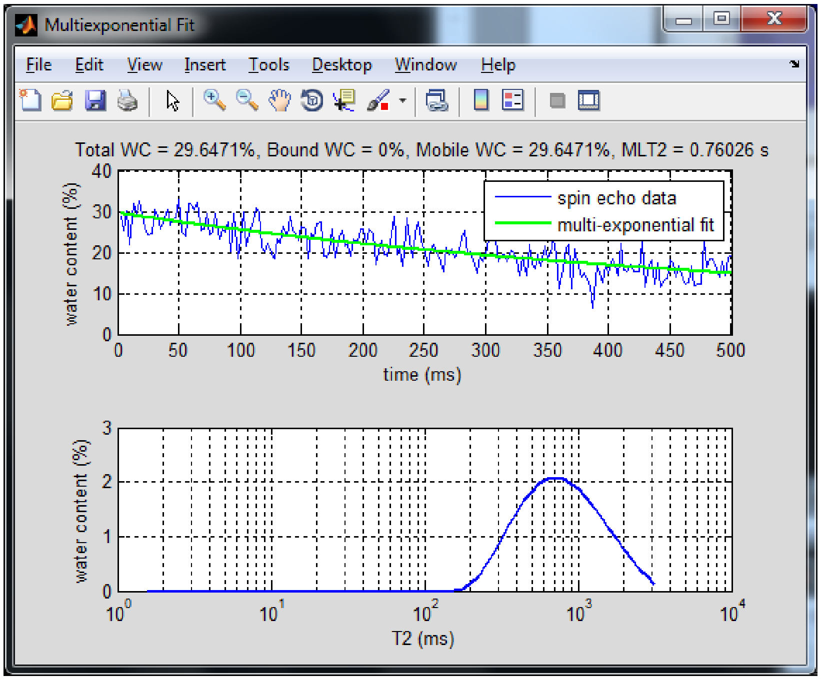
Javelin Log Processing: Noise Cancellation Window

This window displays the results of noise cancellation in the frequency domain. The top two panels show the frequency spectra of the reference coil and detection coil. The bottom panel shows the spectra of the detection coil after noise cancellation.



Javelin Log Processing: Spin Echo Train Window

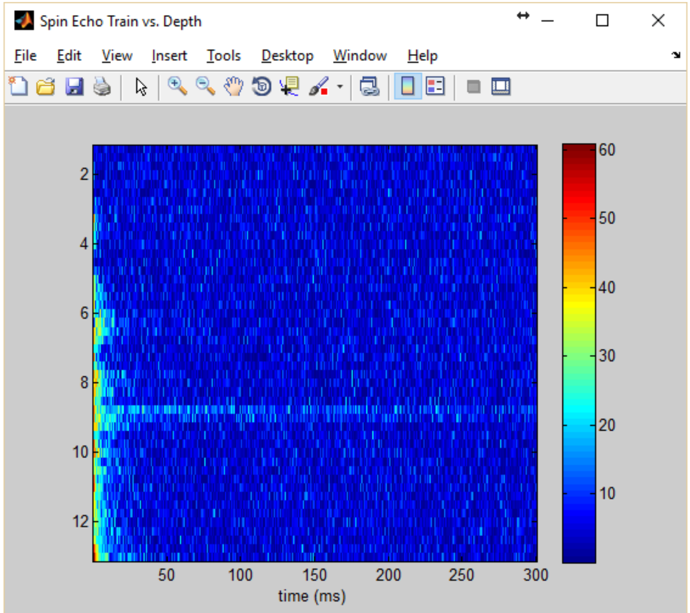
This window displays the spin echo train for the current measurement depth after stacking and noise cancellation. The left panel shows the signal amplitude and the right panel shows the signal phase. In the left panel, the user can observe the decay of the echo amplitudes over time. Each echo signal is windowed, filtered, and integrated along the x-axis (time) to generate a CPMG echo decay curve shown in the next figure.



Javelin Log Processing: Multi-exponential Fit Window
This window displays the time series CPMG decay curve and multi-exponential inversion result. The top panel shows the time series CPMG decay curve scaled to water content. The lower panel shows the T_2 distribution based on a multi-exponential fit to the decay curve. The values listed at the top of the figure indicate estimates of the total water content, bound water content, and mobile water content. Also shown is the mean-log T_2 value.

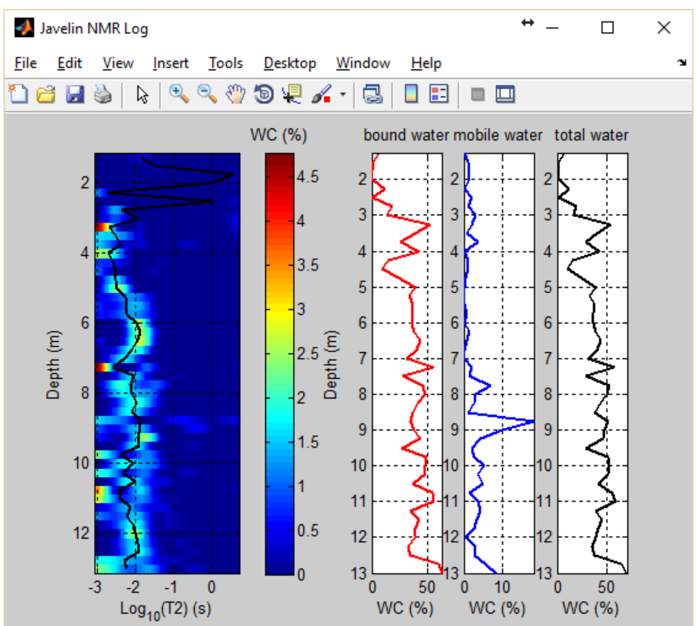
The above process will repeat for all depth levels. If the data include dual-Tr mode, then a second sweep of processing for all depths will be repeated with the second Tr. Upon completion the dual-Tr data will be combined in a final CPMG decay at each depth (plotted red).

Once all files have been processed, two additional figures will be displayed, described below:



Javelin Log Processing: Spin Echo Train vs. Depth Window for 5 depth levels

This window displays the time series CPMG decay curves at each depth interval, shown as a color map. The decay in amplitude from red at left (early time) to blue right (late time) reflects the CPMG decay at each depth.



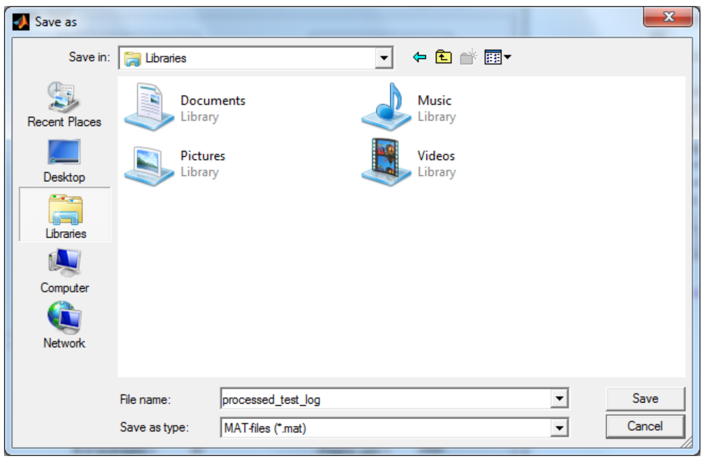
Javelin Log Processing: Javelin NMR Log Window

This window displays the full NMR log. At left, the T_2 distribution at each depth is shown as a color map. At right three curves show the bound water content, mobile water content, and total water content at each depth interval.

Save the processed data: When the software has finished processing all depth files and a dialog box will appear asking the user to save the processed data. To save the processed data, navigate to the desired data folder, enter a desired filename, and click "Save". If you do not wish to save the processed data click "Cancel".

When you save the processed file name, it is good practice to include the frequency in the name since each frequency will be processed and saved separately.

You have now completed processing one frequency. Repeat the above steps to process and save the second frequency.



Javelin Log Processing: File Navigation Window

The resulting data will be "*.mat" data file (Matlab data format) and will include one processed (noise cancelled, filtered, and stacked) CPMG decay curve for each depth interval and a few relevant processing variables. This saved data file is now ready to be interpreted using the "Javelin Log Interpretation" software.

Javelin Log Interpretation Software

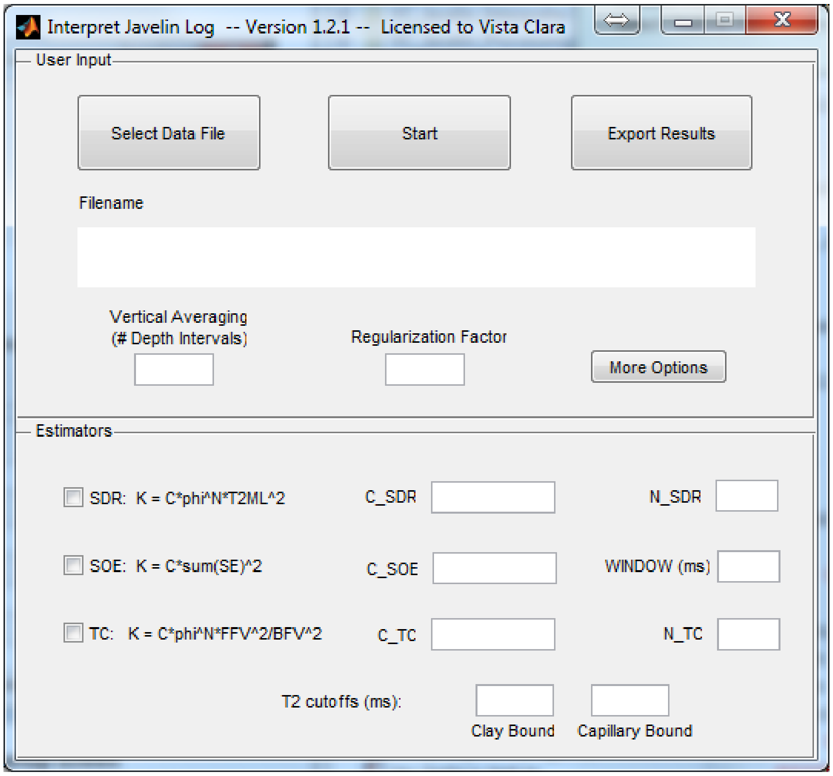
Use the Javelin Log Interpretation software to post-process and interpret a previously processed adn saved Javelin Log "*.mat" file and produce estimated values of

- NMR-measured total/bound/mobile water content.
- NMR T_2 Distributions
- Hydraulic Conductivity

The Interpretation software also completes combination of two-frequency datasets. By integrating multiple frequency datasets together, the SNR can be increased by up to a factor of sqrt(N_{freq}).

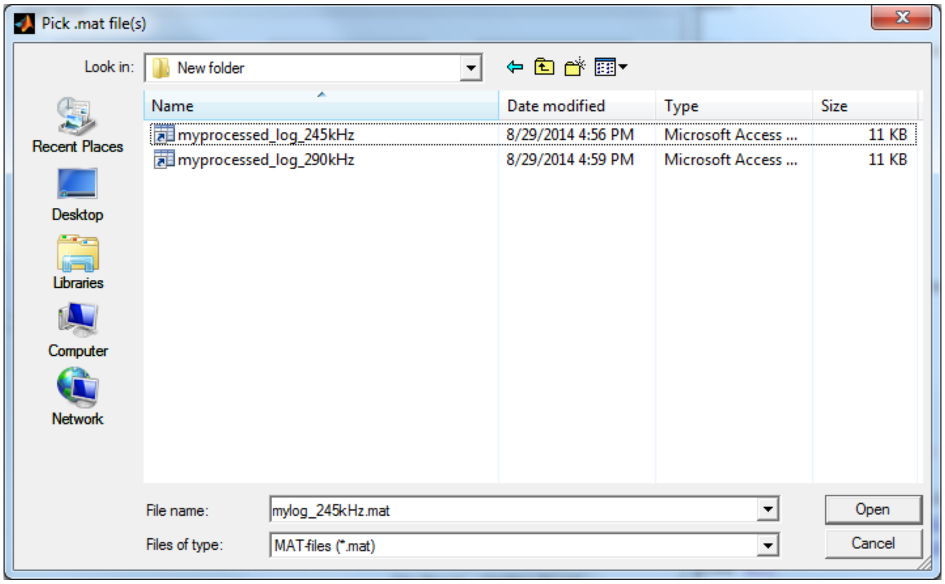
Use the following steps to run the Javelin Log Interpretation software:

1. **Start the Javelin Log Interpretation Software.** Double click the icon for the Javelin Log Interpretation program. The startup screen should appear as shown in the screenshot below:



The Javelin Log Interpretation startup screen

2. **Click "Select Data File"** A file navigation window will appear as shown below. Navigate to the directory in which you previously saved a processed Javelin log "*.mat" file. If both frequencies have been processed, there should be two processed files, one for each frequency. Select both files holding ctrl and clicking both files. Then chose, "Open".



File navigation window showing processed data files for two frequencies

3. **Enter processing variables.** Once the user identifies the logging filename, the program will automatically populate a number of variables in the Javelin Log Interpretation window. These variables are described below and may be changed by the user:

-*Vertical Averaging:* Specifies the number of depth intervals for which CPMG data will be averaged for interpretation. This value is set to 1 by default. If this value is set to N, the software will average CPMG decays over N depth intervals. Increasing the vertical averaging reduces the vertical resolution of the log but can increase the signal to noise ratio. For example, for measurements collected at 1 meter increments, setting a vertical averaging of "3" will reduce the vertical resolution to 3 meters but will increase the signal to noise by a factor of sqrt(3).

- *Regularization Factor*: Specifies the regularization factor for the multi-exponential T_2 inversion. The appropriate value for the regularization factor will depend upon the signal to noise of the dataset. Generally assigning a lower value to the regularization factor will force the inversion to fit the CPMG decay curve more precisely, but will result in a more spikey T_2 distribution that may be influenced by data noise. Assigning a higher value to the regularization factor will force the inversion to produce a smooth out peaks in the T_2 distribution, but the inversion will be less sensitive to data noise.

- *T2 cutoff (ms):* Specifies the threshold T_2 cutoff for distinguishing clay-bound water, capillary water, and free water. Water relaxing with T_2 shorter than the $T_{2,clay}$ cutoff will be interpreted as clay bound water, while water with T_2 longer than $T_{2,cap}$ cutoff will be interpreted as free water. The intermediate fraction will be interpreted as capillary water. The fractions of free and bound water are also used for estimating K based on a Timur-Coates relationship (see below). Default values are T_{2clay}=3ms and T_{2cap}=33ms.

-Remove Impulse Noise: Selecting remove impulse noise will prompt the software to automatically identify and discard data records containing impulse noise above a certain threshold. Impulse noise is often associated with regional thunderstorms and can reduce the data quality if it is not removed from the raw data.

The remaining variables pertain different NMR K estimation equations, i) SDR: the Schlumberger-Doll Research Equation; ii) SOS: the Sum of Squares Equation, and iii) TC: the Timur-Coates equation. The three equations are described in further detail below:

SDR: the Schlumberger-Doll Research Equation

K=C*phi^N*T_{2ML}^2

where phi is the fractional porosity and T_{2ML} is the mean log T_2 value from the distribution; C and N are empirical factors

Squared Mean of Echoes (SOE): the Squared Mean of Echoes Equation

K=C*sum(SE)^2

where sum(SE) is the summed amplitude of all echoes in the CPMG decay; C is an empirical factor

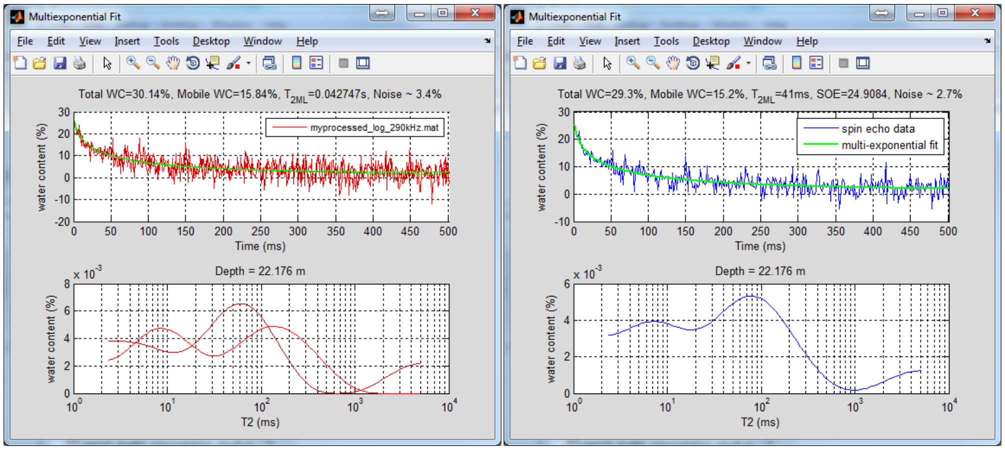
TC: the Timur-Coates Equation

K = C*phi^N*FFV^2/BFV^2

where phi is the fractional porosity; FFV is the fraction free-fluid volume (total water content fraction with $T_2 > T_{2,cutoff}$); BFV is the fraction bound-fluid volume (total water content fraction with $T_2 <= T_{2,cutoff}$); C and N are empirical factors.

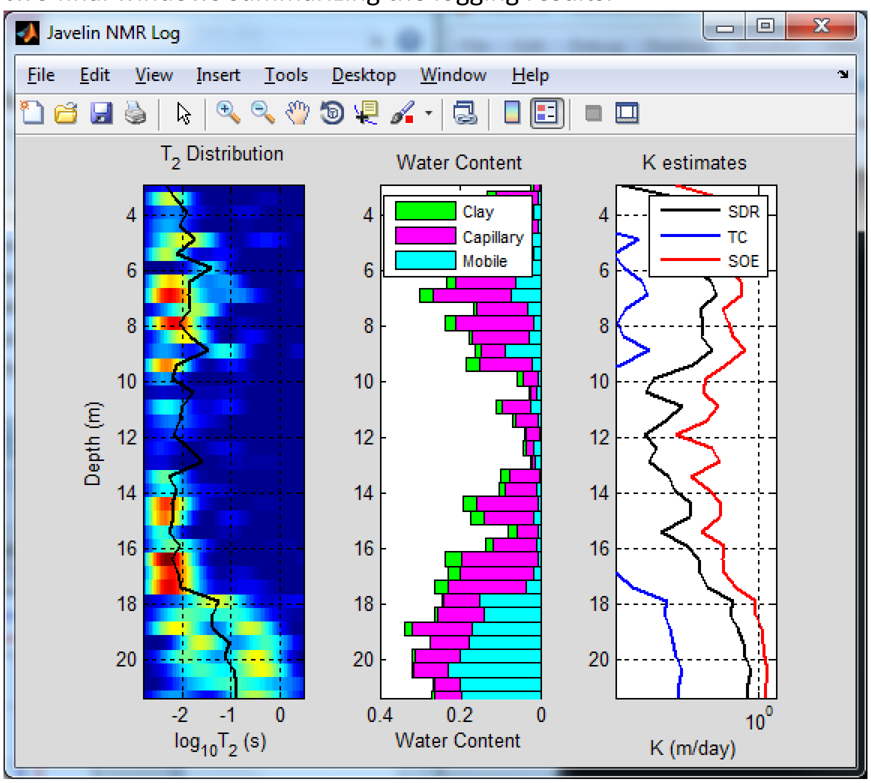
Checking the tick boxes next to each estimation equation will prompt the program to calculate hydraulic conductivity based on that equation. The equations can be calibrated by changing the values assigned to the empirical factors. Default values are taken from the literature and NMR studies on sandstones.

4. **Click “Start”.** The software will load the processed datasets from each depth layer and will display a window showing the processed and vertically averaged spin echo signals versus depth for both frequencies. The program will then scan through each depth and integrate the CPMG data from the both frequencies as shown in the figure below. The red curves show the two datasets from both frequencies plotted on top of one another. The dataset in blue is the integrated data and shows a lower noise level that the individual frequency data. Using the integrated data, the software recalculates a single multi-exponential fit to the CPMG decay curves.



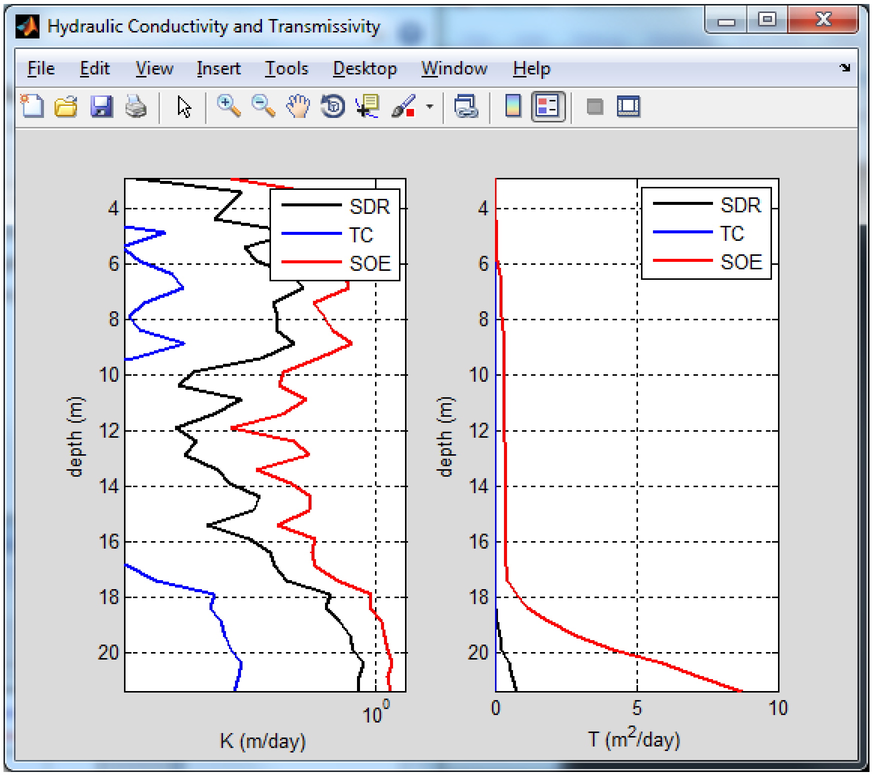
Dual Frequency data before and after combination

5. After recomputing the multiexponential fits for all depths, the software will display two final windows summarizing the logging results.



Javelin Log Interpretation: Javelin NMR Log Window

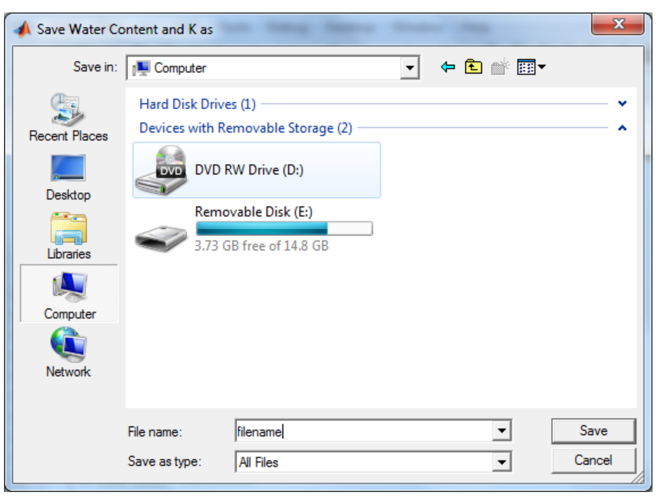
This window displays the full NMR log with estimates of water content and permeability. At left, the T_2 distribution at each depth is shown as a color map with the mean log T_2 (T_{2ML}) shown as a black line. The middle plot shows the bound, mobile, and total water content as a stacked bar graph (In this example there is very little bound water so mobile water ~ total water. The right plot show permeability estimates derived from the three different estimation equations.



Javelin Log Interpretation: Hydraulic Conductivity and Transmissivity Window

This window displays estimates of hydraulic conductivity and transmissivity over the full logged depth.

6. **Export Interpreted Data.** The logging and interpretation results can be exported to a text file by clicking "Export Results." A file navigation window will appear as shown below



Javelin Log Interpretation: Export File Navigation Window

Specify a directory output name. Then click “Save”. The software will automatically generate a folder with the output name and several output files. These files include *.png (image) and *.fig (Matlab figure files) for each of the output plots. Also written are a collection of ASCII files

mylog_T2_dist.txt	10/3/2014 12:44 PM	Text Document	7 KB
mylog_SE_decay.txt	10/3/2014 12:44 PM	Text Document	21 KB
mylog.txt	10/3/2014 12:44 PM	Text Document	1 KB
normechoes.png	10/3/2014 12:44 PM	PNG File	27 KB
noise.png	10/3/2014 12:44 PM	PNG File	18 KB
KandT.png	10/3/2014 12:44 PM	PNG File	23 KB
fulllog.png	10/3/2014 12:44 PM	PNG File	24 KB
normechoes.fig	10/3/2014 12:44 PM	FIG File	18 KB
noise.fig	10/3/2014 12:44 PM	FIG File	9 KB
KandT.fig	10/3/2014 12:44 PM	FIG File	15 KB
fulllog.fig	10/3/2014 12:44 PM	FIG File	20 KB

Example of Data Exported by Javelin Log Interpretation

“filename.txt” contains 8 columns of text corresponding to the NMR water content T2 and K values as described below:

Column 1: Depth (m)

Column 2: Total Water Content

Column 3: Clay Bound Water Content

Column 4: Capillary Bound Water Content

Column 5: Mobile Water Content

Column 6: Mean Log T_2 (s)

Column 7: K_sdr (m/day)

Column 8: K_tc (m/day)

Column 9: K_soe (m/day)

Column 10: Sum of echoes

Column 11: Noise

“filename_T2_dist.txt” contains the multi-exponential T_2 distributions at every depth interval. The first row of the file specifies the T_2 values that define the x-axis for all of the distributions. Each subsequent row contains amplitudes (y-axis) for the T_2 distribution at each depth interval scaled to water content.

"filename_SE_Decay.txt" contains the CPMG decay curves at each depth level (CPMG decay in columns; depth in rows). The first row of data contains the time stamps corresponding to each column. Each subsequent row corresponds to the first, second, third etc. depth with values representing the amplitude of the CPMG decay at each time point.

10. Javelin Data Formats

Raw Javelin Data Format (*.lvm)

The raw Javelin data for each logged depth interval (with ".lvm" extension) are saved as binary files. Each file contains four data channels written with big-endian format and 64-bit double precision.

Channel#	**Data Acquisition Variable**
1	Detection coil in phase data
2	Detection coil quadrature data
3	Reference coil in phase data
4	Reference coil quadrature data

The first 50 entries of each binary raw data file contain header information and are the same for all four columns. The header information is specified below:

Entry#	**Data Acquisition Variable**	**Range/Units**
1	Excitation pulse length	Seconds
2	Echo Time	Seconds
3	Number of Echoes	Integer
4	Measurement Frequency	Hz
5	Number of Averages	Integer
6	Preprocessed Sampling Frequency	Hz
7	Quality Factor	Float
8	Preamplifier Gain	Float
9	Measurement Depth	Meters

10	Acquisition Version	#.#
11	Probe ID	e.g. 175.2001 is 175B-001
12	Cable ID	Meters
13	Operation Mode	Integer (0,1,2)
14	Tr	Seconds
15	Wellhead height above ground	Meters
16	Start Depth	Meters
17	Stop Depth	Meters
18	Depth Increment	Meters
19	Sensor Offset from Logging Head	Meters
20	100% H_2O Calibration Scaling	Float
21	Echo Time Shift	Microseconds
22	Echo Phase Shift	Degrees
23	Echo Frequency Shift	Hz
24	Quality Factor During Calibration	Float
25-50	00000 -- For Future Use	---

Calibration Files

All calibration files are located in a calibration folder. There should be three calibration files in each calibration folder:

1) *seq*.ini -- This file may be edited by any user. It contains the sequencing information that is read in by default to the Logger software. If "Use Seq File?" is selected in the Logger, the parameters of the sequence file will be used.
2) *cal*.in – This file should not be edited. This file contains calibration information for the specific probe/cable combination being used. The only field in this file that should be changed by the user is the echo spacing. Changing other fields may lead to invalid results and may cause system damage.
3) *surf*.ini – It should never be edited by any user. This file specifies interfacing protocols of the surface station and probe.

11. Maintenance

WARNING

The Javelin instrument generates and stores very large amounts of electrical energy. Attempting to service the Javelin internal electronics can cause severe electrical shocks, burns, or even death.

Any of the following actions by the user are **expressly forbidden** and will render all warranties void, unless the user has received prior written authorization from Vista Clara.

-Removal of any Javelin Surface Station instrument panel other than the removable air filter covers.

-Servicing any internal components of the Javelin Surface Station

-Opening the Downhole Probe casing

-Servicing or accessing components inside the Downhole Probe

-Servicing or modifying the Custom Downhole Cable

-Servicing or modifying any primary connection cables

JAVELIN HARDWARE CONTAINS TAMPER EVIDENT SYSTEMS THAT WILL INDICATE ANY OCCURANCE OF UNAPPROVED INTERNAL ACCESS.

Under ordinary circumstances, the customer should not expect to receive authorization for any of the above acions.

Under extraordinary circumstances, Vista Clara will consider such requests subject to the ability of the customer to provide competent electronic technicians trained in the servicing of high voltage power electronics geophysical equipment.

UNAUTHORIZED SERVICING OR ACCESSING OF COMPONENTS INTERNAL TO THE PRIMARY SYSTEM COMPONENTS OR PRIMARY CONNECTION CABLES IMMEDIATELY VOIDS THE MANUFACTURER'S WARANTY AND RENDERS THE SYSTEM UNSAFE FOR USE.

System Care

It is important to provide regular care, maintenance, and inspection of all cases, external surfaces, and connections on the Javelin equipment to enhance the operational lifetime of the system and limit the need for repairs.

O-rings

The connection between the Downhole Probe and Downhole Cable should always remain clean and well lubricated. Whenever connecting and disconnecting a Downhole Probe, check to ensure that the O-rings are clean and well lubricated. If the conncetions become dirty, clean them with a soft cloth which may be dampened with isopropyl alcohol. Periodically apply non-conductive vacuum grease (DOW CORNING high vacuum grease) to the surfaces of the downhole cable connection. In particular, ensure that the O-ring is clean and lubricated.

Downhole Probe Logging Head

Downhole Probe Protection Cap

Inside Down Hole Probe Logging Head

Viton O-ring Size 023 (MINO-8-BCRL)

McMaster Carr 9464K77; $8.06/50pcs.

Inside Downhole Cable Logging Head

Viton O-ring Size 024 (MINO-8-CCPL)

McMaster Carr 9464K78; $9.09/50pcs.

Air Filters

Two washable air filters are located on the back panel of the Javelin. It is importatnt to keep the air filters clean to insure proper air circulation and cooling of the Javelin Surface Station internal electronics. To clean the air filters, unscrew the screws holding on the black filter cover. <u>Only remove the bottom-left and top-right screws which hold on the cover -- do not remove the other screws</u> (refer to the figure below).

Washable Air Filter Covers on Back Panel of Surface Station. Only remove screws where indicated by green check marks. Do not remove other screws.

Storage

After using the instrument, all surfaces and connections on the primary units should be wiped clean of any dirt and moisture, and inspected for damage. Never attempt to clean the system using sprayed water. External surfaces of the instrument (not any of the connection ports) can be cleaned with a damp cloth. If necessary, a mild general purpose detergent without any ammonia may be used (not on any of the connection ports). Flamable residues from any source must never be left on any part of the system to avoid potential fire hazards.

The Javelin system should be kept in a clean, dry area when not in use. The Javelin system should never be left deployed in the field overnight or unattended. The system should be stored upright and all connections should be dried and then capped. During storage or transport of the system, the individual units should never be tilted beyond 45 degrees from the normal vertical upright position.

Connection Cables should be regularly inspected for any cuts or abrasion to the insulation and/or protective jacket. **If damage is present: the cables are not safe to use.** Contact Vista Clara for instructions on repair or replacement of damaged cables or cable connectors.

Cable connectors must be kept clear of debris, soil, sand, oils, conductive fluids and corrosive agents. If exposed to water, be sure that all connectors are completely dry before replacing caps. Fluid should not be used to clean any the connection ports, however, it is acceptable to use pressurized air to blow out any moisture or particulate matter from the connections. It is recommended that the user apply a non-conductive, non-reactive silicone lubricant to the exterior threads or bayonet-style slides of the connection ports to reduce connection friction and wear. Do not use a spray applicator as this may discharge lubricant onto the electrical contacts.

If cuts or significant abrasions to the insulation are observed at any time, the connector cable is unsafe to use. Do not attempt to repair the wire by splicing or by attaching electrical tape. Immediately contact Vista Clara, Inc. to discuss repair or replacement options.

If any component of the Javelin system ceases to function properly, immediately discontinue use and contact Vista Clara, Inc. for further instructions.

System Servicing

WARNING

WITH THE EXCEPTION OF THE O-RING CONNECTION ON THE DOWNHOLE CABLE AND THE AIR FILTER, THE JAVELIN CONTAINS NO USER-SERVICEABLE PARTS. UNAUTHORIZED SERVICING OR ACCESSING OF COMPONENTS INTERNAL SURFACE STATION OR DOWNHOLE PROBES WILL RENDER THE MANUFACTURER’S WARRANTY IMMEDIATELY

AND ENTIRELY VOID, AND THE SYSTEM UNSAFE FOR USE. JAVELIN HARDWARE CONTAINS TAMPER EVIDENT SYSTEMS THAT WILL INDICATE UNAPPROVED ACCESSING OF INTERNAL COMPONENTS.

Contact Vista Clara for all servicing requirements.

12. Troubleshooting Guide

This section describes basic troubleshooting procedures if the user encounters common problems with the system:

Problem: Javelin NMR Logger program appears non-responsive.

Reason #1: The computer is not communicating with the Data Express Card because the Javelin Surface Station is not powered or was powered on after the computer was turned on. If the computer is turned on before the surface station is powered, the data express card will not be recognized. Turn off the computer and restart it after the Javelin surface station is repowered.

Reason #2: The Javelin NMR Logger software was terminated improperly. If the Logger software was terminated using a "hard kill", such as closing the window or using the "abort" control (the red stop sign), or if the embedded Data connection was displaced in the middle of a data collection, then the system should be shut down and the computer rebooted.

Problem: No NMR signal is detected

Reason #1: No groundwater is present in the investigated zone. Some formations (granite) have very little groundwater. Also very little water is likely to be present above the water table.

Reason #2: Extremely short decay times prevent signal detetion. Water in very fine grained materials (such as certain clays) will exhibit very short decay times (sometimes less than 0.5 ms). As a rule of thumb, the Javelin system will only decect water having T_2 decay times greater than ½ the echo time.

13. Additional Documentation

Safety Information

The Javelin system is designed for the sole purpose of conducting NMR logging investigations. The system is only approved for use as specifically outlined in this Manual. Unsanctioned or improper use of the system can result in physical damage to the instrument, personal injury, or even death. It is the responsibility of the owner to ensure that any person using the instrument is qualified and capable of safely operating the system.

In order to ensure safe operation of the system, a qualified operator should have read the complete contents of the Manual and Documentation, and also must have been provided extensive on-site training by an experienced user (Vista Clara recommends a minimum of 3 days). The owner of the system should develop a formal training course to properly train additional operators of the Javelin instrument. The system should never be operated by minors or any person under the influence of drugs or alcohol.

The Javelin system should be operated only by geoscientists or engineers who have previous experience operating geophysical instruments in the field.

Safety Checklist

The following safety checklist should be reviewed by all users and field assistants prior to handling or operating the Javelin system:

Always be aware of the strong magnetic fields surrounding the downhole probes.

Do not allow magnetic objects (such as steel) near the probes.

Do no allow persons with implanted medical device, such as defibrillators or pacemakers within 5 meters of any instrument components.

Always secure probes inside steel shielding tubes and secure other steel objects during transport.

Do not connect or disconnect the High Voltage NMR Winch Cable, Downhole Cable, or Downhole probe when the system is powered on.

Ensure that all connection ports are capped when not connected to cables.

The Javelin system should never be left deployed in the field overnight or unattended.

Do not attempt to operate the system if there is damage to the Downhole Cable, High Voltage NMR Winch Cable, or damage to any other parts.

System components are heavy. At least four people should work together to lift and move the main component units.

Always check the O-rings on the downhole cable connection to ensure they are clean and free of any dirt or debris. Apply vacuum grease if they O-rings require lubrication.

Always check the system for damage before use. Do not attempt to use the system if any case, seal, meter, connector, or cable is visibly damaged.

Do not stand or sit or place any heavy objects on any of the cases, even when closed. Do not stack cases on eachother.

Do not use the system if there is a chance of electrical storms with lightning. The user must respond responsibly to changing weather conditions and discontinue use before a danger becomes present. If lightning is nearby, abandon the sytem without regard to its currrent state and seek shelter immediately!

Hazardous Materials

All components included the Javelin system are RoHS compliant. Batteries are not included with the system, but likely contain hazardous chemicals. Batteries should be handled and disposed of in a safe manner as prescribed by the battery manufacturer.

Storage, Transport, and Handling

The following guidelines for storage, transport, and handling must be followed to maximize the lifetime of your Javelin system and to prevent unnecessary hazards from arising.

Magnets in the downhole probes create very strong magnetic field that are always present, even when now power is connected. Use extreme caution when transporting the probes. Do not allow magnetic objects (such as steel) near the probes; magnetic objects and probes will be attracted and may become projectiles if not properly secured. Magnetic fields can cause damage to electronics and devices with magnetic encoding (e.g. hard drives and credit cards); keep all such objects away from probes.

During storage, all panels on the instrument should be covered and all ports should be capped. The Javelin system should only be stored indoors; no component of the system should ever be left outdoors or unattended. The storage environment must be dry and maintain a temperature between -20°C and 50°C with a relative humidity of less than 95% non-condensing. The storage space should be free of rodents or other pests that are known to bite or otherwise damage the insulation material on electrical cables. Components should never be stacked, nor have heavy items placed upon them. Any structures or shelving used to support instrument components must be appropriately rated for the load to be carried.

During transport, the Javelin system should be treated and handles as sensitive electronic equipment. When placed in any vehicle for transport, the system should be well-secured to prevent sliding. Additionally, padding should be placed under and between instrument components to prevent them from banging against one another or against other objects; connectors and external ports can be easily damaged as a result of such impacts. When traveling on rough roads, transport the system in vehicles with adequate suspension and drive slowly to avoid unnecessary bouncing or vibration. If extensive transport in rough conditions is required, ensure that the instrument components are adequately packaged, with soft padding and a hard outer casing, to resist shock and hard impact.

Appendix

Table 1

	Outer Diameter (in)	Low Freq Radial Sensitivity (in)	Logging Head Vertical Offset (m)	Nominal Vertical Res (m)	Rec Echo Time (ms)	Min Echo Time *Expert* (ms)	N Freq (#)	Min Freq (kHz)	Max Freq (kHz)
JP525	5.25	10	0.868	0.5	1.5		2	250	300
JP350	3.5	7.5	0.868	0.5	1.5		2	250	300
JP350F	3.5	7.5	1.19	0.5	1	0.6	4	250	425
JP238	2.38	6	1.1	0.5	1		2	250	300
JP238F	2.38	6	1.54	0.5	1	0.6	4	250	425
JP175A	1.75	4	1.12	1	2		2	250	300
JP175B	1.75	5	1.32	1	1.5	1.1	2	250	300
JP175Dart	1.75	3	0.94	0.25	0.5		2	425	475

14. Contact Information

Vista Clara, Inc.

12201 Cyrus Way, Suite 104,

Mukilteo, WA, USA 98275

For fastest contact with Vista Clara Inc., please phone, fax, or email. Check our website frequently for changes of address and other contact information: www.vista-clara.com. If contact information is changed on our website, record the new contact information here on this page of this manual, and strike the any outdated contact information.

Phone:

+1 (425) 493-8122

Fax:

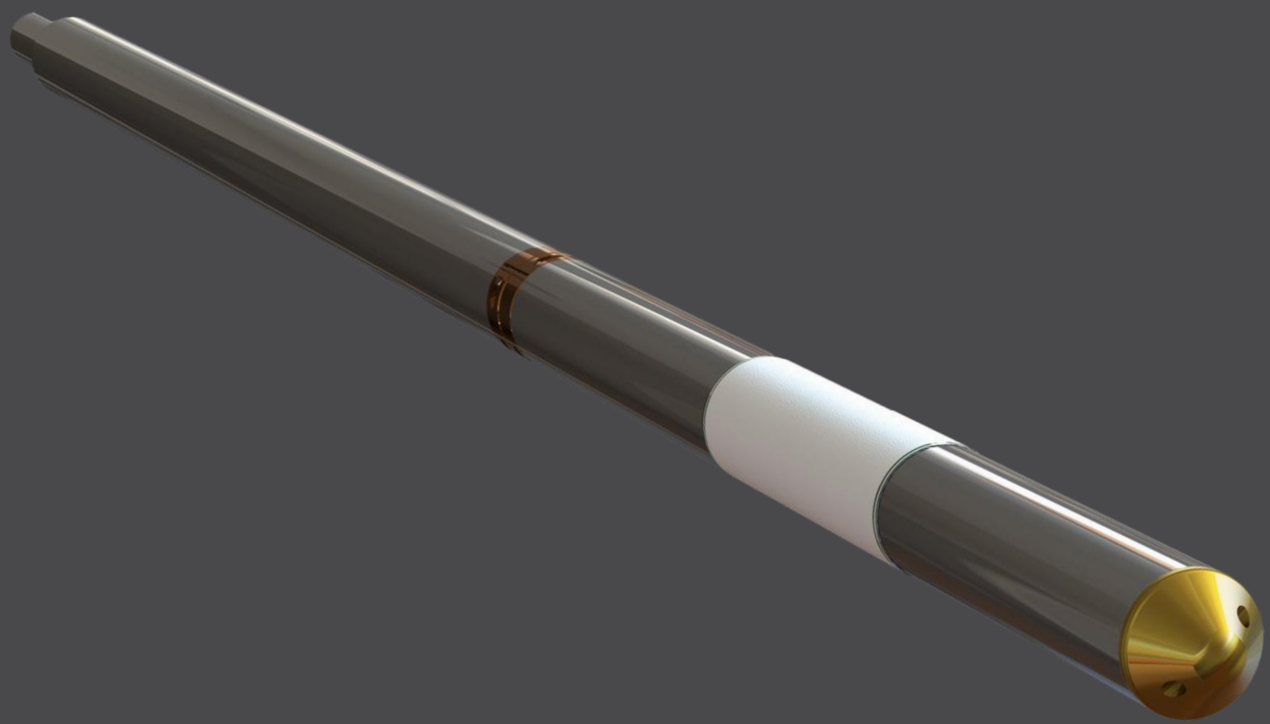
+1 (425) 493-8223

Email:

info@vista-clara.com

Economic Innovations

Borehole Magnetic Resonance (BMR)



Borehole Magnetic Resonance (BMR)

BMR Logging Equipment

Specifications	QL40-BMR-60		QL40-BMR-90			
Physical Dimensions						
Tool Diameter	60 mm	2 ⅜ in	90 mm		3 ⅝ in	
Tool Length	2.01 m	6.6 ft	2.16 m		7.1 ft	
Operating Pressure	200 bar	2,900 psi	200 bar		2,900 psi	
Operating Temperature	100 °C	212 °F	100 °C		212 °F	
NMR Field						
Diameter of Investigation*	230 mm	9 $^{1}/_{16}$ in	360 mm	14 ⅛ in	220 mm	8 ⅝ in
Vertical Sensor Aperture	11.5 cm	4 ½ in	23.8 cm	9 ⅜ in	9.8 cm	3 ⅞ in
Echo Spacing (TE)	450 µs		600 µs		250 µs	
Wait Time (TW)	Multi		Multi			
T2 Distribution	0.5 x TE – 5 seconds		0.5 x TE – 5 seconds			
Porosity Range	0 – 100 pu		0 – 100 pu			
Total Porosity Precision	2 pu – 2 level averaging		2 pu – 3 level averaging			
Well Parameters						
Hole Sizes	75 – 186 mm	3 – 7 ¼ in	122 – 312 mm 4 ¾ – 12 ¼ in		122 – 176 mm 4 ¾ – 6 ⅞ in	
Hole Condition	Open hole, Fiberglass or PVC casing					

* Other diameters of investigation possible in consultation with Qteq.

Logging Environments

The BMR Tool has been run in a wide variety of logging environments:

Hard Rock	Iron Ore, Copper, Lead, Zinc, Gold, Diamond Platinum, Coal
In-Situ Recovery	Potash, Lithium, Uranium, Copper
Oil & Gas	Coal Seam Gas
Groundwater	State Departments, Water Corporations, Agricultural Irrigation, Local Council Water, Industrial Water

In all of these situations, we are measuring only the water content (in special cases hydrocarbon) in the pore space of the rock. The measurement is lithology independent and is free of chemical radiation sources.



Borehole Magnetic Resonance (BMR)

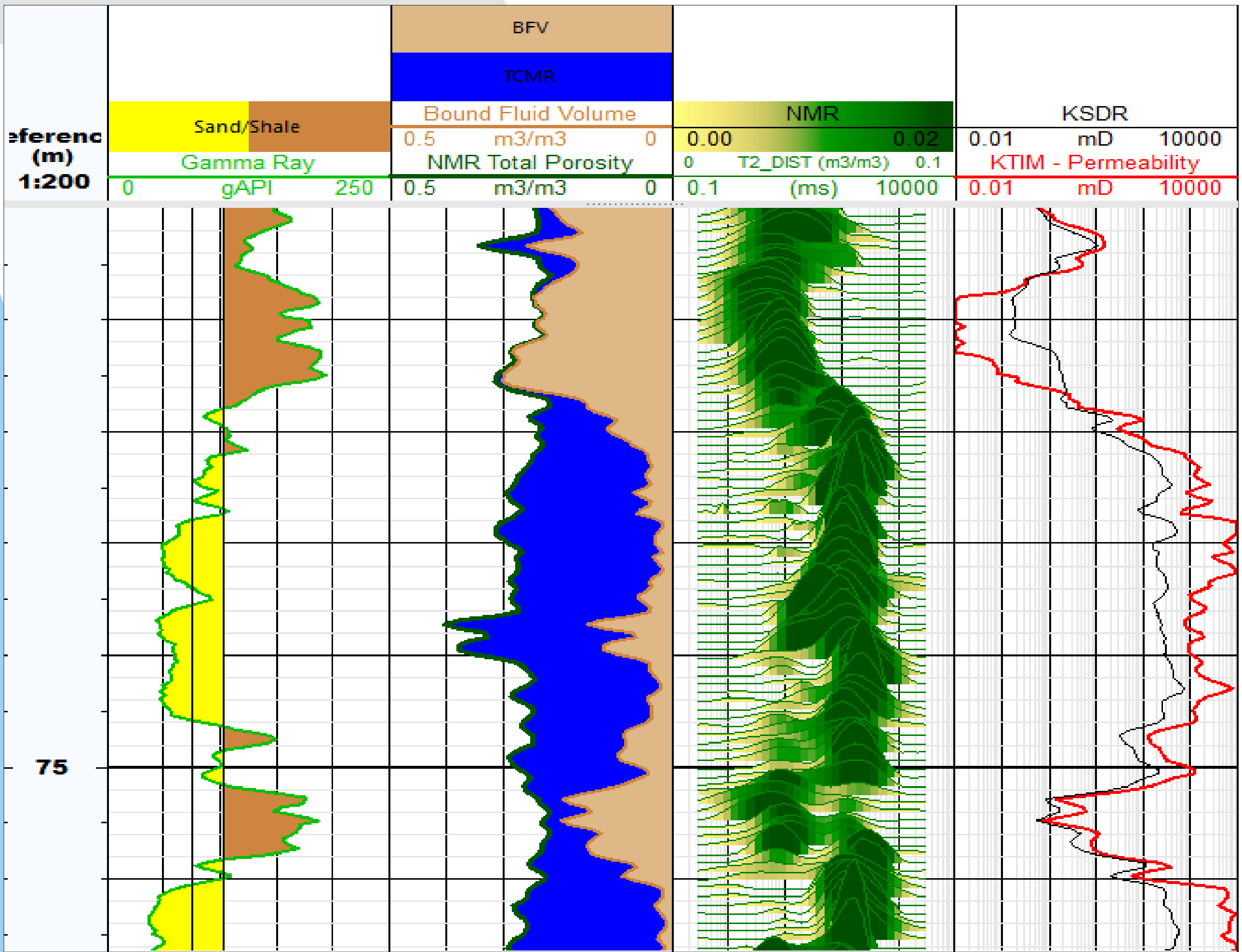
BMR Answers

Measured Parameters	Computed Parameters
Total porosity	Permeability
Pore size distribution (PSD)	Dry weight density (need bulk density)
Free water porosity (specific yield)	Adsorbed and free gas content of coals
Capillary-bound porosity	Multi-mineral modelling (with other log suites)
Clay-bound porosity	Specific retention (capillary + clay bound porosity)

Basic BMR Log

A shallow Sandstone Aquifer example

- NMR data is inverted to give a continuous T2 distribution for the logged interval.
- T2 distribution readily interrogated to derive:
  - Total Porosity
  - Bound Fluid (specific retention)
  - Free Fluid (specific yield)
  - Permeability (hydraulic conductivity)
  - Track 3 is the NMR T2 distribution, which represents a pore size distribution (small pores at left, large pores at right).

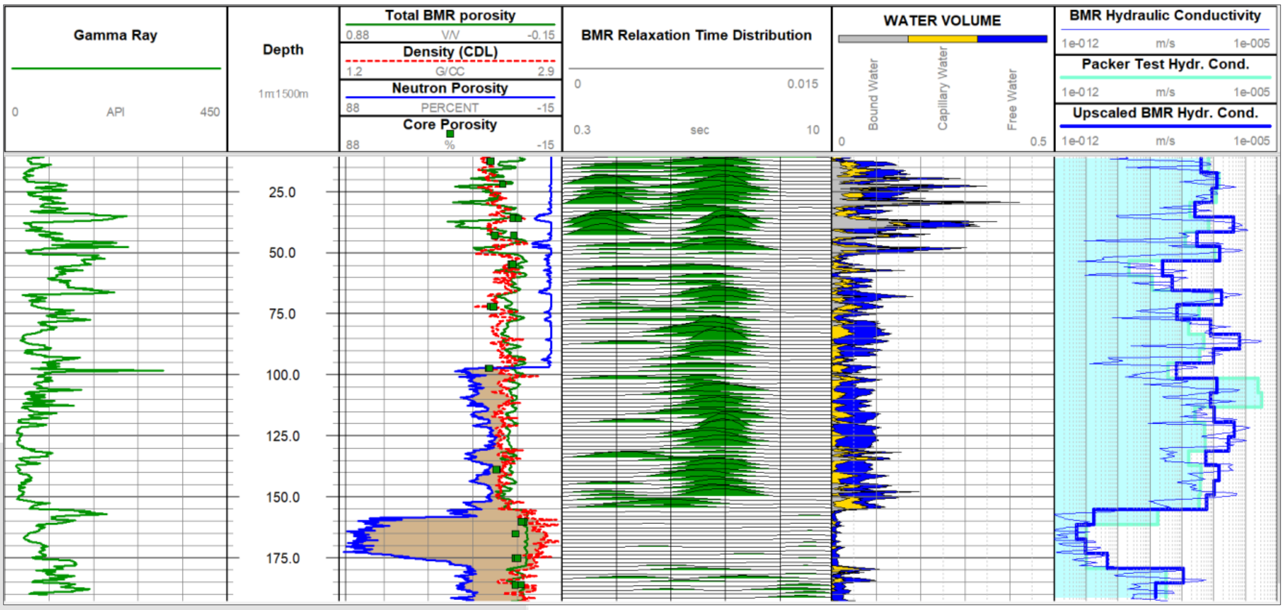


Borehole Magnetic Resonance (BMR)

BMR Logging in Coal Overburden

Comparison of BMR data to packer testing and lab core results

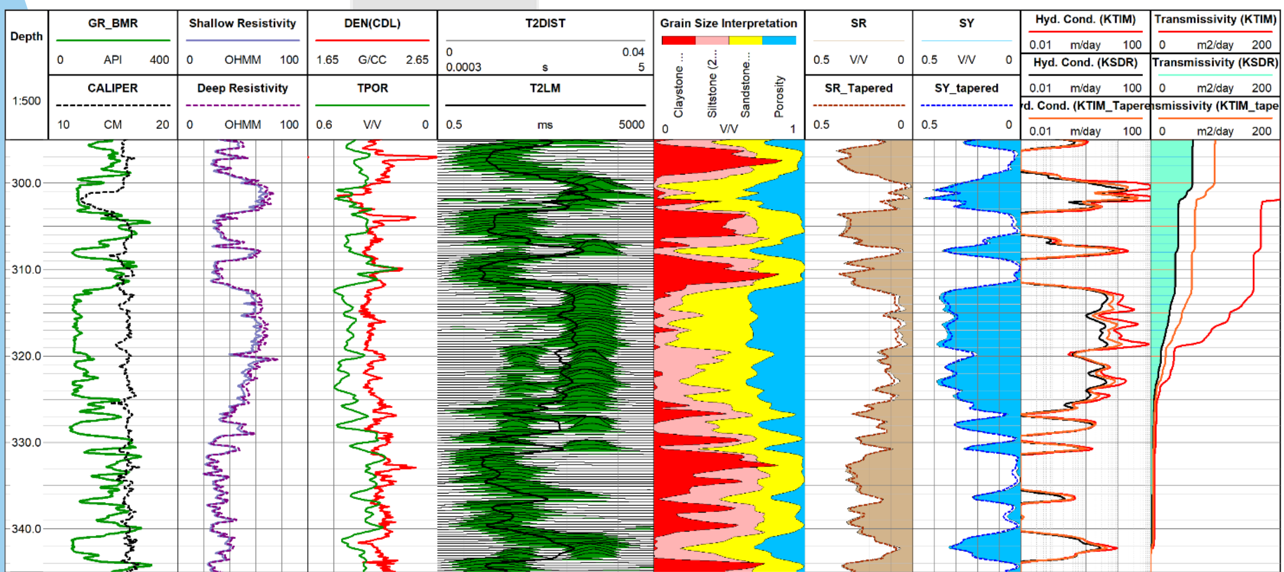
- Shaded blue (far right track) shows 6 m interval packer tests. They correlate well with thick blue BMR data over the same 6 m intervals. The thin blueline is full-resolution BMR data.
- Total BMR porosity (green, track 3) correlates well with lab results on cores (green dots).



BMR in Hydrogeology

Generate complete hydraulic characterisation of the lithology

- BMR has been extensively used to obtain hydraulic characterization of formations.
- A range of answers can be gained from BMR Logs including porosity (3), specific retention (6), specific yield (7), hydraulic conductivity (7) and borehole integrated transmissivity (8).
- A grain size distribution log can be generated from the T2 Distribution (5).
- In combination with resistivity, formation water salinity can be quickly calculated.

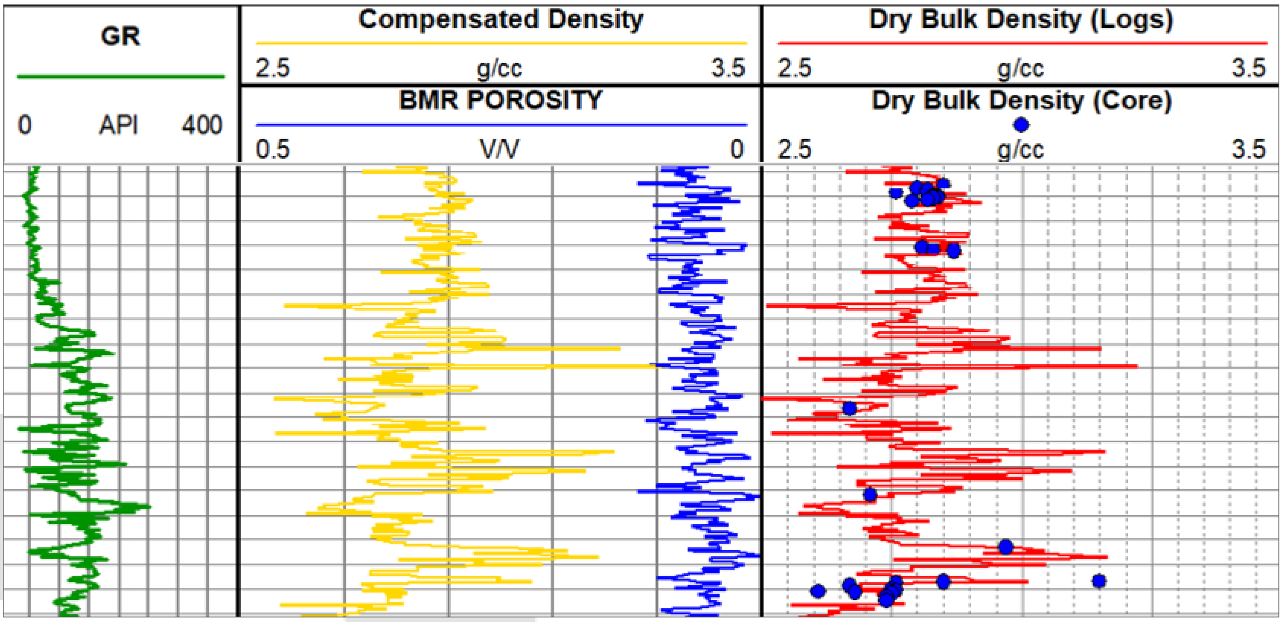


Borehole Magnetic Resonance (BMR)

Dry Bulk Density

Calculate dry bulk density at the wellsite

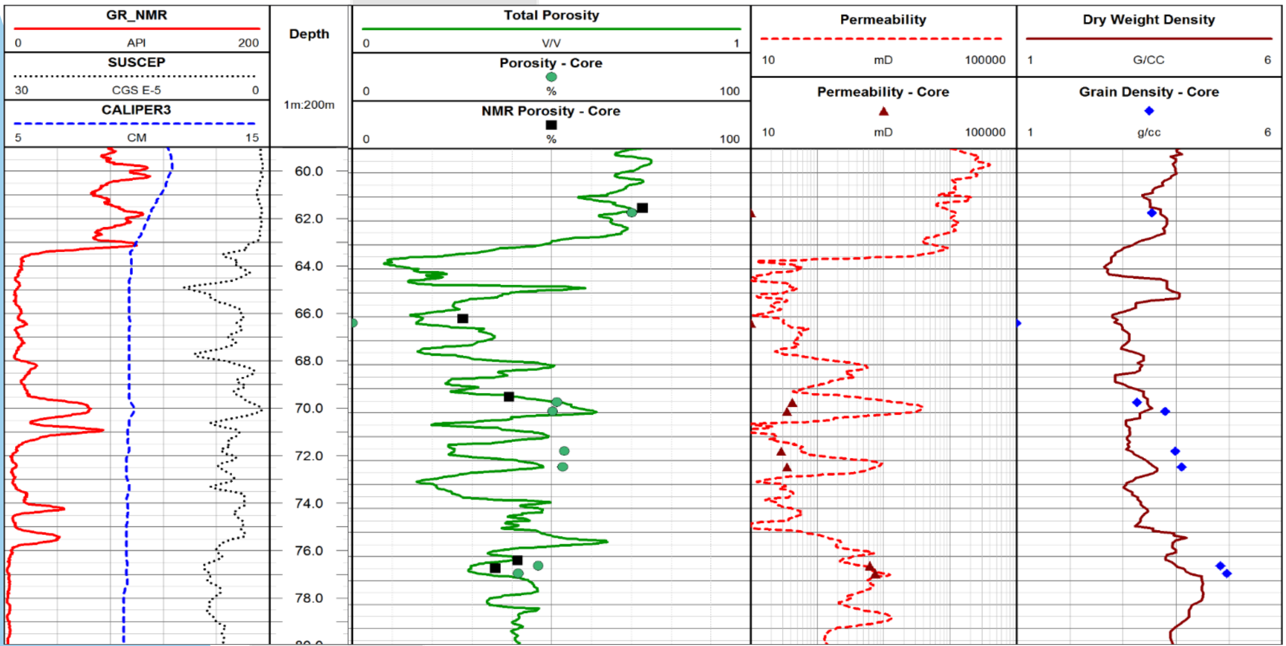
- Combining density and total porosity from BMR allows for the calculation of matrix grain density and dry bulk density.
- Matrix density is used for lithology determination.
- Dry bulk density is a key parameter in resource estimation, mine and process planning.



BMR in Banded Iron Formation (BIF)

BIF BMR Logs

- BMR has been extensively tested in BIF formations with hundreds of logs performed.
- This data was validated using core plugs measured in the laboratory.

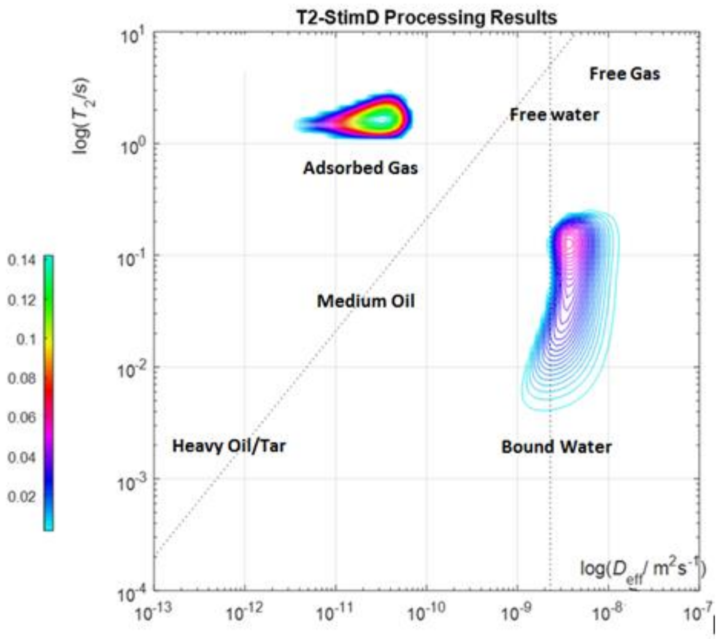


Borehole Magnetic Resonance (BMR)

BMR for Adsorbed Gas

Qteq has developed a propriety BMR acquisition method that enables the accurate measurement of adsorbed gas in-situ

- This acquisition sequence is designed to be sensitive to the high T1/T2 ratio of adsorbed gas as well as delineate other fluid types in the hole.
- It requires a station measurement to ensure a high SNR.



Key Benefits of BMR Measurement

Measure

- Lithology Independent measure of **total porosity**
- Can divide total porosity into:
  - Bound Water (Specific Retention)
  - Free Water (Specific Yield)

Calculate

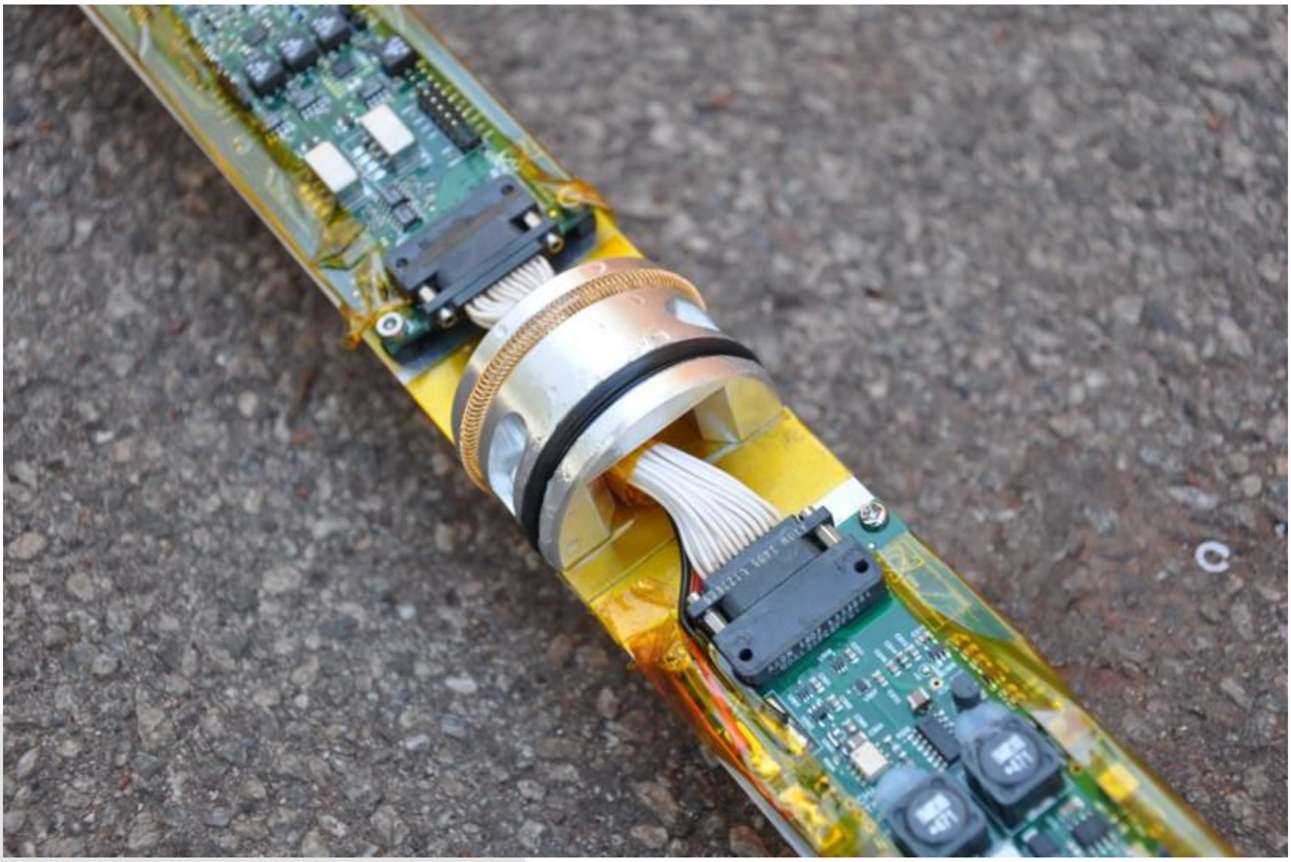
- Can obtain continuous permeability / hydraulic conductivity log
- Grain size distribution
- In combination with other logs
  - Matrix density
  - Dry bulk density
  - Formation water salinity

Cost Savings

- Reduces / replaces need for pump testing / packer tests
- Removes need for use of chemical sources (density / neutron)

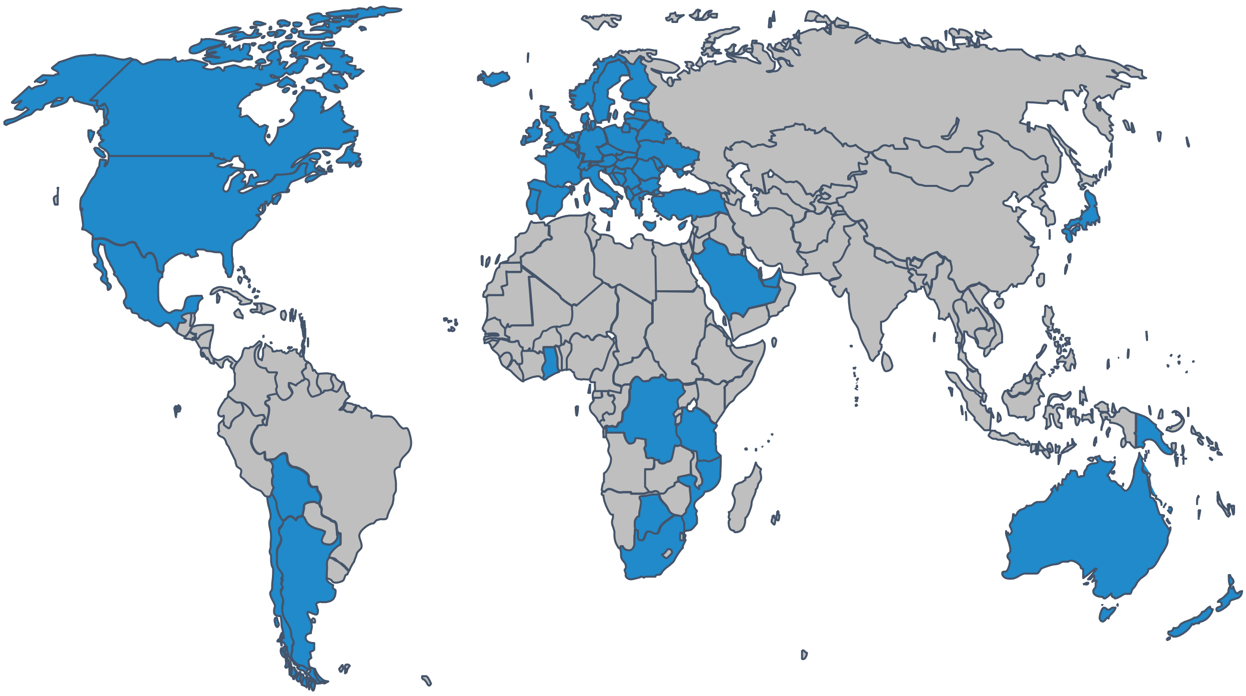
Completely safe – no chemical sources, no radiation, no worries…

Borehole Magnetic Resonance
(BMR)



qteq.com.au

MEASURE MONITOR MANAGE MITIGATE



Economic Innovations

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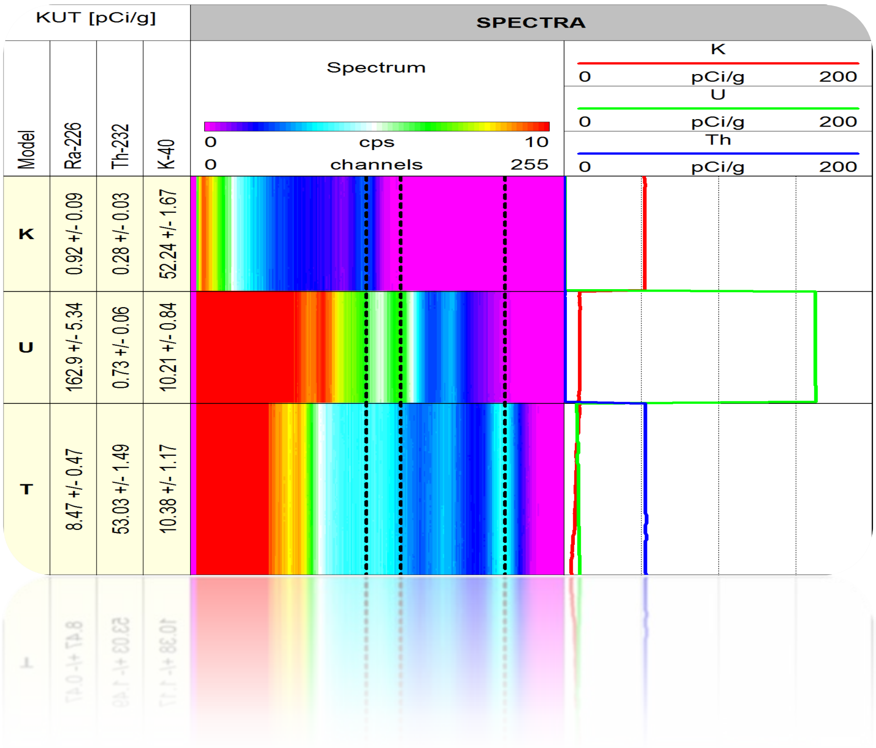

User Guide

QL40 SGR – Spectral Gamma Ray Probe

MOUNT SOPRIS
INSTRUMENTS

ALT
Advanced Logic Technology

V17.03.03

Advanced Logic Technology sa

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Table of Contents

1 General Information

The **QL40-SGR** tool measures the energy of the gamma emissions occurring naturally within the formations crossed by a borehole and counts the number of gamma emissions associated with each energy level. A scintillation Sodium Iodide crystal (or a BGO crystal) is used to detect the gamma rays. Gamma rays are produced mainly by isotopes of potassium, thorium, uranium and their decay products. The gamma ray log is widely used in the mining and oil industry for the identification of lithology, correlation between boreholes and clay content analyses.

The tool is supplied as an inline sub of the Quick Link (QL) product line and can be combined with other QL40 tools to form a tool string or it can be run as a stand alone tool.
The QL40 SGR operates with the ALTLogger and Matrix logging systems and can be run on any standard wireline (mono, 4 or 7 conductor, coax).

1.1 Dimensions

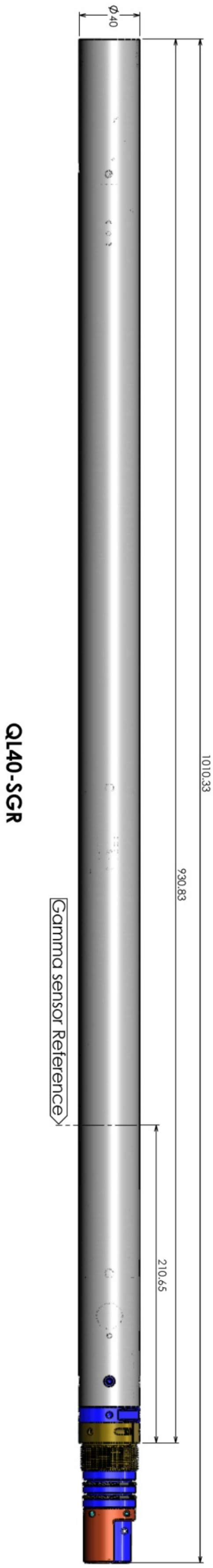


Figure 1-1 *QL40 SGR Dimensions*

1.2 Technical Specification

Tool

Diameter:	40 mm (1.6”)
Length:	0.93 m (36.6”)
Measurement point:	0.210 m (8.29”) from bottom
Weight:	6 kg (13 lbs)
Max. Temp:	70 °C (158 °F)
Max.Pressure:	200 bar (2900 psi)

Cable:

Cable type:	Mono, Coaxial, 4 or 7 conductor
Digital data transmission:	Up to 500 Kbits per second depending on wireline
Compatibility:	ALTlogger – ABOX – Matrix

Sensors:

Scintillation NaI(Tl) crystal:	2.22 cm x 10.16 cm (0.875” x 4.00”)
BGO crystal	2.22 cm x 10.16 cm (0.875” x 4.00”)

2 Measurement Principle

The **tool** is equipped with a scintillation Thallium doped Sodium Iodide crystal - NaI(Tl) or by a BGO, which, when struck by gamma rays, emits pulses of light. These pulses of light are amplified by a photo multiplier tube and are then converted into electrical pulses. The number of pulses are counted, digitized and transmitted up the wireline to the surface acquisition system.

In addition to the “total natural gamma counts” the tool records the energy spectrum of the gamma radiation emitted by the formations. A real time process on the energy spectrum is applied and computes the concentration of the three main radioisotopes K, Th and U.

Figure 2-1 shows a data set acquired with the tool in a test pit.

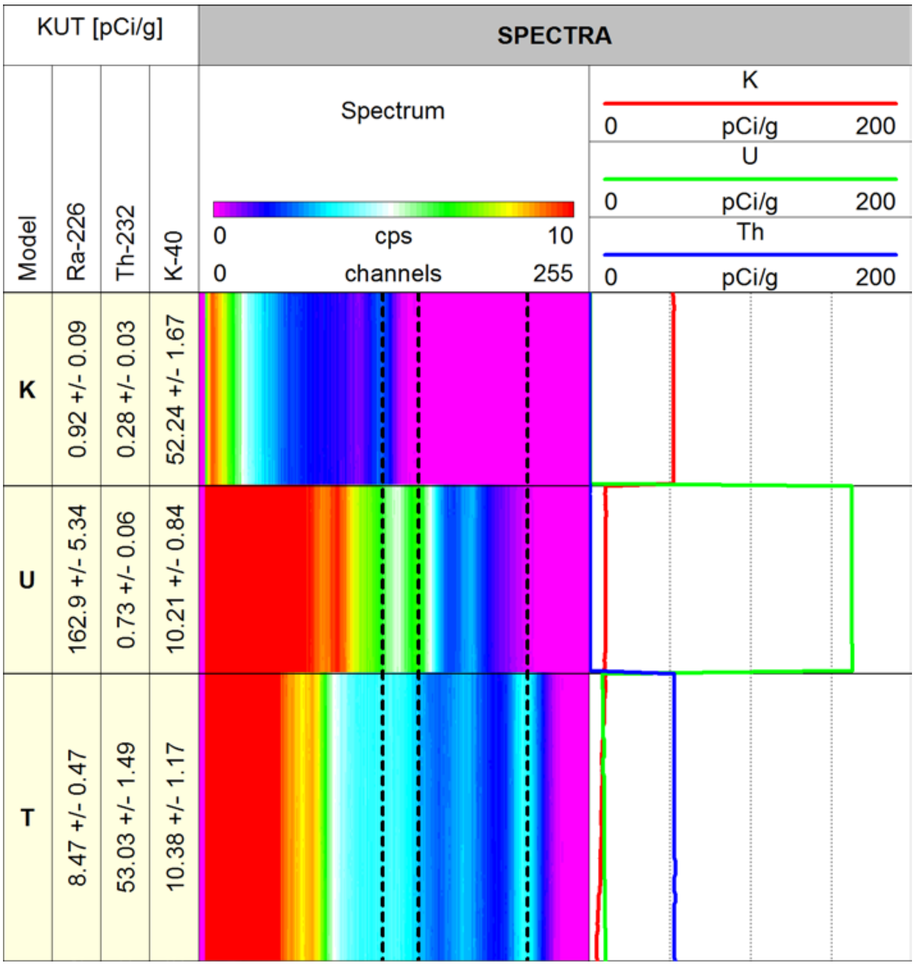


Figure 2-1

3 Notes on QL tool assembly

QL stands for **Q**uick **L**ink and describes an innovative connection between logging tools (subs) allowing to build custom tool stacks. QL40 describes a specific family of logging tools. Each sub is equipped with its own Telemetry board, Power supply element and A/D converter allowing an operation as stand-alone tool or as a stack in combination with other subs of the QL product family.
The QL40 probe line deals with two types of subs - Bottom Subs and Mid Subs.

Bottom Sub
A bottom sub is a tool that must have one or more sensors located at the bottom. It can be operated in combination with other QL subs connected to the top but it is not possible to connect another sub below. When used in stand-alone mode the bottom sub only needs a QL40 tool top adaptor, which fits the cable head.

Mid Sub
A mid sub is a tool that can be integrated anywhere within a stack of tools. When used at the bottom of a tool string a QL40 bottom plug must be used to terminate the string. If the mid sub is used as a stand-alone tool it needs a QL40 bottom plug at the lower end and a QL40 tool top adaptor at the top.

3.1 QL40 stack assembly

QL40 tool stacks are terminated by either a QL40 bottom sub or a QL40 bottom plug. At the top of the stack a QL40 tool top is required to connect the tool string to the cable head. Several tool tops are already available, special ones can be made on request.

To assemble and disassemble the subs the C-spanner delivered with the tool must be used (Figure 3-1). It is recommended that before each assembly the integrity of the O-rings (AS216 Viton shore 75) is verified. Prime the O-rings with the silicon grease that was supplied with the subs.

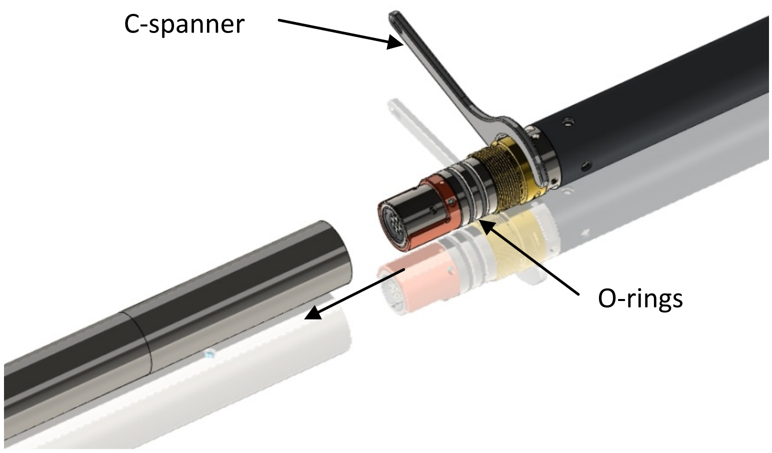


***Figure 3-1** C-spanner and O-rings of QL connection*

The following example of a QL40-ABI, QL40-SGR and QL40-GO4 (Figure 3-2) describes how to replace the QL40-ABI with a QL40-Plug in order to run the QL40-SGR sub stand-alone.

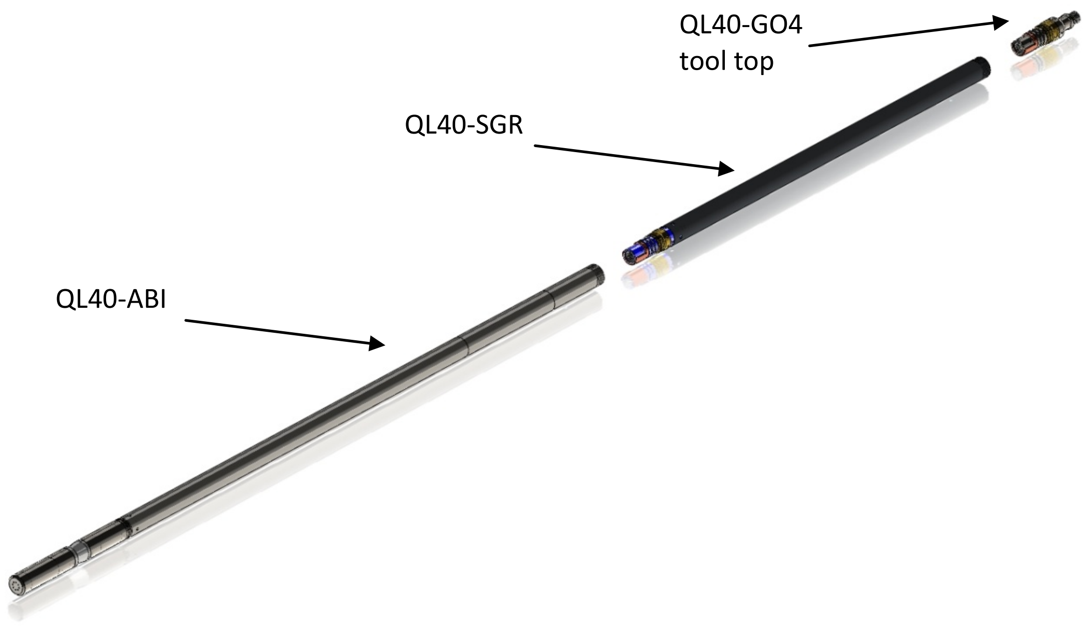


Figure 3-2 *Tool stack example*

To remove the QL40-ABI bottom sub attach the C-spanner to the thread ring as shown in Figure 3-3, unscrew the thread ring and remove the QL40-ABI bottom sub.

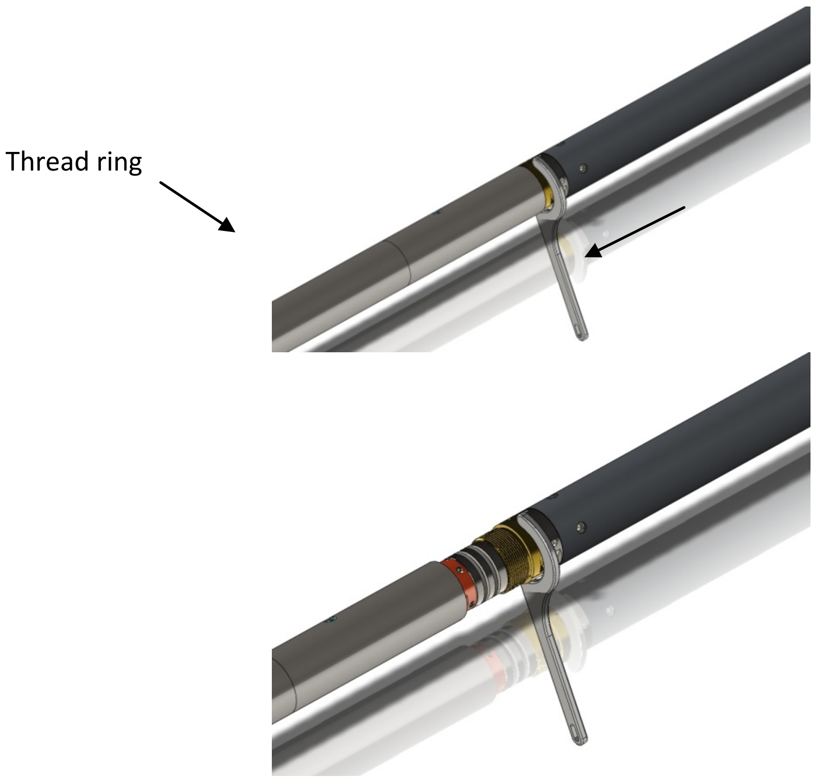


Figure 3-3 *Unscrewing the thread ring and removing the bottom sub*

After checking the O-ring integrity slip the QL40-Plug over the exposed QL connector (Figure 3-4) attach the C-spanner and screw the thread ring until the plug fits tight.

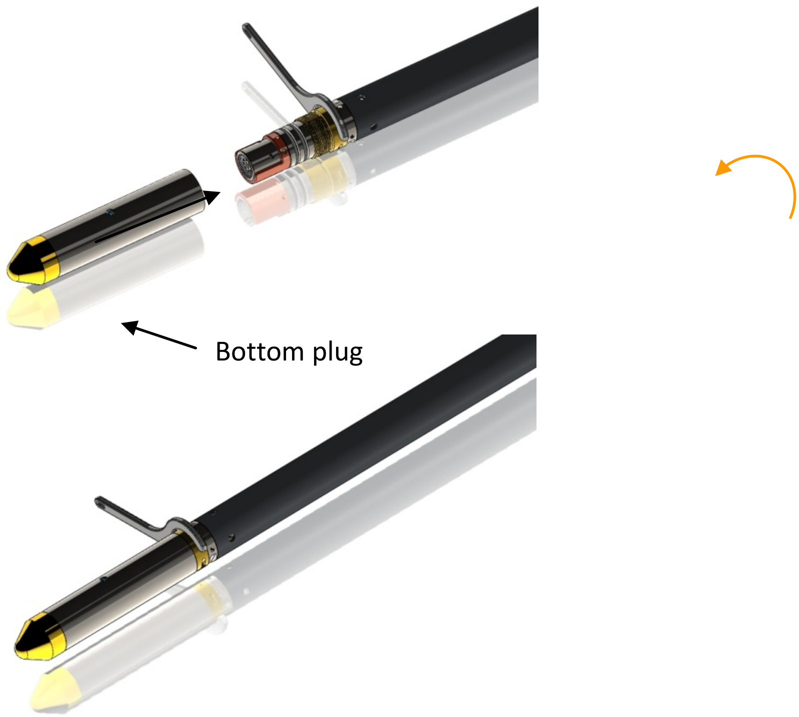


Figure 3-4 *Attaching the QL40-Plug*

The QL40-SGR can now be run stand-alone (Figure 3-5).

Figure 3-5 *QL40-SGR mid sub with tool top and bottom plug*

4 Operating Procedure

Note: Parts of the topics discussed in the sections below assume that the user is familiar with the data acquisition software. Refer to the corresponding operator manuals for more details. Information about assembly and configuration of tool stacks can be found in the same manuals.

4.1 Quick Start

1. Connect the tool to your wireline and start the data acquisition software.

2. Select the relevant QL40 SGR tool from the drop down list (Figure 4-1) in the software's **Tool** panel (if your tool is not listed check that your tool configuration file is stored in the designated folder on your computer).

3. In the **Tool** panel, switch on the tool (click **On** button) and verify that the power indicator shows a valid (green) level. The system goes through a short initialization sequence which sets the default parameters and communication settings held in the tool configuration file. The configuration returned by the tool is also checked during this procedure. (Setup tool communication as explained in chapter **4.2** if error message is displayed.)

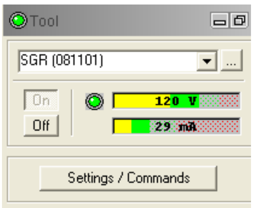


Figure 4-1 *Tool panel*

4. On the **Tool** panel (Figure 4-1) click the **Settings / Commands** button to configure your tool (see chapter **4.5** for details).

5. In the **Acquisition** panel (Figure 4-2) select the sampling mode (depth or time). Click on **Settings** and specify the corresponding sampling rate. Switch on the sampling (click the **ON** button).

6. Press the **Record** button in the **Acquisition** panel (Figure 4-2), specify a file name and start the logging.

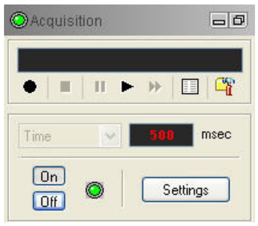


Figure 4-2 *Acquisition panel*

7. During logging observe the controls in the **Telemetry** panel (Figure 4-3):
   - Status must be valid (green light);
   - Bandwidth usage in green range;
   - Memory buffer should be 0%;
   - Number of **Data** increases and number of **Errors** negligible.

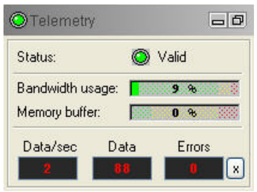


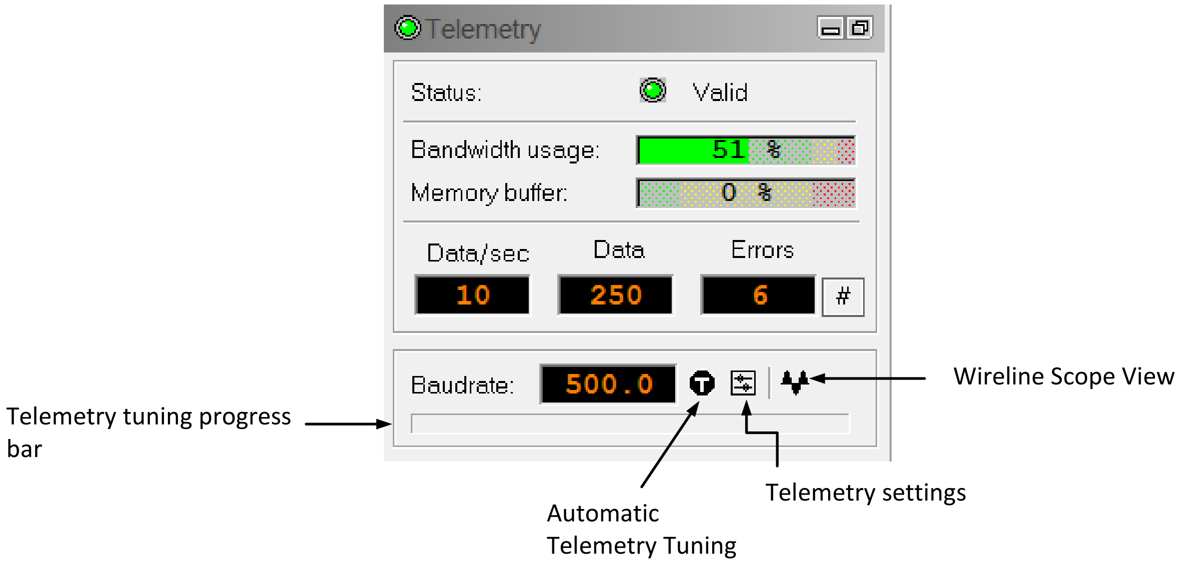
Figure 4-3 *Telemetry panel*

8. To end the logging procedure press the **Stop** button in the **Acquisition** panel and turn off the sampling (click **OFF** button).

9. In the **Tool** panel power off the tool.

4.2 Tool Communication with OPAL/SCOUT (ALT MODEM)

The telemetry provided through the **OPAL-SCOUT** systems implementing the **ALT MODEM** controls and configures **AUTOMATICALLY** the telemetry settings for any wireline. In case communication status is not valid the user has different options to adjust manually the telemetry settings from the telemetry panel of the dashboard:



Baud rate:
Indicates the default baud rate or optimal baud rate in kbps found by the system for the selected winch/telemetry scheme

Automatic Telemetry Tuning:

The Tune button  resets the telemetry tuning automatically. This process defines:

- the optimum baud rate for the winch configuration selected
- a transfer function and a filter to re-construct at the surface the shape of the pulse trains distorted by the wireline.

A **progress bar** at the bottom of the telemetry window shows the progression of the telemetry tuning. At the end of the process the baud rate display is refreshed with the optimal baud rate value.

Refer to **Appendix** at the end of this manual for more information on the **advanced telemetry settings**.

4.3 Tool Communication with ALT Logger

The telemetry provided through the ALTLogger is self-tuning**.** In case communication status is not valid the user can manually adjust the settings. In the **Telemetry** panel of the dashboard click on **Settings** to display the **Configure Tool Telemetry** dialog box (Figure 4-4). A procedure to achieve valid communication is given below:

- Change the **Baudrate** to 41666 kbps.

- Verify that the **Downhole Pulse width** knob is set on 20 (default value). This value is the preferred one and is suitable for a wide range of wirelines. For long wireline (over 2000m), increasing the pulse width could help to stabilize the communication. The reverse for short wireline (less than 500m).
- Set the **Uphole** discriminators in the middle of the range for which the communication status stays valid.
- Increase the **Baudrate**, check the communication status stays valid and the **Bandwidth usage** (in **Telemetry** panel of the dashboard) is below the critical level.
- When **Uphole** discriminators are properly set, store the new configuration as default. The tool should go through the initialisation sequence the next time it is turned on.

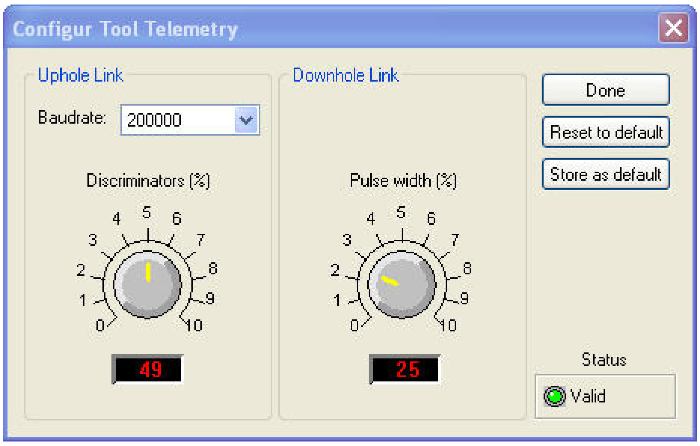


Figure 4-4 *Tool communication settings*

4.4 Tool Communication with MATRIX

The tool telemetry can be configured through the **Telemetry** panel of the Matrix dashboard. By clicking on **Settings**, the operator has access to the **Configure ALT Telemetry** dialog box (Figure 4-5) providing various controls to adjust the telemetry settings and monitor its current status.
The **Analysis View** displays the current discriminator levels (vertical yellow lines) and a histogram of the up-hole data signal. The scales of the **Analysis View** can be adjusted using the **Vertical Scale** and **Horizontal Scale** knobs and the **lin**ear / **log**arithmic scale buttons.
The status of the configuration should be flagged as Valid (indicated by the LED being green). In any other case (LED red) the telemetry should be adjusted (we assume a pulse signal is displayed in the analysis view). Click on the **Advanced** button to display additional controls to tune the telemetry.
The Automatic settings option is the preferred mode and should allow the telemetry to be configured for a wide range of wirelines without operator input. For wirelines with a more limited bandwidth, the operator might need to turn off the automatic mode and adjust the telemetry settings manually.
For each wireline configuration, the discriminators (vertical yellow lines) for the **positive** and **negative** pulses must be adjusted in order to obtain a valid communication status (see Figure 4-5) for an example of a suitable discriminator position). There is also the option to alter the **baudrate** in order to optimize the logging speed. The input **gain** can be increased

(long wirelines) or decreased (short wirelines) in order to set up the discriminator levels correctly.

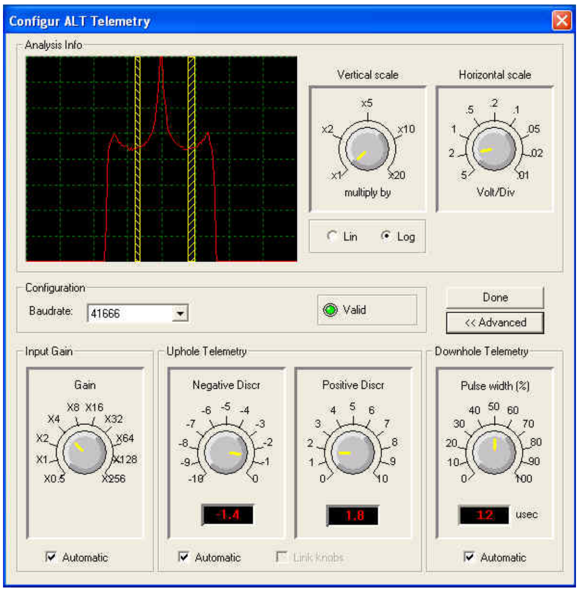


***Figure 4-5** Matrix telemetry settings*

Once the telemetry is correctly set, store the new settings as default. The tool should go through the initialization sequence in "Valid" status the next time the power is turned on.

4.5 Configuring Tool Parameters

The QL40 SGR has the following configuration options.

The "Spectra" page allows you to choose whether or not to enable recording of the instant and stacked spectrum. The stack size can be adjusted with the corresponding control knob.

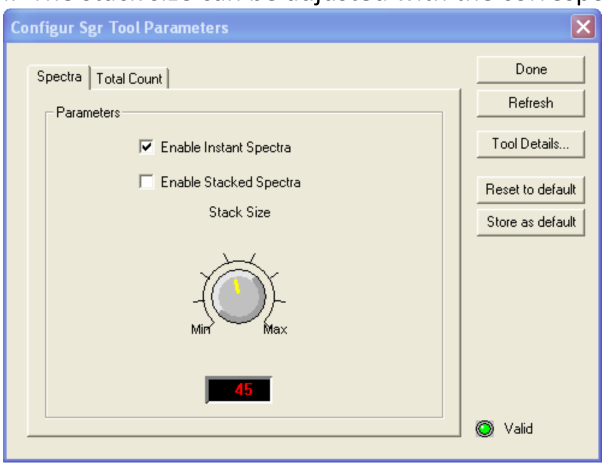


***Figure 4-6** Tool configuration - Spectra*

The second page "Total Count" allows the user to adjust the energy capture limit for the lower part of the spectrum.

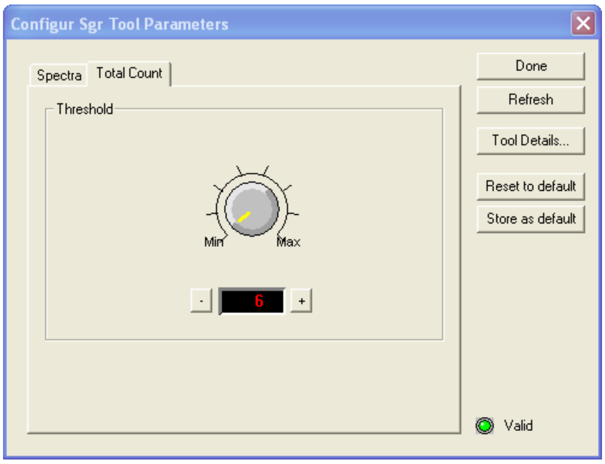


Figure 4-7 *Tool configuration – Total Count*

The tool details (serial number, firmware version,…) are listed in the dialog box displayed when clicking on the "Tool Details…" button. This dialog allows also the tool firmware upgrade (See Appendix)

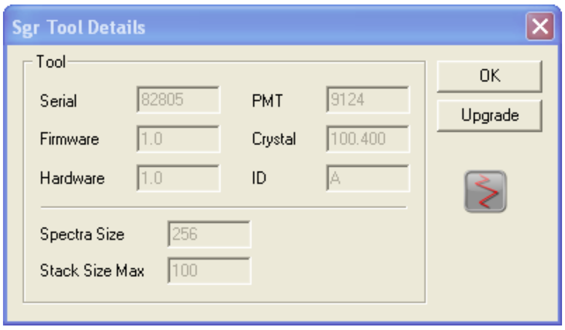


Figure 4-8 *Tool details*

4.6 Recorded Parameters, Processors and Browsers

4.6.1 Recorded parameters

The following data channels are recorded by the QL40 SGR tool.

Temperature	Temperature at CPU board in °C
Counts	Raw gamma ray counts
Time	Sampling time in seconds
Stack Counts	Stacked raw gamma ray counts
Stack Time	Stacked sampling time in seconds
EHT	High voltage [V]
Instant Spectrun	256 samples spectrum
Stacked Spectrum	Stacked 256 samples spectrum

The total GR is computed by the MChProc processor

GR	Total Gamma ray in cps or API

Additional channels are computed and produced by the SgrProc processor – See below.

4.6.2 SgrProc Processor

The SgrProc processor processes the spectra acquired by the tool in two different ways according to the tool configuration file :

- Standard : Window counts mode
- Full Spectrum Analysis (Medusa)

In its standard configuration, only the number of counts related to user-defined windows are computed.

The second configuration applies the gain shift correction and a full spectrum analysis to compute the concentrations in Bq/kg of the nuclide elements. This process requires a master calibration file provided by the Medusa company.

In both configurations, the channels produced by the processor are listed in the About dialog box displayed when selecting “About SgrProc…” from the context menu.

4.6.2.1 Standard Process

The configuration of the processor is done by right-clicking on its window title and by selecting “Parameters” from the context menu.

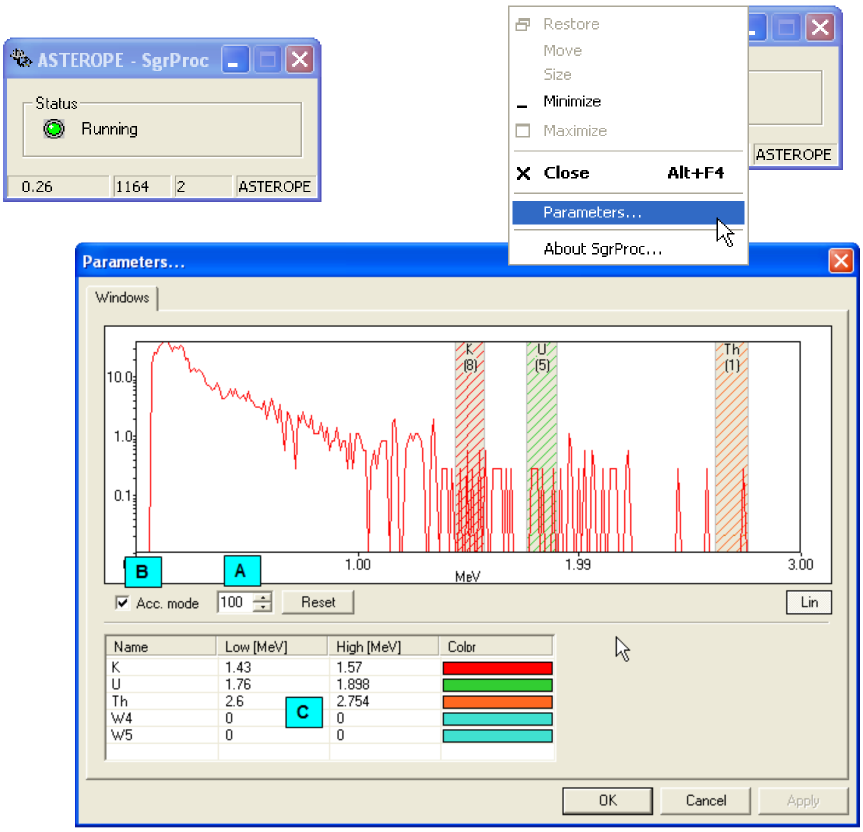


Figure 4-9 *SgrProc configuration*

Raw spectra acquired by the tool can be stacked for a user defined number of samples and averaged. The stack size can be adjusted with the control A. Unchecking the control B (Acc. Mode) will deactivate the stacking operation. At any moment, the stack can be reset by clicking on the Reset button.

Up to five windows can be set. Their tanges may be adjusted from the list (C). The processor computes the number of counts of the stacked spectrum on each window.

K	Counts in K window [cps]
U	Counts in U window [cps]
Th	Counts in Th window [cps]
W4	Counts in the window W4 [cps]
W5	Counts in the window W5 [cps]

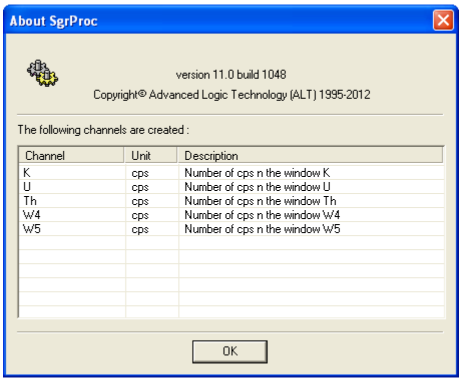


Figure 4-10 *SgrProc About dialog*

4.6.2.2 Full Spectrum Analysis Process – Medusa[1]

This process does the spectrum stabilization and computes the concentration of the nuclides. It's based on a calibration file delivered by the Medusa Company.

K	Concentration of K [Bq/kg]
U	Concentration of U [Bq/kg]
Th	Concentration of Th [Bq/kg]
K-Error	Concentration Error of K [Bq/kg]
U-Error	Concentration Error of U [Bq/kg]
Th-Error	Concentration Error of Th [Bq/kg]
A1	Spectrum Stabilization factor
Chi2	Spectrum Fitting Chi2
StabSpectrum	Energy Stabilized Spectrum

These are the most current channels. The list can be extended depending on the calibration file used by the processor (ex : Cs concentration, …)

[1] *Full-spectrum analysis of natural γ-ray spectra, PHGM Hendriks, J. Limburg, R.J> de Meijer Journal of Environmental Radioactivity 53 (2001) 365-380*

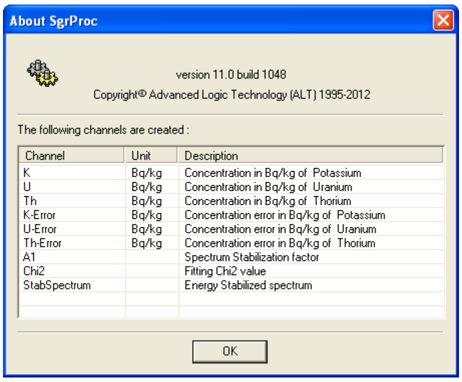


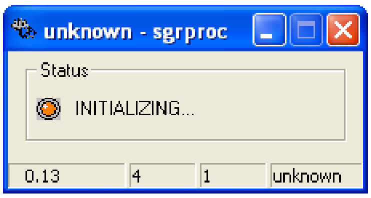
Figure 4-11 *SgrProc About dialog*

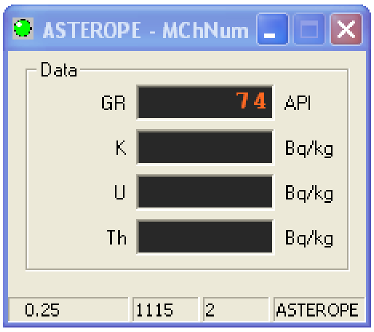
The values of the channels can be expressed in other units. This can be done by using the MChNum calibration pages. The following are the conversion factors (CalA) from Bq/kg to % and ppm

1 % K	= 315.99 Bq/kg K^{40}	1 Bq/kg K^{40}	= 0.0031645 %K
1 ppm U	= 12.35 Bq/kg U^{238}	1 Bq/kg U^{238}	= 0.081 %U
1 ppm Th	= 4.06 Bq/kg Th^{232}	1 Bq/kg Th^{232}	= 0.2457 % Th

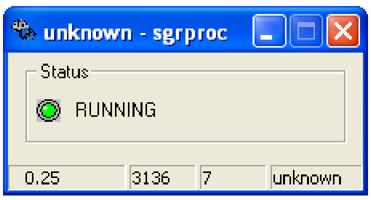
How to log :

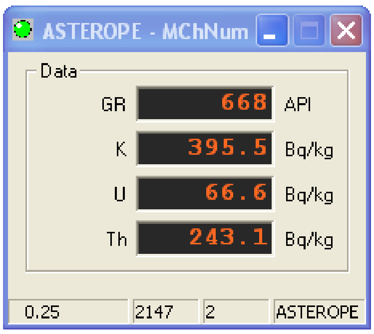
The processor should collect a certain number of spectra to initialize the stabilization process. During this period of time, no outputs are produced and the MChNum numerical displays corresponding to the nuclide concentrations remain black.



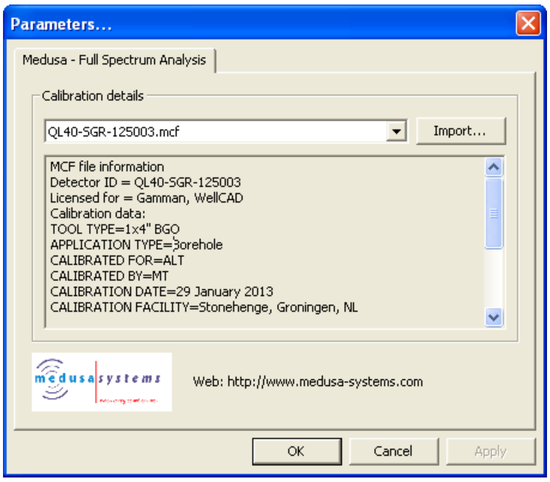


When this phase is completed, the real-time stabilization process is running and the concentration of the nuclides are computed and displayed in the MChNum browser.



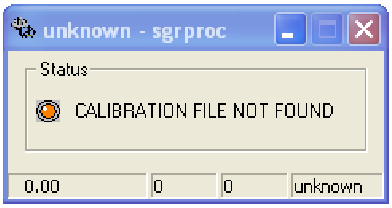


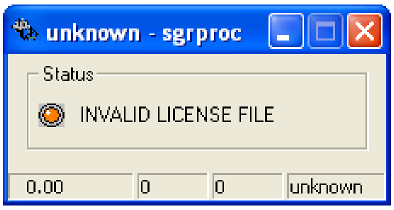
The calibration file details can be accessed from the "Parameters" entry of the menu displayed when right-clicking on the window title.



It is possible from this window to select another calibration file or to import a new one. Calibrations files are stored in the \Tools\Calibrations folder and are displayed in the list.

If the calibration file indicated in the sub file is not found, the corresponding error message is displayed. Select the right calibration file from the "Parameters" dialog box. If a calibration file is not provided, the system still collects the spectra from the tool but does not apply any process to them.
The calibration should be tagged to be used with LoggerSuite or WellCAD. If not, the following message Is displayed. The system still collects the spectra from the tool but does not apply any process to them.





4.6.3 SgrSpectra Browser

The SgrSpectra browser displays the instant spectrum acquired by the tool as well as the stacked spectra generated by the tool or by the browser itself (Settings menu entry). Windows and their related count rates, isotopes, … can be displayed by choosing the corresponding options in the menu.

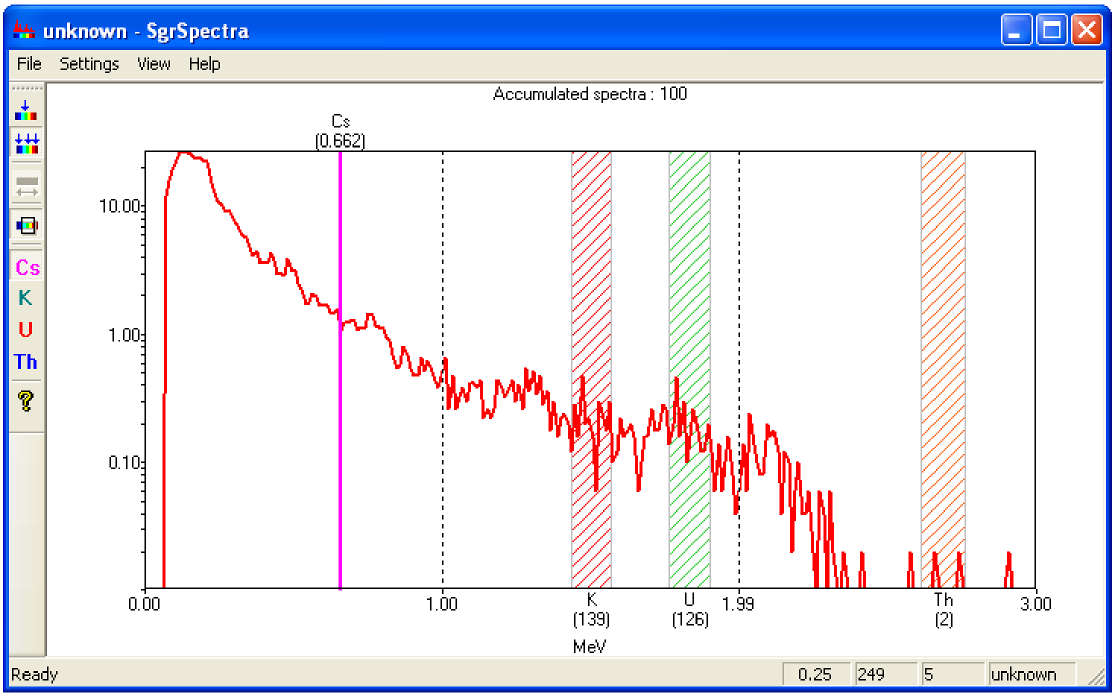
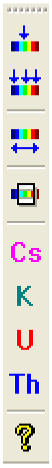


Figure 4-12 *SgrSpectra browser*



Show / hide the current spectrum

Show / hide the stacked spectrum

Show / hide the energy stabilized spectrum (if available) – see figure below

Show / hide windows

Show / hide the Cs energy peaks

Show / hide the K energy peaks

Show / hide the U energy peaks

Show / hide the Th energy peaks

Display the About dialog box

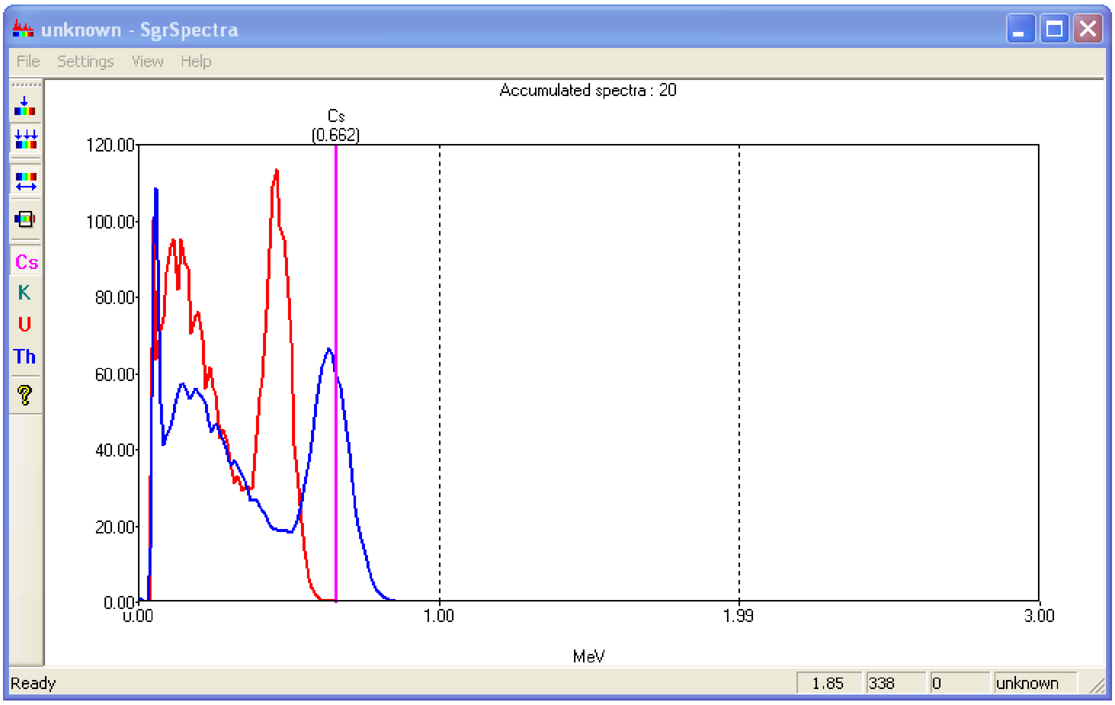
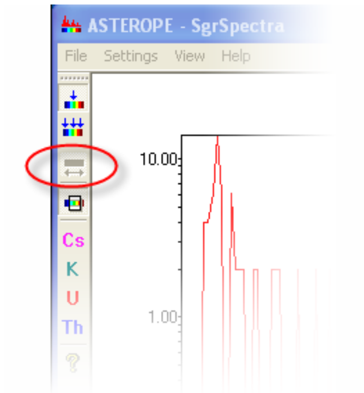


Figure 4-13 *SgrSpectra browser*

The "Stabilized Spectrum" button remains disabled until the processor has acquired enough spectra to stabilize the spectra.



4.6.4 MChNum Browser

The MChNum browser is used to display the numerical values of the channels. The list of channels that can be displayed depends on the process running with SgrProc.

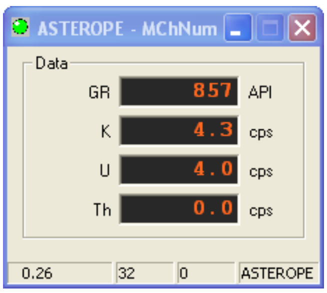
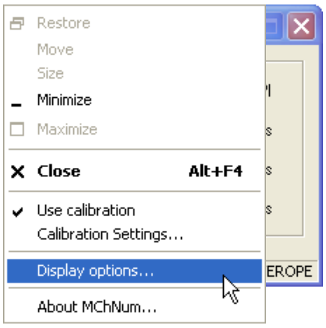
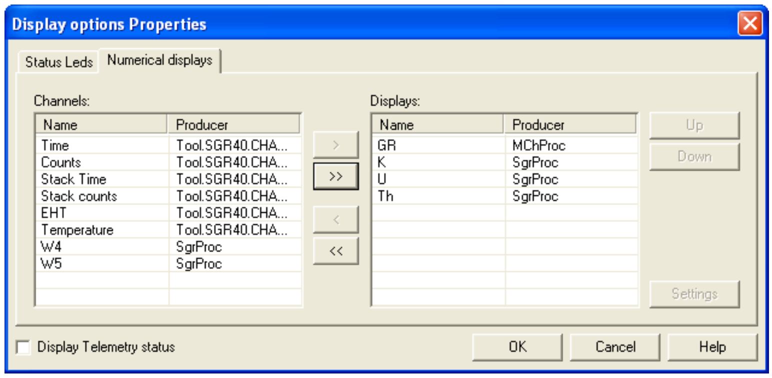


Figure 4-14 *MChNum Browser during operation*

Additional channels can be displayed by right-clicking on the window title and selecting “Display options…” from the context menu.





4.6.5 MChCurve Browser

The MChCurve browser displays the recorded parameters by means of curves in real time (Figure 4-7).

The user is allowed to modify the curve presentation by double clicking on the log title (colours, column position, scale, filter, gridding,….)

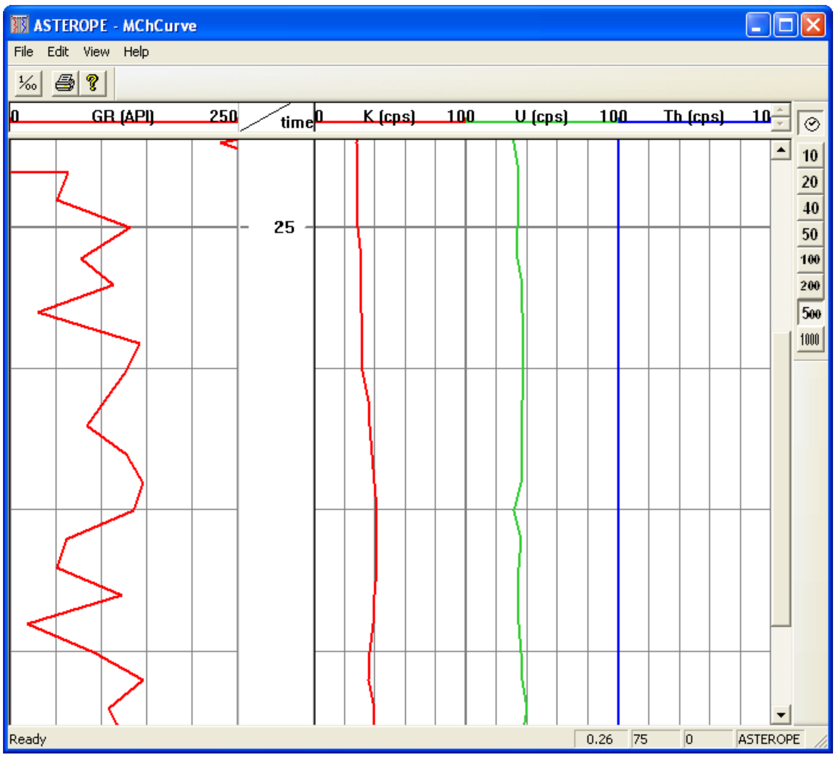


Figure 4-15 *QL40 SGR MChCurve Browser Window*

5 Performance Check & Calibration

Calibrations are performed at the factory and require a basic knowledge and understanding of the tool. Performance checks for the gamma measurement can be made on the surface before logging. With the tool powered on and viewing data on the computer screen a small source of natural gamma radiation can be placed in close proximity to the detector area about 21 cm above the bottom of the probe. An increase in gamma counts will then be observed in the MChNum and MChCurve window if the tool is working properly.

Prepare to Calibrate:

1. Assemble the tool sub(s) and connect to the wireline.
2. In the **Tool Panel**:
   Select the proper tool/stack;
   Turn tool power **On**;
3. In the **Acquisition Panel** select **Time** and turn it **On**.
4. Click the Green LED at the top left corner of the MCHNum Browser window or right click the top pane to display the MCHNum context menu (Figure 5-1).
5. Select **Calibration Settings**.

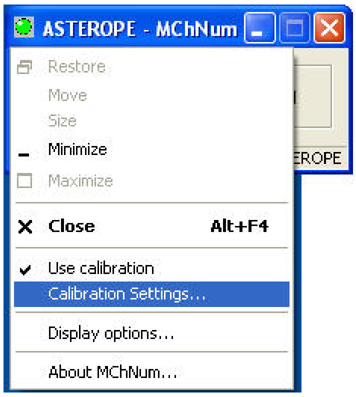


Figure 5-1 *MChNum context menu*

Calibration Settings

1. In order to measure the background radiation, place the tool away from any radioactive material at least 1.5m above the ground or, if available, place the tool in a water tank.
2. In the **Tool Panel**:
   Select the proper tool/stack;
   Turn tool power **On**;
3. In the **Calibration Settings** dialog box (Figure 5-2) click on **Sample** in the **Background Only** section and wait until an average value has been determined. The corresponding **Value** will be updated automatically. (The number of samples taken can be changed under **Options**.)

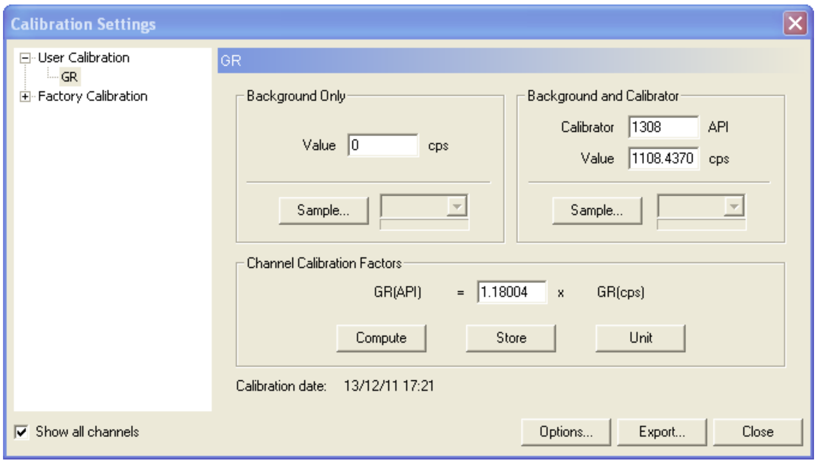


Figure 5-2 *Calibration Settings dialog box*

4. Place the calibrator on top of the sensor or lower the tool into the test pit.
5. Enter the known source strength into the **Calibrator** edit box. If necessary change the units by clicking on the **Unit** button.
6. Click on **Sample** in the **Background and** Calibrator section to determine an average value. The corresponding **Value** will be updated automatically. Click on **Compute** in order to compute the calibration factor.
7. **Store** the new calibration settings in the sub file by clicking on the corresponding button.

On the **Browsers & processors** panel click **Close All** then **Start All** to refresh the other Browsers and Processors. This must be done as they only read the calibration constants from the sub file once when they start.

6 Maintenance

6.1 Upgrading firmware

In accordance with the ALT policy of continuous development the tool has been designed to allow firmware upgrades.

Firmware upgrade procedure is as follows:

1. Checking the communication is valid.
2. Upgrading firmware

6.1.1 Checking the communication

- Connect the tool to your acquisition system.
- Start the data acquisition software.
- In the **Tool** panel select the appropriate tool and turn the power on.
- In the **Communication** panel, select **Settings**. Check **baud rate** is set to **41666** and **communication status** is **valid** (Figure 6-1 or Figure 6-2).

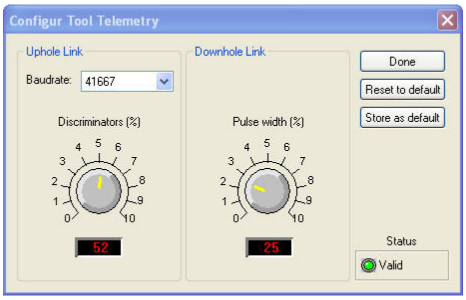


Figure 6-1 *Tool communication settings - ALTLog*

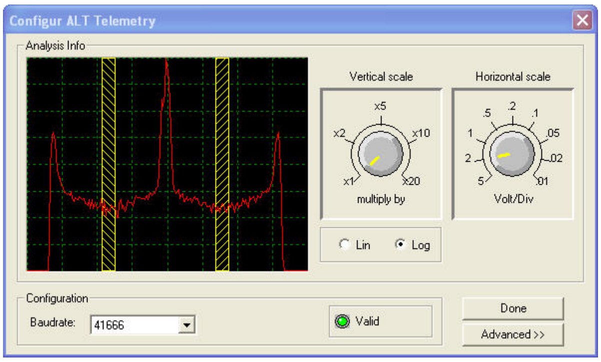


Figure 6-2 *Tool communication settings - Matrix*

Warning: The telemetry must be tuned properly. Bad communication may abort the upgrade of the firmware!

6.1.2 Upgrading the firmware

Check that the communication status is valid. **Click** on the “Settings/Commands” button and on the the “Tool Details” button in the dalog. **Click on Upgrade** (Figure 6-3).

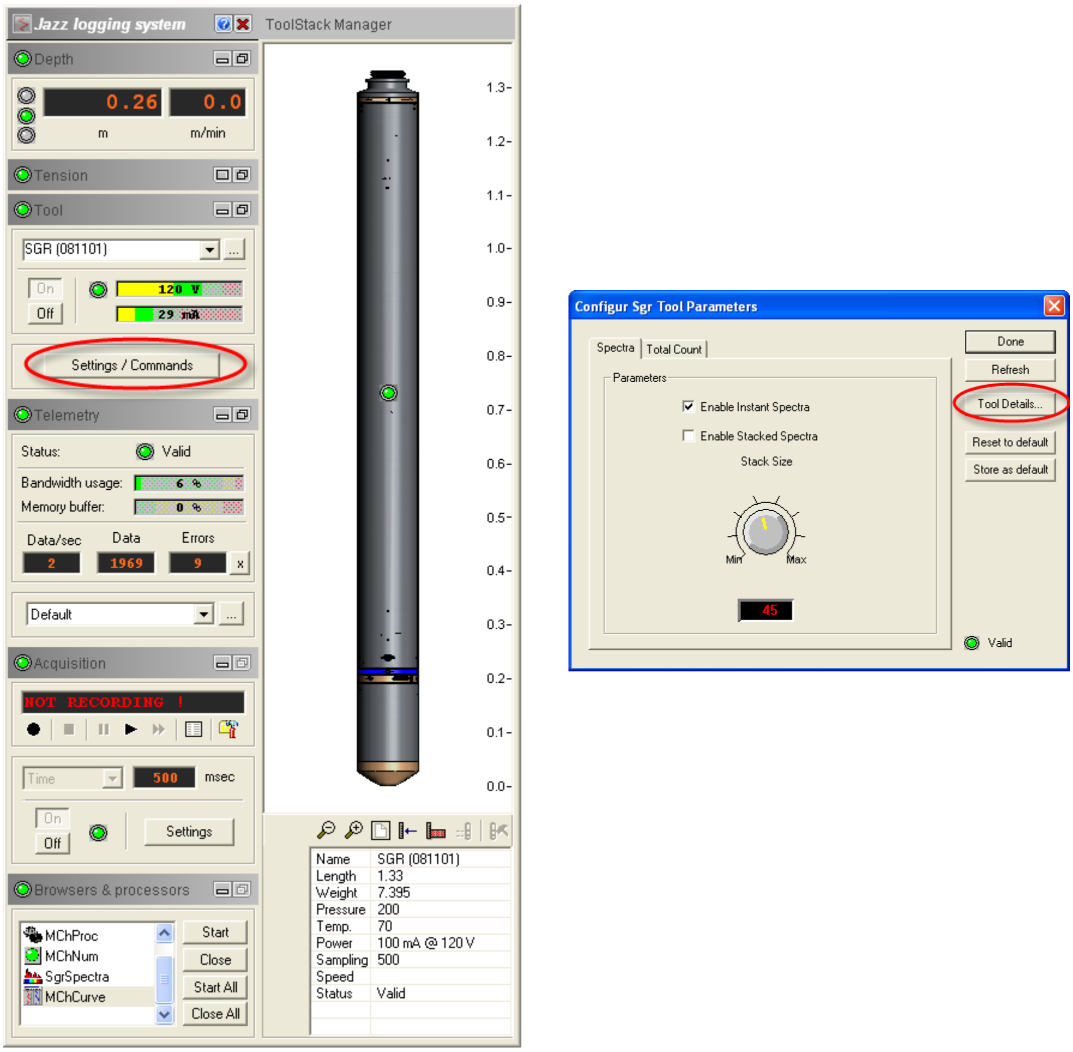


Figure 6-3 *Click on the “Settings/Commands” buttonand on the “Tool Details” button*

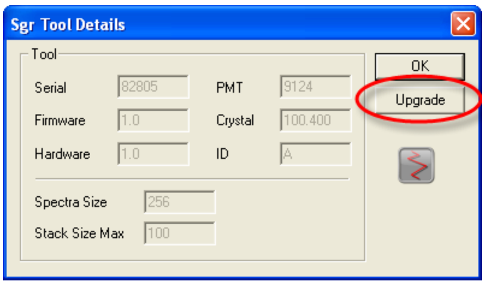


Figure 6-4 *Click Upgrade*

- By clicking on the “Upgrade” button, the following message will appear (Figure 6-4). Click **Yes** to validate your selection.

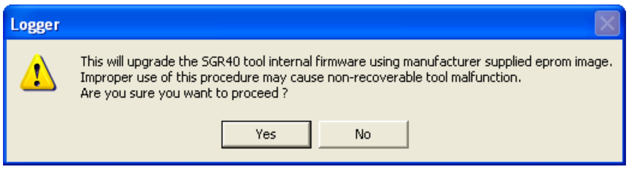


Figure 6-4 *Warning Message during firmware upload*

- Select and open the appropriate **.hex** file provided. The upgrade will start.
- During the upgrade procedure, the following message is displayed:

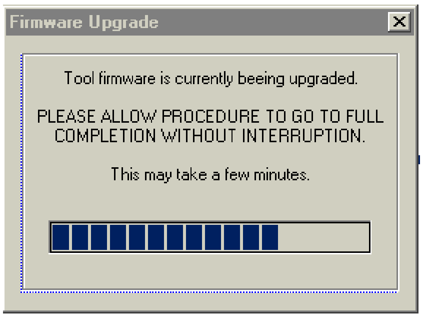


Figure 6-5 *Firmware upgrade progress window*

- Once the upgrade has been successfully completed (Figure 6-6), click on **OK** to turn the tool off.

Figure 6-6 *Successful upgrade*

- Power the tool on to start the upgraded firmware.

Note that the following error message (Figure 6-7) will appear at the end of the procedure when the tool firmware upgrade has failed or has been aborted. Verify the tool communication settings in this case.

Figure 6-7 *Error message*

6.2 General Tool Maintenance

The QL40-SGR tool should require no maintenance other than a few salient points.

- Keep the probe and the tool top/bottom connectors clean.
- When the probe is transported, it needs to be contained in a vibration damped container to minimize stress on the sensors.
- The probe top/bottom connector should be periodically cleaned with oil free contact cleaning solvent.

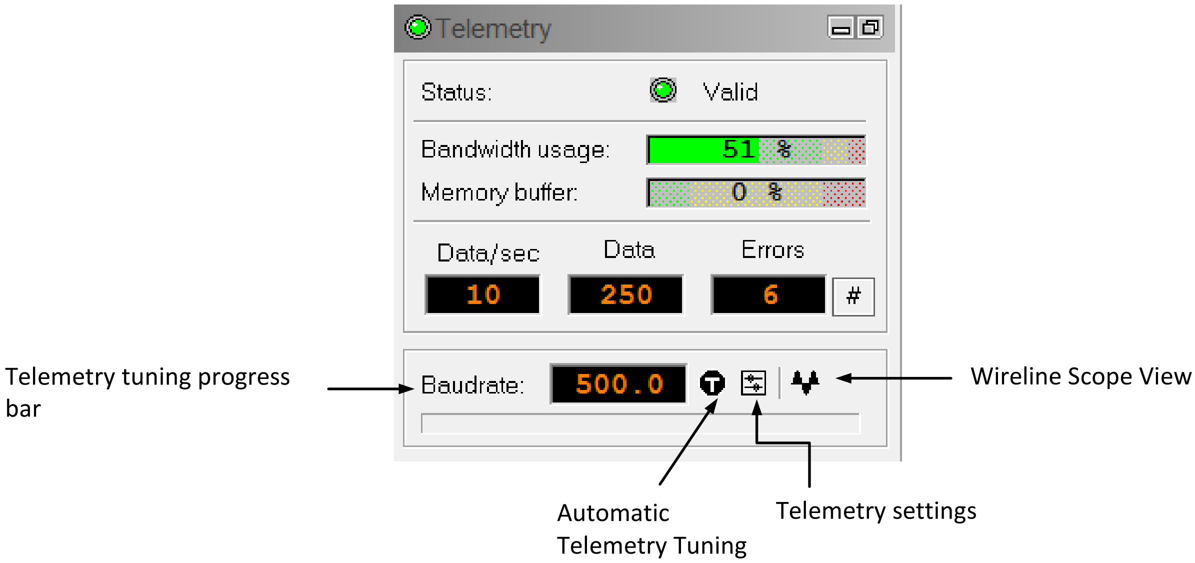
7 Troubleshooting

Observation	To Do
Tool not listed in Tool panel drop down list.	- Do you have a configuration file? - Has the configuration file been imported using the Logger Settings application (refer to the corresponding manual)? - Did you configure a stack for your tool (at least top, tool body and bottom plug)?
Tool configuration error message when powering on the tool.	- Check all connections. - Adjust the telemetry settings for your wireline configuration (see chapter 4.2 or 4.3) and store the new settings as default. Apply the appropriate tool settings for your logging run (see chapter 4.5).
Tool panel - No current.	- Verify that the wireline armour is connected to the logging system. Test your interface cable between winch and data acquisition system. - Verify cable head integrity. - Verify voltage output at the cable head (it should be 120V).
Tool panel - Too much current (red area).	**! Immediately switch off the tool !** **-**Possible shortcut (voltage down, current up): Check for water ingress and cable head integrity - wireline continuity. - Verify the interface cable between winch slip ring and data acquisition system is not loose at the connectors. Check for possible source of a shortcut. - If the above shows no issues, use test cable provided by ALT to verify tool functionality. - If the problem still occurs, please contact service centre.
Telemetry panel - status shows red.	- Verify the telemetry settings for your wireline configuration (see chapter 4.2 or 4.3). - If problem cannot be resolved contact support@alt.lu .
Telemetry panel - memory buffer shows 100%.	- Indicates that the systems internal memory buffer is full. PC can't receive incoming data streams fast enough. Ensure your PC has enough resources available.
Telemetry panel – bandwidth usage shows 100%. *(Overrun error message.)*	- Set the baudrate to highest value allowed by your wireline configuration. - Reduce logging speed, decrease azimuthal resolution and/or increase vertical sample step.
Telemetry panel - large number of errors.	- Verify the telemetry settings for your wireline configuration (see chapter 4.2 or 4.3). - Check bandwidth usage and telemetry error status.

8 Appendix

8.1 Tool Communication with OPAL/SCOUT

The telemetry provided through the OPAL-SCOUT systems implementing the ALT MODEM adapter is self-tuning. In case communication status is not valid the user has different options to adjust manually the telemetry settings from the telemetry panel of the dashboard:



Baud rate:
Indicates the default baud rate or optimal baud rate in kbps found by the system for the selected winch/telemetry scheme

Automatic Telemetry Tuning:

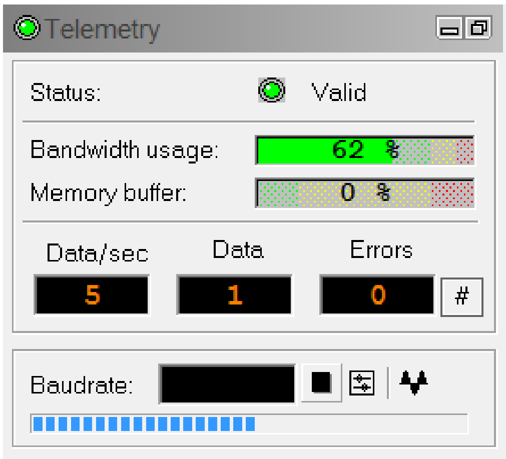
The Tune button  resets the telemetry tuning automatically. This process defines:

- the optimum baud rate for the winch configuration selected
- a transfer function and a filter to re-construct at the surface the shape of the pulse trains distorted by the wireline.[2] Refer to the **Equalizer** paragraph for more details.

The Automatic Tuning is very useful on wireline over 1000m length to optimize the telemetry performance and logging speed.

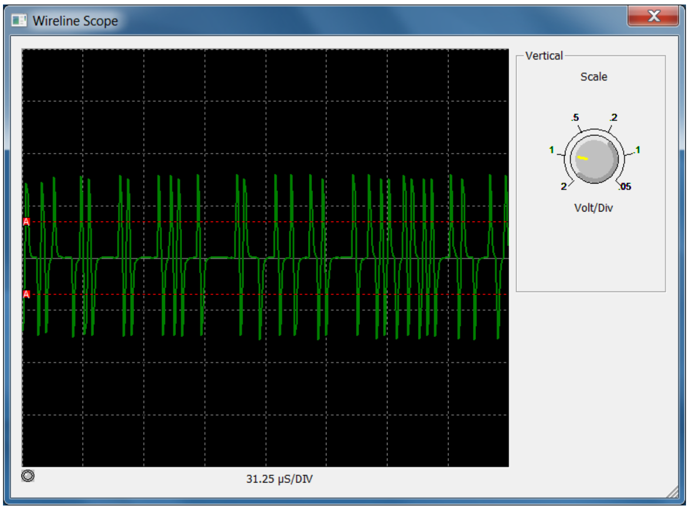
A **progress bar** at the bottom of the telemetry window shows the progression of the telemetry tuning. At the end of the process the baud rate display is refreshed with the optimal baud rate value.

[2] The transfer function and filter concept are only valid for tools implementing the latest generation of ALT MODEM telemetry board (i.e. QL40-ABI2G, ABI-GR-2G, QL40-OBI2G, OBI-GR-2G, QL43-ABI2G,…)



Scope:

Pressing the scope button  on the **Telemetry Panel** brings up a **Wireline Scope** view (Figure x), which displays the pulse strings transmitted through the wireline and received by the system at the surface.



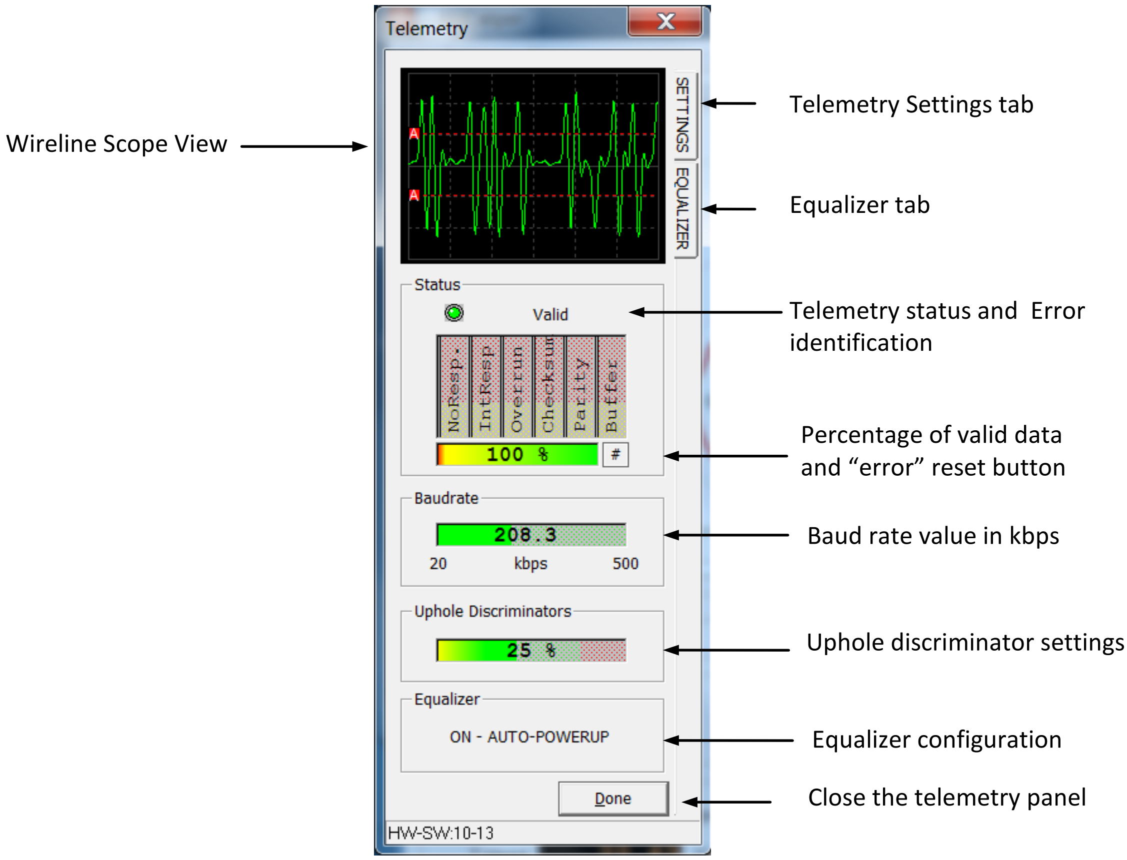
The two red-dashed horizontal lines help to visualize the position of the discriminator levels set for detecting the pulses at the surface. Discriminator levels can be tuned in the **Telemetry Settings** dialog – refer to section 3.6.1 for more information.

The Scale knob can be adjusted to show more or less vertical details. This view has no effect on the communications and is a visual aid only.

Telemetry Settings:

The Telemetry Settings button  opens a **Telemetry** control panel summarizing the telemetry status and configuration.

If the system cannot establish a stable communication with the tool, the **Settings and Equalizer tabs** allow the user to modify the telemetry settings and to apply a telemetry filter (Equalizer option)

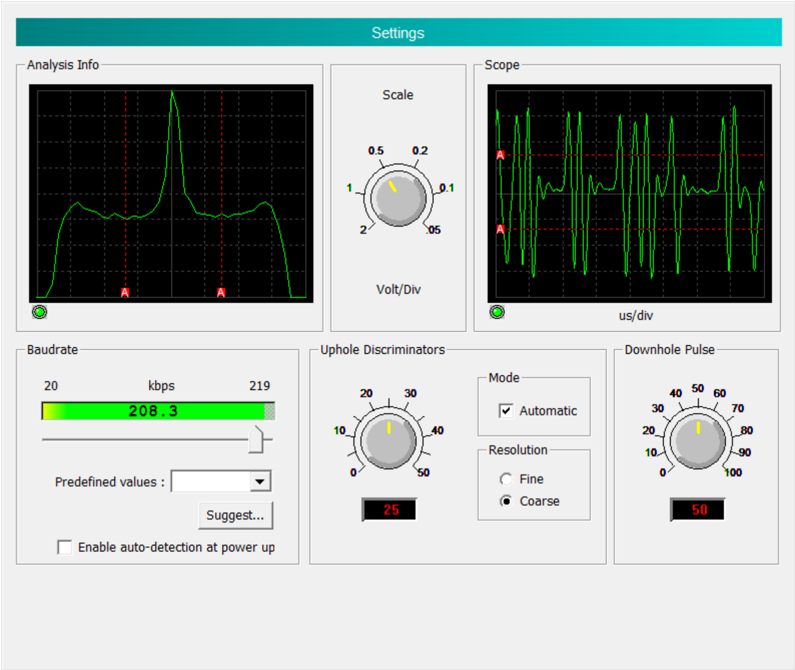


Adjusting the Telemetry Settings:

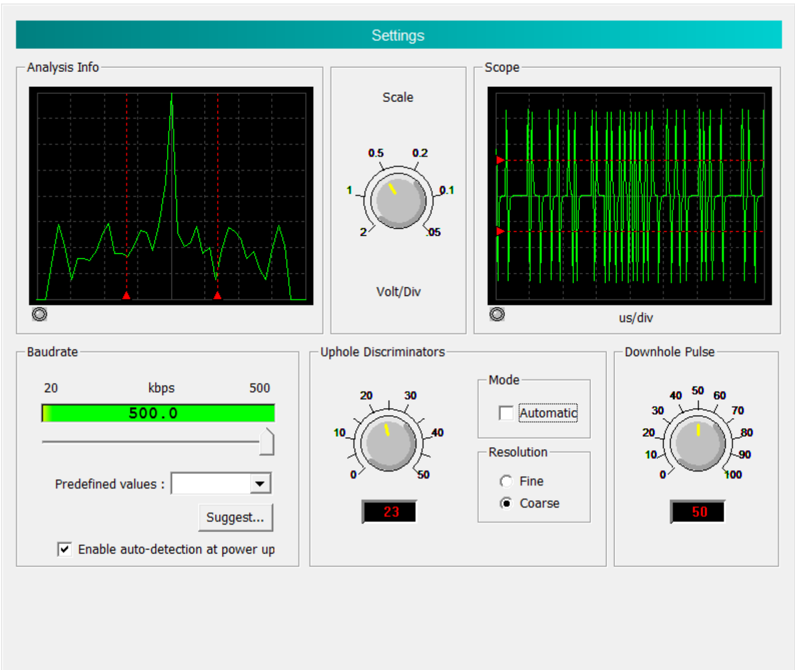
By default the telemetry settings are set to Automatic mode and should stay in this configuration. When more advanced tuning is required (i.e. long wirelines having a limited bandwidth) the manual mode can be activated.

In Automatic mode the uphole discriminators are set automatically to detect the pulse strings.
The position of the discriminator levels are visible on the Scope and Analysis views and are represented by two red dashed lines – one for the positive pulses and the other for the negative pulses.
The “A” letter on the red square means that the discriminators are set in automatic mode.
The **Scale knob** controls the scale for the Analysis and Scope displays.

<u>*Position of the discriminator lines should be set as illustrated below.*</u>



When the automatic mode is unchecked user has the option to adjust manually the uphole discriminators using either the discriminator knob or by moving interactively the red dashed lines in the Analysis and Scope displays. The red triangles located at the extremities of the red dashed lines refer to manual mode. For fine tuning of the discriminators the **Fine resolution** can be chosen.



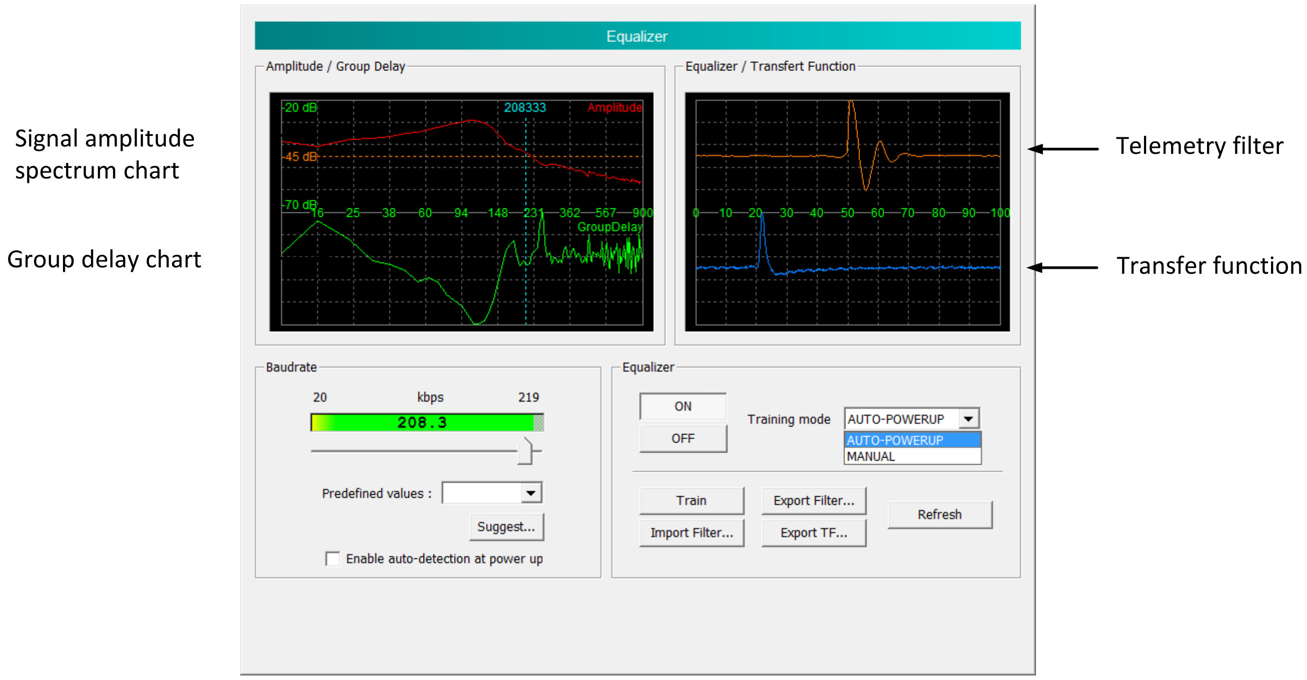
The **Downhole Pulse knob** controls the width of the pulse commands sent to the tool. It is set on 50 as a default value. This value is the preferred one and is suitable for a wide range of wirelines. For long wireline increasing the pulse width could help to stabilize the communication. The reverse for short wireline.

The **Baudrate** is generally set to the maximum value for which the communication status stays valid in order to optimize the logging speed for the wireline configuration.
The baudrate can be adjusted by moving the cursor below the baudrate bar meter or by selecting a predefined baudrate value from the select box.

When clicking the **Suggest** button the system is searching for the optimum baudrate value and keeps this value for the data transmission.

The **Enable auto-detection at power-up** configures the system such a way that the baudrate is reset to its optimum value each time a tool is powered up.

Applying the Equalizer



The **Equalizer** dialog provides some advanced telemetry settings described hereafter.

- The **Train** button computes the transfer function of a wireline - refer to the blue signal.
  When clicking on Train the tool sends a pilot pulse frame to the surface. The received signal at the surface is compared with the original pilot pulse frame to measure the distortion of the signal through the wireline. The result of this process is the definition of a transfer function specific to the wireline used.

  A filter is then derived from the transfer function - refer to the orange signal. The filter will be applied on the telemetry signal to counteract the distortion of the pulse strings through the wireline.
  Applying the filter will thus improve the telemetry performance of the system and logging speed on wirelines with unfavorable band width.

- The **Equalizer ON/OFF** buttons enables or disables the filter. The activation of the equalizer can be configured to **MANUAL** mode or to **AUTO-POWERUP**.

The AUTO-POWERUP feature applies the telemetry filter upon tool power-up.

- The **Export TF** option exports the **Transfer Function** defined by the wireline training process in a ASCII file format
- The **Export Filter** option exports the **Filter** derived from the transfer function in a ASCII format
- The **Import Filter** option loads a saved filter configuration
- The **refresh** button is refreshing the Equalizer/transfer function display

The **Amplitude/Group Delay** charts are mostly used by ALT developers for telemetry signal and performance analysis.

The Equalizer dialog repeats the **Baudrate** settings already discussed in the previous paragraph “Adjusting telemetry settings”.

8.2 Parts list

8.2.1 Spare parts

Item No.	Qty	Part No.	Description
1	1	1673840	Molykote 111 compound
2	2	55459	DIN1810B 40-42 Hook wrench w.pin
3	6	AS215-V-75	O-ring Viton 51414 26.57X3.53 -75°
4	1	L0034-086	Grease Lubriplate

8.2.2 Other parts

Item No.	Part No.	Description
1	QL40GO1	QL40-GO1 tool top
2	QL40GO4	QL40-GO4 tool top
3	QL40GO7	QL40-GO7 tool top
4	QL40MS1	QL40-MSI tool top
5	QL40BOT	QL40 bottom plug

8.3 Technical drawings

The following technical drawings are available on request:

- 19” Rack connection diagram.
- QL40-SGR Wiring Diagram

Index

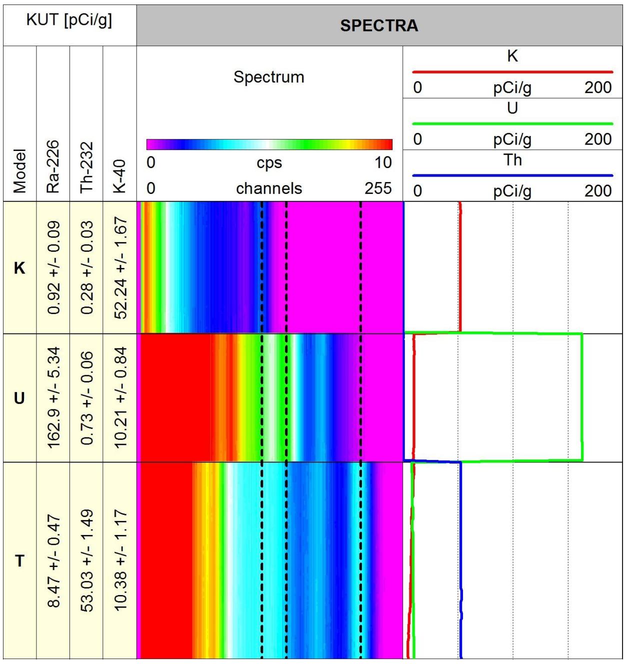
QL40 SGR Spectral Gamma Ray probe

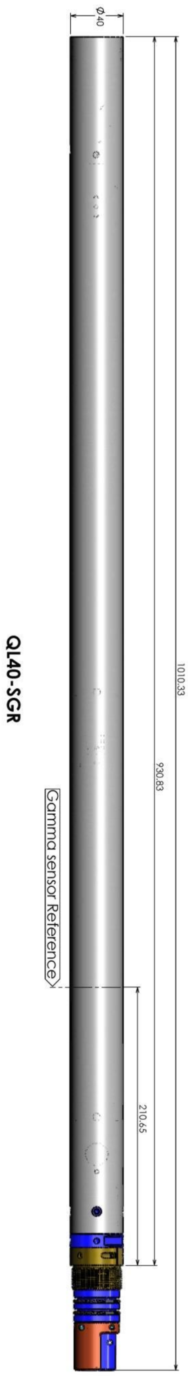
The QL40 SGR spectral gamma tool provide insight into the mineral composition of formations. It analyses the energy of spectrum of gamma radiation from naturally occurring isotopes in the formation surrounding a borehole. The tool is offered with several sensors options depending on the field application.

The QL40-SGR is supplied as an inline sub. It can be combined with other logging tools of the QL40 (Quick Link) product line or can be operated as a standalone tool. It is compatible with Matrix, BBOX and ALTlogger acquisition systems.

Application

- mineral detection
- recognition of radioactive material
- detailed well to well correlation
- lithology characterization
- sedimentology (definition of facies and depositional environment)
- contamination studies.





Advanced Logic Technology

MOUNT SOPRIS INSTRUMENTS

QL40 SGR Spectral Gamma Ray probe

Principle of measurement

The QL40 SGR spectral gamma tool analyses the energy of spectrum of gamma radiation from Unlike a total count gamma –ray probe, the spectral gamma-ray probe measures the energy of each gamma ray detected. K, U, and Th emit gamma rays with characteristics energies, so estimates of the concentrations of the three radioelements can be bmade.

Measurements / Features

· 256 channels spectrum
· spectrum stabilized (software)
· Nuclides concentrations
· Window gamma counts
· Total gamma counts

Operating Conditions

· Open or cased hole
· Water filled or dry borehole
· Compatible with Matrix, Bbox and ALTLogger 3 systems
· Can be combined with other QL Subs

Technical Specifications

Tool

· Diameter : 40 mm (1.6")
· Length : 0.93 m (36.6")
· Weight : 6 kg (13.2 lbs)
· Operating Temp. : 0-70°c (32-158 F)
· Max. Pressure : 200 bar (2900 psi)

Measurement point

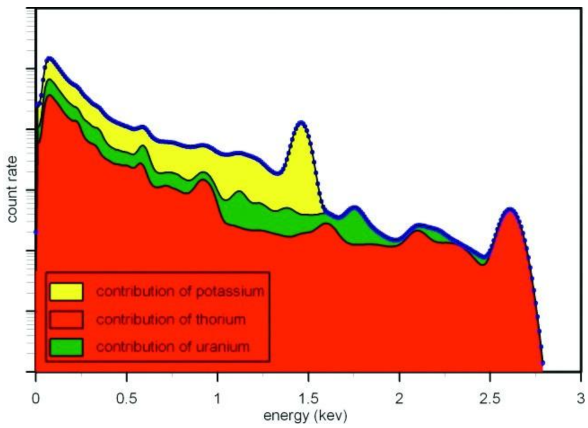
0.21 m (8.3") from bottom

Measurement range

up to 3000 kev

Sensors

· Scintillation NaI(Ti) crystal : 1"x4"
· BGO crystal : 1"x4"



MOUNT SOPRIS INSTRUMENTS
Mount Sopris Instrument Co. Inc. | 4975 E. 41 st Ave. Denver | C0 80216 | USA | Ph. 303 279 3211 | www.mountsopris.com
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36th Floor, Menara Maxis | Kuala Lumpur City Centre | 50088 Kuala Lumpur | Malaysia | Tel. +60 3 2615 7261 | www.alt.lu

Downhole Fluid Sampling

COLOG utilizes a 1.5-inch diameter downhole discrete-point fluid sampler manufactured by MLS. After flow zones have been identified by flow logging (Hydrophysics, Heat Pulse, Corehole Dynamic Flowmeter or Spinner Flow Meter tests) discrete-point sampling is conducted at selected intervals. The samples are procured just above each identified producing zone to insure complete mixing of the inflowing formation waters fluid moving up the fluid column towards the pump (pump is typically placed inside blank casing). The samples are procured by sending the closed, sealed sampler down to a given depth. By sending a specific voltage down the wireline the sampler ports open up and expose a 1 or 2 liter barrel to the wellbore fluids. Once the sample barrel is filled, the ports are closed and the sealed sample barrel is brought to the surface for decanting. Between each procured sample, the sampler tool is thoroughly cleaned with a solution of deionized water and Alconox or Liquinox soap and rinsed with deionized water. The disassembled sampler is then left to air dry or swab-dried before being reassembled.

Using the results from laboratory analysis of each sample procured in the field, the pore water or actual contaminant concentration may be estimated for each sampled inflow point using the mass-balance equation where:

$$C_o = \frac{\sum q_i C_{i\ actual}}{\sum q_i}$$

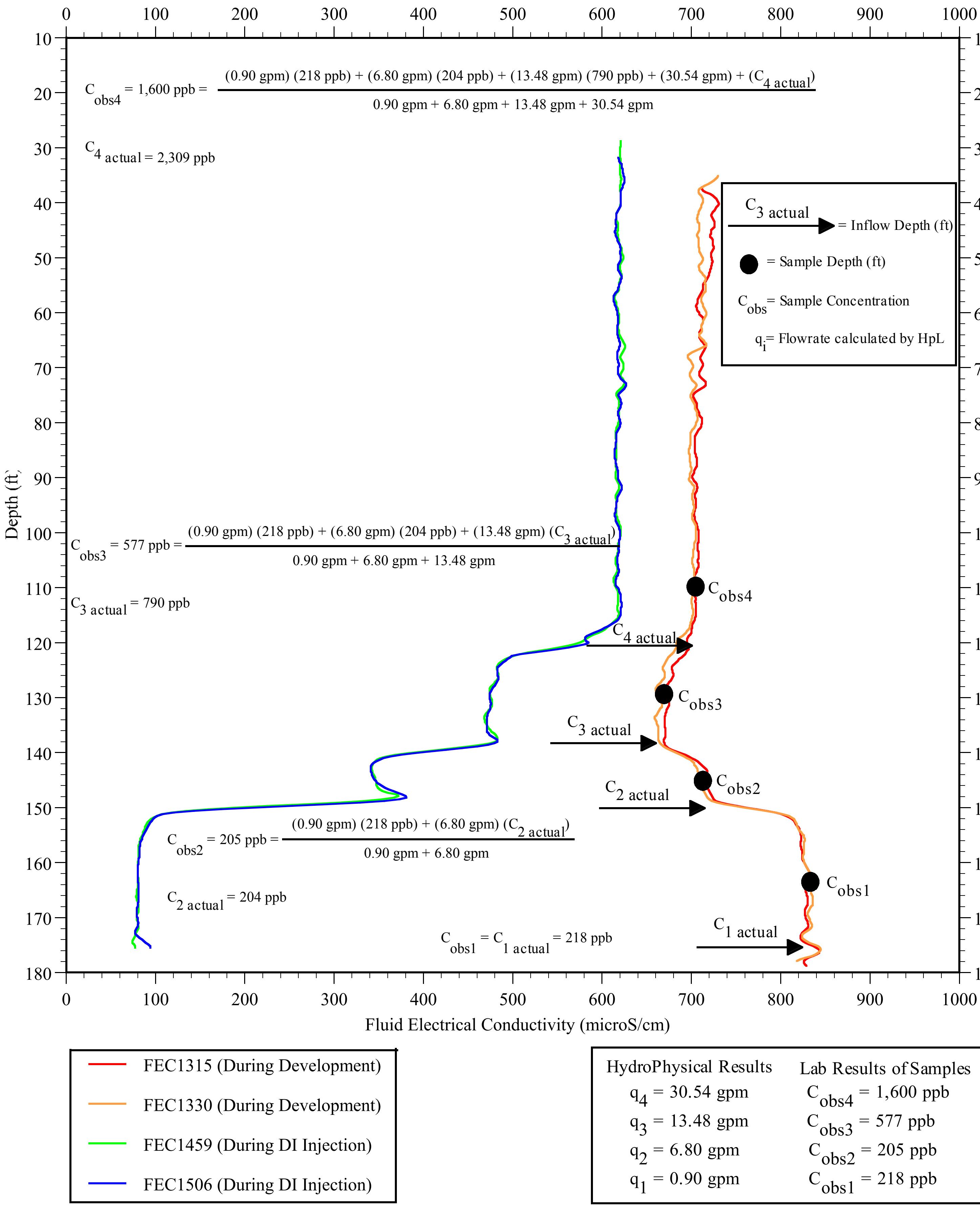
C_o = Contaminant concentration of procured sample at a given depth as reported by laboratory analysis.

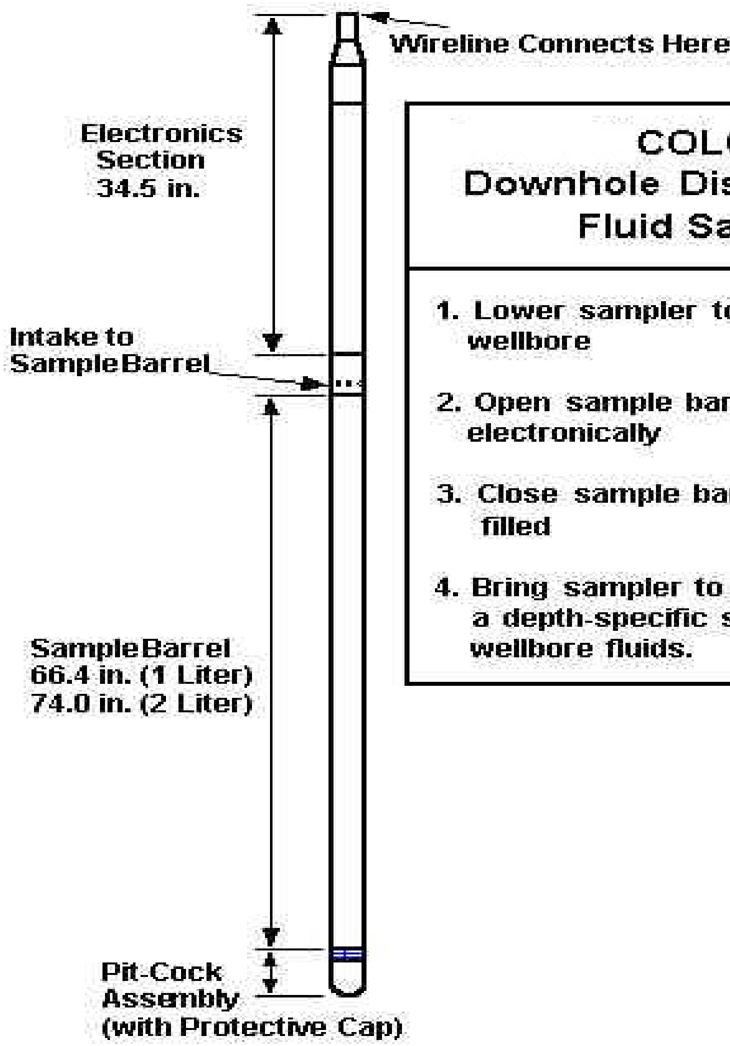
q_i = Interval specific inflow rate for each hydraulically conductive interval beneath the sample location as determined by code BORE.

$C_{i\ actual}$ = Estimated actual contaminant concentration associated with the sampled interval(s).

The accuracy of the results obtained using the Mass-Balance equation is affected by the inputs into the equation and their variability. For example, “error bars” or a range of estimations from the laboratory analysis of the samples or q_i estimations would be magnified in their magnitude as a result of the Mass-Balance equation.

FIGURE 1. EXAMPLE OF MASS BALANCE CALCULATIONS OF ACTUAL INTERVAL-SPECIFIC CONTAMINANT CONCENTRATIONS USING THE RESULTS FROM THE HYDROPHYSICAL TESTING AND LABORATORY ANALYSIS OF DOWNHOLE SAMPLES.





COLOG Downhole Discrete-Point Fluid Sampler

1. Lower sampler to specific depth in wellbore
2. Open sample barrel intake electronically
3. Close sample barrel intake when filled
4. Bring sampler to the surface for a depth-specific sample of the wellbore fluids.

borehole geophysics / hydrophysics

Technical Procedure and Work Instructions for

Optical Televiewer (OBI or BIPS)

TP-2

Prepared by: David A. Renner Date: 7/6/15

Approved by: Nathan O. Davis Date: 7/6/15

CONTROL DOCUMENT No. TP2090407

Colog, Inc. Technical Procedure TP- 2

Revision History

Revision Level	Issue Date	Change Summary
0.00	4/22/97	New procedure, issued as TP-14.
1.00	7/31/97	Changes to original draft, renamed to TP-2.
1.10	3/12/98	Minor grammatical changes, added copyright protection.
1.20	6/21/99	Included revisions to incorporate the purchase of COLOG, Inc. by Layne GeoSciences, Inc.
1.21	2/3/00	Include revisions for name change Layne GeoSciences, Inc. to Layne Christensen Company
1.22	9/5/07	Include / update procedure to include OBI
1.30	7/6/15	Included revisions to incorporate the sale of the COLOG division of Layne Christensen Company to Colog, Inc.

Table of Contents

1.0 SCOPE

1.1 Purpose

1.1.1 This procedure provides instructions for performing BIPS measurements to assure the accuracy, validity, and applicability of the methods used.

1.1.2 This procedure further describes the components of BIPS logging, the principles and limits of the methods used, the methods used for calibration and performance verification of the equipment, and the requirements for data acceptance and for documentation.

1.1.3 This procedure includes by reference those sections of TP-1 which are common to all measurements.

1.1.4 In applying this procedure to the BIPS measurement, the requirements of this procedure shall supersede those stipulated in TP-1.

1.2 Applicability

1.2.1 This procedure applies to all personnel who perform work referred to in paragraph 1.1.).

1.2.2 This procedure applies to video image data acquisition using the Borehole Image Processing System (RaaX Model BPR-551).

1.2.3 All data derived from this procedure, and any equipment calibrations or recalibrations that may be required shall be in accordance with this technical procedure. Deviation from these procedures shall be permitted only under the conditions set forth in Section 6.3 of TP-1.

2.0 REFERENCES

2.1 Keys, W. Scott, and MacCary, L.M., Application of Borehole Geophysics to Water-Resources Investigations: USGS, Techniques of Water-Resources Investigations, Book 2, Chapter E1.

2.2 Hearst, J.R., and Nelson, P.H., Well Logging for Physical Properties, McGraw Hill, 1985.

2.3 Standard Guide for Planning and Conducting Borehole Geophysical Logging, ASTM Designation D 5753-95, October, 1995.

2.4 SPWLA Reprint Series, BOREHOLE IMAGING, 1990

2.5 RaaX, Co., Ltd., BIP-300 Field Subsystem Operation Manual

2.6 RaaX, Co., Ltd., Analyzing Subsystem Operation Manual

3.0 DEFINITIONS

Definitions shall be in accordance with ASTM D 5753-95. In addition, definitions common to all logging procedures are provided in TP-1.

3.1 BIPS downhole probe

The BIPS (Borehole Image Processing System) consists of a downhole probe containing a light source, a video camera, and focusing equipment which acquires and transmits a video image of the borehole wall to surface processing and recording equipment. (Appendix 1).

3.2 Surface recording equipment

The surface recording equipment mounted in the logging truck provides DC power to the probe, which is otherwise entirely self-contained and runs independently of the surface system. The surface electronics receives and displays the video signal and orienting pulses and processes them for digital data acquisition and display.

3.3 Fluxgate magnetometer orientation

The downhole probe contains a fluxgate magnetometer which provides an orienting pulse at a known azimuth with respect to magnetic north, and a reference mark for use in magnetically active materials. A mechanical compass, mounted at the center of the conical mirror, should not be used in a quantitative manner.

3.4 Raw signal

The raw signal is identical to the unprocessed video signal transmitted up the cable, with a superimposed radial line which serves as an orientation mark. The orientation mark is either the azimuth of an arbitrary reference within the downhole probe or at a fixed orientation relative to the magnetometer orientation. The signal looks like a disk and contains an image of a compass at its center which does not provide a quantitative orientation but is provided for qualitative assessment of tool function. A raw image is shown in Appendix 7.2.

3.5 Processed signal

The processed signal is obtained by extracting a circular scan from the raw signal using a user-selectable radius. This signal is re-displayed and stored so as to provide an image for interpretation which represents the borehole as a rectangular image with the left-hand margin aligned with magnetic North determined by the fluxgate magnetometer. Vertical position in the borehole varies along the “y axis” of the image, and orientation varies along the “x axis”. An example is shown in Appendix 7.3.

3.6 Personnel

Personnel are as defined in TP-1.

3.7 Colog, Inc.

Colog, Inc. located in Lakewood, CO, provides BIPS services.

4.0 REQUIREMENTS

4.1 Prerequisites

In addition to the prerequisites stipulated in TP-1:

4.1.1 The borehole shall be either dry and air-filled or filled with optically clear fluid. If necessary, the borehole fluid shall be replaced by optically clear fluid prior to logging. The choice of fluids is not quality affecting, provided that the replacement fluid is optically clear and colorless. The method shall be approved by the project geochemist.

4.1.2 The borehole wall shall not be obscured by mud cake or optically opaque materials.

4.1.3 The borehole shall be clear of restrictions which prevent entry of the tool (including centralizers).

4.2 Tools, Material, Equipment

The RaaX Borehole Image Processing System is an oriented digital video system. It visualizes the borehole wall with an axial view camera lens looking down upon a special conical mirror and includes a light source to illuminate the well bore. The data is transmitted from the probe to the surface on a coaxial wireline as a raw NTSC video image. This image is displayed on a monitor in the logging truck. Appendix 7.2 shows a typical raw image. The raw NTSC video signal (raw signal) is stored on VHS video tape during logging.

To produce a digital image of the well bore which is undistorted, a circular disk with a user-selected radius and centralization is extracted from the raw NTSC video image every 0.5 mm vertically along the well. This disk is sampled 360 times around its circumference to produce RGB values at each point. The resulting data is stacked vertically to produce an image of the well as if it were sliced along magnetic South and laid flat. This digital image is displayed on a second monitor, and the individual traces are also stored on magneto-optical disk.

The raw signal recorded on videotape can be played back and reprocessed where regeneration of the digital data is needed or required.

4.2.1 Colog, Inc. utilizes a BIPS probe Model BPR-551 manufactured by RaaX Company, Ltd.

4.2.2 The BIPS shall be run on a coaxial logging cable.

4.2.3 Recording Equipment: The raw NTSC image shall be recorded during data acquisition. If desired, the processed video image may also be recorded (in real time), however, it is generally recorded from a playback of the digital data to avoid pauses created when the probe is stopped.

The processed data is recorded on magneto-optical disks in the field then transferred to a personal computer to be processed with RaaX's BIP Analysis Software. The final data is then transferred to CD-ROM for archiving. The raw NTSC video may later be replayed and redigitized using the same type of processing and recording unit.

4.2.4 Portable aluminum cradle or down hole tool stand to facilitate assembly and breakdown of the probe.

4.2.5 Sprayer and a clean water supply to clean drilling fluid from tool after use.

4.2.6 BIPS centralizers

4.2.7 Calibration Apparatus (Appendix 7.4)

The calibration apparatus consists of a cylinder large enough for the BIPS probe to fit inside. The cylinder shall be fitted with a cap on the top with a hole just large enough for the probe to pass through. This cap is designed to restrict outside light from entering the tube and creating glare on the inner surface of the tube. Inside the cylinder is a removable color palette with eight color bars (including black and white) covering the full circumference of the tube. The color palette also includes three charts from the "Munsell" soil color reference guide. The color bars are aligned axially with the tube along with two reference lines annotated "N" and "S" with which to orient the tube to magnetic North. A thin black reference line inside the tube is aligned with the "North" reference line on the color palette.

4.2.8 Brunton compass or equivalent for orientation of calibration tube.

4.2.9 Data information, calibration sheets, and operating procedures.

4.2.10 Reference calibration image, for comparison to the image(s) recorded in the field. This image shall be a processed image played back on a standard printer using standard software and settings.

4.2.11 The BIPS probe shall be calibrated for the following purposes:

1) To verify system operation in terms of image color, clarity and stability.

2) To verify (and re-orient if necessary) the stability of the digital compass used to provide image orientation.

3) To provide a color reference to aid in analysis of the wellbore image.

4.2.12 Pre-log Calibration Procedure

Calibration of the digital compass shall be performed under controlled conditions in a laboratory when calibration checks indicate a problem or after probe repair.

During pre-log calibration, the digital compass may be adjusted (if necessary) to align with the reference lines of the calibration tube oriented with a Brunton compass to magnetic North and South. After that time, and until the post-log calibration check is completed, no further adjustment of the digital compass shall be made.

Calibrations shall be performed before leaving the home office for the logging location.

In the field, the probe shall be calibrated prior to logging and the calibration shall be checked following logging every borehole.

4.2.12.1 Set up the calibration apparatus with a minimum of two feet lateral clearance from any magnetic objects as shown in Appendix 7.4. Use a Brunton compass to orient the North and South reference lines in the calibration tube to magnetic North and South.

4.2.12.2 Attach the BIPS tool to the cable.

4.2.12.3 Hang the tool vertically in the calibration tube with the recording window just inside the light restricting cover. Be sure to attach the temporary (rubber or plastic) centralizer to the bottom of the probe prior to hanging it in the tube (see Appendix 7.4). The calibration tube shall be dry and air-filled.

4.2.12.4 Attach the probe to the downhole cable and connect the cable to the surface recording equipment. Open the "centering" window in the acquisition program and turn power on to the probe. Set all of the video adjustment knobs on the dual monitors to the neutral position. Monitor power settings and the raw signal on the color monitor to ensure correct operation.

4.2.12.5 Set up the BIPS acquisition system to record a data file as described in Reference 2.5.

4.2.12.6 Set logging depth to zero.

4.2.12.7 Record the calibration.

Start recording a data file, but prior to moving the tool down into the calibration tube, adjust the digital magnetometer needle to align with the black reference line oriented to magnetic North. Use the winch to begin lowering the probe in a downward direction past the color palette at approximately 1 m/min (***Note:*** The "Logging Too Fast" warning will come on if the speed exceeds the maximum allowed for the processing unit).

The digital data shall be recorded on magneto optical disc, while the raw NTSC video signal shall be recorded on video tape.

Acquire data over the length of the calibration image.

4.2.12.8 Check proper image orientation, color, and resolution on the processed image displayed on the color monitor.

4.2.12.9 Compare the processed image to the reference calibration image (Appendix 7.5).

4.2.12.10 Make adjustments to match the reference image if necessary.

4.2.13 Calibration Check Procedure

A calibration check is identical to a calibration except that no adjustment of the tool shall be made. The purpose of the calibration check is to verify that no change in system performance has occurred during logging.

4.2.14 Calibration Records

Calibration data shall be recorded on the form specified for both the pre-log calibration and the post-log check. These shall be performed prior to and at the completion of “continuous” logging operations for a particular well. The calibration forms shall include the probe identification number, well location, date and time calibration was performed, person executing calibration procedure, and any pertinent observations.

Calibration and calibration check data shall be recorded as raw data on videotape and as processed data on optical disc.

4.3 <u>Precautions and Limits</u>

4.3.1 The BIPS log shall be recorded in an uncased hole unless the condition of casing is to be investigated. When logging in casing, steel casing may necessitate turning off the automatic digital compass resulting in non-oriented images.

4.3.2 The quality of the image depends on the optical properties of the fluid in the borehole and the condition of the borehole wall.

4.3.3 The image is interpreted as if the probe is perfectly centralized. If the tool is eccentered, the geometry of the observed features will be distorted.

4.3.4 During analysis, the probe axis is assumed to be aligned with the axis of the borehole.

4.3.5 The maximum length of cable on which the probe can be run is 5000 ft.

4.3.6 The operational temperature and pressure limits for the BIPS system provided by the manufacturer should be adhered to while running the log. The maximum operating pressure is approximately 2400 PSI (165 bars). The practical operational temperature range is from 0 to 46°C (32 to 140°F).

4.3.7 The recommended minimum borehole diameter is 60 mm (2.36”). The recommended maximum diameter is 230 mm (9.0”). In ideal circumstances, BPR-551 can be run successfully in holes as large as 16”.

4.3.8 Washout zones will affect the resolution of the photographic image if the zones extend beyond 230 mm (9.0”).

4.3.9 Bridges or constrictions in the borehole diameter will make it impossible to lower the probe into the borehole and difficult to retrieve the probe.

4.3.10 The magnetometer is approximately 3 feet above the image measurement point. Thus, if the borehole is cased with magnetically active material, the uppermost approximately 4 feet of image immediately below casing will be more difficult to orient.

4.3.11 The log is generally recorded with the tool moving down the borehole in order to acquire data in the undisturbed fluid column. However, data may be recorded in the opposite direction as well.

4.4 Acceptance Criteria

This log shall be accepted for use based on the expectation that the results will be interpreted quantitatively.

The following acceptance criteria shall be evaluated using the digital data recorded on magneto-optical disk.

4.4.1 The orientation of the pre- and post-logging calibration images shall be within 5°.

4.4.2 The orientation of features on the repeat section shall be within 5° of their orientation recorded during the main logging run.

4.4.3 The pre-log calibration shall result in an acceptable level of color matching and resolution to the reference image.

4.4.4 The post-log calibration check shall result in an acceptable level of similarity of the color and resolution to that of the pre-log calibration.

4.4.5 The image quality of the digitized data shall be evaluated by the Logging Engineer for resolution.

4.4.6 The orientations and characteristics of features observed in the repeat log shall be similar to those observed in the main log. However, it should be kept in mind that the quality of the repeat log may be degraded due to loss of fluid clarity caused by the initial log.

4.4.7 After Survey Depth Error (A.S.D.E.) shall be within required tolerances.

4.4.8 The processed image should be compared by the on-site geologist to core from the well or from a nearby core hole, if available, to establish if an adequate level of resolution of color variations and other features is present in the log images.

5.0 DETAILED PROCEDURE

The processed BIPS image shows the borehole wall as if it were split vertically and laid flat. Vertical fractures appear as vertical straight lines, while bedding and fractures dipping between vertical and near horizontal appear as sinusoidal traces.

The vertical distance between digitized video scans is typically 0.5 mm. The angular distance subtended by each color value is (360°/number of points).

The BIPS images can be used:

- To evaluate the stratigraphic, structural, diagenetic, weathering, textural and mineralogical features detectable in the borehole wall.
- To locate and orient fractures and bedding planes to aid in the analysis and interpretation of in situ physical and hydrologic properties.
- To perform direct comparison between BIPS log and recovered core from the same well.
- To locate and orient any stress-induced wellbore failure (breakouts) for determination of the orientation and magnitude of in situ stresses.
- To locate and orient any drilling induced hydraulic and other tensile fractures for determination of the orientation and magnitude of in situ stresses.

BIPS logs are typically run as one of a suite of logs during a single visit to a well site. Procedures prior to and upon arrival as described here pertain only to the specific requirements of the BIPS. Where they do not conflict with the procedures detailed here, all of the procedures specified in TP-1 shall also be adhered to.

5.1 Prior to arrival

In addition to those procedures detailed in TP-1.

5.1.1 Select the appropriate centralizers for use in the well.

5.1.2 Assure that the logging truck has a coaxial cable of sufficient length to perform the log.

5.2 On arrival

No added procedures are necessary beyond those detailed in TP-1.

5.3 While Logging

Throughout the logging process, two sets of data shall be obtained. The first is a raw videotape of the data provided by the logging probe. The second is digital files recorded on magneto-optical disk of the digital data.

5.3.1 The BIPS shall be run centralized in the borehole. Adjust the probe centralizer for optimal centralization in the interval to be logged.

5.3.2 Visually inspect all joints on the BIPS to be sure they are tight, and check the clear lens to verify that it is free of scratches.

5.3.3 Prepare optical disk media for data storage.

5.3.4 Perform a pre-log calibration.

5.3.5 Set the software depth counter to read zero when probe measuring point is depth referenced to the measurement datum (land surface, top of casing, etc.). The depth zero should be taken with tension on the wireline similar to that expected while logging, to prevent slack in the cable from biasing the datum.

5.3.6 Lower the probe to the top of the interval to be logged.

5.3.7 Begin logging at approximately 0.7 meters per minute to the bottom of the hole (or interval to logged). The raw signal shall be recorded on video tape, while the digital data shall be recorded on magneto-optical disc. Probe operation is verified by observing the raw and projected (2D) video images on dual monitors.

5.3.8 Even if the logged interval extends to the bottom of magnetically active casing, no attempt shall be made to adjust the magnetometer orientation during the logging of the complete interval. If it is desired to obtain a more stable image in this section of the hole, a repeat log shall be obtained for this purpose.

5.3.9 If logging needs to be stopped for any reason a brief overlap interval should be recorded, to ensure that no data are missed.

5.3.10 After completion of the log, a minimum 50 ft repeat section of the hole shall be logged with the tool moving downward at a rate of 0.7 m/min. Proper tool operation is verified by monitoring the video images on the dual monitor.

5.3.11 After completion of logging and acceptance of the logged data, a VHS copy of the projected image shall be recorded by playing back the digital data. This videotape shall be labeled as to well, logged interval, date, etc.

5.3.12 Unless otherwise noted all azimuth orientation data shall be recorded on magnetic north orientation. Field plots unless otherwise noted shall be based upon magnetic north.

5.3.13 Determine after survey depth error.

5.3.14 Record a Post-log calibration check.

5.4 Prior to departure

In addition to the requirements of TP-1:

5.4.1 Immediately after logging the well, the digital data recorded on magneto optical disk during the log (see 5.3) shall be replayed and an oriented 2D video image shall be generated, monitored, and recorded on VHS tape. This video image is necessary to verify that the digital data recorded on optical disc is valid.

6.0 RECORDS

Records shall be provided as detailed in TP-1. In addition the following records shall be provided:

6.1 Completed "BIPS BPR-551 Checkout/Calibration" Forms (Appendix 7.5).

6.2 Observer's logs (or records) of all pertinent information, including data, time, recording parameters, borehole data, water level casing information, unusual conditions, etc.

6.3 The VHS videotape (5.4.1) containing the 2D oriented image.

6.4 Color paper copies of all of the requested BIPS images (see 5.5.2).

6.5 Data Deliverables

The data provided by the BIPS system cannot be presented using the standard database software. However, the processed digital data may be provided on CD-Rom upon client's request.

7.0 APPENDICES

7.1 BIPS Tool Diagram.

7.2 Example Raw BIPS Image.

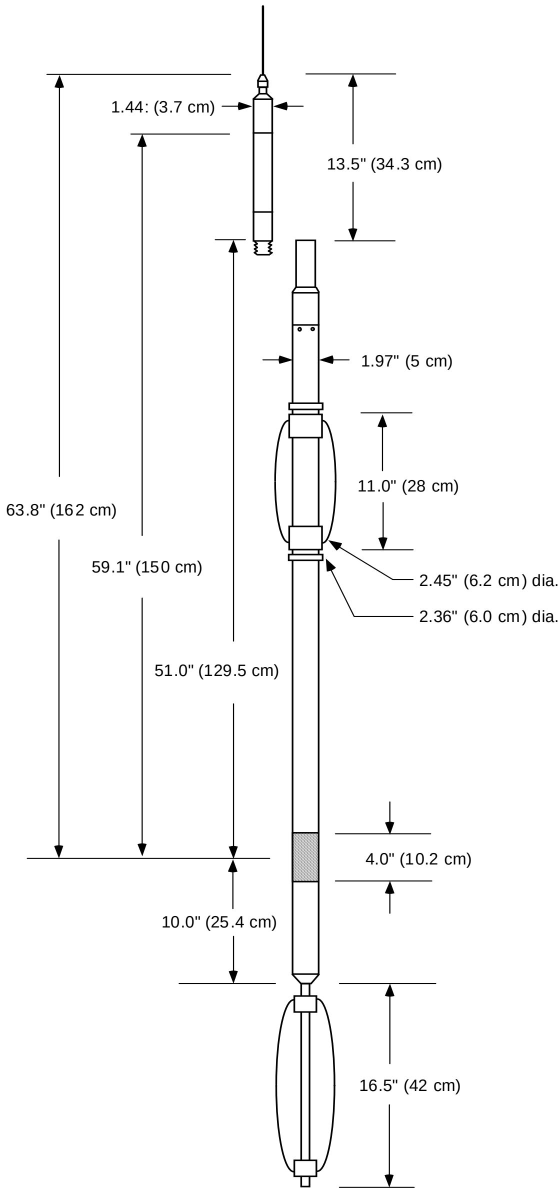
7.3 Example Processed BIPS Image.

7.4 Calibration Apparatus and Set-up

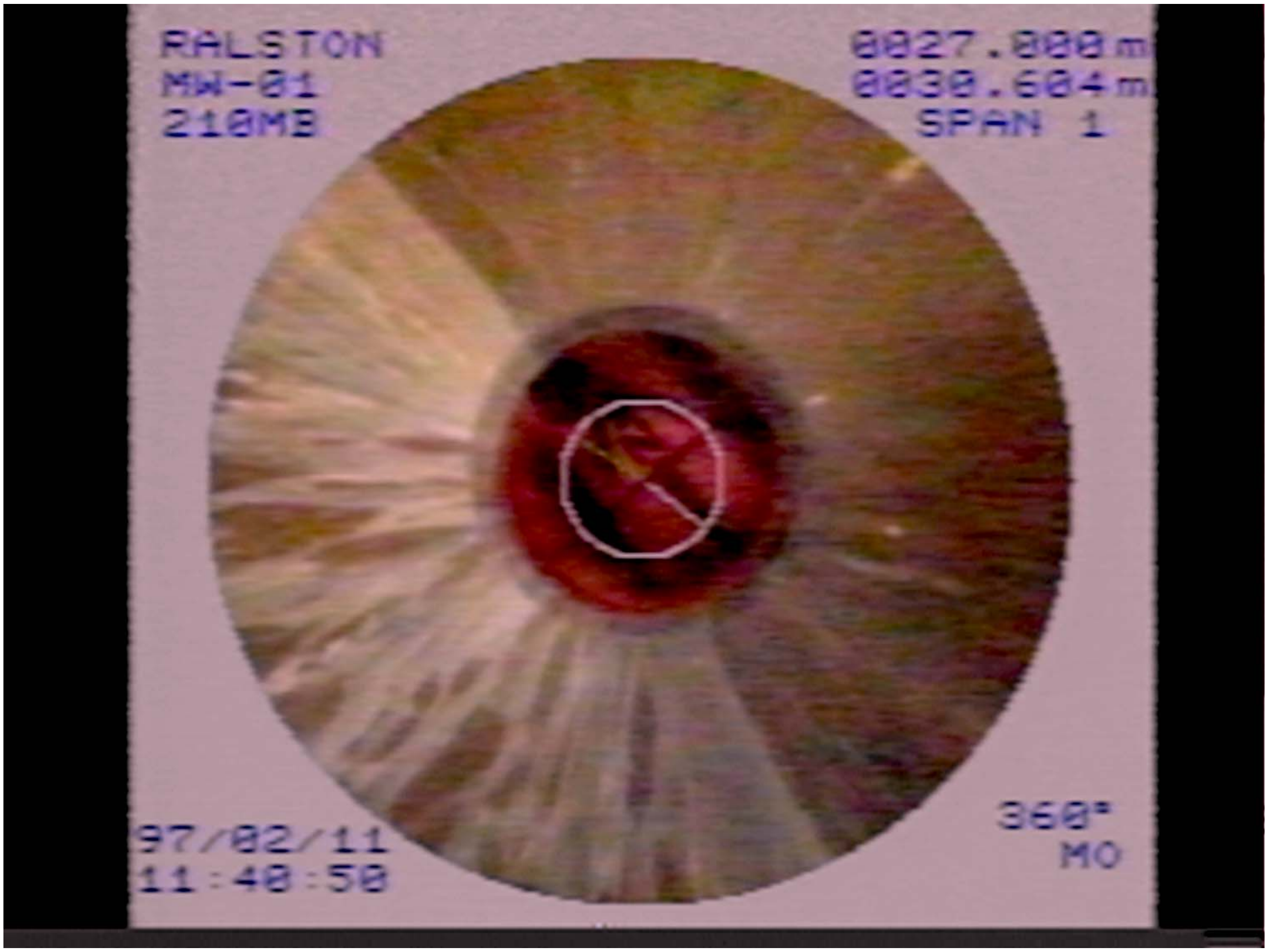
7.5 “BIPS BPR-551 Checkout/Calibration” Form.

Appendix 7.1

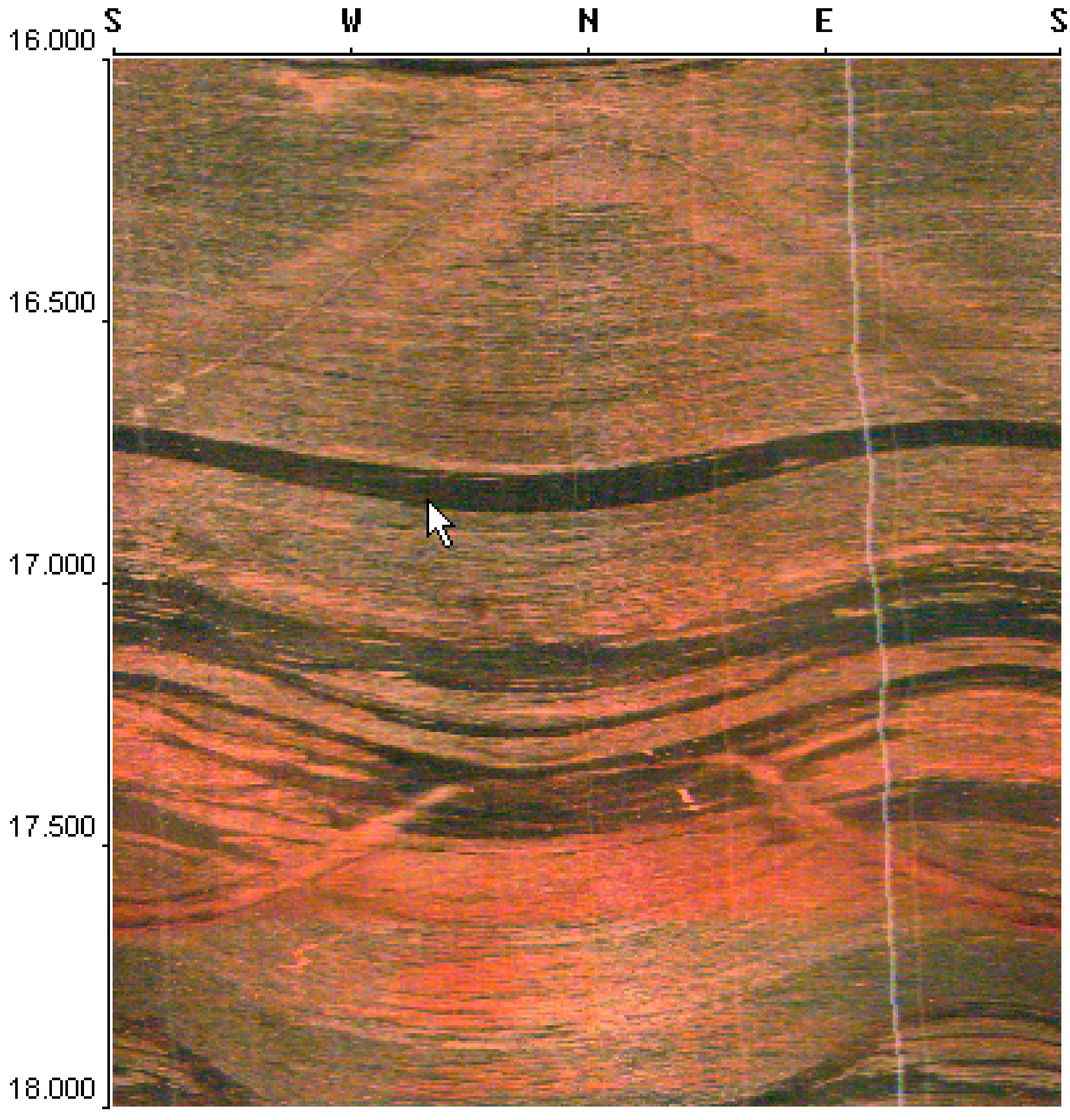
Borehole Image Processing System, Model: BPR-551



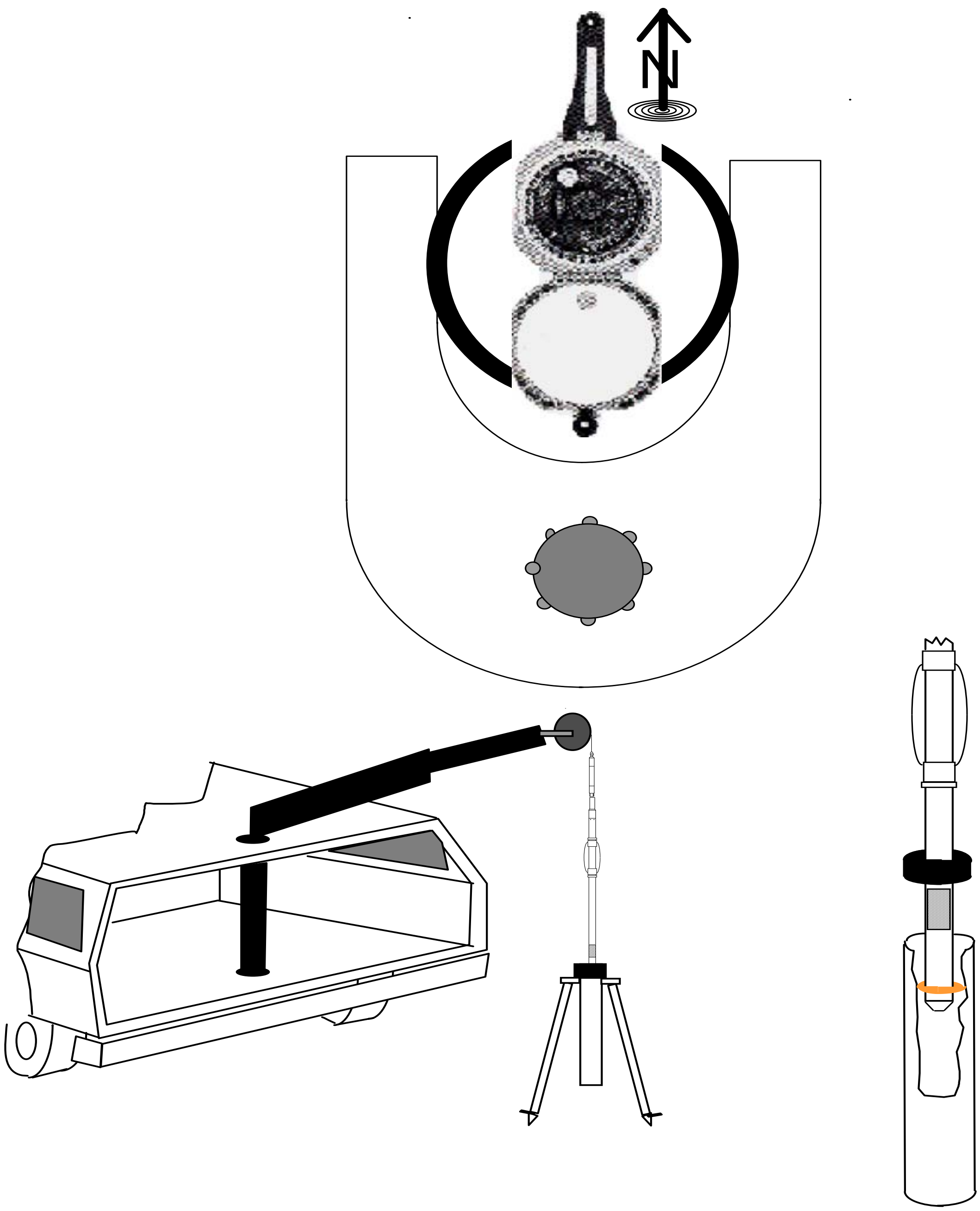
Appendix 7.2 Example Raw Image Recorded During a BIPS Log



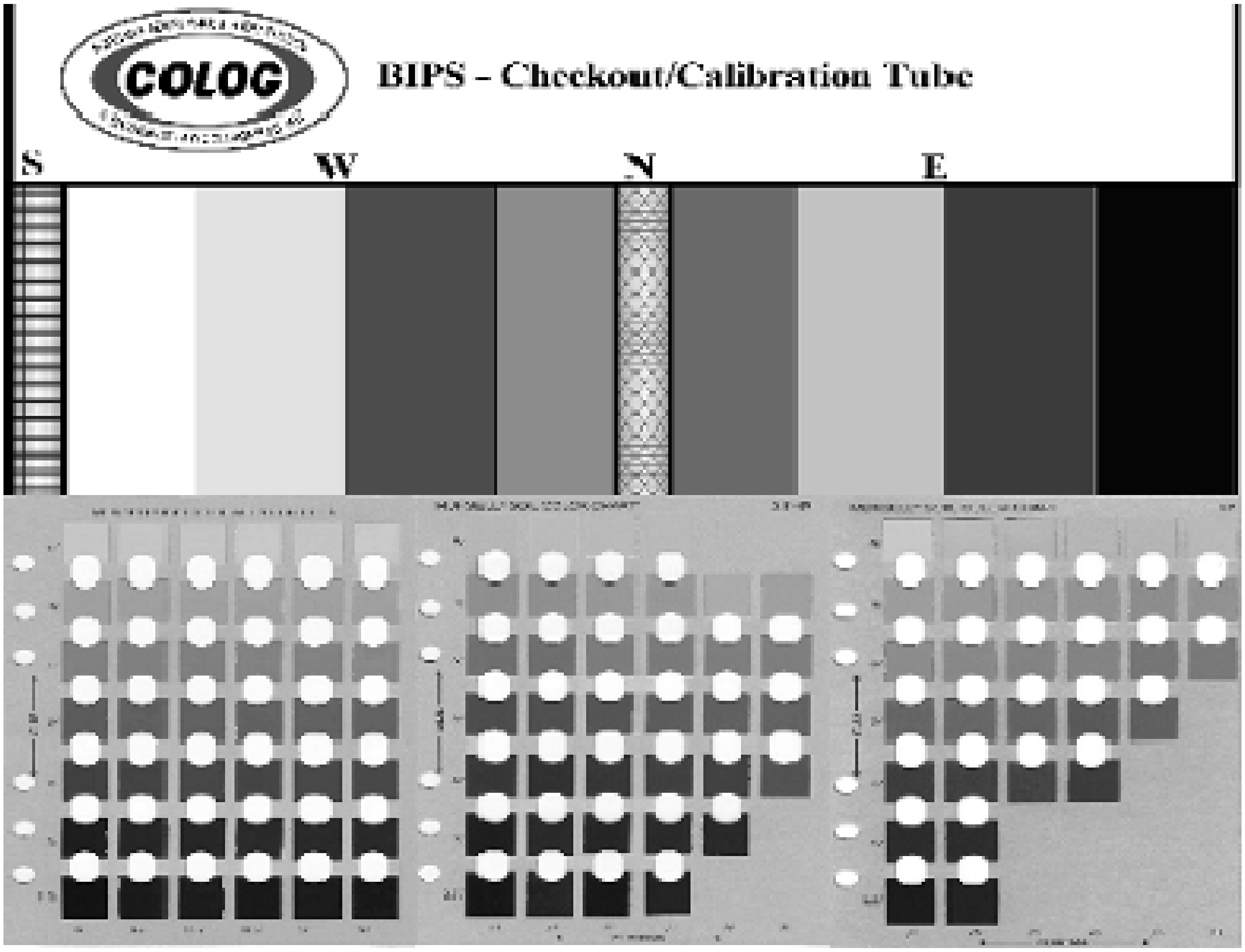
Appendix 7.3 Example Processed OBI / BIPS Image



Appendix 7.4 Calibration Apparatus and Set-up


N

Appendix 7.5 Reference Calibration Image



borehole geophysics / hydrophysics

Optical Televiewer Checkout/Calibration

Engineer:____________________ Location or Well Name:___________________ Truck/Unit No:___________

Probe Serial No:____________________

Pre-Log Calibration:

Date:_______________ Time:_______________

Calibration Filename:___________________

Post-Log Check:

Date:_______________ Time:_______________

Calibration Filename:___________________

Calibration Standards:

1.) Calibration Apparatus oriented to North and South, using a Brunton compass, set clear of metal objects.

Technical Procedure and Work Instructions for

FAC-40 Acoustic Televiewer

TP-3

Prepared by: David A. Renner Date: 7/6/15

Approved by: Nathan O. Davis Date: 7/6/15

CONTROL DOCUMENT No. TP3020300

Colog, Inc. Technical Procedure TP-3

Revision History

Revision Level	Issue Date	Change Summary
0.00	3/10/97	New procedure.
1.00	6/17/97	Changes to original draft.
1.10	7/9/97	Minor grammatical changes, clarification of records to be provided
1.11	3/12/98	Minor grammatical changes, added copyright protection.
1.20	6/21/99	Included revisions to incorporate the purchase of COLOG, Inc. by Layne GeoSciences, Inc.
1.21	2/3/00	Include revisions for name change Layne GeoSciences, Inc. to Layne Christensen Company
1.30	7/6/15	Included revisions to incorporate the sale of the COLOG division of Layne Christensen Company to Colog, Inc.

Table of Contents

1.0 SCOPE

1.1 Purpose

1.1.1 This procedure provides instructions for performing FAC-40 Acoustic Televiewer (ATV) measurements to assure the accuracy, validity, and applicability of the methods used.

1.1.2 This procedure further describes the components of FAC-40 logging, the principles and limits of the methods used, the methods used for calibration and performance verification of the equipment, and the requirements for data acceptance and for documentation.

1.1.3 This procedure includes by reference those sections of TP-1 which are common to all measurements.

1.1.4 In applying this procedure to the FAC-40 measurement, the requirements of this procedure shall supersede those stipulated in TP-1.

1.2 Applicability

1.2.1 This procedure applies to all personnel who perform work referred to in paragraph 1.1.

1.2.2 This procedure applies to ATV data acquisition using the FAC-40 Acoustic Televiewer.

1.2.3 All data derived from this procedure, and any equipment calibrations or re-calibrations that may be required shall be in accordance with this technical procedure. Deviation from these procedures shall be permitted only under the conditions set forth in Section 6.3 of TP-1.

2.0 REFERENCES

2.1 Keys, W. Scott, and MacCary, L.M., Application of Borehole Geophysics to Water-Resources Investigations: USGS, Techniques of Water-Resources Investigations, Book 2, Chapter E1.

2.2 Hearst, J.R., and Nelson, P.H., Well Logging for Physical Properties, McGraw Hill, 1985.

2.3 Standard Guide for Planning and Conducting Borehole Geophysical Logging, ASTM Designation D 5753-95, October, 1995.

2.4 SPWLA Reprint Series, Borehole Imaging, 1990.

2.5 COLOG, Inc. FAC-40 ATV Data Acquisition Procedures, 1997.

2.6 Rockware, Inc. ROSE™ and ROCKWORKS™/STEREO software instruction manuals, 1991.

2.7 Advanced Logic Technology (ALT), FAC-40, The New Slimhole Televiewer operations manual, 1996.

2.8 Advanced Logic Technology (ALT), WELLCAD for Windows software instruction manual, 1997.

3.0 DEFINITIONS

Definitions shall be in accordance with ASTM D 5753-95. In addition, definitions common to all logging procedures are provided in TP-1.

3.1 Facsimile 40 (FAC-40) downhole probe

The FAC-40 Acoustic Televiewer (ATV) utilizes a fixed transducer and a variable speed, rotating reflective surface which measures variations in the acoustic properties (Amplitude and Travel Time) of the borehole wall, and transmits the digital information uphole (Appendix 7.1).

3.2 Surface recording equipment

The surface panel mounted in the logging truck provides DC power to the probe, which is otherwise entirely self-contained and runs independently of the surface system. The computer receives the digital output from the probe along with orienting pulses and processes them for recording and real-time display.

3.3 3-axis magnetometer orientation

The downhole probe also contains a 3-axis magnetometer which provides an orienting pulse at a known azimuth with respect to magnetic North, and a reference mark for use in magnetically active materials.

3.4 Raw Data

Although the “real-time” display of the images on the computer screen can be oriented to magnetic North, the raw data from the probe are recorded in an “non-oriented” state. Orientation of the raw data is accomplished subsequent to the data acquisition during processing.

3.5 Processed Data

The processed data is obtained by importing the raw data into the processing software “WellCAD™”. During this process, the raw data is oriented to magnetic North using the various output vectors from the three-axis magnetometer, along with the known offset between the position of the magnetometer and the tool reference. The data can then be re-displayed and stored so as to provide an image for interpretation which represents the borehole as a rectangular image with the left-hand margin aligned with magnetic North determined by the 3-axis magnetometer. Vertical position in the borehole varies along the “y axis” of the image, and orientation varies along the “x axis”. An example is shown in Appendix 7.2.

3.6 Personnel

Personnel are as defined in TP-1.

3.7 Colog, Inc.

Colog, Inc. located in Lakewood, CO, is one of the leading providers of FAC-40 ATV services in the U.S.

4.0 <u>REQUIREMENTS</u>

4.1 <u>Prerequisites</u>

In addition to the prerequisites stipulated in TP-1:

4.1.1 The borehole shall be fluid-filled with either water or light mud. Heavier mud may diminish the amplitude of the acoustic signal particularly in larger holes.

4.1.2 The borehole shall be clear of restrictions which prevent entry of the tool (including centralizers).

4.2 <u>Tools, Material, Equipment</u>

The FAC-40 ATV provides oriented digital acoustic images of both the 1st arrival Amplitude as well as the Travel Time. It features a variable speed reflective surface, adjustable scan rate and automatic gain control for superior horizontal and vertical resolution in hole sizes ranging from 46 to 400 mm depending on mud conditions. The digital data is transmitted from the probe to the surface on the logging cable. The “real-time”amplitude and travel time images are displayed on a computer monitor in the logging truck (similar to Figure 7.2). The raw log data is stored on the computer’s hard disk until it is backed up onto a storage media.

The FAC-40 ATV collects oriented “rings” of data composed of either 72, 144 or 288 amplitude and travel time values in each ring depending on the sample rate selected (typically 144). The rings are then stacked vertically (typically every centimeter) to produce an image of the well as if it were sliced along magnetic North and laid flat. This digital image is displayed on the computer monitor, and the data values are recorded on the computer’s hard disk.

4.2.1 Colog, Inc. utilizes the FAC-40 ATV manufactured by Advanced Logic Technology (ALT) sarl of Luxembourg.

4.2.2 The FAC-40 may be run on either coaxial logging cable, or armored single or multi-conductor steel wireline.

4.2.3 Recording Equipment: The raw data shall be recorded on the acquisition computer’s hard drive.

The raw data recorded in the field may be processed using the “WellCAD™” software developed by ALT, sarl. Both the raw and processed data shall be archived on suitable storage media.

4.2.4 Tool stand to facilitate assembly and breakdown of the probe.

4.2.5 Sprayer and a clean water supply to clean drilling fluid from tool after use.

4.2.6 ATV centralizers.

4.2.7 Calibration Apparatus (Appendix 7.3)

The calibration apparatus consists of an aluminum cylinder large enough for the FAC-40 ATV probe to fit inside, enclosed on one end. A smaller diameter, half cylinder sleeve, fits inside the outer cylinder, resting in a circular groove cut into the base of the apparatus. The top of the sleeve is marked with “N” , “W” and “S” which are to be matched up with similar markings on the outer cylinder (see Appendix 7.3). A circular notch is cut into the center of the base which the probe will sit in during the calibration. two semi-circular caps, with notches cut for the probe, will hold the probe centered vertically inside the calibration apparatus.

4.2.8 Brunton compass or equivalent for orientation of calibration apparatus.

4.2.9 FAC-40 ATV calibration forms and operating procedures.

4.2.10 The FAC-40 probe shall be calibrated for the following purposes:

1) To verify (and re-orient if necessary) the stability of the 3-axis magnetometer used to provide image orientation.

2) To provide reference diameter standards with which to convert travel time values to acoustic caliper measurements.

4.2.11 Calibration Procedure

Calibration of the magnetometer shall be performed under controlled conditions in a laboratory when calibration checks indicate a problem or after probe repair.

Calibrations shall be performed before leaving the home office for the logging location.

In the field, the probe shall be calibrated prior to logging and the calibration shall be checked following logging every borehole.

4.2.11.1 Set up the calibration apparatus vertically with a minimum of two feet lateral clearance from any magnetic objects. Use a Brunton compass (or equivalent) to orient the North and South reference marks on the top of the calibration tube to magnetic North and South (ensure that the inner sleeve is aligned properly with the outer tube).

4.2.11.2 Attach the FAC-40 tool to the cable.

4.2.11.3 Fill the calibration apparatus with water (or sample fluid from the hole to be logged).

4.2.11.4 Place the tool vertically in the calibration apparatus and insert the caps to hold the probe centered.

4.2.11.5 Set up the “ALTLogger” acquisition program to record a data file as described in Reference 2.5. Set up the image and caliper displays to “Orient to North”.

4.2.11.6 Record the calibration.

Record a data file on time drive as described in Reference 2.5.

4.2.11.7 Check proper image orientation. The sleeve should be apparent as a lighter (higher reflectivity) image on the S-W-N half of the amplitude image on the computer monitor. The caliper display should also indicate the same relative position (S-W-N) for the sleeve which should show a faster travel time than the outer cylinder.

4.2.11.8 Complete the “Pre-Log” portion of the “FAC-40 ATV Checkout/Calibration” form (Appendix 7.4)

4.2.12 Post-Log Calibration Check Procedures

A calibration check is performed after the log has been completed to verify that no change in system performance has occurred during logging.

4.2.13 Calibration Records

Calibration data shall be recorded on the form specified for both the pre-log calibration and the post-log check. These shall be performed prior to and at the completion of “continuous” logging operations for a particular well. The calibration forms shall include the probe identification number, well location, date and time calibration was performed, person executing calibration procedure, and any pertinent observations.

4.3 Precautions and Limits

4.3.1 The FAC-40 ATV log shall be run in an uncased hole unless the condition of casing is to be investigated. When logging in casing, steel casing may necessitate turning off the 3-axis magnetometer resulting in non-oriented images.

4.3.2 The quality of the image depends on the acoustic properties of the fluid in the borehole and the condition of the borehole wall.

4.3.3 The image is interpreted as if the tool is perfectly centralized. If the tool is eccentered, the geometry of the observed features may be distorted.

4.3.4 During analysis, the tool axis is assumed to be aligned with the axis of the borehole.

4.3.5 The operational temperature and pressure limits for the FAC-40 probe provided by the manufacturer should be adhered to while running the log. The maximum operating pressure is approximately 4650 PSI (240 bars). The practical operational temperature range is from 0 to 70°C (32 to 158°F).

4.3.6 The recommended minimum borehole diameter is 46 mm (1.81”). The recommended maximum diameter is 400 mm (15.75”). In ideal circumstances, the FAC-40 can be run successfully in holes as large as 432 mm (17”).

4.3.7 Washout zones will adversely affect the resolution of the acoustic image.

4.3.8 Bridges or constrictions in the borehole diameter will make it impossible to lower the probe into the borehole and difficult to retrieve the probe.

4.3.10 The magnetometer is approximately 2 feet above the transducer assembly. Thus, if the borehole is cased with magnetically active material, the image immediately below casing will be more difficult to orient.

4.3.11 The log is generally recorded with the tool moving up the borehole, but can be logged downward if necessary.

4.4 Acceptance Criteria

This log shall be accepted for use based on the expectation that the results will be interpreted quantitatively.

The following acceptance criteria shall be evaluated using the images generated on the computer monitor during data acquisition.

4.4.1 The orientation of the pre- and post-logging calibration images shall be within 5° of magnetic North.

4.4.2 The orientation of features on the repeat section shall be within 5° of their orientation recorded during the main logging run.

4.4.3 After Survey Depth Error (ASDE) shall be within required tolerances as specified in TP-1.

5.0 DETAILED PROCEDURE

The real-time FAC-40 images show the borehole wall as if it were split vertically and laid flat. Vertical fractures appear as vertical straight lines, while bedding and fractures dipping between vertical and near horizontal appear as sinusoidal traces.

The FAC-40 images can be used:

- To evaluate the stratigraphic, structural, diagenetic, weathering, textural and mineralogical features detectable in the borehole wall.

- To locate and orient fractures and bedding planes to aid in the analysis and interpretation of in situ physical and hydrologic properties.

- To locate and orient any stress-induced wellbore failure (breakouts) for determination of the orientation and magnitude of in situ stresses.

- Casing integrity and/or completion evaluation.

FAC-40 ATV logs are typically run as one of a suite of logs during a single visit to a well site. Procedures prior to and upon arrival as described here pertain only to the specific requirements of the FAC-40. Where they do not conflict with the procedures detailed here, all of the procedures specified in TP-1 shall also be adhered to.

5.1 Prior to mobilization

In addition to those procedures detailed in TP-1.

5.1.1 Select the appropriate centralizers for use in the well.

5.1.2 Assure that the logging truck has a sufficient cable length to perform the log.

5.2 On arrival

No added procedures are necessary beyond those detailed in TP-1.

5.3 During Logging

5.3.1 The FAC-40 ATV shall be run centralized in the borehole. Adjust the probe centralizer for optimal centralization in the interval to be logged.

5.3.2 Visually inspect all connections and screws on the logging probe to be sure they are tight.

5.3.3 Attach the probe to the logging cable and turn power to the tool on.

5.3.4 Perform a pre-log calibration.

5.3.5 Set the software depth counter to read zero when probe measuring point is depth referenced to the measurement datum (land surface, top of casing, etc.). The depth zero should be set with tension on the wireline similar to that expected while logging, to prevent slack in the cable from biasing the datum.

5.3.6 Maintain a record of depth measurements according to procedures specified in TP-1.

5.3.7 Lower the probe to the bottom of the interval to be logged. Monitor the tool's response, and adjust settings for recording as stipulated in Reference 2.5.

5.3.8 Begin logging up at appropriate speed for the sample rate selected (Reference 2.5). Typically, a 50 foot repeat section is run first, followed by the main log. However, the repeat may be run after the main log in order to identify a more interesting interval to repeat. Correct tool operation is verified by observing the Amplitude, Travel Time and Caliper images on the computer monitor. Note the orientation of key features to use to verify the repeatability during the 2nd run.

5.3.9 If logging needs to be stopped for any reason a brief overlap interval (typically 10 feet) should be recorded, to ensure that no data are missed.

5.3.10 After completion of the 1st logging run, lower the probe back down to the bottom of the interval to be logged. Verify that the orientation of features is within 5° between the repeat and main logs. At the completion of each run, the data file should be played back to verify that it was recorded properly.

5.3.11 After completion (and acceptance) of both a repeat section and a main run, all of the data (including the pre-log calibration) should be backed up onto a storage media.

5.3.12 Unless otherwise noted all azimuth orientation data shall be recorded on magnetic North orientation. Field plots unless otherwise noted shall be based upon magnetic North.

5.3.13 Determine after survey depth error.

5.3.14 Record a Post-log calibration check, and back up the file with the log data.

5.4 <u>Prior to departure</u>

In addition to the requirements of TP-1:

5.4.1 A black and white paper copy of both the repeat and main logging runs which includes the Travel Time and Amplitude plots shall be provided as detailed in Reference 2.5.

5.5 After return to Colog's Lakewood office:

5.5.1 The digital backed up data shall be uploaded to Colog's computer network for additional processing and interpretation prior to archiving.

6.0 RECORDS

Records shall be provided as detailed in TP-1. In addition the following records shall be provided upon client's request:

6.1 A black and white paper copy of the FAC-40 ATV log (see 5.4.1). Additionally, FAC-40 ATV data may be processed with interactive software to provide a variety of data presentations depending on project objectives.

6.2 Data Deliverables

Digital data may be provided in raw (proprietary manufacturer's format), ASCII or WellCAD™ format.

7.0 APPENDICES

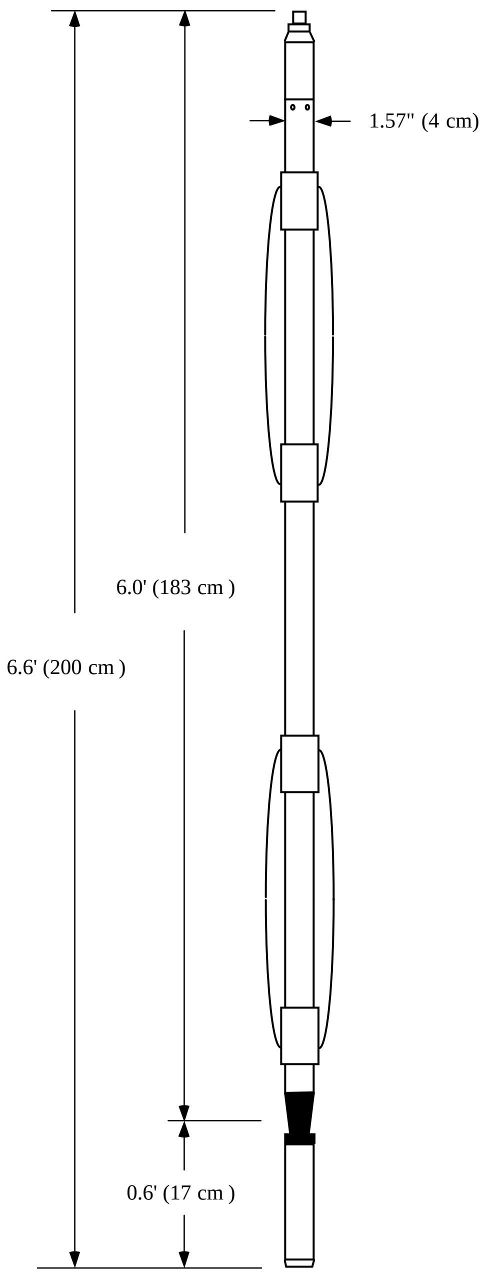
7.1 FAC-40 ATV Tool diagram.

7.2 Example FAC-40 Image display (Travel Time and Amplitude).

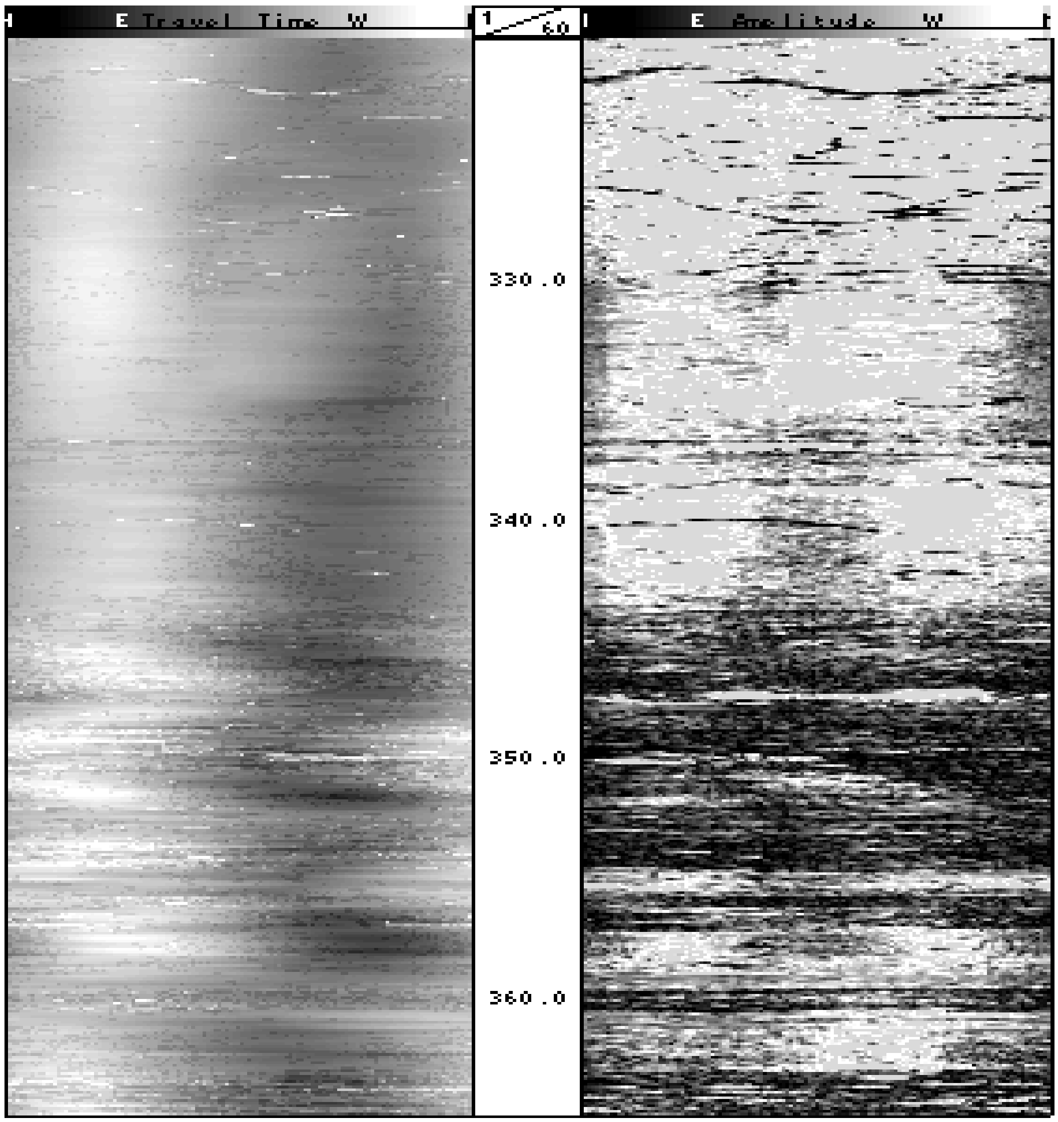
7.3 Calibration Apparatus.

7.4 "FAC-40 ATV Calibration/Checkout" Form.

Facimile 40 (FAC-40) Acoustic Televiewer

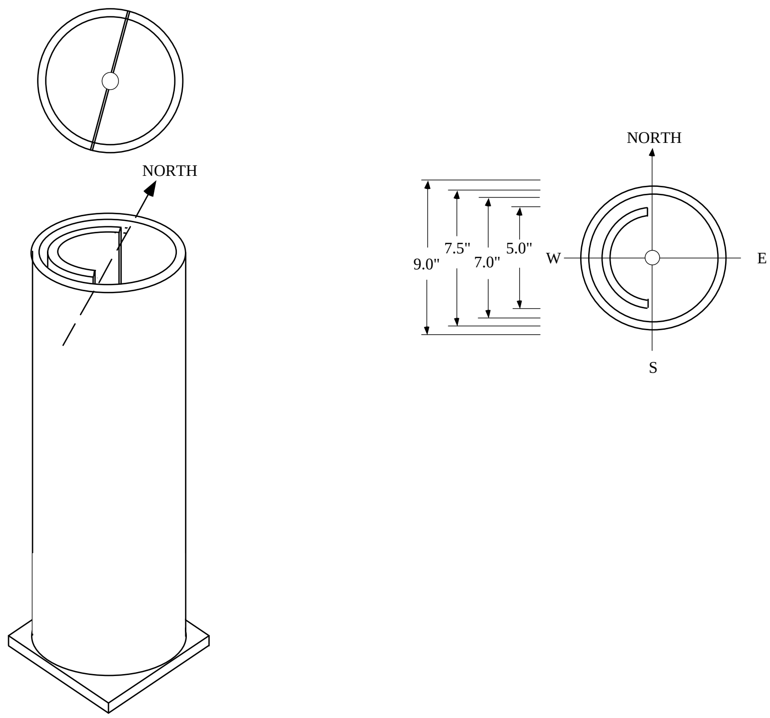


Appendix 7.1 FAC-40 ATV Tool Diagram



Appendix 7.2 Example FAC-40 Image Display

Appendix 7.3 FAC-40 Calibration Apparatus



Fac-40 ATV
Checkout/Calibration

Engineer:____________________ Location or Well Name:___________________ Truck/Unit No:___________

Probe Serial No:___________________

Pre-Log Calibration:

Date:_______________ Time:_______________

Calibration Filename:__________________

Post-Log Check:

Date:_______________ Time:_______________

Calibration Filename:__________________

Calibration Standards:

1.) Calibration Apparatus oriented to North and South, using a Brunton compass, set clear of metal objects.

COLOG

borehole geophysics / hydrophysics

Technical Procedure and Work Instructions for

Temperature and Fluid Conductivity

TP-12

Prepared by: Nathan Davis Date: 6/24/08

Approved by: Michael J. Culig Date: 6/25/08

CONTROL DOCUMENT No. TP12062408

Note: **This Technical Procedure has been prepared for the benefit of COLOG. It is the property of COLOG, and will not be cited, reproduced or changed without the written consent of COLOG. Changes will be documented in accordance with COLOG's internal Quality Assurance Plan.**

COLOG Technical Procedure TP-12

Revision History

Revision Level	Issue Date	Change Summary
0.00	1/9/97	New procedure.
1.00	1/15/97	Revised according to phone comments by REC.
1.10	4/11/07	Format changed to correspond with standard TPs; GDB
2.00	6/24/08	Addition of Fluid Conductivity and incorporation of probe from Robertson Geologging

Table of Contents

1.0 SCOPE

1.1 Purpose

1.1.1 This procedure provides instructions for performing temperature and fluid resistivity measurements, to assure the accuracy, validity, and applicability of the methods used.

1.1.2 This procedure further describes the components of fluid logging, the principles and limits of the methods used, the methods used for calibration and performance verification of the equipment, and the requirements for data acceptance and for documentation.

1.1.3 This procedure includes by reference those sections of TP-1 which are common to all measurements.

1.1.4 In applying this procedure to temperature measurement, the requirements of this procedure shall supersede those stipulated in TP-1.

1.2 Applicability

1.2.1 This procedure applies to temperature and fluid resistivity measurements acquired using wireline logging probes.

1.2.2 This procedure applies to all COLOG and contractor personnel who perform work referred to in paragraph 1.1 or who use data obtained from this procedure if it is deemed to potentially affect public health and safety.

1.2.3 All data derived from this procedure, and any equipment calibrations or recalibrations that may be required, shall be in accordance with this technical procedure. Deviation from these procedures shall be permitted only under the conditions set forth in Section 6 of TP-1.

2.0 REFERENCES

2.1 Keys, W. Scott, and MacCary, L.M., Application of Borehole Geophysics to Water-Resources Investigations: USGS, Techniques of Water-Resources Investigations, Book 2, Chapter E1.

2.2 Hearst, J.R., and Nelson, P.H., Well Logging for Physical Properties, McGraw Hill, 1985.

2.3 Standard Guide for Planning and Conducting Borehole Geophysical Logging, ASTM Designation D5753-95, October, 1995.

3.0 DEFINITIONS

Definitions shall be in accordance with ASTM D5753-95. In addition, definitions common to all logging procedures are provided in TP-1.

3.1 Temperature probe - measurement probe that contains a thermal sensing detector (thermistor, IC, etc.) that electrically responds to borehole fluid temperature and changes in fluid temperature.

3.2 Fluid conductivity probe - measurement probe that contains an array of electrodes that respond to borehole fluid conductivity (and resistivity) and changes in fluid conductivity.

3.3 Recording equipment - Data from the temperature and fluid conductivity probe is sent to the surface as electrical signals which are translated into engineering units, and recorded along with depth, to produce a measurement of the fluid temperature and fluid conductivity as a function of the depth of that fluid in contact with the temperature probe. The log data is recorded digitally as engineering values and displayed while the log is being run.

3.4 Personnel - Personnel are as defined in TP-1.

4.0 REQUIREMENTS

4.1 Prerequisites

In addition to the prerequisites stipulated in TP-1.

4.1.1 The borehole shall be filled with a fluid over the entire interval to be logged.

4.2 Tools, Material, Equipment

4.2.1 Temperature and fluid conductivity measurement probe. The measurement sensors shall be at the bottom of the probe. COLOG utilizes four probe models for measuring temperature and fluid conductivity. From Mount Sopris Instruments (MSI), the MLP 2492, powered by a MSI Unimod or MSI MLM module; and the 2WQA-1000, powered by an MSI MGX-II or MSI Matrix; from Robertson Geologging (RG), the model 25-046 Temperature/Conductivity probe, powered by an RG Micrologger-II; and from COLOG, the Slimline HydroPhysics probe, powered by a COLOG HydroPhysics module.

4.2.2 A digital thermometer, calibrated to NIST standards, and a minimum of two temperature baths is required for a calibration check. A digital fluid conductivity or resistivity meter, calibrated to NIST standards, and a minimum of two conductivity baths is required for a calibration check.

4.2.3 Calibration

Temperature probe calibration is performed under controlled conditions in a laboratory. Shop calibrations shall be performed before leaving for the field and upon return at the completion of a survey.

An accurate thermometer and conductivity meter is used, in a stabilized fluid bath, in the laboratory. The actual temperature and conductivity of the fluid bath is recorded, and the output of the temperature probe is recorded, for a suitable range of temperatures. This output may be converted to a pulse or frequency, or to a digital signal in the probe, for transmission to the recording equipment. The output values are converted to degrees Fahrenheit or Celsius and to Ohm-meters and recorded on disc.

Calibration records shall be maintained by the logging contractor.

4.2.4 Calibration check

The purpose of the calibration check is to allow temperature data to be used in a quantitative manner. The procedure to be followed shall be the same as that used for calibration in the shop, except that the calibration check shall include the measurement of a minimum of two temperatures which span the range of the expected log. The temperatures and conductivities shall be measured simultaneously by the probe and by a thermometer and conductivity meter referenced to NIST standards.

The calibration check shall be documented on the calibration form.

4.3 Precautions and Limits

4.3.1 Temperature and pressure limits of temperature probes are specified in the appropriate operating manuals.

4.3.2 Measurement range typically spans the operational limits of the probe.

4.3.2 Temperature logs respond to the temperature of fluid in contact with the probe. Because of the finite thermal inertia of the probe, and the requirement that the material in the hole have a finite viscosity, temperature logs shall be obtained only in fluid-filled holes.

4.3.3 The sensitivity of a typical temperature probe depends on the logging rate and the properties of the probe.

4.3.4 The log shall be recorded with the probe moving **down** the borehole, to maximize the sensitivity of the temperature probe to ambient conditions and to minimize disturbance of the fluid due to the passage of the probe.

4.4 Acceptance Criteria

This log shall be accepted for use based on the expectation that the results will be interpreted **quantitatively**.

4.4.1 Repeat sections are not typically recorded, as the first pass of the temperature probe disturbs the ambient temperature profile.

4.4.2 Depths of features in the log agree with other logs, if run, particularly caliper or fracture imaging logs.

4.4.3 After survey depth error shall be within required tolerances, as stipulated in TP-1.

4.4.4 Pre-log and post-log calibration checks shall be within 0.2°C, and within 5% of the bath conductivity span. The baths should span the ranges measured in the borehole.

4.4.5 Logs show reasonable values, consistent with experience. That is, values do not vary erratically, and generally show slowly increasing temperature with depth. Decreases with depth may occur in exceptional circumstances associated with a variety of flow related conditions.

5.0 DETAILED PROCEDURE

Temperature and fluid conductivity logs are typically recorded with a 0.1 foot sample interval.

Temperature and fluid conductivity logs shall be recorded before any other logs, to prevent disturbance to the ambient fluid profile.

If there is no fluid motion in or adjacent to a borehole, the temperature generally increases with depth at a rate which is a function of the vector geothermal heat flux, the orientation of the borehole, and the thermal diffusivity of the rock. Temperature logs are used to determine the heat flux, and to characterize local and near-wellbore fluid motion. Additionally, temperature data can be used to correct all logs sensitive to temperature. Fluid conductivity logs vary as a function of the concentration of ions within the fluid, and can be converted from conductivity units to units of total dissolved solids.

Temperature and fluid conductivity logs are typically run as part of a suite of logs during a single visit to a well site. Procedures prior to and upon arrival as described here pertain only to the specific requirements of temperature and fluid conductivity logging. Where they do not conflict with the procedures detailed here, all of the procedures specified in TP-1 shall also be adhered to.

5.1 Prior to arrival

In addition to the procedures detailed in TP-1:

5.1.1 The detailed history of the well shall include information regarding procedures, which are likely to perturb the thermal profile. These include but are not limited to information regarding locations and amounts of lost fluids, and times and characteristics of active or recent hydrologic tests, time since drilling or pumping equipment has been removed from the borehole.

5.1.2 The temperature and fluid conductivity probe shall be calibrated according to the procedure detailed in 4.2.3.

5.2 On arrival

In addition to the procedures detailed in TP-1:

5.2.1 Verify the information from 5.1.1.

5.2.2 Rig up while protecting the borehole from disturbance, specifically, avoid lowering or dropping any probes objects into the borehole unnecessarily.

5.3 While Logging

5.3.1 Verify the integrity of the wireline.

5.3.2 Attach temperature probe to the logging cable.

5.3.3 Perform a pre-log calibration check.

5.3.4 Set wireline depth zero at the measurement point. The depth zero should be taken with tension on the wireline similar to that expected while logging, to prevent slack in the cable from biasing the datum.

5.3.5 Temperature and fluid conductivity logs shall be obtained with the probe moving down the hole at a rate not to exceed 10 feet per minute, to reduce the induction of fluid turbulence.

5.3.6 Record a log of the entire hole during the first pass into the well. Tool operation is verified by monitoring surface displays for slow changes with depth of the temperature.

5.3.7 Return probe to surface.

5.3.8 Check depth zero.

5.3.9 Perform a post-log calibration check as detailed in 4.2.4.

5.4 Prior to departure - no additional requirements beyond TP-1.

6.0 RECORDS

Records shall be provided as detailed in TP-1.

6.1 Data Deliverables

Data deliverables shall be as described in TP-1.

7.0 APPENDICES

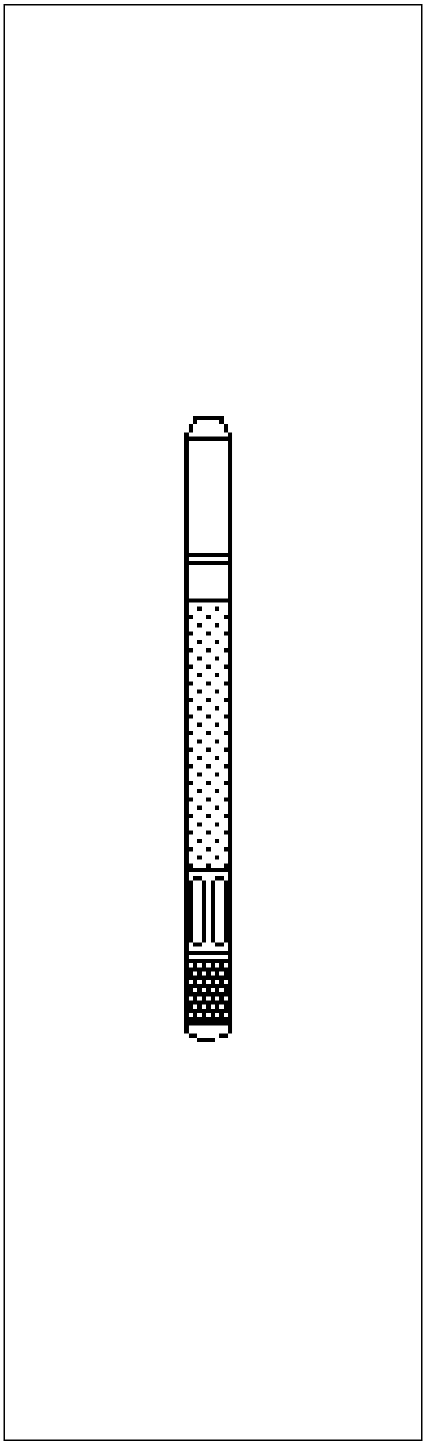
7.1 Temperature and Fluid Resistivity Probe Diagrams

7.2 "Temperature and Fluid Resistivity Checkout and Calibration" form

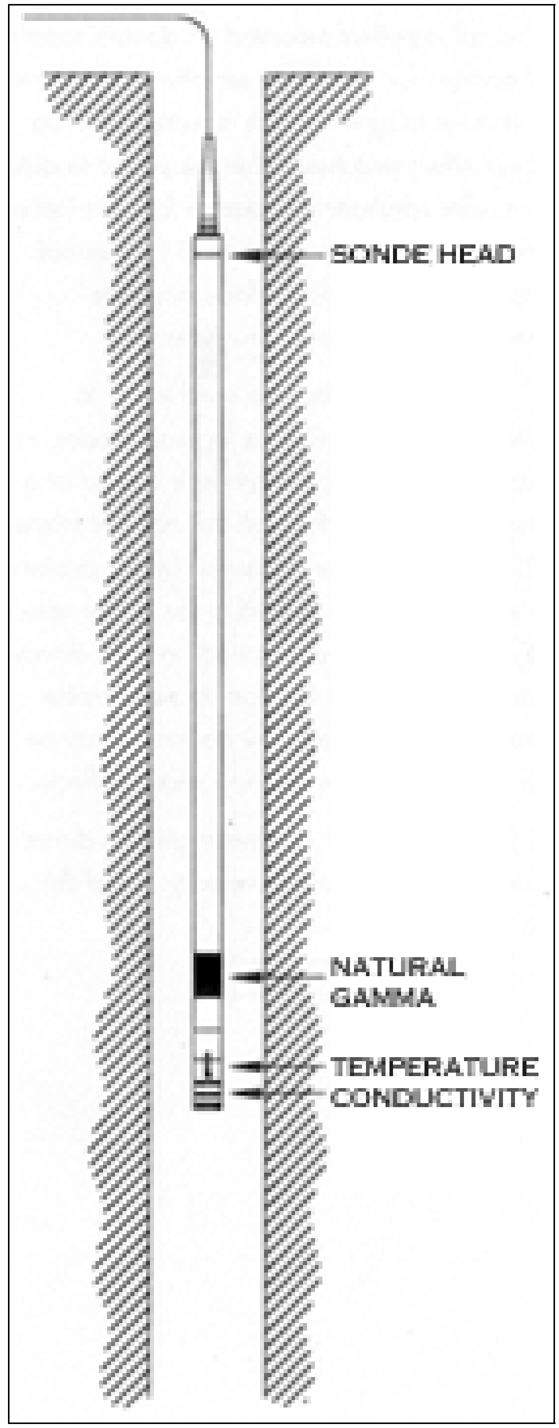
Appendix 7.1

Temperature and Fluid Resistivity Probes

2WQA-1000



RG 25-046



Appendix 7.2

borehole geophysics / hydrophysics

Temperature and Fluid Conductivity Checkout and Calibration

Engineer___________ Location_________________Unit No. ______

Probe Type S/N________________ Module S/N_________________

Digital Bench Thermometer Model_____________

Pre-Log Calibration:

Date:___________ Time:___________

Calibration Bath #1				
Temperature (°C)	Probe CPS	Resistivity (Ohm-m)	Probe CPS	Digital File Name
Calibration Bath #2				
Temperature (°C)	Probe CPS	Resistivity (Ohm-m)	Probe CPS	Digital File Name

Post-Log Calibration:

Date:___________ Time:___________

Calibration Bath #1				
Temperature (°C)	Probe CPS	Resistivity (Ohm-m)	Probe CPS	Digital File Name
Calibration Bath #2				
Temperature (°C)	Probe CPS	Resistivity (Ohm-m)	Probe CPS	Digital File Name

Technical Procedure and Work Instructions for

Electromagnetic **Dual Induction** Conductivity

TP-15

Prepared by:	David A. Renner	Date:	7/6/15
Approved by:	Nathan O. Davis	Date:	7/6/16

CONTROL DOCUMENT No. **TP15050407**

Colog, Inc. Technical Procedure TP-15

Revision History

Revision Level	Issue Date	Change Summary
0.00	2/16/07	New procedure.
1.00	5/4/07	Formatting, pagination and spelling revisions
1.10	7/6/15	Included revisions to incorporate the sale of the COLOG division of Layne Christensen Company to Colog, Inc.

Table of Contents

1.0 SCOPE

1.1 Purpose

1.1.1 This procedure provides instructions for performing electromagnetic induction conductivity logging measurements (EM), with a dual detector spacing, to assure the accuracy, validity, and applicability of the methods used.

1.1.2 This procedure further describes the components of dual induction probes, the principles and limits of the methods used, the methods used for calibration and performance verification of the equipment, and the requirements for data acceptance and for documentation.

1.1.3 This procedure includes by reference those sections of TP-1 which are common to all measurements.

1.1.4 In applying this procedure to dual induction logging measurement, the requirements of this procedure shall supersede those stipulated in TP-1.

1.2 Applicability

1.2.1 This procedure applies to conductivity measured using dual induction probes.

1.2.2 This procedure applies to all personnel who perform work referred to in paragraph 1.1.

1.2.3 All data derived from this procedure, and any equipment calibrations or recalibrations that may be required shall be in accordance with this technical procedure. Deviation from these procedures shall be permitted only under the conditions set forth in Section 6.3 of TP-1.

2.0 REFERENCES

2.1 Keys, W. Scott, and MacCary, L.M., Application of Borehole Geophysics to Water-Resources Investigations: USGS, Techniques of Water-Resources Investigations, Book 2, Chapter E1.

2.2 Hearst, J.R., and Nelson, P.H., Well Logging for Physical Properties, McGraw Hill, 1985.

2.3 Standard Guide for Planning and Conducting Borehole Geophysical Logging, ASTM Designation D 5753-05, June, 2005.

3.0 DEFINITIONS

Definitions shall be in accordance with ASTM D 5753-05. In addition, definitions common to all logging procedures are provided in TP-1.

3.1 Induction logging involves measuring the conductivity of the formation surrounding a borehole, and typically also reporting the calculated resistivity.

3.2 Resistivity is defined as the ratio of voltage to current per unit distance per unit area. The units are typically Ohm-meters. Conductivity is the inverse of resistivity, and is expressed in milliSiemens/meter.

3.5 Electromagnetic induction is a technique whereby formation conductivity is measured by inducing an electromagnetic field the formation and measuring the ability of the formation to sustain that field. This technique requires no direct electrical connection between the formation and the coils (i.e. The presence of electrically conductive fluid, typically water, in the borehole, is not required).

3.6 Recording equipment - Data from the dual induction probe is sent to the surface as electrical signals which are translated into engineering units and recorded along with depth to produce a conductivity log of the hole. The log data is recorded digitally as engineering values and displayed while the log is being run.

3.7 Personnel

Personnel are as defined in TP-1.

4.0 REQUIREMENTS

4.1 Prerequisites

4.1.1 The borehole to be logged need not be filled with a conductive fluid. The log may be run in dry holes, or with water or drilling mud.

4.1.2 The borehole to be logged must be either open (uncased) or cased with non-conductive pipe, such as PVC or fiberglass.

4.2 Tools, Material, Equipment

4.2.1 Measurement apparatus

Colog, Inc. utilizes two probes to collect dual induction logs: The Advanced Logic Technology DIL-45 probe, with source to detector spacings at 22” & 33”, and an operating frequency of 25.6

kHz. The probe communicates with uphole interface consoles, including the Advanced Logic Technology ALT Logger, the Mount Sopris Instruments MGX-II Digital Logging System, and the Mount Sopris Instruments Matrix Geophysical Logging System. The Robertson Geologging DUIN 25-061 probe, with source to detector spacings at 20” & 32”, and an operating frequency of 39 kHz, communicates with the Robertson Geologging Micrologger 2. Once calibrated, the responses of both probes are essentially identical.

4.2.2 Model specific calibration coil.

4.2.3 Pre-log calibration procedure for the MSI DIL-45

This procedure shall be performed before logging each well. The required tolerances are specified in 4.4.4.

The purpose of the pre-log calibration is to adjust conversion factors to force the tool output to read known conductivity values induced in a manufacturer supplied conductive coil.

4.2.3.1 Using a nonconductive jig, suspend the probe at least 60” above the ground, away from metallic objects (including the logging vehicle) and away from sources of electromagnetic noise (high voltage power lines, generators, motors, and engines). Place the calibration coil around the probe, so that the coil’s center tube is centered between the marks on the probe (the marks should be at 20.25” and 28.75” from the bottom of the probe). In this configuration the probe output should be forced to 1986 mS/m and 576 mS/m on the Medium and Deep channels, respectively.

4.2.3.2 While still suspended in the nonconductive jig, remove the calibration coil. In this configuration the probe output should be forced to 0 mS/m on both the Medium and Deep channels.

4.2.3.2 Pressing the “Store” button in the software will automatically calculate a linear equation to convert the probe’s counts/second into mS/m.

4.2.3.4 With the time sample rate at 1 second, record a calibration file for a minimum of 30 seconds each with and without the calibration coil. The filename should indicate the probe model and serial number. For example, if using the DIL-45 SN2599, the calibration file name would be DIL2599a.RD (or DIL2599a.TFD if using the Matrix). Subsequent files should use “b”, “c”, etc. to differentiate pre from post, and with coil from without

4.2.3.5 Complete the Pre-Log portion of the “Dual Induction Checkout/Calibration” form.

4.2.4 Pre-log calibration procedure for the RGL DUIN

This procedure shall be performed before logging each well. The required tolerances are specified in 4.4.4.

The purpose of the pre-log calibration is to adjust conversion factors to force the tool output to read known conductivity values induced in a manufacturer supplied conductive coil.

4.2.4.1 Using a nonconductive jig, suspend the probe at least 60” above the ground, away from metallic objects (including the logging vehicle) and away from sources of electromagnetic noise (high voltage power lines, generators, motors, and engines).

4.2.4.2 Place the calibration coil around the probe, so that the coil’s center is directly over the lower mark on the probe (this marks should be at 18.75” from the bottom of the probe). In this configuration the probe output should be forced to 5231 mS/m on the Medium channel.

4.2.4.3 Place the calibration coil around the probe, so that the coil’s center is directly over the upper mark on the probe (this marks should be at 30.75” from the bottom of the probe). In this configuration the probe output should be forced to 6009 mS/m on the Deep channel.

4.2.4.4 While still suspended in the nonconductive jig, remove the calibration coil. In this configuration the probe output should be forced to 0 mS/m on both the Medium and Deep channels.

4.2.4.5 Pressing the “Store” button in the software will automatically calculate a linear equation to convert the probe’s counts/second into mS/m.

4.2.4.6 With the time sample rate at 1 second, record a calibration file for a minimum of 30 seconds each with and without the calibration coil. The filename should indicate the probe model and serial number. For example, if using the DUIN SN5550, the calibration file name might be DUI5550a.LOG. Subsequent files should use “b”, “c”, etc. to differentiate pre from post, and with coil from without.

4.2.4.7 Complete the Pre-Log portion of the “Dual Induction Checkout/Calibration” form.

4.2.4 Post-Log Calibration Check Procedure

The purpose of the post-log calibration check is to verify that no change in system performance has occurred during logging.

To perform the post-log calibration check, repeat the procedures for the pre-log calibration. The same file name should be used for the post-log check as was used for the pre-log calibrations, but “b”, “c”, etc. should be substituted, to differentiate pre from post, and with-coil from without..

Complete the “Post-Log” portion of the “Dual Induction Checkout/Calibration” form.

4.3 Precautions and Limits

4.3.1 Temperature and pressure limits are specified in the operations manuals of the specific logging probes.

4.3.2 Extreme differences between the downhole logging temperature and the uphole calibration temperature will cause a shift in the data.

4.3.3 The range within which a given device is accurate is different for the different measurement techniques. This range shall be specified for each device, and the appropriate device shall be selected for the borehole under investigation.

4.3.4 The properties of the borehole fluid should not influence the response of dual induction logs, provided the borehole diameter is less than about 10 inches. As the hole diameter increases, these effects become more influential.

4.3.5 The geometry of the logging probe, such as the positions of the source and measurement coils, affects the measurement values.

4.3.5.1 The ability of a given measurement to accurately measure resistivity across a thin bed is a function of the geometry and of the conductivity contrast and bed thickness.

4.3.5.2 The radius of investigation, away from the borehole, is a function of the geometry and the radial distribution of electrical properties.

4.3.6 The log should be recorded with the tool moving up the borehole, but measurements can be made while logging down, also. In fact, it is suggested that data be recorded while running into the well, just in case hole conditions or tool problems prevent getting a good log in the up direction.

4.4 Acceptance Criteria

Induction conductivity, and calculated resistivity, values shall be accepted for use based on the expectation that the results will be interpreted quantitatively.

4.4.1 Repeat sections for all measurements shall be similar to the main log, such that features visible in each match in depth and in the value of the measured data.

4.4.2 Depths of features in the log shall agree with other logs, if run.

4.4.3 After Survey Depth Error (ASDE) shall be within required tolerances as specified in TP-1.

5.0 DETAILED PROCEDURE

Dual Induction logs are typically recorded at 0.1 foot sample intervals. They are used to obtain information on the electrical properties of the geologic section including the soil, rock, and groundwater.

Dual Induction logs are typically run as one of a suite of logs during a single visit to a well site. Procedures prior to and upon arrival as described here pertain only to the specific requirements of Dual Induction logs. Where they do not conflict with the procedures detailed here, all of the procedures specified in TP-1 shall also be adhered to.

5.1 Prior to arrival

No added procedures are necessary beyond those detailed in TP-1.

5.2 On arrival

Establish the borehole total depth, diameter, and expected fluid temperature.

5.4 During Logging

5.4.1 Attach the logging probe to the wireline.

5.4.2 Perform a pre-log calibration.

The purpose of pre-log validation is to adjust conversion factors to achieve desired accuracy for the desired range.

The pre-log validation also provides data for comparison to a post-log validation check.

5.4.3 Set wireline depth zero at the measurement point. The depth zero should be taken with tension on the wireline similar to that expected while logging, to prevent slack in the cable from biasing the datum.

5.4.4 Lower the probe to the bottom of the interval to be logged.

5.4.5 Begin logging up at a rate not to exceed 30 feet per minute (20 ft/min, if a gamma is logged in conjunction).

5.4.6 Typically, a 50 foot repeat section is run first, followed by the main log. However, the repeat section may be run after the main log in order to identify a more interesting interval to repeat.

5.4.7 After completion of the first run, lower the probe back down to the bottom of the interval to be logged. Verify that the log response between the two runs is repeatable.

5.4.8 Upon completion of the second (or last) run, all of the data (including the pre-log calibration) should be backed up onto a storage media.

5.4.9 Return probe to the surface and determine the A.S.D.E.

5.4.10 Perform a post-log calibration check, and back up the file with the log data.

5.5 Prior to departure - no additional requirements beyond TP-1.

6.0 RECORDS

Records shall be provided as detailed in TP-1.

6.1 Data Deliverables

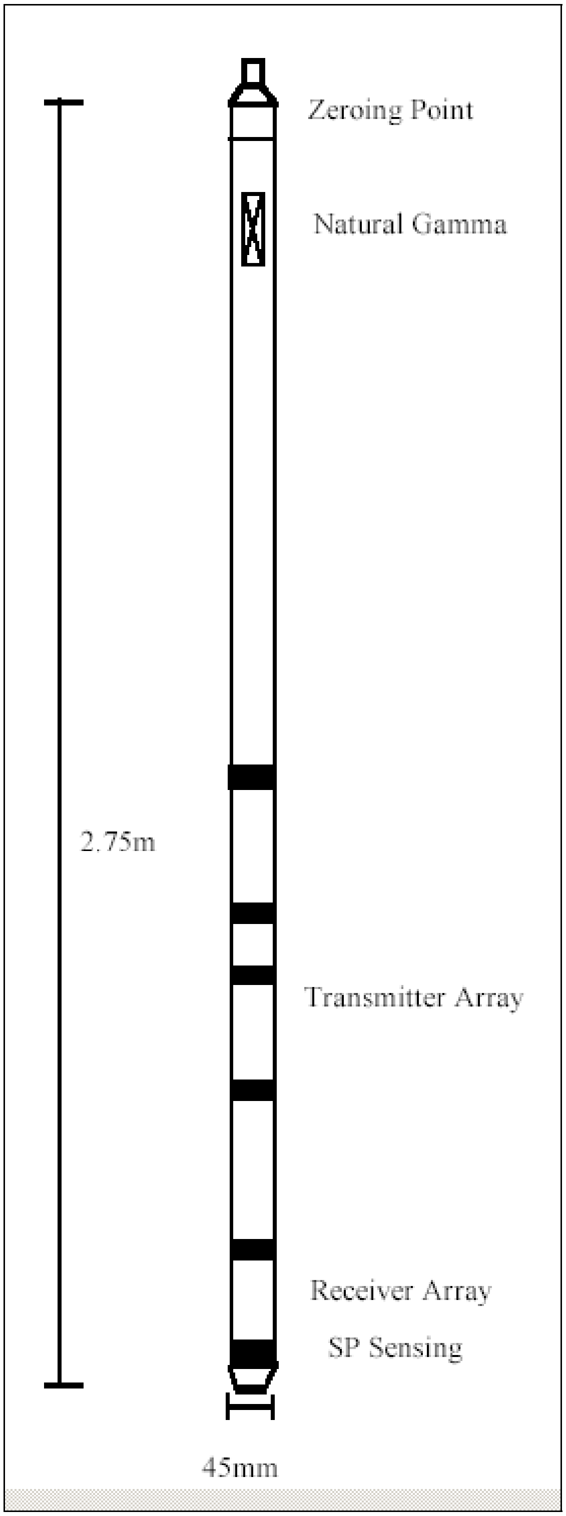
Data deliverables shall be as described in TP-1

7.0 APPENDICES

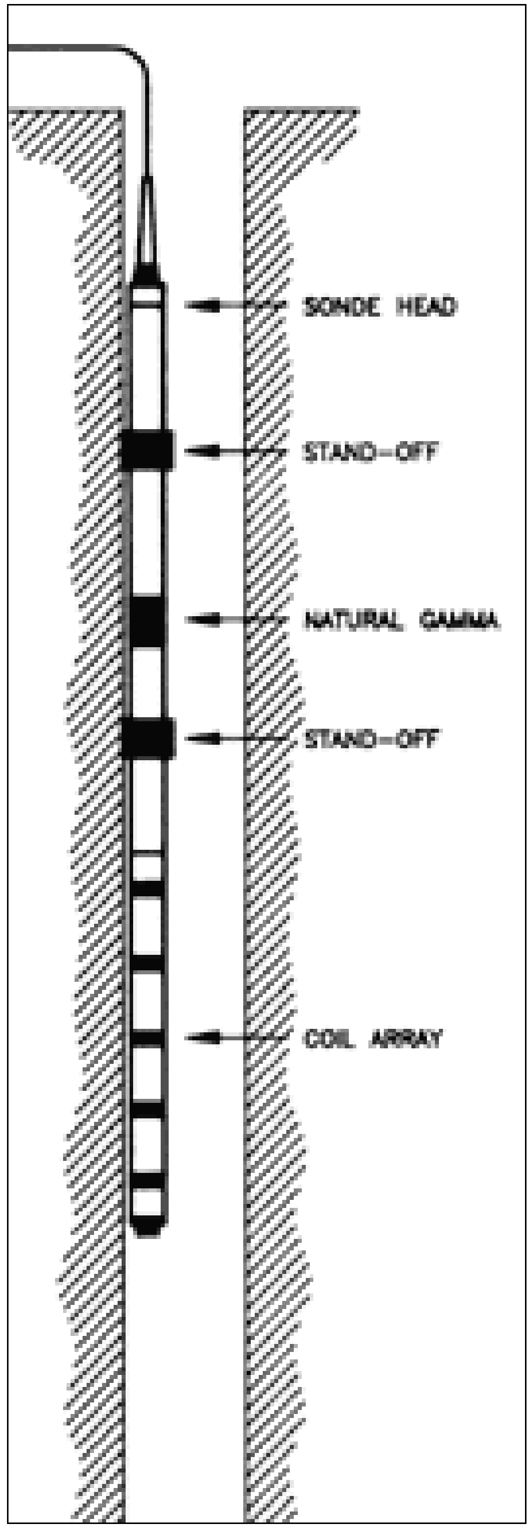
7.1 Dual Induction Tool Diagrams

7.2 "Dual Induction Checkout/Calibration" Form

Appendix 7.1



DIL-45



DUIN

Appendix 7.2

Dual Induction
Checkout/Calibration

Engineer:___________________ Location or Well Name__________________Unit No:___________

Probe Type & Serial No:______________________

Acquisition System Type & Serial No.:______________________

Pre-Log Check:

Date:_______________ Time:_______________

	Coil Value	Measured Value	Coil Value	Measured Value	File Name
Deep Induction	_________	___________	_________	___________	_____________
Medium Induction	_________	___________	_________	___________	_____________

Post-Log Check:

Date:_______________ Time:_______________

	Coil Value	Measured Value	Coil Value	Measured Value	File Name
Deep Induction	_________	___________	_________	___________	_____________
Medium Induction	_________	___________	_________	___________	_____________

Technical Procedure and Work Instructions for

Corehole Dynamic Flowmeter Logging

TP-20

Prepared by: David A. Renner Date: ____________

Approved by: Greg D. Bauer Date: ____________

CONTROL DOCUMENT No. ______________________

Colog, Inc. Technical Procedure TP-20

Revision History

Revision Level	Issue Date	Change Summary
1.00		New procedure.

Table of Contents

1.0 SCOPE

1.1 Purpose

1.1.1 This procedure provides instructions for performing corehole dynamic flowmeter (CDFM) logging measurements to assure the accuracy, validity, and applicability of the methods used.

1.1.2 This procedure describes the components of corehole dynamic flowmeter probes, the principles and limits of the methods used, the methods used for calibration and performance verification of the equipment, and the requirements for data acceptance and for documentation.

1.1.3 This procedure includes by reference those sections of TP-1 which are common to all measurements.

1.1.4 In case of a conflict with the requirements of TP-1, the requirements of this procedure shall take precedence.

1.2 Applicability

1.2.1 This procedure applies to measurements of vertical flow in wells and boreholes using corehole dynamic flowmeter probes.

1.2.2 This procedure applies to all personnel who perform work referenced in paragraph 1.1.

1.2.3 All data derived from this procedure, and any equipment calibrations or recalibrations that may be required shall be in accordance with this technical procedure. Deviation from these procedures shall be permitted only under the conditions set forth in Section 6.3 of TP-1.

2.0 REFERENCES

2.1 Keys, W. Scott, and MacCary, L.M., Application of Borehole Geophysics to Water-Resources Investigations: USGS, Techniques of Water-Resources Investigations, Book 2, Chapter E1.

2.2 Hearst, J.R., and Nelson, P.H., Well Logging for Physical Properties, McGraw Hill, 1985.

2.3 Standard Guide for Planning and Conducting Borehole Geophysical Logging, ASTM Designation D 5753-05, June, 2005.

2.4 Vertical Flowmeter Logging, USGS Groundwater Information, Branch of Geophysics, http://water.usgs.gov/ogw/bgas/flowmeter/

3.0 DEFINITIONS

Definitions shall be in accordance with ASTM D 5753-05. In addition, definitions common to all logging procedures are provided in TP-1.

3.1 Corehole dynamic flowmeter logging involves measuring the vertical flow of water in a borehole or well. Both vertical upward and vertical downward flow can be measured.

3.2 Flow is defined as the volume of water moving through the measuring chamber in a given time period. The units are gallons or liters per minute.

3.5 Corehole dynamic flowmeter logging is a technique whereby the logging tool is fitted with flow diverters which force water moving up or down in the well to pass through a chamber in the logging tool. Water moving through the chamber produces a voltage that may be measured and calibrated to a known flow rate.

3.6 Recording equipment - Data from the CDFM probe is sent to the surface as electrical signals with respect to a given depth. The software calculates the flow rate at the measuring point and records the rate

3.7 Personnel

Personnel are as defined in TP-1.

4.0 REQUIREMENTS

4.1 Prerequisites

4.1.1 The borehole to be logged must be filled with clean water. The presence of drilling mud may plug the measuring chamber.

4.1.2 The borehole to be logged may be either open (uncased) or cased holes. There is no restriction on the type of casing that can be used. Flow outside casing is not detected by the CDFM.

4.2 Tools, Material, Equipment

4.2.1 Measurement apparatus

Colog, Inc. utilizes Century Geophysics model 9721 EM Flowmeters. The tools are rated to 70 degrees Celsius. The tools are capable of measuring flow rates from 0.01 to 10.6 gpm, with an accuracy and resolution of 0.005gpm The probes communicate with uphole interface consoles, including the Mount Sopris Instruments Matrix Geophysical Logging System.

4.2.2 CDFM logging tools are calibrated in a vertical flow chamber at Colog's Colorado facility. Tool calibration settings are recorded in serial number specific probe files for the logging software.

4.2.3 Pre-log operation procedure for the CDFM:

This procedure shall be performed before logging each well. The required tolerances are specified in 4.4.4. The purpose of the pre-log procedures is to assure proper tool operation and the collection of representative flow data.

4.2.3.1 Determine the hole diameter by consulting a caliper log of the well, or from information supplied by the Owner or Client.

4.2.3.2 Select the proper size flow diverters and centralizer based on the hole diameter. The flow diverters shall be manufactured from flexible materials to allow them to conform to the hole when placed therein. They should be cut such that their diameter is approximately one-half to one inch larger than the hole diameter (smaller in small-diameter holes, larger in large diameter holes). Four to six diverters shall be placed between the upper and lower chambers of the probe such that any openings in the diverters are covered above and below with petals of the adjoining diverters.

4.2.3.3 A centralizer shall be placed near the top of the tool in order to keep the tool from leaning over inside the borehole. This helps to assure the flow diverters form an effective seal with the borehole wall. The centralizer should be the same diameter or up to 1/2-inch smaller than the borehole or well diameter, and should be designed such that there is minimum interference with flow around the tool. It should be placed at least one foot above the flow diverters.

4.2.3.2 Connect the tool to the wireline, place in the well, and power up the systems. Start the corehole dynamic logging software, and select the calibration settings stored in the software, specific to the probe serial number and flow range. Record both the tool serial number and the calibration settings in the field notes.

4.2.3.4 Prepare to collect the log as described in TP-1.

4.2.4 Post-Log Check Procedure

The purpose of the post-log calibration check is to verify that no change in system performance has occurred during logging. This consists of checking tool condition and connections. Inspect the diverter petals to assure no twisting or shifting occurred during use which may have allowed flow to bypass the measurement chamber. The centralizer should not have moved from its initial position. The screens around the measuring chamber should be intact and clean, and no mud should be in the measuring chamber.

4.3 Precautions and Limits

4.3.1 Temperature limits are specified Section 4.2.1 and in the CDFM operations manual.

4.3.2 The CDFM tool is a delicate instrument and can be easily damaged by shocks due to drops and bumps. Care should be taken when handling and shipping. The CDFM probe should only be powered on when the flow chamber is in fluid, to dissipate heat and prevent damage to the sensor.

4.3.3 CDFM measurements are made at stationary locations in the well. Locations are selected based on a review of hole conditions as revealed by other logs, such as caliper, temperature, fluid resistivity, televiewer, and other logs, as well as lithologic logs and information provided by the driller. If the hole is larger than expected at a given depth, the diverters may not seal properly, allowing water to bypass the measuring chamber. The ability of the CDFM log to accurately represent the subsurface flow conditions is severely limited in the event detailed borehole diameter and subsurface fracture information is not available.

4.3.4 The properties of the borehole fluid should not influence CDFM log results, provided turbidity is low enough to prevent clogging of the measuring chamber.

4.3.5 Moving the CDFM tool through the borehole causes the diverters to become concave up (when the tool is moving down the hole) or concave down (when the tool is moving up the hole), and they remain in this orientation when the tool stops at a depth station. When the diverters are concave up, they more effectively seal against downward-flowing water than upward flowing water, and vice versa. As such, both concave up & concave down measurements should be made at each depth station to check for both up and down flow.

4.3.6 Moving the CDFM tool through the borehole causes water to flow into and out of fractures in the rock. To minimize this effect, winch speed should not exceed 10 – 15 feet minute while moving from one depth station to another. In the event the tool is moved faster than this, longer waiting times will be needed at each station to allow flow in the well to stabilize.

4.3.6 While data from each depth station can be recorded and saved to the computer for later review, results for each measurement should be manually recorded while logging the well as a backup in the event of computer problems.

4.3.7 Do not allow the probe to touch the bottom of the well. Well bottoms frequently collect mud and other debris that clog the flow chamber or cause the tool to get stuck. If a bottom of the hole reading is needed, it should be taken at least three feet off the bottom of the well. If available information (such as a video survey) indicates the bottom of the well is clean and free of obstructions, the tool can be run nearly to the bottom.

4.4 Acceptance Criteria

CDFM measurements shall be accepted for use based on the expectation that the results will be interpreted qualitatively.

4.4.1 A depth station reading shall consist of three readings each for diverters up and diverters down, for a total of six readings at each depth station. The three readings shall be compared to one another for repeatability. They should be within +/-20% of one another, unless flow rates are at the very low end of the measuring range. For flow rates below 0.1 gpm, readings will be considered repeatable when they are within +/-0.02 gpm.

4.4.2 The diverters up or down readings can be skipped at a station if other information indicates flow is known to be going in one direction.

4.4.3 After Survey Depth Error (ASDE) shall be within required tolerances as specified in TP-1.

5.0 DETAILED PROCEDURE

Corehole dynamic flowmeter logs are recorded at varying sample intervals. They are used to obtain information on vertical distribution and direction of groundwater flow in the subsurface.

CDFM logs are typically run as one of a suite of logs during a single visit to a well site. Procedures prior to and upon arrival as described here pertain only to the specific requirements of CDFM logs. Where they do not conflict with the procedures detailed here, all of the procedures specified in TP-1 shall also be adhered to.

5.1 Prior to Arrival

In addition to those procedures detailed in TP-1, select appropriately sized flow diverters and centralizers.

5.2 On Arrival

Establish the total depth, diameter, and expected fluid level in the borehole. Review available information (e.g., caliper, temperature, fluid resisitivity logs) for selection of depth stations.

5.4 During Logging

Note: The CDFM probe should only be powered on when the flow chamber is in fluid, to dissipate heat and prevent damage to the sensor.

5.4.1 Attach the logging probe to the wireline.

5.4.2 Prepare the logging tool as described in Section 4.2.3.

5.4.3 Set wireline depth zero at the measurement point. The depth zero should be taken with tension on the wireline similar to that expected while logging, to prevent slack in the cable from biasing the datum.

5.4.4 Lower the probe to the first depth station to be logged. Logging speed should not exceed 10 to 15 feet per minute when moving through water.

5.4.5 Upon reaching the first depth station, stop the tool and wait several minutes for water flow to re-equilibrate in the well. Two to three minutes should be sufficient, depending on logging speed and hole diameter. The diverters will be in concave up position, which is the preferred orientation for measuring downward flow.

5.4.6 Begin recording CDFM data. In very low flow rate wells (less than 0.05 gpm) data recording may extend out to 30 seconds. Wait 30 seconds to one minute in between readings. Collect two additional readings and compare to the first. The three readings should be within +/-20% of one another, unless flow rates are at the very low end of the measuring range. For flow rates below 0.05 gpm, readings will be considered repeatable when they are within +/-0.01 gpm.

5.4.7 In the event the three readings are not repeatable, take three additional readings. Check to see if readings are converging around a given value, and if so continue with up to four more readings. If they do not converge, there may be problems with the diverter seal, values may be too close to the calibration endpoints of the tool, the fluid column may still be recovering from the diverter movement, or the tool may not be operating properly (see Section 5.5).

5.4.8 After completing the concave up measurements, slowly lower the probe approximately two feet deeper into the well, stop, and pull back up two feet to the same measuring point. The diverters will now be in the concave down position, suitable for measuring upward-flowing water in the well. Collect CDFM data as described in 5.4.6.

5.4.9 Upon completing concave-up and concave-down measurements at the first station, lower the tool to the next station and repeat data collections procedures. The results of each measurement should be recorded in a notebook as well as saved to the computer.

5.4.10 After collecting the deepest measurement, return probe to the surface and determine the A.S.D.E. Perform post-log check procedures, and back up the computer data file.

5.5 Evaluation of Non-Repeatable Data: CDFM measurements may not repeat at a given station. This most commonly occurs at or near the upper and lower calibration end points. In this case, readings may cease after three or four repeats. Other causes of nonrepeating measurements, and their possible solution, are:

Poor Diverter Seal	*Station located on a fracture (relocate station) *Change in hole diameter (relocate station, replace diverters with appropriate diameter) *Excessive borehole rugosity (relocate station) *Excessive winch speed when moving from station to station (slowly move tool up or down from station, then reoccupy) *Debris in well (slowly move tool up or down from station then reoccupy, relocate station, or rework the well) *Deviated well causing tool to lay against borehole wall (no

	solution) *Debris in diverters (remove tool, clean diverters)
Turbulent Flow/Well Not at Equilibrium	*Excessive winch speed when moving from station to station (wait longer after occupying station before beginning measurements) *Strong horizontal flow zone (relocate above or below suspected zone) *Localized strong vertical flow (relocate above or below suspected zone)
Tool Damage	*Flow chamber plugged with mud (remove tool and clean) *Flow sensor broken (replace tool)

5.6 Prior to departure

Remove the flow diverters and centralizer. Clean these items and the flow chamber, to prevent mud hardening or the buildup of other debris.

6.0 RECORDS

Records shall be provided as detailed in TP-1.

6.1 Data Deliverables

Data deliverables shall be as described in TP-1

7.0 APPENDICES

7.1 Vertical Flowmeter Logging, USGS Groundwater Information, Branch of Geophysics, http://water.usgs.gov/ogw/bgas/flowmeter/

7.2 CDFM Cleaning Procedure, IVM Instructions for Silver-Silver Chloride (Ag-AgCl) Electrodes.

High Flow, Low Flow,
Temperature, and Fluid Conductivity
Checkout and Calibration

Engineer___________ Location________________Unit No. ______

Probe Type S/N_________ Module S/N___________ Bench Thermometer/Conductivity Meter___________

Pre-Log Calibration: Date:___________ Time:___________

Calibration Bath #1				
Temperature (^oC)	Probe CPS	Resistivity (Ohm-m)	Probe CPS	Digital File Name
Calibration Bath #2				
Temperature (^oC)	Probe CPS	Resistivity (Ohm-m)	Probe CPS	Digital File Name
Low Flow				
Up GPM	Probe CPS	Down GPM	Probe CPS	Digital File Name
High Flow				
Up GPM	Probe CPS	Down GPM	Probe CPS	Digital File Name

Post-Log Calibration: Date:___________ Time:___________

Calibration Bath #1				
Temperature (^oC)	Probe CPS	Resistivity (Ohm-m)	Probe CPS	Digital File Name
Calibration Bath #2				
Temperature (^oC)	Probe CPS	Resistivity (Ohm-m)	Probe CPS	Digital File Name
Low Flow				
Up GPM	Probe CPS	Down GPM	Probe CPS	Digital File Name
High Flow				
Up GPM	Probe CPS	Down GPM	Probe CPS	Digital File Name

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